Crowds inside out

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JIE LI

CROWDS INSIDE OUT

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Proefschrift

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SUMMARY

With the growth of global population, the big cities become increasingly crowded. It is not rare to see large crowds in public transportations and events with masses of visitors, such as music festivals and football matches. The question "How to deal with crowds" is receiving attention, both from academia and practical crowd management.

This thesis aims at contributing to a better understanding of crowds from the perspective of individual crowd members' experiences, including their well-being, emotional experiences and action tendencies. In addition, we want to understand the emotional contagion effect between groups in crowds. To achieve this, we chose to go into the crowds, get in touch with the crowd members, and try to find out what factors sustain their well-being, how their emotional experiences can be measured in a playful and non-intrusive manner, what they tend to do when they have certain emotions, and how the grouping behavior reflects their experiences.

The key contributions of this thesis are highlighted as follows:

Crowd experts' expectations: go into the crowds. Through interviews conducted with crowd experts (Chapter 2), we understand that crowd management is well-established. Crowd experts are very experienced in managing large crowds. They have developed effective strategies to be well prepared before a crowd event, to monitor the crowd density and flows during the event and to simulate possible evacuations in diverse emergent scenarios. However, they have realized, when certain problems become explicit on the surveillance cameras, it is already too late to take effective action. In addition to their current strategies that are mainly at the crowd level, they would like to know in advance about how the crowd situation is likely to develop from insights obtained from individual crowd members, for example, from the assessment of the emotions of the crowd members. Assessing the emotions of crowd members is a step towards better understanding and predicting crowd behavior.

Factors contributing to well-being in crowds: autonomy, competence and relatedness. Our first step in approaching crowd members was to bring them together in context mapping groups and to encourage them to talk about their experiences in crowds (Chapter 3). We found that the needs to be independent and self-decided (autonomy), to be capable and effective (competence), and to have a sense of belongingness and closeness (relatedness) are important for sustaining the well-being of crowd members. These three factors are also the main motivations for people to join a crowd. Besides these three factors, a non-negligible factor is people's safety concerns, which form the primary reason for people to leave or avoid a crowd.

Measuring emotions in crowds. Apart from the existing crowd management strategies, measuring emotions of crowd members during an event is considered by crowd experts an effective addition to predict crowd behavior. As an exploration, a playful, rewarding and non-intrusive application (*EmoApp*) was designed to collect emotions of crowd members and was tested at a music

festival (Chapter 4). The type of emotions collected was based on Russell's (1980) valence-arousal emotion model, which includes four main types, namely happy, relaxed, angry and bored. Participants were prompted to report the emotions of themselves and the emotions of other crowd members in their proximity. As a reward, they could redeem free drinks at the festival. The collected emotion reports reflected the real situations at the festival. Participants' movements were consistent with their emotional changes as well as the activity programs at the festival. For example, the negative emotion reports received near the main stage reminded the festival organizers of the unsatisfied performance on the stage. Suppose this kind of information could be delivered directly to the festival organizers, they could, for example, intervene in the programs.

Emotional feelings and action tendencies of crowd members. In a separate study, participants were requested to reflect on their emotional feelings and related action tendencies according to their memories of recent crowd experiences and to fill in a questionnaire. In addition to emotions, action tendencies are behavior-related aspects that contribute to the understanding of individual crowd members' experiences (Chapter 5). The results showed that emotional feelings in crowds are not exactly the same as daily emotions. For example, *feeling connected* and *feeling warm* are two specific emotional feelings in a crowd context. Based on the answers in the questionnaires, a set of typical emotional feelings in crowd situations was proposed, consisting of six positive ones (i.e., *feel connected, excited, relaxed, feel warm, curious* and *happy*) and seven negative ones (i.e., *anxious, feel stuffy, angry, feel small, alert, confused*, and *bored*). We have found that people generally feel more *curious, excited, connected* and *happy* in event crowds than in non-event crowds. Negative emotions are not necessarily connected with negative action tendencies. When people feel positive, no matter whether it is an event or non-event crowd, they tend to behave positively. When people feel positive in non-event crowds, they tend to help others more than in event crowds.

Type of crowds and its influence on emotion and behavior of crowd members. Event crowds, spectator crowds and non-event crowds are the three main types of crowds defined in this thesis. An event crowd is mostly event- or activity-based where crowd members enjoy the activities and want to interact and share experiences with others (e.g., festival, concerts etc.). In contrast, a non-event crowd usually involves no activities, and crowd members generally aim at achieving some external goal or benefit (e.g., crowds at public transportation, crowds waiting in queues for free goods etc.). Crowd members in a spectator crowd are not fully involved in activities, but are watching the activities of an event crowd, like the audiences in a concert who are far away from the stage and can only see the performance of the artists from the big screens. To investigate the differences and possible emotional contagion between the three crowd types, a lab experiment was conducted in which the participants wore proximity sensors during the experiment and reflected directly afterwards about their experiences (Chapter 6). The results showed that crowd members in the event crowd felt more positive than those in the non-event crowd and the spectator crowd. The emotional contagion effect was visible, since the number

of reported positive emotional feelings in the spectator crowd was more than in the non-event crowd. However, the types of emotional feelings, especially the negative emotional feelings reported in the spectator crowd, were more similar to those in the non-event crowd than those in the event crowd.

Overall, this thesis aims at enriching the understanding of crowds by conducting research from within the crowd and having close contact with crowd members. It has explored some possibilities to understand crowds at the individual level. In addition, it also looked at the emotional contagion effects within a crowd. We have explored three aspects in understanding individual crowd members, namely well-being, emotions and action tendencies. Technologically, we have shown that very primitive proximity sensors could already reveal differentiating trends in terms of connectivity rate and grouping behavior. Further research is needed to find appropriate (sensor) technology that can provide added value in measuring crowds and to investigate solutions that can better link and visualize different types of real-time data, such as emotions and grouping behavior. An ideal future scenario for crowd management is to have a system that can effectively assess and visualize the real-time experiences of crowd members. Accordingly, crowd managers can better predict crowd situations and provide timely guidance to crowd members. The ideal future also calls attention to privacy protection and ethical considerations in assessing crowds.

SAMENVATTING

Met de groei van de wereldbevolking worden de grote steden steeds drukker. Het is niet ongebruikelijk om grote menigten te zien in het openbaar vervoer en op evenementen met hoge bezoekersaantallen, zoals muziekfestivals en voetbalwedstrijden. De vraag "Hoe om te gaan met menigten" krijgt aandacht van zowel de academische wereld als van menigtemanagement in de praktijk.

Dit proefschrift heeft als doel een bijdrage te leveren aan een beter begrip van menigten vanuit het perspectief van de ervaringen van individuele menigteleden, waaronder hun welzijn, emotionele ervaringen en actietendensen. Daarnaast proberen we het emotionele besmettingseffect tussen groepen in menigten te begrijpen. Om dit te bereiken hebben we ervoor gekozen om de menigten in te gaan, contact op te nemen met de menigteleden en geprobeerd te achterhalen welke factoren hun welzijn ondersteunen, hoe hun emotionele ervaringen op een speelse en niet-indringende manier kunnen worden gemeten, wat hun gedragsneigingen zijn wanneer ze bepaalde emoties hebben en hoe het groepeergedrag hun ervaringen weerspiegelt.

De belangrijkste bijdragen van dit proefschrift zijn als volgt:

De verwachtingen van menigte-experts: ga de menigten in. Dankzij interviews met menigte-experts (hoofdstuk 2) begrijpen we dat menigte-management goed ingeburgerd is. Menigte-experts zijn zeer ervaren in het omgaan met grote menigten. Ze hebben effectieve strategieën ontwikkeld om goed voorbereid te zijn op massa-evenementen, om de dichtheid van het publiek en de stromen tijdens het evenement te bewaken en om mogelijke evacuaties in verschillende scenario's te simuleren. Ze realiseren zich echter dat wanneer bepaalde problemen expliciet worden op de bewakingscamera's, het al te laat is om effectief actie te ondernemen. Naast hun huidige strategieën die zich vooral op het niveau van de menigte bevinden, willen ze van tevoren weten hoe de situatie in de menigte zich waarschijnlijk zal ontwikkelen aan de hand van inzichten verkregen van individuele menigteleden, bijvoorbeeld uit de beoordeling van de emoties van de menigteleden. Het beoordelen van de emoties van menigteleden is een stap in de richting van het beter begrijpen en voorspellen van groepsgedrag.

Factoren die bijdragen aan het welzijn van menigten: autonomie, competentie en verbondenheid. Onze eerste stap in het benaderen van menigteleden was om ze samen te brengen in contextmapping-groepen en hen aan te moedigen om te praten over hun ervaringen in menigten (hoofdstuk 3). We ontdekten dat de behoeften om onafhankelijk en zelfbeschikkend te zijn (autonomie), om capabel en effectief te zijn (competentie), en om een gevoel van verbondenheid en nabijheid (verbondenheid) te hebben, belangrijk zijn voor het ondersteunen van het welzijn van menigteleden. Deze drie factoren zijn ook de belangrijkste drijfveren voor mensen om zich bij een groep te voegen. Naast deze drie factoren is een niet-verwaarloosbare factor het veiligheidsbelang van mensen; dit is de voornaamste reden waarom mensen vertrekken of een menigte vermijden.

Het meten van emoties in drukte. Naast de bestaande strategieën in menigtemanagement, wordt het meten van emoties van menigteleden tijdens een evenement door menigte-experts beschouwd als een effectieve toevoeging om het gedrag van de menigte te voorspellen. Ter verkenning werd een speelse, belonende en niet-intrusieve applicatie (*EmoApp*) om emoties van menigteleden te verzamelen ontworpen en getest op een muziekfestival (hoofdstuk 4). Het soort emoties dat werd verzameld is gebaseerd op Russell's (1980) valentie-activatie-emotiemodel dat vier hoofdtypen omvat, namelijk blij, ontspannen, boos en verveeld. Deelnemers werden gevraagd om de emoties van zichzelf en de emoties van andere menigteleden in hun nabijheid te melden. Als beloning konden ze gratis drankjes verkrijgen op het festival. De verzamelde emotierapporten weerspiegelden de daadwerkelijke situaties op het festival. De bewegingen van de deelnemers waren consistent met hun emotionele veranderingen evenals de activiteitenprogramma's op het festival. De meldingen van negatieve emoties die bij het hoofdpodium werden ontvangen, herinnerden de festivalorganisatoren bijvoorbeeld aan de onbevredigde prestaties op het podium. Wanneer dit soort informatie rechtstreeks aan de festivalorganisatoren geleverd kan worden, kunnen ze bijvoorbeeld in de programma's ingrijpen.

Emotionele gevoelens en actietendensen van menigteleden. In een afzonderlijke studie werden de deelnemers gevraagd na te denken over hun emotionele gevoelens en gerelateerde actietendensen volgens hun herinneringen aan recente belevingen in menigten en om een vragenlijst in te vullen. Naast emoties zijn actietendensen gedragsgerelateerde aspecten die bijdragen aan het begrip van de ervaringen van individuele menigteleden (hoofdstuk 5). De resultaten toonden aan dat emotionele gevoelens in menigten niet precies hetzelfde zijn als dagelijkse emoties. Gevoelens van verbondenheid en warmte zijn bijvoorbeeld twee specifieke emotionele gevoelens in de context van een menigte. Op basis van de antwoorden in de vragenlijsten werd een reeks typische emotionele gevoelens in menigtesituaties voorgesteld, bestaande uit zes positieve (namelijk, zich *verbonden*, *opgewonden*, *ontspannen*, *warm*, *nieuwsgierig* en *gelukkig* voelen) en zeven negatieve (namelijk, zich *angstig*, *benauwd*, *boos*, *klein*, *alert*, *verward* en *verveeld* voelen). We hebben ontdekt dat mensen zich over het algemeen vaker nieuwsgierig, opgewonden, verbonden en gelukkig voelen in het geval van evenementsmenigten dan in niet-evenementsmenigten. Negatieve emoties zijn niet noodzakelijk verbonden met negatieve actietendensen. Wanneer mensen zich positief voelen, ongeacht of het een evenementsmenigte of niet-evenementsmenigte is, hebben ze de neiging zich positief te gedragen. Wanneer mensen zich positief voelen in niet-evenementsmenigten, hebben ze meer de neiging om anderen te helpen dan in evenementsmenigten.

Type menigten en de invloed ervan op de emoties en het gedrag van menigteleden. Evenementsmenigten, toeschouwersmenigten en niet-evenementsmenigten zijn de drie hoofdtypen van menigten die in dit proefschrift worden gedefinieerd. Een evenementsmenigte is meestal gebeurtenis- of activiteitsgericht, waarbij menigteleden genieten van de activiteiten, willen communiceren en ervaringen willen delen met anderen (bijv. festivals, concerten, enz.). Echter, een niet-evenementsmenigte omvat meestal geen

activiteiten, in het algemeen streven de menigteleden naar het bereiken van een extern doel of voordeel (bijv. menigten in het openbaar vervoer, menigten in de wachtrij voor gratis goederen, enz.). Menigteleden in een toeschouwersmenigte zijn niet volledig betrokken bij activiteiten, maar kijken naar de activiteiten van een evenementsmenigte, zoals het publiek in een concert dat ver van het podium af staat en het optreden van de artiesten alleen op grote schermen kan zien. Om de verschillen en mogelijke emotionele besmetting tussen de drie soorten menigten te onderzoeken, werd een laboratoriumexperiment uitgevoerd waarbij de deelnemers tijdens het experiment nabijheidssensoren droegen en direct daarna terugblikten op hun ervaringen (hoofdstuk 6). De resultaten toonden aan dat de leden in de evenementsmenigte zich positiever voelden dan degenen in de niet-evenementsmenigte en de toeschouwersmenigte. Het emotionele besmettingseffect was zichtbaar, aangezien het aantal gemelde positieve emotionele gevoelens in de toeschouwersmenigte groter was dan in de niet-evenementsmenigte. De soorten emotionele gevoelens, met name de negatieve emotionele gevoelens die in de toeschouwersmenigte werden gerapporteerd, waren echter beter vergelijkbaar met die in de niet-evenementsmenigte dan die in de evenementsmenigte.

Samenvattend probeert dit proefschrift het begrip van menigten te verrijken door onderzoek vanuit de menigte te doen en nauw contact te hebben met menigteleden. De thesis heeft enkele mogelijkheden onderzocht om menigten op individueel niveau te begrijpen. Daarnaast werd gekeken naar de emotionele besmettingseffecten binnen een menigte. We hebben drie aspecten onderzocht om individuele menigteleden te begrijpen, namelijk welzijn, emoties en actietendensen. Vanuit technologisch perspectief hebben we aangetoond dat zeer primitieve nabijheidssensoren al diverse trends kunnen onthullen in termen van connectiviteitspercentages en groepeergedrag. Verder onderzoek is nodig om geschikte (sensor-)technologie te vinden die toegevoegde waarde kan bieden bij het meten van menigten en om oplossingen te onderzoeken die verschillende soorten realtime-gegevens, zoals emoties en groepeergedrag, beter kunnen koppelen en visualiseren. In het ideale toekomstscenario voor menigtemanagement bestaat er een systeem dat de realtime-ervaringen van menigteleden effectief kan beoordelen en visualiseren. Aan de hand daarvan kunnen menigtemanagers situaties beter voorspellen en tijdig begeleiding bieden aan menigteleden. De ideale toekomst vraagt ook aandacht voor privacybescherming en ethische overwegingen bij het beoordelen van menigten.

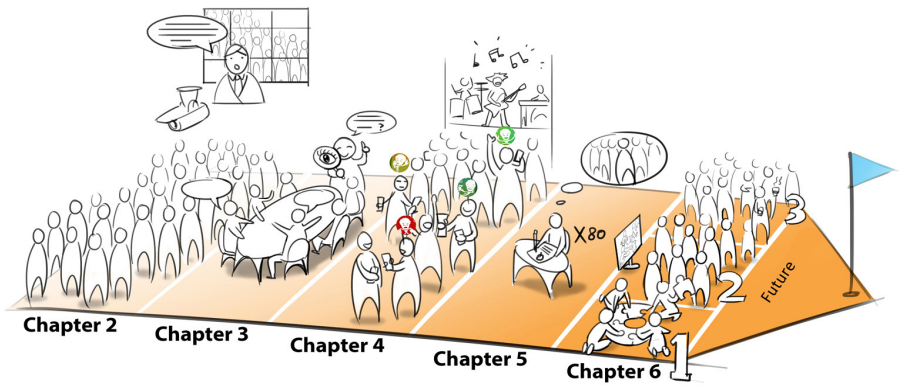
CONTENTS

"Never stop being amazed."

— Cake Researcher

CHAPTER 1

Introduction



May 4, 2010, around 20,000 people, with the presence of the royal family, gathered on the Dam Square in Amsterdam for *the annual National Remembrance Day (Dodenherdenking)* in the Netherlands. During the two-minute silence that started at 8:00 pm, an unexpected loud shout from a man lasted a few seconds and panicked the silent crowd, resulting in an uncontrollable dispersion of "human waves". Barriers were crushed down and dozens of people got trampled. Many people, especially children, were so scared and started to cry. The royal family was immediately discharged to a safe area, and the yelling man was nabbed by the security men and taken away from the crowd. When the crowd gradually calmed down, the royal family returned and the commemoration continued. However, this incident caused injuries to over 50 visitors.[1]

June 9, 2014, between 7:30 pm and 8:30 pm, the famous Dutch annual music festival *Pinkpop* was ravaged by furious storms. The storms came at very short notice, and the normal evacuation procedure of 67,000 visitors was impossible to be accomplished within 15 minutes. Therefore, the organizers decided to let the visitors stay on the ground, away from the towers, trees and tents. Crowds of visitors were shrouded in ponchos and huddled in groups against each other as instructed. Fortunately, most visitors were regulars of *Pinkpop* festival, who were used to large crowds and did not panic. There were no injuries, and the crowd continued celebrating after the storms.[2]

The two examples above represent extremely large crowds that have many characteristics in common. They both had a large number of visitors (≥ 20,000 visitors) with high crowd density and limited mobility. The visitors were generally well behaved and experienced, since both events were annual. In both cases, the crowd members shared the same interest and gathered for the same purpose: either for the remembrance or for the festival. Both management teams were experienced and had well planned the event. Yet, both experienced disturbances: an unexpected, inexplicable sudden shout within the crowd and a furious storm at short notice (Figure 1.1).

Despite having many characteristics in common, the two crowds behaved differently. The experiences of the crowd members were also fundamentally different: the first crowd was so frightened that many of the people were reluctant to participate in next years' commemoration, while the enthusiasm of the second crowd was not influenced at all (Figure 1.2). Many influential factors could have resulted in such distinct behavior in the two crowds, one of which being that the crowd managers (e.g., event organizers, the police) for the *Pinkpop* festival were able to warn and give advice to the crowd members about how to act while this was not possible in the commemoration crowd.

There is only a thin line between a well-behaved crowd and a chaotic swarm. Comparing the two crowds before and after the disturbances showed that the emotions of the *Pinkpop* crowd remained mostly positive (see Figure

1 More details about this incident were reported on www.nu.nl. Please see http://www.nu.nl/binnenland/2240864/man-chaos-veroorzaakte-bekende-van-politie.html, retrieved on September 5, 2016.

2 More details about the Pinkpop 2014 storms were reported on www.nrc.nl. Please see https://www.nrc.nl/nieuws/2014/06/10/pinkpop-2014-metallica-noodweer-en-andere-hoogtepunt-en-a1464699, retrieved on September 5, 2016.

1.2-b), whereas that did not happen in the other crowd: the crowd members in the *Remembrance* event showed quite panic and painful expressions afterward (Figure 1.2-a). One may wonder whether such changes of emotions and behavior of individual crowd members can be used as an indicator and maybe even as a predictor of changes in crowd behavior. This idea formed the inspiration for the research described in this thesis. Particularly, it resulted in research aiming at understanding the emotional experience of crowd members, and its relation to crowd behavior.

a b

Figure 1.1. Comparison of the two crowds: (a) The crowd gathering on the Dam Square in Amsterdam, for the annual National Remembrance Day (Dodenherdenking)[3]; (b) The crowd attending the Pinkpop festival[4].

a b

Figure 1.2. Comparison of the two crowds in Figure 1.1 after the disturbances: (a) The frightened crowd on the Dam Square[5]; (b) The enthusiastic Pinkpop crowd in the storm[6].

3 This photo is reused and modified from the original one, which can be found on http://www.contrastleiden.nl/life-in-leiden-remembrance-day-and-independence-day/, retrieved on September 5, 2016. It is labeled for non-commercial reuse with modification on Google Images Search.

4 This photo is reused and modified from the original one, which can be found on https://esnutrecht-blog.com/2015/02/20/pinkpop/, retrieved on September 5, 2016. It is labeled for non-commercial reuse with modification on Google Images Search.

5 This photo is reused and modified from the original one, which can be found on http://www.parool.nl/amsterdam/dodenherdenking-zonder-damschreeuwer~a3647877/, retrieved on September 5, 2016. It is labeled for non-commercial reuse with modification on Google Images Search.

6 This photo is reused and modified from the original one, which can be found on http://nos.nl/op3/artikel/2040609-pinkpop-bereidt-zich-voor-op-onweer-met-nieuw-control-centre.html, retrieved on September 5, 2016. It is labeled for non-commercial reuse with modification on Google Images Search.

1.1 WELL-BEING OF CROWD MEMBERS

When talking about the emotional experience of crowd members, one also refers to their well-being (Fredrickson & Joiner, 2002). Various studies have been inspired by the notion that emotional experience is involved in and contributes to human well-being. For instance, Fredrickson (1998) and Lyubomirsky et al. (2005) showed that people who experience positive emotions more frequently, have better well-being than people with negative emotions. In general, human well-being is a complex concept which not only refers to the absence of (mental) illness, but also concerns optimal (life) experience and functioning (Ryan & Deci, 2001). There are mainly two perspectives on achieving well-being (Ryan & Deci, 2001), namely the eudaimonic (Waterman, 1993) and the hedonic one (Kahneman et al., 1999). The first perspective refers to, for example, human flourishing and self-realization, while the latter one refers to pleasure attainment and pain avoidance. Reflecting on the eudaimonic and hedonic perspectives in terms of well-being in crowds, we infer that the well-being of crowd members can be related to both perspectives. For instance, the well-being of crowd members in a prestigious scientific conference can be sustained through fully engaging them in the activities, being absorbed in the new knowledge, networking with other scholars and having the feeling of self-development (eudaimonic well-being). The well-being of crowd members in a festival is more associated with relaxation, happiness and staying away from problems (hedonic well-being).

People may have opposite opinions towards crowds: some people's eyes will light up, thinking about exciting festivals while others might exaggerate the negativity of crowd experience due to the exhausting daily commute in crowded public transportations (Filingeri et al., 2017). It is not difficult to imagine that the well-being of crowd members is more supported and sustained in some crowds than others. For example, people generally have better experiences in a festival crowd than in a queuing crowd (Li et al., 2013). Reicher and Potter (1985) found that over-emphasis on the negativity is one of the misunderstandings about crowds. These negative assumptions about crowds probably explain why the majority of crowd management practices still put efforts on preventing potentially dangerous situations by detecting suspicious crowd members through surveillance cameras and security scouts (Li et al., 2013). Surveillance cameras can assist crowd managers (e.g., event organizers, train station managers) in keeping track of the crowd density, flows, and identifying misbehavior from an outsider's point of view but are probably not able to reach out to the internal states of the crowd members, such as understanding how they feel and what they tend to do. There seems to be a need for mechanisms that allow accurate estimation of the psychological aspects such as emotional experiences of crowd members (Li et al., 2013).

1.2 CROWDS INSIDE OUT

The discussion so far has suggested that, to have a richer understanding of crowds, one should not only view crowds as an outsider, but also go inside the crowds. To measure the crowd behavior from within the crowd is the main goal of the project EWIDS[7] (Extreme Wireless Distributed Systems). As one of the PhD topics of the EWIDS project, this thesis takes the perspective of individual crowd members and focuses on understanding their emotional experiences.

In the EWIDS project, large networks of distributed wearable sensors were applied to measure crowd density and movement patterns based on sensing individual crowd members. For example, Martella et al. (2014) used a network of wearable RFID-based sensors to represent crowds in the form of proximity graphs. Suppose every crowd member is wearing an RFID sensor, and the sensors can detect each other within a specific range, which is typically 1.5-2.0 meters. If two sensors S_A and S_B can recognize each other at a certain moment, and crowd members C_A and C_B are respectively wearing S_A and S_B, it is assumed that C_A and C_B are adjacent at that moment. On a proximity graph, C_A and C_B are represented as vertices V_A and V_B, and an edge is connecting V_A and V_B. Generalizing this representation of all crowd members results in a proximity graph consisting of a number of vertices and edges (Van Steen, 2010). As Martella et al. (2014) explained, each proximity graph at a particular moment is, in fact, a snapshot of the *texture* of the crowd at that specific moment. What is meant by *texture* is that proximity graphs capture the spatial closeness relationship between crowd members who are wearing sensors over time. A time series of proximity graphs allow the detection of changes in a crowd in real time, such as detecting congestion, flows and social groups. According to Martella et al. (2014)'s descriptions, Figure 1.3 illustrates two proximity graphs at a specific moment. The strength of the connections is defined according to the length of previous time when two sensors were connected. Weak connections indicate that two sensors shortly discover each other, but the link does not last long enough to establish a normal connection. As can be seen in Figure 1.3-a, since many weak connections are identified, it is assumed that two counter flows of crowd members are passing the narrow corridor. Normal connections indicate that two sensors are close to each other for a certain period (e.g., longer than 60 seconds). The length of that "certain period" can vary in different crowd situations. Strong connections indicate that two sensors are together for a significantly long period. For instance, in a conference, a group of researchers standing closely and chatting for over five minutes will be represented as strongly connected on a proximity graph. This usually suggests that they form a separate group within a crowd. Note that, with the RFID sensor, the absolute position of each crowd member remains unknown (Martella, 2017).

7 This thesis is one of the research topics sponsored by the Dutch National COMMIT program, EWIDS project (Extreme Wireless Distributed Systems).

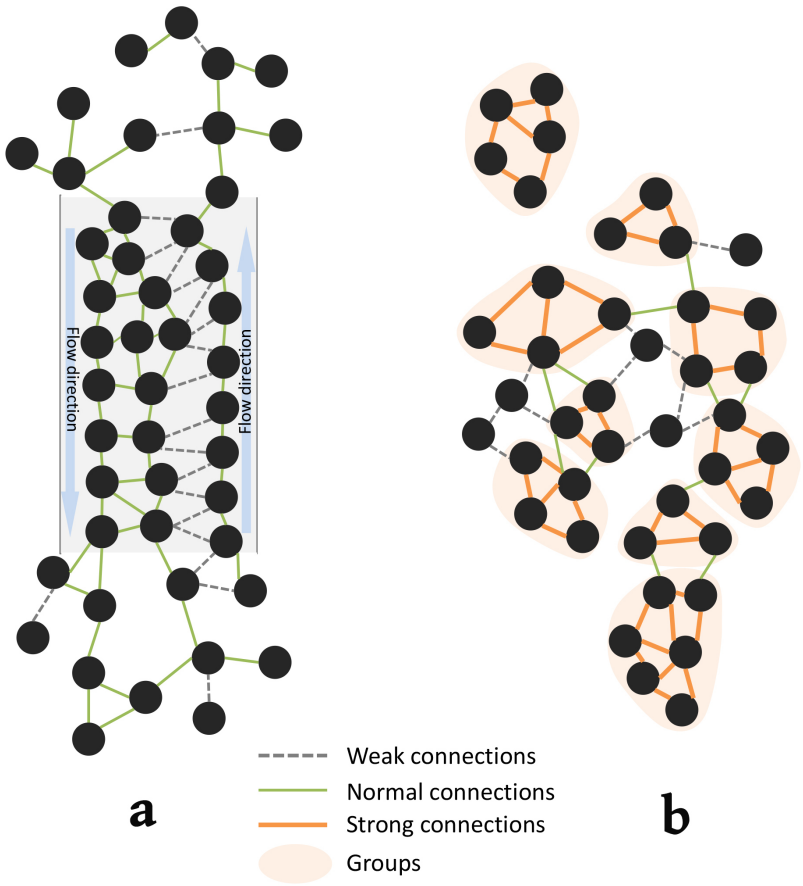


Figure 1.3. Two examples of proximity graphs: (a) Identifying over-crowdedness in a "bottleneck" situation and counter flows of crowd members, (b) identifying groups in a crowd.

Compared to the surveillance cameras that typically observe crowds from the outside, wearable sensors provide an opportunity to sense from within the crowds. Proximity graphs succeed in representing crowd *texture* based on sensing from within the crowds, which illustrates the relations every individual has with others in a crowd. Proximity graphs also reveal how the changes in the relations between crowd members indicate the changes in crowd behavior (Martella et al., 2014). However, are proximity graphs sufficient to represent the richness of crowd members' experience?

Figure 1.4 visualizes two crowd situations that will result in proximity graphs that are not so different from each other, since both crowds are densely packed with limited mobility. However, the emotional experiences of crowd members are distinct: the happy crowd standing in front of the stage are enjoying themselves (Figure 1.4-a) while the negative emotions of some crowd members in the other crowd might spread to others and lead to unexpected dangerous situations. When these critical situations are apparent enough to be

identified on proximity graphs or surveillance cameras, the time pressure for crowd managers (e.g., crowd event organizers) to effectively intervene increases.

The ideal scenario is that the negative emotions and the tendencies to behave wrongly can be captured at the beginning stage so that crowd managers have sufficient time to reflect on the situation and arrange proper interventions to stop these negative "seeds" from reaching out to other crowd members. Besides measuring the emotions of crowd members, crowd managers need additional information about the psychological states of the crowd members to better predict crowd behavior. One intermediate step is to predict the action tendencies of crowd members (Frijda et al., 1989), and to investigate how emotions lead to certain action tendencies (Frijda et al., 1989).

In this thesis, the focus is on understanding crowds from the perspective of individual crowd members' emotional experiences and how their emotions lead to certain behavior or tendencies to behave. By connecting these experiences to proximity graphs (Martella et al. 2014), we will investigate whether and if so, how changes in individual crowd members' experience might be related to changes in crowd behavior.

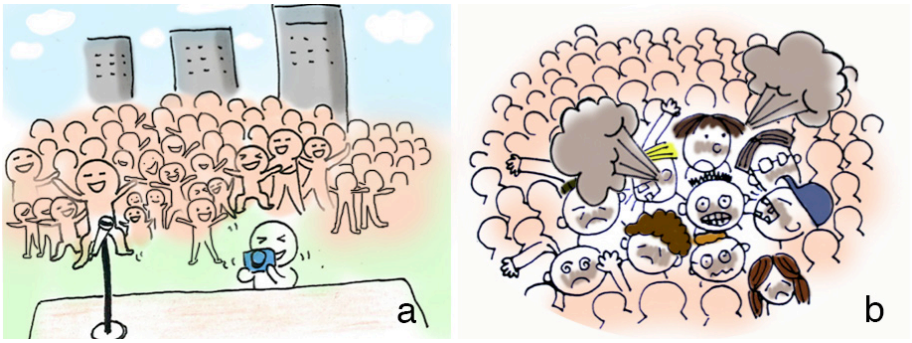


Figure 1.4. A comparison between two crowds with different emotions: (a) A happy, cheerful crowd versus (b) an aggressive crowd.

1.3 RELATIONS BETWEEN A CROWD AND ITS CROWD MEMBERS

Apart from considering individual crowd members, we can also focus on their relations with the crowd that they belong to. We may wonder what defines a crowd, and what is the appropriate way to categorize crowds? Which perspective is taken on crowds in (scientific) literature, for example, does existing research mainly focus on discrete individuals in crowds or does it emphasize a global view of continuous crowd dynamics?

With the specific lens about relations between crowds and crowd members, this section presents a literature review about what defines a crowd and what are existing crowd typologies (Section 1.3.1). A historical review of crowd research

is presented in Section 1.3.2. This review shows that the focus of crowd research has gradually expanded from seeing a crowd as an entity with mindless and irrational crowd members (the crowd level), via articulating the social aspects of crowds within which crowd members are forming groups and following certain norms (the group level), towards a growing trend with an emphasis on the individual crowd members and especially their internal states, such as emotions, thoughts and needs (the individual level). Figure 1.5 summarizes the three main perspectives in the existing crowd research and indicates a growing trend towards the individual level, especially towards understanding the internal states of crowd members.

In this review, we also briefly address technological trends, among others the use of pervasive sensing, automation in video data processing, and (location-aware) smartphones. Such technologies promise effective support to the crowd research at the individual level.

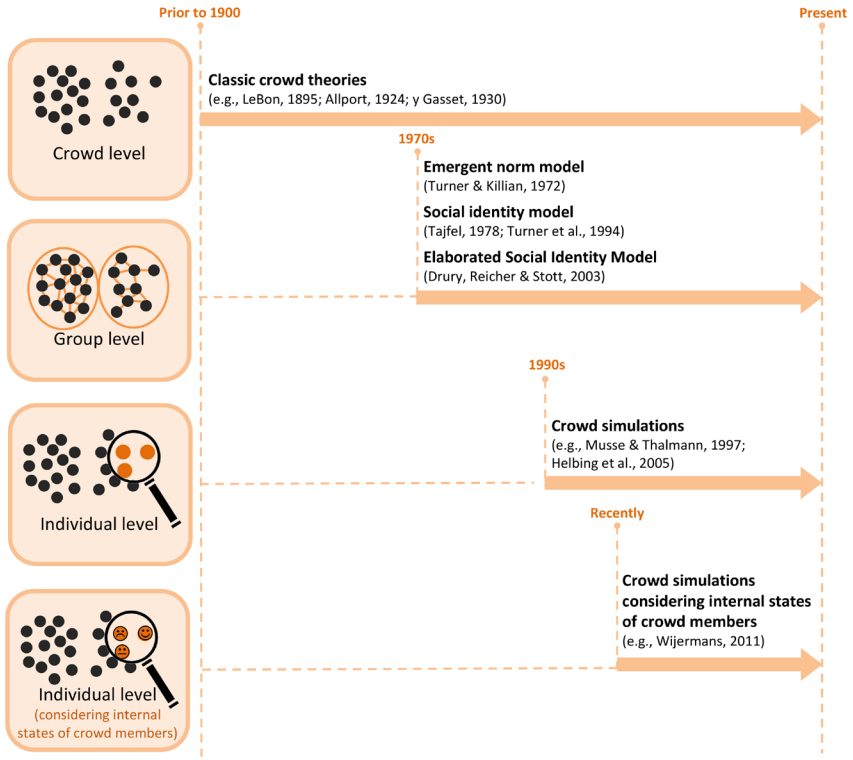


Figure 1.5. A timeline of the crowd research and three main perspectives, namely crowd, group and individual levels.

1.3.1 Crowd definition and typology

The existing literature exhibits a variety of definitions and typologies of crowds, but most of them revolve around the relations between crowds and their crowd members.

Definitions of crowds. Tsouros and Efstathiou (2007) consider the relations between crowds and their crowd members as relatively static. They describe a crowd as a "mass gathering", that is, a large number of people gathering in a defined space during a defined period. Kenny et al., (2001), on the other hand, see a crowd as a dynamic process. They use "an assembling process" to illustrate a crowd, where crowd members come and leave. Here, a crowd is not a static entity but has a beginning, middle and ending phase. Park and Burgess (1924) look at crowds from the perspective of interactions and influences between crowd members. They describe a crowd as collective behavior: a gathering of individuals from anywhere, in a casual way, who act socially under the influence of each other. Accordingly, the conventions in crowds emerge spontaneously when crowd members interact with each other. Reicher (2001) pays attention to the common interest among crowd members. He defines a crowd as a temporary gathering of individuals who share a focus of interest or social identity. As a summary of the above-mentioned views of crowds, Challenger et al., (2010) defined, in their book *Understanding crowd behaviors (Volume 1): Practical guidance and lessons identified*, a crowd as follows:

"A sizable gathering of people in a given location, with a sufficient density distribution, who have come together for a specific purpose over a measurable period of time and who, despite being predominantly strangers or in an unfamiliar situation, feel united by a common identity and are, therefore, able to act in a socially coherent manner."

More recently, there is a tendency to expand this definition. For example, Wijermans (2011) pointed out that indeed a crowd is a gathering of diverse individuals at the same physical location and at the same time, but that they do not necessarily share the same goal or interest or act coherently. Tosin (2014) also considers a crowd as a living complex system composed of living entities, who take part in group dynamics while trying to chase individual purposes. For example, today, a modern railway station has become a social place and attracts other people than only travelers. It is not rare to see people meet and shop at a central station. This illustrates that the interest may diverge among the individuals in crowds who are gathering at the same location simultaneously.

In summary, based on the crowd definitions proposed above, in this thesis, we consider a crowd to be a gathering of diverse individuals at the same physical location and at the same time, for some shared or different goals or interests. They might feel connected, sharing the same interest and a sense of social identity, and act coherently; or they might pursue different goals, and act differently.

Typologies of crowds. Variations also exist in the typology of crowds. Some researchers proposed to classify crowds by investigating the relations between crowds and their crowd members (e.g., Canetti, 1962). Some suggested to focus

on crowd members (e.g., their goals, shared interests and dominant behavior) to differentiate crowds (e.g., Brown, 1954; Canetti, 1962; Mombroisse, 1967; Turner & Killian, 1957, 1972). Others tended to metaphorically think that a crowd has multiple personalities (e.g., Berlonghi, 1995) or has a prevailing emotion or mood (e.g., Canetti, 1962; Zeit et al., 2009). In the following, a number of classifications (or typologies) will be presented in a more or less historical order, again displaying the expansion from crowd level via group level to individual level.

Brown (1954) developed a classification of crowds regarding dominant crowd behavior. This resulted in two main types of crowds, namely active crowds (mobs) and passive crowds (audiences). Active crowds are aggressive (e.g., football riots), escapist (e.g., crowd evacuations), acquisitive (e.g., crowds fight for limited resources) or expressive (e.g., strikes, festivals or parades). Passive crowds are casual (e.g., curious spectators) or intentional (e.g., movie theater crowds for recreation and conference crowds for seeking information). This typology is at the crowd level.

Canetti (1962) proposed another classification based on (1) relations between crowds and their crowd members (e.g., limited or unlimited growth of a crowd; the denser a crowd is, the more people it attracts), (2) relations among crowd members (e.g., keeping the same rhythm and feeling equal to others) and (3) goals of crowd members. This resulted in six types of crowds, each with its own characteristics (for details, see Table 1.1). This typology is mainly at the crowd level.

Table 1.1 Canetti (1962)'s crowd typology based on three relations between crowds and their members.

Characteristic	Crowd Type	Explanations
Growth	The **open** crowd	-Has no limit to its growth -Be open everywhere in any direction without houses, doors or locks to restrict the entrances
	The **closed** crowd	-Has boundaries -Has a limited number of entrances
Density & Equality	The **stagnating** crowd	-Be closely compressed & patient to a degree -It is impossible to move freely -The denser it is, the more people it attracts (E.g., spectators in theaters)
	The **rhythmic** crowd	-Keep the same rhythm with the other members in the crowd -Be blended in feelings, feel equal to others (E.g., the dancing crowd)
Remoteness of the goal	The **slow** crowd	-Be remote to its goal
	The **quick** crowd	-Be close to its goal -The goal is reachable in short time

Momboisse (1967) differentiated crowd types by focusing on shared interests and behavior of crowd members. The crowd types described by Momboisse (1967) include casual crowds, conventional crowds, expressive crowds and aggressive crowds. Casual crowds are the least organized or unified crowds, in which crowd members share a very temporary common interest and are usually without intense emotions and extensive interactions (e.g., crowds at an accident). Conventional crowds are deliberately gathered for a specific purpose. Crowd members follow pre-established rules or guidelines (e.g., people watching a film, a tennis match). Expressive crowds are emotionally charged at an event and behave expressively, but not destructively (e.g., crowds dancing, singing at a rock concert, people gathering for counting-down on New Year's Eve). Aggressive crowds concentrate intensely on an objective and engage in hostile or even illegal behaviors to achieve it (e.g., demonstrators, riots). This typology appears to expand towards group level.

Turner and Killian (1957, 1972) also took a close look at the crowd members to classify crowds. They defined five types of crowd "participants", namely the ego-involved, the concerned, the insecure, the spectators and the exploiters. The ego-involved crowd participants usually care about what happens and have ideas what should be done. The concerned care about what happens but have no idea what to do. The insecure members seek out crowds for a sense of power and security. The spectators are motivated by curiosity, who gather to see what happens. The exploiters are present for personal purposes and detached from the crowd objectives. For instance, the food sellers or thieves who do not care about the events in crowds and do not involve in any of the main activities. This typology expands further towards the individual level.

Berlonghi (1995) used a psychological metaphor to think of crowds. As he described, "*..., we tend to think of a crowd as having one personality... In reality [,] a special event crowd has multiple personalities*." He classified eleven crowd types, and emphasized that "*During most special events [,] all of the following specific types of crowds [the eleven crowd types] are either likely or possible.*" The explanations and examples of the eleven crowd types are presented in Table 1.2. This typology seems to be focused more on the crowd level, despite the individualistic metaphors.

Interestingly, another line of classification can be discerned that concentrates on the (emotional) condition of the crowd members. For example, Canetti (1962) also proposed to classify crowds "according to the prevailing emotion" of crowd members. Based on the assumption that a crowd is dominated by uniform moods and feelings, he classified crowds as the baiting crowds (e.g., collective killing), the flight crowds, the prohibition crowds (e.g., strike), the reversal crowds (e.g., the revolution) and the feast crowds. In a similar vein, Zeitz et al. (2009) took a perspective based on the crowd mood. They believed that crowds are either passive, active or energetic. For the passive crowds, there is little talking, physical movements, physical contacts or audience participation. The active crowds have a moderate degree of talking, physical movements etc. The energetic crowds involve a considerable degree of physical movements or audience participation. There might be episodes of violence due

to the intense crowd mood.

Table 1.2 Berlonghi (1995)'s 11 types of crowds.

Crowd Type	Explanations & examples
Ambulatory	**Crowds are walking, usually calmly.** (E.g., walking in and out of a venue, to and from parking areas, walking to use restroom or concession facilities, etc.)
Disability/ Limited Movement	**Crowds have limited or restricted movement.** (E.g., requiring additional planning according to the level or lack of ability to walk, see, hear or speak)
Cohesive/ Spectator	**Crowds are watching specific activities.** (E.g., watching an event or a scene of accident, etc.)
Expressive/ Revelous	**Crowds are involved in an emotional release.** (E.g., cheering, celebrating, dancing, chanting or singing, etc.)
Participatory	**Crowds are involved in actual activities of an event.** (E.g., professional performers, athletes, participating in a marathon, etc.)
Aggressive/ Hostile	**Crowds are becoming verbally aggressive, getting threateningly rowdy and are open to lawlessness.** (E.g., fighting)
Demonstrator	**Crowds are organized to some degree by some established leadership.** (E.g., picketing, marching, chanting or demonstrating at a particular location for a specific purpose)
Escape/ Trampling	**Crowds are attempting to escape from (real or imagery) danger.** (E.g., an organized evacuation procedure, a panic mob pushing and shoving with no order, etc.)
Dense/ Suffocating	**Crowds are in extremely high density and resulting in restricted physical movement.** (E.g., over-crowded concerts)
Rushing/ Looting	**Crowds purpose obtaining, acquiring or stealing something.** (E.g., rushing to get the most preferred seats, autographs or stealing property)
Violent	**Crowds are attacking, terrorizing and rioting with complete disregard for laws and the rights of others.** (E.g., riots)

Finally, Challenger et al. (2010) suggested ten potential dimensions to classify crowds in their book *Understanding crowd behaviors (Volume 1): Practical guidance and lessons identified*. These ten dimensions are (1) purpose of the crowd; (2) duration of the events; (3) start time (e.g., a football match or a concert has a fixed start time); (4) event boundaries (e.g., indoor or outdoor event); (5) event atmosphere (e.g., peaceful or aggressive crowd); (6) crowd membership identification: the extent to which crowd members share a sense of social identity (e.g., acquaintances or strangers, allies or opponents, groups of family or friends); (7) level of interaction; (8) heterogeneity of crowd membership; (9)

size of group unit (e.g., mainly singletons or mainly groups); and (10) amount of luggage. In this thesis, these ten dimensions will be used as a check list for identifying types of crowds (particularly in Chapter 3).

1.3.2 Historical views on crowds: From masses to individual crowd members

Documentations about crowd research date back to decades prior to 1900. As shown below, crowd theories have evolved from de-contextualization to contextualization of crowd behavior, from de-socialized to socialized conceptions of self and identity (Reicher, 2001), and from regarding a crowd as an entity of irrational, mindless mass to social categories of crowd members who express feelings and interacts with others.

The classic theories (i.e., crowd theories published from the second half of the 19th century until the 1930s) focus on the crowd level, considering a crowd as a mass, a homogeneous entity, within which the crowd members are mindless, irrational, suggestible and irresponsible. In this way, they ignored the context in which a crowd exists and the sociality of its crowd members.

Around the 1970s, researchers started to shift their attention to the group level. They realized that a crowd is not necessarily a violent and dramatic mass but consists of a variety of individuals who express different feelings but share the same social identity. Their behavior was considered to be governed by the norms emerged within the crowd or the subgroups.

More recently, computer simulations of diverse crowd situations allow crowd research to be conducted simultaneously at multiple levels, especially at the individual level, without the restriction of ethical issues. In general, simulated crowd members are represented as agents that follow laws of physics or more realistically, are guided by certain social forces. Laws of physics could be the ones derived from Newton's equation of motion or the kinetic theory of gases, concerning the attractions or collisions among particles. Social forces may be concerned with being attracted by other agents or "objects", accelerating toward a desired velocity of motion, and keeping a distance to other agents and the borders of pre-defined spaces (e.g., Helbing et al., 2005). At the moment, including an extensive set of variables concerning physical and social environments, human cognition and emotions in a simulation model remains difficult.

1.3.2.1 Classic crowd theories: A whole crowd of irrational, anonymous and irresponsible riots

As early as the 19th century, researchers had already tried to explain crowd behavior. Mackay (2002, originally published in 1841) offered an illuminating look at the madness of crowd in the Holland's 17th-century "Tulipomania" (when people went into debt collecting tulip bulbs). When mad and naïve crowd members were fired by greed, they mindlessly followed others and became gullible.

French physician and anthropologist Gustave LeBon, who was considered the most influential theorist of crowd psychology in his time (Nye, 1975; Triandis 1987), claimed that individuals in a crowd are entirely predominated by a collective mind and subject to contagion. They become irrational, feel anonymous and irresponsible for their acts (Le Bon, 1895). The idea of a collective mind refers to individuals in crowds losing self-identities and cognitive controls and behaving according to the collective will (Le Bon, 1895). In other words, crowd contexts serve as the "off switch" for self-identity (Reicher, 2001). After Le Bon, for a long period, crowd events have been written as if crowds were homogeneous, as if crowds were acting in isolation, and as if crowds were inherently monsters that were mindless and violent. For instance, Spanish philosopher y Gasset (1993, originally published in 1930) used the term "masses" in his book *The Revolt of the Masses*[8] to describe crowds. A mass is a crowd of intrinsically mindless members, who set no values on themselves, feel themselves "just like everybody". They are, in fact, happy about following everybody, believing that "to be different is to be indecent", because being different runs the risk of being eliminated. However, the mindless mass, in y Gasset's point of view, wishes to have opinions, but is unwilling to accept conditions or presuppositions. It forces to impose opinions but does not want to give reasons or to justify. It even decides to rule society without the capacity to do so, like *Fascism*.

Crowd theory, at this period, was decontextualized: individual behavior in crowds is neither shaped by society nor governed by self-controls (Reicher, 2001). Crowd behavior has been regarded as extraordinary or even pathological and not governed by the same rules that hold outside crowd situations (Allport, 1924; Mcphail, 1991). Individuals in crowds are de-individualized due to factors such as anonymity and lack of social constraints. These factors free them from the necessity to show normal social behavior (Zimbardo, 1969). All these so-called *classic crowd theories* (Reicher, 2001) tend to ignore the context in which the crowd is situated. They view a crowd as an entity, in this way, not only neglecting possible differences at the individual level and the group level, but also narrowly emphasizing disordered and violent aspects of crowds.

1.3.2.2 Emergent norms and shared social identity: Groups and social categories

A few decades later, the consideration of crowd research shifted from a thorough ignorance of context to sociality in crowds. The *Emergent Norm Model* proposed by Turner and Killian (1972) is regarded as an important step toward understanding the sociality of crowd behavior (Reicher, 2001). This model addresses the social coherence of crowd behavior by claiming that crowd behavior is normal rather than pathological or irrational. As Wijermans (2011) concluded:

"The mechanisms that underlie crowd behavior are the same mechanisms that give rise to behavior in general. This is an important realization as it makes clear that crowd behavior should not be considered as a special kind of behavior that needs its own set of dedicated theories."

8 The Spanish original, *Le Rebelión de las Masas,* was published in 1930.

Couch (1968) examined some stereotypes about crowds held by sociologists and claimed that crowds are not always irrational, suggestible or destructive. It is not rare to see cheerful crowds at festivals or well-behaved crowds at theaters. Even a crowd marked by violence is usually not guided by chaos or primitive instincts but by consensus: crowd members act in a well-organized manner against some common targets (Postmes and Spears, 1998). In contrast with Le Bon's belief that people in a crowd have no will, Postmes and Spears (1998) stated that people within a crowd are still capable of making conscious decisions, even though they are affected by a high number of variables that lead to de-individuation.

The reason why classic theorists (e.g., LeBon) considered crowds to be monsters is that they were facing the rapid change of society, especially the emergence of densely packed, big industrialized cities, such as Paris and Milan. "Crowd" at that moment was still a quite abstract concept and gradually growing as a common phenomenon in big cities (Nye, 1975). Viewing this new phenomenon, classic theorists concentrated mainly on its violent and dramatic moments, ignoring that the violence almost always happened after a period of "sense-making", during which crowd members communicate with each other, seek to redefine the situations and make sense of the confusion. Rather than viewing crowds as homogenous, Turner and Killian (1972) argued that crowds are characterized by different people expressing different feelings. But crowd behavior is not norm-less. It is governed by norms that emerge from the interactions among crowd members. Usually, these norms are dominated by the prominent members ("keynoters") (Reicher, 2001).

The *Social Identity Model (SIM)* proposed by Reicher (1982) differs from the *Emergent Norm Model* in that it emphasizes the shared identity of crowd members instead of shared norms. Crowd members are faced with a prolonged period of "sense-making" of the situations through interacting with others in the crowds (Reicher, 1982, 1987). Both Tajfel (1978) and Turner et al. (1994) have made a distinction between personal identity and social identity. The former refers to the unique characteristics of the individual compared to other individuals while the latter refers to an individual's self-understanding as a member of a social group compared to members of other social groups. Therefore, the key difference between *ENM* and *SIM* is that *SIM* stresses that the "sense-making" tasks are done by crowd members who consider themselves being part of a specific group instead of regarding themselves as separate individuals. Moreover, individuals in crowds do not lose self-identity but shift to a shared social identity that governs their behavior (Reicher, 2001). In other words, individuals in crowds do not simply care about what is the norm to follow in this context, but what is the norm to follow as members of this social group (Reicher, 2001).

Unlike the *classic crowd theories*, many theories from this period have received support from both experimental and field studies. The ideas behind *SIM* have repeatedly been confirmed and extended in diverse settings using different manipulation strategies of anonymity (e.g., Reicher, 1984; Lea & Spears, 1991). Postmes and Spears (1998) conducted a meta-analysis of a majority of these studies and concluded that anonymous individuals tend to conform to the norms

that are appropriate to the groups that they belong to. They do not lose their identities in crowds because they share a group identity that acts as a social determination of their behavior. However, *SIM* turns out to be less successful in explaining social and psychological changes in crowds over time (Reicher, 1996, 2001).

The *Elaborated Social Identity Model (ESIM)* incorporates the dynamics of group characteristics and norms by introducing intra-group and inter-group interactions (Reicher, 1996, 2001; Drury et al., 2003). Intra-group interactions refer to communication with other crowd members in the same group, while inter-group interactions are the communication between different groups in a crowd. *ESIM* stresses that changes of group characteristics and norms are caused by the asymmetric relationships between different groups, implying different perceptions of the same situation by these groups, which tends to lead to increased tension between these groups (Reicher, 2001). For instance, the cheerful behavior of football fans of Team A is regarded as annoying and inappropriate by football fans of Team B, while Team A fans consider themselves as normal and appropriate since Team A wins. This kind of asymmetric relationships can also be seen between crowd members and crowd managers (e.g., event organizers, police): an intervention that is regarded as an optimization of the situation by crowd managers, can be perceived as inappropriate by the crowd members. Thus, this difference in perception might lead to a new group norm that might regard revolt against the crowd managers as appropriate (Stott & Drury, 2000).

ESIM is one of the best available explanations underlying crowd behavior. It has made a valuable contribution in explaining the disorder of crowds (Scott et al., 2007, 2008; Schreiber, 2010). Schreiber (2010) further confirmed the explanatory value of *ESIM* for most instances of crowd violence, with her application of *ESIM* in field studies in different cultural contexts. However, it remains practically challenging to validate the explanations by performing experiments that might lead to situations involving ethical concerns. For instance, it is impossible to do real-life experiments on crowd evacuation in case of emergencies such as a fire, storm or other disastrous situations. Furthermore, the focus of *ESIM* lies on the inter-group interactions. The intra-group interactions, e.g., the details of how individuals within the crowds communicate, and how and why an individual behavior is chosen at a given moment, have not been included (Wijermans, 2011).

1.3.2.3 Computer simulations of the crowds: Crowds, Groups and Individuals

Currently, computer simulation models are used to understand and predict the aggregation and movements of crowds. Simulations of crowd behavior generally focus on visual animations to demonstrate how a crowd is likely to move and behave, and how it develops over time. They have made a great contribution to training in crowd management and control (Ulicny & Thalmann, 2001) and evacuation preparation (Farahmand, 1997).

Computer simulation models provide a means to test crowd theory at the crowd, the group and the individual levels. Some simulation models start with modeling individual behavior at the microscopic scale of single agents (i.e., computational individuals). Then, the simulation is scaled up through interactions among individuals to the generation of collective behaviors at the macroscopic scale of the group or the crowd. At the same time, the collective state of the crowd will impact locally on the behavioral rules adopted by individuals (Tosin, 2014). By representing crowd members as agents following certain rules based on the laws of physics (Bouvier, Cohen & Najman, 1997), the *Social Force Model* (Helbing & Molnar, 1995) and so on, computer simulation especially allows focusing on the individual level of crowd research without ethical restrictions. There are other models that focus on simulating crowd patterns emerging at group or crowd level, for example, crowds during evacuations and disasters (e.g., Sime 1983, Helbing et al., 2000), collective aggression and riots (e.g., Epstein 2002; Schwarz & Mosler, 2005), and pedestrian behavior and movement (e.g., Helbing et al., 2005, Duives et al., 2013). Most simulation models either propose a methodology of predicting a specific crowd behavior (e.g., crowd behavior at emergency evacuation, Dombroski et al., 2006) or generate a realistic type of crowd behavior (e.g., self-organizations of pedestrian crowds, Helbing & Molnar, 1998).

Still (2000) suggested that humans do not simply act like isolated computational agents following a set of rules enforced on them, and that crowd dynamics should be included. Henderson (1971) made an analogy between crowds, gases and fluids. The gas or fluid models describe the movement of individuals within a crowd as being continuous and fluid-like, with changes in density and velocity over time. Although the fluid dynamics and gas kinetics models were widely acknowledged as effective in describing the movement of crowds, Tosin (2014), however, pointed out that conservation laws of physics, typically expressing the fact that some physical quantities, such as mass, linear momentum, and energy of the system, do not change during evolution over time. These laws can hardly confine living systems such as human crowds because humans have the ability to elaborate behavioral strategies for chasing a purpose. In other words, humans in a crowd continuously "put and remove energy from the 'crowd' system in unconventional manners". Lee and Hughes (2007) also stressed that crowd members have the ability to think rationally, and to behave in a rational and goal-directed manner. Individuals in crowds have their own free choices and can stop and start at will. The complexity of human beings seems impossible to be completely captured by computational models.

In the review paper by Duives et al. (2013), seven types of computer simulation models that were developed in the last decade, were examined and compared with respect to their capabilities of modeling not only typical crowd motion and self-organization phenomena in high-density pedestrian crowds, but also other model applicability factors such as the internal decision processes (that is, physiological, psychological, sociological or physical considerations), route choice algorithms and computational burden. Duives et al. (2013) found that these models can be roughly divided into two classes: slow but highly precise microscopic models and very fast but behaviorally questionable macroscopic

models. In practice, the microscopic models are preferred. Three of them are capable of reproducing large sets of crowd motion phenomena: (1) the *Cellular Automata* (e.g., Bandini et al., 2011) that implement grid-based motion decision and long-range interactions, (2) the *Social Force Model* (e.g., Helbing & Molnar, 1995) with continuous representation of the space, and (3) the *Activity-Choice Model* (Hoogendoorn & Bovy, 2004) that incorporates a strategic decision-making process as a generalization of *Social Force Model.* In addition, the *Activity-Choice Model* (Hoogendoorn & Bovy, 2004), and the *Social Force Model*s (Helbing & Molnar, 1998; Xi et al., 2010) are capable of simulating most of the self-organization phenomena such as lane formation of pedestrians. This goes at the expense of either a large computational burden, or difficulties with internal processing of simulated "crowd members (agents)".

In the simulation model *CROSS*, Wijermans (2011) and Wijermans et al. (2013) acknowledged these difficulties and proposed a more "general sense" of focus on crowd behavior in two ways. First, they extended the focus on all types of crowds rather than only on the usual deviant crowd behavior (e.g., crowds at emergencies, stampedes or riots). Second, they enriched their agents by providing them with a physiology component (body), a memory component (knowledge representation) and two main processes (perception and behavior selection) to interact with the world. Consequently, the agents were influenced by both the external context (including both physical and social aspects of the environment) as well as their internal states. Therefore, these agents interact with their environment and produce behavior as a result of the interplay between their internal and external world. For instance, a *CROSS* agent can choose its behavior to be close to the stage or with friends, to dance, to go to the toilet or to go to the bar. The simulated behavioral patterns at the group or the crowd level are determined by the "individual behavior" of the agents. Wijermans (2011) applied the *CROSS* model in a festival context. It showed the importance of incorporating that the agents could choose between alternative behaviors for better understanding crowd behavior. However, Wijermans (2011) pointed out that, no matter how accurate an agent is "embodied and embedded", it is still an agent that is much simpler than a real human. Considering computational complexity, it remains difficult to include an extensive set of variables in a simulation model to represent real humans. That is the reason why the individual level of crowd research focusing on the internal states of crowd members does not play a main role in computer simulations.

In conclusion, from the classic theories prevailing more than a century ago, to diverse computer simulation models developed recently, and the notion of "the wisdom of crowds" (e.g., Surowiecki, 2005) as contrary to "the madness of crowds", crowd research has shifted its focus from merely on the negative aspects of crowds to a richer understanding of crowd behavior. Crowd researchers begin to realize the necessity to go into the crowd. There is a growing appeal for the individual level of crowd research, especially understanding the internal states of crowd members, such as their emotional experiences, because individuals in crowds are the ones who are affected and generate behavior. Reicher (2001) also argued that emotions in crowds have been largely ignored. Reicher (2001) suggested that progress in crowd research should

explore how emotions relate to the self-understandings of crowd members. He explained this with two examples: a crowd member may feel joyful to be part of a crowd, to be fully recognized as a group member, and to be able adequately to express one's identity. But a crowd member may also be angry at outgroup attempts to impede such expression.

1.3.3 Technological trends: For individuals in crowds

Nowadays, many technologies for crowd management focus on predicting crowd behavior at the crowd and the group level. Counting cameras, Wi-Fi sensors, GPS trackers and Bluetooth are applied to monitor crowds in terms of pedestrian speed, density and flow (Yuan et al. 2016; Duives et al., 2018). Yuan et al. (2016) developed a real-time crowd monitoring dashboard for a large nautical event (SAIL Amsterdam), which can process and visualize real-time data collected from the crowds. Weppner and Lukowicz (2013) presented and evaluated a technique for estimating crowd density by equipping just a few crowd members with a standard mobile phone to scan the environment for discoverable Bluetooth devices. Through the comparison and fusion of the data from the mobile phones, the technique showed over 75% recognition accuracy in identifying seven discrete classes of crowd density.

Recent developments demonstrate trends that technologies such as automatic data processing and pervasive sensing start to expand from the crowd level to the individual level (Pentland, 2014). Social media data, which are believed to provide real-time semantically rich insights into crowd behavior, are used not only for crowd density estimation (Gong et al., 2018) but also for sentiment analysis (El Ali et al., 2018). Computer-vision techniques have been employed to process videotaped crowd situations, aiming at characterizing and automatically detecting individuals with abnormal behavior in a crowd (e.g., Zhan et al., 2008; Yaseen et al., 2013), or aiming at recognizing the individual faces with high accuracy (e.g., Schroff et al., 2015) to assist the police in investigating the suspects.

The diffusion of pervasive and ubiquitous technologies such as smartphones and smart watches, wearable sensors and ambient sensors has enabled the monitoring of (crowd or social) behavior based on collected individual data through a wide range of sensing modalities, such as temperature, movement and spatial proximity (Atallah and Yang, 2009; Martella et al., 2014). Ubiquitous sensing technologies collect data from the individuals. Accumulated individual insights assist in understanding the overall crowd situations. For example, Wirz et al. (2013) have used smartphones to detect crowd dynamics, especially the social groups. Franke et al. (2015) developed a smartphone-based participatory crowd management platform. It gathers sensor data from the individuals using the app and enables smartphone-based delivery of event or space-specific information to more individuals in crowds. According to the location and situation of different areas, personalized instructions are provided to the people in those areas.

With the advances in technologies, making embedded systems that equip computation, communication, and sensing capabilities will become feasible. Ideally, such systems obtain data from the individual crowd members, and in return provide guidance and rich experiences to them.

1.4 THESIS OUTLINE

So far, three crowd levels have been identified. The crowd level focuses on issues like identifying critical density, flows and congestions in crowds. The group level articulates the social aspects of crowds, within which crowd members are forming groups and following norms based on intra- and inter-group interactions. The individual level focuses on crowd members themselves and especially their internal states (e.g., psychological, sociological or physical needs). The trends in crowd research and the technological development both point to the growing efforts into researching crowds at the individual level. In line with this trend, the focus of this thesis is at the individual level of crowd research. The goal is *to contribute to a better understanding of crowds from the perspective of individual crowd members' experiences.*

We carried out research on three aspects of experiences in crowds that are hypothesized to be influential in predicting crowd behavior: well-being (Chapter 3), emotional experience (Chapter 4, 5 & 6) and action (behavioral) tendency (Chapter 5 & 6). Well-being and emotional experience in crowds are two interwoven aspects of experiences. As discussed earlier in Section 1.1, positive emotional experiences that are involved in pleasurable and meaningful activities lead to better well-being (Kahneman et al., 1999). Action tendency is a reactive experience component that triggers a certain action or behavior when the person experiences a particular emotional state. Emotional experiences can result in certain action tendencies (Frijda et al., 1989). Besides emotional experiences, understanding the action tendency of crowd members is assumed to be one step closer to predicting crowd behavior.

This thesis is divided into two parts. Part 1 (Chapter 1 & 2) frames the state of the art of crowd research and crowd management practices. Part 2 (Chapter 2-6) is centered on the assumed relations between the three aspects of experiences of individual crowd members. Figure 1.6 illustrates the relations between the three aspects of crowd members' experiences investigated in this thesis and how these aspects are addressed in chapters.

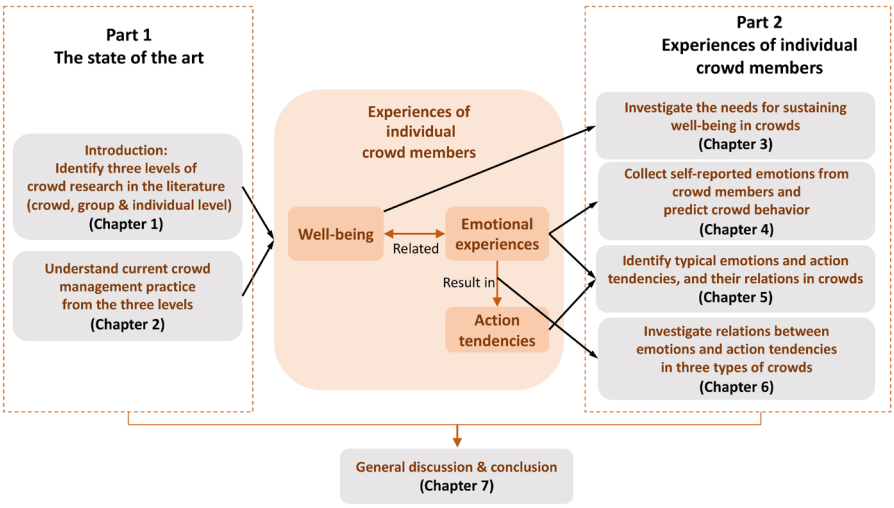


Figure 1.6. The assumed relations between the three aspects of crowd members' experiences (well-being, emotional experiences and action tendencies) and how these aspects are addressed in chapters.

1.4.1 Research questions

Five research questions have been raised according to the goal of this thesis: to contribute to a better understanding of crowds from the perspective of individual crowd members' experiences. These questions are addressed in Chapter 2 to 6, respectively. In Chapter 1, crowd research literature of the past decades was extensively reviewed and three levels of understanding crowd were identified (i.e., the crowd, the group and the individual level). To follow up, we approached the experts in crowd management, to learn how the current crowd management practice works. We asked:

RQ1: At what level do crowd experts understand crowd?

Chapter 2 is centered on RQ1. It starts with the review of the existing theories concerning different phases of crowd management and the current monitoring and communication strategies in understanding crowd behavior. Then, it presents the interviews with ten crowd experts, showing their strategies and how crowds are categorized by them in practice. Chapter 2 concludes that both the existing crowd management strategies in theories as well as those in practices emphasize *all three levels of crowd research*. Crowd managers indicated that they need to *have more knowledge about the individual crowd members, such as their emotions*. Therefore, we asked:

RQ2: What factors influence the experience and well-being of individual crowd members?

In Chapter 3, we explored, *from the individual level*, what factors contribute to the well-being of crowd members through context mapping studies with ten participants who were frequent visitors of crowd events. A classification of two distinct crowd types were identified in the studies, namely event crowds and non-event crowds. The factors concerning sustaining well-being are different in these two crowd types: crowd members in non-event crowds are more concerned about safety than those in event crowds. Safety does not contribute to but is an important consideration for obtaining well-being. In event crowds, relatedness, autonomy and competence are three prominent needs for sustaining well-being. After exploring well-being needs in event and non-event crowds, we wanted to investigate another aspect of crowd experience: emotions. We asked:

RQ3: How to obtain emotion data in crowds? How to use the data to predict crowd behavior?

In Chapter 4, we explored the possibility of measuring the emotions of crowd members from within an event crowd. To do so, a field study was conducted in an indoor music festival with approximately 800 visitors, where approximately 10% of the crowd members used a playful smartphone application (i.e., *EmoApp*) to report their locations, their emotions and the perceived emotions of others in their proximity. From tracking the individuals using the *EmoApp* anonymously, we were able to sample the emotions at different locations of the festival. The collected information reflects the real situations: participants' movements, emotional changes and the activities at the festival were consistent with each other.

Then, we realize that only measuring the emotions is not sufficient in predicting the behavior of crowd members, because we have noticed that negative emotions (e.g., bored, anxious) do not necessarily lead to negative behaviors (e.g., fight and flight). Therefore, we investigated a third aspect of crowd experience: the action tendency of crowd members, which is believed to predict crowd behavior more directly than emotions. We asked:

RQ4: What are emotions and action tendencies in crowds? What are the relations between emotions and action tendencies?

In Chapter 5, we investigated the typical emotions in crowds and identified the relation between crowd emotions and action tendencies based on a questionnaire study. Participants reported their emotions and action tendencies according to their recent crowd experiences (< 6 months ago). We defined a set of typical crowd emotional feelings and investigated relations between typical emotions and typical action tendencies in crowds. We concluded that people generally feel more curious, excited, connected and happy in event crowds than in non-event crowds. When they feel positive, they tend to have positive action tendencies, whether in event or non-event crowds. This study is one step further in predicting crowd behaviors. The studies conducted in Chapter 5 are based on the participants' recalled experiences. To validate the findings in Chapter 5, and

to further investigate the relations between emotions and action tendencies in different types of crowds, we asked:

RQ5: What are the emotions and action tendencies in three different crowds (event, spectator and non-event crowds)?

Chapter 6 addresses RQ5 by presenting a lab experiment. The three lab conditions respectively simulate three types of crowds[9], namely event crowds, spectator crowds and non-event crowds. A network of RFID sensors was used to measure the relative spatial positions (proximity) of crowd members. We investigated the relations between emotions and action tendencies based on the self-reported data from the crowd members, and explored whether it makes sense to look for possible relations between the emotion data and the relative spatial positions of the crowd members measured by the proximity sensors. To interpret the sensor data, we selected two analyses based on the proximity graphs: (1) the averaged sensor connectivity rate over time and (2) the number of groups identified. We chose these two analyses because we hypothesized, based on the characteristics of the proximity sensors, that a higher connectivity rate indicated bigger and well-connected groups in a crowd. According to the well-being needs identified in Chapter 3, connectedness (relatedness) is a necessary need for sustaining well-being and positive experiences in crowds. However, the sensor data (e.g., connectivity rate over time and number of groups in crowds) did not exhibit clear effects and, thus, clear relations with the self-reported emotions and action tendencies could not be established. In addition, we found indications that a positive emotional contagion effect might exist. The event crowd reported the greatest number of positive emotional feelings, the non-event crowd reported the least. The positive emotional feelings reported in the crowd was in-between the other two crowds. Finally, the findings suggest that changing a non-event crowd to an event crowd can bring positive emotional experiences to the crowd members.

Chapter 7 discusses the thesis contributions and the answers to the research questions. It reflects on three potential limitations of the methodologies applied in this thesis. It suggests, with better technological support in real-time big data processing, future research could implement the measured emotional experiences of individual crowd members to the crowd level, to support the crowd management team in better predicting and steering crowds. Figure 1.7 provides an overview of the questions, methods and answers in each chapter.

9 We called the three experimental groups "three crowds", because they were physically separated during the experiments, not within the same crowd. In a real crowd, these "three crowds" can be three groups coexisting in the same crowd.

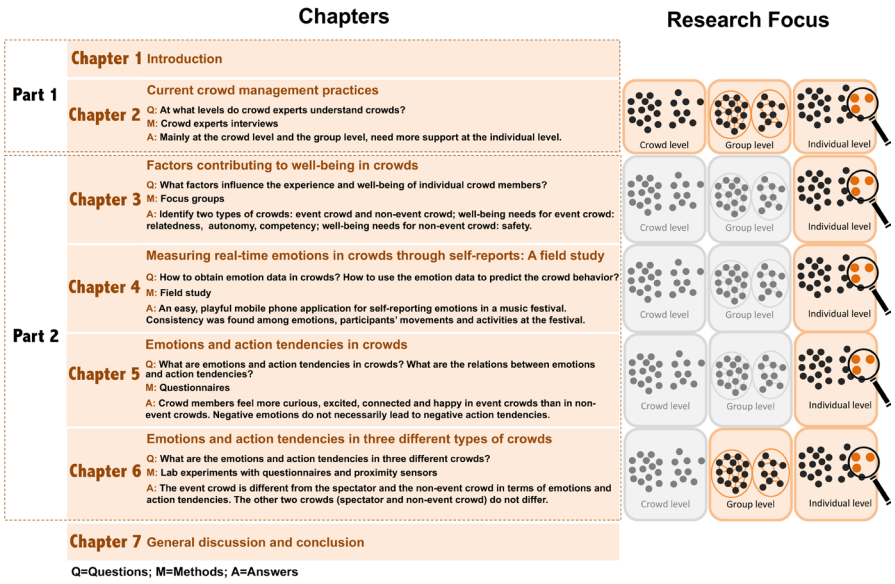


Figure 1.7. Thesis outline: Chapters and research focus (crowd level, group level or individual level)

1.5 MAIN CONTRIBUTIONS

The main contributions of this thesis are split in three types of contributions, including empirical findings, methods and design.

1.5.1 Empirical findings

- **Crowd types and factors contributing to well-being in crowds:** In the context mapping studies with crowd members, we identified a new way of classifying crowds based on the presence of events, namely event crowds and non-event crowds. For event crowds, the most prominent need for sustaining well-being is relatedness. For non-event crowds, the need for security and autonomy is the top priority. These findings provide a new way to look at crowd typology.
- **Collect self-reported emotions in crowds:** In the field study at the music festival, we collected emotion reports from about 10% of the visitors, using an easy-to-use mobile phone application based on the valence-arousal emotion model (Russel, 1980). The reports consisted of two categories: the emotion of the reporter himself or herself, and the perceived emotion of others in their proximity. The reported self-emotions and perceived emotions of others are highly related. The visitors' movements and emotional changes were consistent with the activities at the festival. This

study was a valuable trial to sample emotions in crowds.

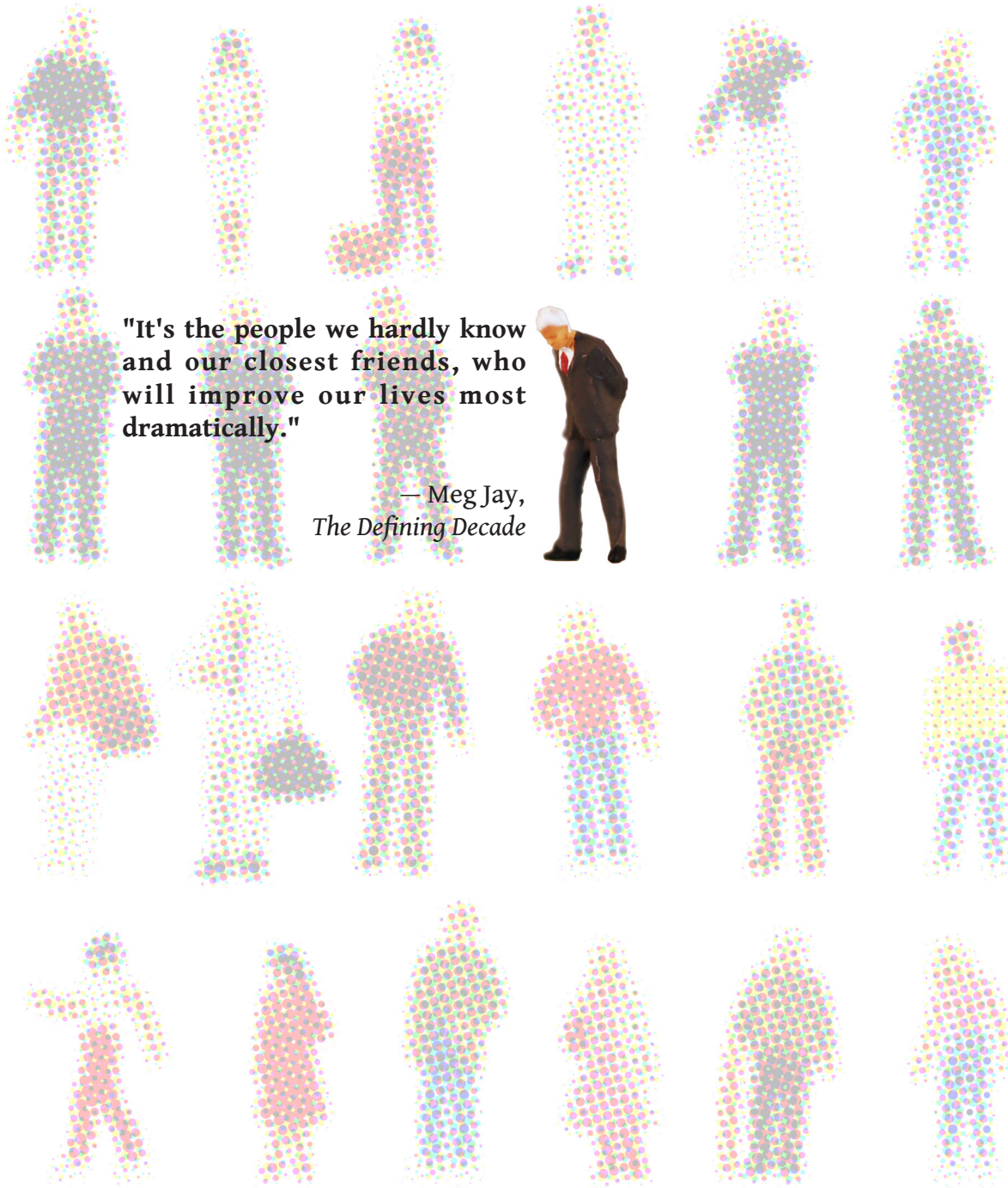
- **Identify typical crowd emotions and action tendencies in crowds:** We developed a set of thirteen typical emotional feelings in crowds and also identified eleven typical action tendencies based on the work of Frijda et al. (1989). Some frequently elicited emotional feelings in crowds, such as *togetherness*, *warm (psychologically), bustling, awkward,* and *breathless* are different from daily emotions. The findings suggest that this specific set of emotional feelings should be used to measure emotional experiences of crowd members, as an extension to the use of the valence-arousal emotion model (Russell, 1980). We also found that negative emotions do not necessarily lead to negative action tendencies. This suggests that only knowing the emotions may not be sufficient in predicting crowd behavior. A combination of emotions and action tendencies would provide a richer understanding of individual crowd members.

1.5.2 Methods

- **A field study to collect self-reported emotions through a smartphone application (*EmoApp*):** We introduce a self-reporting smartphone application to assess emotions in crowds. The reason why we choose the smartphone as the platform to run the self-report application is that most people use it daily. It is a more time- and cost-efficient way of collecting self-reporting data than paper-based questionnaires. The application was graphically designed with a reward mechanism to motivate crowd members to report their own emotion, real-time location and the perceived emotion of other crowd members in their proximity in a fast, playful and non-intrusive manner. To test the reliability of the application, a field study was conducted at a music festival. This field study provided an alternative way to assess crowd emotion and capturing its changes, which is valuable for the further design of self-report emotion applications.
- **A questionnaire with visualized typical crowd emotional feelings:** The thirteen typical crowd emotional feelings are visualized into cartoon characters. The questionnaire was applied in the study of Chapter 5 and the lab experiment in Chapter 6 as a tool to assess emotional feelings of crowd members.
- **A network of RFID-based wearable sensors for measuring the grouping activities in crowds:** Next to the self-report questionnaire, crowd members participating in the lab experiment wore RFID-based sensors that can detect each other within a distance of 2 meters. The collected sensor data partially reflected the grouping behavior in the crowds. The results suggest that future research should consider using sensors with more advanced functions, such as accurate positioning and physiological sensors.

1.5.3 Design

- **The graphical interface of the *EmoApp*:** The design of the interfaces followed three requirements: intuitiveness, non-intrusiveness and attractiveness. Following the three requirements, a set of four emotion cartoon characters were designed and placed on a circular interface, along with appropriate background colors for each emotion type and a game-reward component to motivate crowd members to use the application.
- **The graphical visualization of the thirteen typical crowd emotional feelings:** In addition to the four types of emotions used in the EmoApp, the study in Chapter 5 identified nine extra typical crowd emotional feelings. These emotional feelings are also visualized into cartoon characters that are in the same style as the ones in the *EmoApp*. The idea is to incorporate the emotion visualizations into the future version of the *EmoApp*.

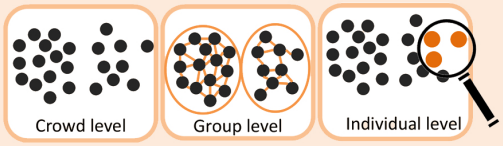


"It's the people we hardly know and our closest friends, who will improve our lives most dramatically."

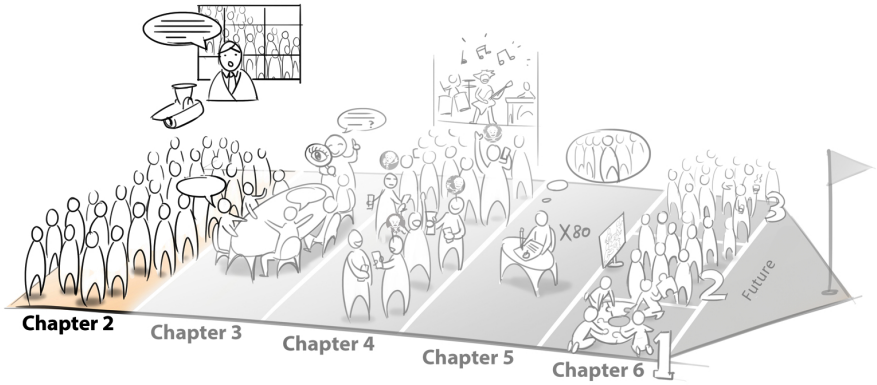
— Meg Jay,
The Defining Decade

CHAPTER 2

Current Crowd Management Practices



Chapter 2 reviews the existing theories concerning different phases of crowd management and the current monitoring and communication strategies in understanding crowd behavior. It presents the findings of interviews with ten crowd experts, showing their strategies and how crowds are categorized by them in practice. It concludes that, most efforts in crowd management are placed on the crowd level and the group level. The strategies concerning individuals in crowds are limited. Crowd managers had explicitly expressed their expectations in having support at the individual level of crowd management.



This chapter is written based on the following published articles:

- Li, J., de Ridder, H., Vermeeren, A., Conrado, C. & Martella, C. (2013). Designing for crowd well-being: Current designs, strategies and future design suggestions. In *Proceedings of 5th International Congress of International Association of Societies of Design Research*, IASDR'2013, Tokyo, Japan, 2278– 2289.
- Li, J., Vermeeren, A. & de Ridder, H. (2014). Designerly ways of exploring crowds. *International Journal of Cultural and Creative Industries, 2*(1), 4-17.
- Martella, C., Li, J., Conrado, C., & Vermeeren, A. (2017). On current crowd management practices and the need for increased situation awareness, prediction, and intervention. *Safety science, 91*, 381-393.

2.1 INTRODUCTION

The introduction chapter (Chapter 1) provided an overview of the history of crowd research and the development of the enabling technology. It introduced three levels of approaching crowds, namely at the crowd level, the group level and the individual level. The overview also described how the focus of crowd research has shifted from seeing a crowd as a mass to seeing it as a gathering of rational individuals. The recent developments in technology have also directed crowd research toward the individual level.

One way to gain a better understanding of crowds and individuals in crowds is to approach those who have good knowledge about crowds: crowd experts in practice. A crowd manager is one such expert: he or she is well-trained in, and responsible for the systematic planning and monitoring of an orderly movement or gathering of people (Zacherle, 2010). With the objective of preventing problems, securing, protecting and preserving the well-being of all individuals present and involved in a crowd, the tasks of a crowd manager concern all three levels at the same time: the individual, the group and the crowd level. To proactively execute planned strategies, crowd managers systematically prepare before crowd events taking place, and continuously monitor and analyze movements of crowds, group dynamics, and behavior of individuals during the event (Runkel & Pohl, 2012).

From June until September 2012, we interviewed ten crowd experts to establish what the current strategies in crowd management are and how effective these strategies are in terms of monitoring, understanding, predicting and steering crowds. This chapter discribes the procudure of the interviews and the findings, which is organized as follows. Based on the literature, Section 2.2 presents the state of the art on crowd management including crowd monitoring and understanding, how communication is organized, what strategies are widely applied and what challenges today's crowd management faces. Section 2.3 describes the interviews with the crowd experts, resulting in a refined definition of crowd management and crowd control. This section introduces nine types of crowd situations from the perspective of crowd experts. Conclusions can be found in Section 2.4. The main finding is that current crowd management focuses on monitoring crowds from the outside, and that there is a growing necessity for assessing emotions of crowd members to enhance the understanding and prediction of crowd behavior.

2.2 UNDERSTANDING CROWDS FROM THE PERSPECTIVE OF CROWD MANAGEMENT: THE STATE OF THE ART

When talking about crowd management, two terms always pop up: crowd management and crowd control. The distinction between these two terms is

somewhat blurred because they are interrelated (Abbott & Geddie, 2000). Yet, they are different, because, in general, crowd management is proactive while crowd control is reactive (Berlonghi, 1995). *Crowd management* aims at facilitating the movement and enjoyment of crowd members in normal crowd situations (Berlonghi, 1995). The tasks in crowd management include (1) thorough planning and preparation by considering a number of critical matters, like potential crowd behavior, seating arrangements, transportation, time, parking, weather conditions, demographics, crowd size (Berlonghi, 1994), (2) creating a wide range of "what-if" scenarios, and (3) personnel training in planning for and managing crowd events (Challenger et al., 2010; Alghamdi, 1993). To ensure that a wide range of knowledge, expertise and perspectives are carefully considered, crowd management is usually done in teams of experts with different backgrounds, such as event organizers, coordinators of public transportation, government, security personnel, emergency services, and police (Challenger et al., 2010). *Crowd control* aims at restraining unlawful and unsafe behaviors. It is usually taken care of by law enforcement officers (e.g., police) and security personnel (Berlonghi, 1995) when the crowd (or part of it) is beginning to or has already got out of control, for example, behaving in a disordered or dangerous manner such as fighting (Abbott & Geddie, 2000).

Ideally, a well-conceived crowd management plan will eliminate the need for extensive crowd control. In other words, most crowd problems can be prevented or quickly resolved when all aspects of crowd management are well organized (Berlonghi, 1995). This thesis, therefore, focuses on crowd management.

2.2.1 Communicating with the crowds

Understanding crowds is based on good communication between the crowd management team and the crowd members. As Health and Safety Executive (2000) stressed:

"*Good communication is an essential feature of managing crowd safety. Organizers, their staff and other personnel all have a key role to play*".

Speaking of good communication in crowd management raises the question of what communication methods are applied and what is a good way of communication. Watt (1998) suggests five means of communication in coordinating crowd management, namely verbal, nonverbal (e.g., body language, gestures, facial expressions), written, visual and electronic communication. Electronic communication is considered as the most effective method nowadays. It includes the use of two-way radios, cell phones, instant messaging services, and the Internet, etc. These electronic facilities can help crowd managers to communicate at larger distances and faster than the other four methods. Communication in crowd management has several objectives: (1) send a message, (2) have a message received, (3) ensure understanding, (4) achieve corrective action, and (5) exchange information (Watt, 1998). Figure 2.1 shows the general structure of crowd management in which these objectives have been incorporated.

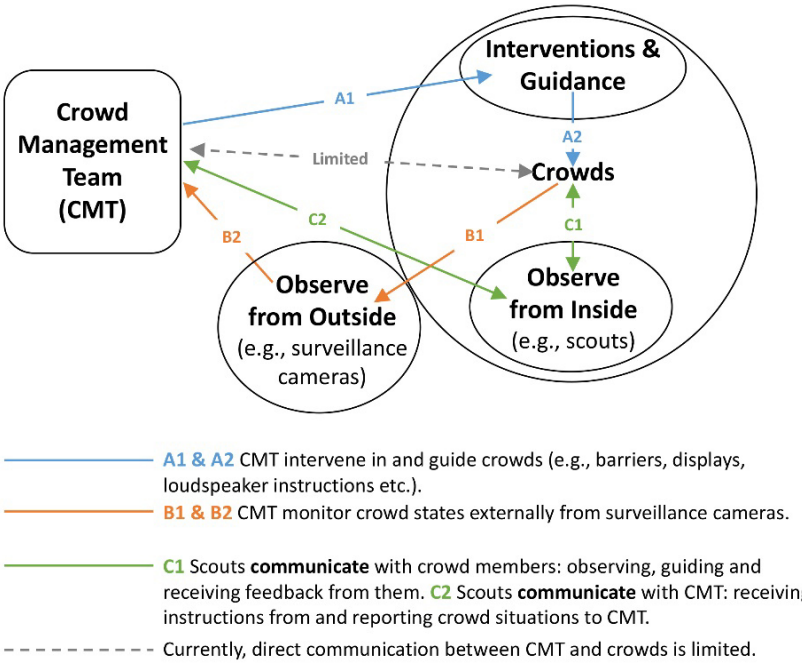


Figure 2.1. The main structure of crowd management before and during crowd events.

Sime (1999) pointed out that the communication between the management team and the crowd members is usually delayed. This delay becomes critical during crowd events. Many crowd disasters happened when crowd members received inadequate or no information about a potential danger in advance. For instance, the 2010 Love Parade tragedy in Germany, where a large crowd of people got trapped in a narrow tunnel. People outside the tunnel did not receive a warning in time, so they kept on moving towards the tunnel. This accident resulted in the death of 21 people (Helbing & Mukerji, 2012). Sime (1999) suggested the following for preventing the delay of warnings for potential dangerous situations: a control center (CC) for the crowd management team, a closed-circuit television (CCTV) system and a public address system[10].

Sime (1999) also pointed out the importance of way-finding design and guidance systems, such as exit signals and visual display signs. Abbott & Geddie (2000) found that signage is widely used as a significant communication method between the management team and crowd members. Signage can function as a warning (e.g., caution: overcrowding on the square) or instruction (e.g., smoking free venue), or serve to inform (e.g., raining in 15 minutes) or to direct a crowd (e.g., take the blue path to the event field). Health and Safety Executive (2000)

10 A public address system (PA system) is an electronic system comprising microphones, amplifiers, loudspeakers, and related equipment. PA systems are used in any public venue that requires that an announcer, performer, etc. be sufficiently audible at a distance or over a large area. Explanations are adopted from https://en.wikipedia.org/wiki/Public_address_system, retrieved on October 31, 2017.

also suggested some effective ways to communicate with crowd members. For instance, provide extended information on the tickets or other promotional materials of the crowd event (e.g., about transportation, venue entry details, venue layout, rules and prohibitions). Use electronic screens or boards to announce essential information about changes such as a delay of transportation. Open alternative entrances or emergencies. Use public address systems to inform, direct and advise crowd members. Give specific guidance to crowd members by personnel. Use an information desk as a point to collect questions and to give advice.

Good communication needs to be ensured before a crowd event taking place, allowing crowd members to receive sufficient information and be well prepared for the event. During the crowd event, good communication is particularly important for crowd managers to understand, predict and properly intervene in crowds. Currently, crowd behavior is mainly understood through constant monitoring by video surveillance cameras based on CCTV systems and personnel patrolling in crowds (Health and Safety Executive, 2000). Crowd monitoring considers three main aspects: (1) monitoring the overall number of people to ensure that the crowd size will not exceed the overall venue capacity; (2) monitoring the distribution of people to make sure that local over-crowdedness does not exist; (3) monitoring and identifying potential crowd problems, such as disordered or dangerous behavior. Potential problematic areas, such as entrances and exits, attractions, stairs, escalators, queues, enclosed spaces should always get more attention (Health and Safety Executive, 2000).

CCTV systems in crowd management are technologically varied. They can range from a system consisting of a few fixed cameras at key locations (e.g., potential problematic areas), a system using remote operation cameras with a zoom lens that have extensive coverage, to a system using cameras that can automatically identify abnormal behavior (Dee & Velastin, 2008). A CCTV system allows the crowd management team in the control room to have an overview of several key areas. The use of CCTV is helpful in crowd management, largely reducing the workload of personnel patrolling in crowds (Health and Safety Executive, 2000). Technological advancement in the video surveillance cameras has initiated many investigations into their potential for topics like crowd density estimation, crowd behavior monitoring, face detection and recognition in crowds (Saxena et al., 2008; Johansson et al., 2008). Despite all technological developments, it remains a challenge to continuously monitor changes in crowds, and distinguish and track individuals in crowds, especially in a large and dense crowd (Dee & Velastin, 2008; Versichele et al., 2012).

Besides surveillance cameras, another way of monitoring crowds during events is to place well-trained security personnel (e.g., scouts) in crowds. In this way, the security personnel stay close to crowd members, so that they can observe facial expressions of crowd members, identify pushing and surging, and search for signs of negative emotions or atmosphere. They can also assist people in way-finding or discourage dangerous behavior such as running on a slippery floor (Health and Safety Executive, 2000).

However, both surveillance cameras and security personnel have their limitations. The security personnel are good at certain tasks (e.g., sensing crowd emotions, detecting unusual behavior), but for them, it is impossible to take care of large areas. For instance, it is difficult for them to detect abnormal behavior far away or detect a small abandoned package in a crowd. The CCTV systems can cover larger areas but require much effort to observe all the camera scenes in real time. As acknowledged by Wallace and Diffley (1988), each operator in the control room can only monitor one to four screens at a time. In practice, only a small fraction of the information collected by cameras is ever watched in real time. Following an accident, the remainder can only be viewed in recorded time (Dee & Velastin, 2008). Automation of data processing and anomaly detection by CCTV systems are still limited. Automatic estimation of the crowd density from the video data, can be performed in not too complex crowd situations, but not for crowds of hundreds or thousands of members (Idrees et al., 2013). In addition, the psychological aspects of crowd members (e.g., emotions, tendencies to behave) remain difficult to address via CCTV systems. Insights into the psychological aspects of crowd members may be obtained by analyzing data from social media (Martella et al., 2017) or self-reports by crowd members (Li et al., 2013a).

Besides CCTV systems and personnel in crowds, counting systems are nowadays used to estimate the number of people in a crowd. For instance, some events provide wristbands to the crowd members. Wristbands function as tickets. Issuing an agreed number of wristbands can prevent overcrowding. Turnstiles linked to an automatic counting system can count the number of people entering a venue and control the speed of the crowd flow (Health and Safety Executive, 2000). Versichele et al. (2012) applied Bluetooth for detecting crowd size and movements during the 2010 Ghent Festivities. They had recognized 80,828 visitors over ten days. Besides, they estimated the ratio of people who had turned on their Bluetooth on their mobile phones to be about 12%. The extrapolated number of visitors was close to the estimation made by the city government. While effective in estimating, Bluetooth can generate biased results by oversampling certain segments of the total population (Rice & Katz, 2003). For example, adolescents might carry more Bluetooth-enabled devices than seniors and young children. Versichele et al. (2012) admitted that the visitors to the Ghent Festivities indeed had multiple profiles that might significantly influence the estimations.

In conclusion, referring to the tasks of crowd management as introduced at the beginning of Section 2.2, most efforts are spent on preparations before crowd events. During crowd events, direct communication in real time between the crowd management team (CMT) and the crowd is mostly missing. As illustrated in Figure 2.1, communication between CMT and crowd members happens from the outside with the help of either external observations (e.g., surveillance cameras) or from the inside through internal observers (e.g., scouts). Indirect communication may result in a delay of message transmission. Therefore, an "interface" between CMT and crowd members is needed to allow direct communication between them. Such an "interface" belongs to the *crowd-interaction subsystem* of the INCROWD framework developed by Wijermans et al.

(2016). This framework is introduced in the following subsection.

2.2.2 INCROWD framework: Four subsystems for supporting crowd management

Wijermans et al. (2016) developed a framework named INCROWD, which is used as a lens to organize existing models (e.g., theoretical models, computational models) about crowd research. This framework represents an architecture for organizing decision support for crowd management and serves as a basis for identifying various "instruments", including both computational and non-computational ones necessary for crowd management. The connections between the four subsystems of INCROWD illustrate the overall flow of crowd management (Arrow 1 to 5 in Figure 2.2). Examples of computational and non-computational instruments are included in the descriptions of the four subsystems below.

(1) The **crowd-interaction subsystem** works as an "interface" between crowd members and crowd management teams. Through this subsystem, the crowd management team collects data about crowd states, meanwhile providing intervention, guidance or feedback to crowd members. Two types of interfaces, namely actuators and sensors, serve different functions. Actuators that are typically applied to intervene in a crowd are mobile barriers, traffic lights, billboards, displays, turnstiles and feedback through smartphone apps, etc. These actuators are computational instruments when they are autonomous and fully controlled by computers. Interventions given by security personnel, manually controlled traffic lights and mobile barriers are examples of non-computational instruments, as they are not autonomous but controlled by humans. Sensors are used to measure or sense the state of a crowd. If (simple) data collected by sensors (e.g., crowd density, flow speed, keywords of conversations, etc., collected by surveillance cameras, microphones, digital sensors, social media, or a human) can be directly fed into a computer for analyzing, they belong to the computational instruments. Advanced data (e.g., crowd emotions, behavior, expectations) collected by the patrolling security personnel, for example via questionnaires, are non-computational.

(2) The **mining subsystem** is meant to reduce the complexity of collected crowd data coming from the crowd-interaction subsystem (Figure 2.2, Arrow 1) by filtering the noises or searching for patterns. Then, it interprets the mined data to capture the state of a crowd. Typically, it employs a variety of data-mining techniques, including computational instruments that can (in principle) analyze the data in a fully automatic manner as well as non-computational instruments, such as theoretical models about crowd behavior, knowledge and interpretations provided by crowd experts.

(3) The **predicting subsystem** is for predicting developments or dynamics in a crowd, based on the interpretations made in the mining subsystem (Figure 2.2, Arrow 2). It may incorporate computer simulation models to generate synthetic crowd data sets. These synthetic data sets can then be fed into the mining subsystem for further analysis and interpretations (computational) (Figure

2.2, Arrow 3). Another critical element in this subsystem is the knowledge of crowd experts, which contributes significantly in predicting future crowd states (non-computational) by using theoretical or mental analysis, such as scenario thinking.

(4) The **decision-making subsystem** contains computational and non-computational techniques and methods that support decision making about what interventions should be implemented in crowds. Based on input from the mining subsystem (Figure 2.2, Arrow 4), it involves generating or selecting an intervention, which is put into crowds through the actuators in the crowd-interaction subsystem (Figure 2.2, Arrow 5).

Note that the INCROWD framework is envisioned as a continuous loop. The effects of the implemented interventions may be evaluated by feeding the new crowd data into the mining subsystem, and the crowd-interaction subsystem.

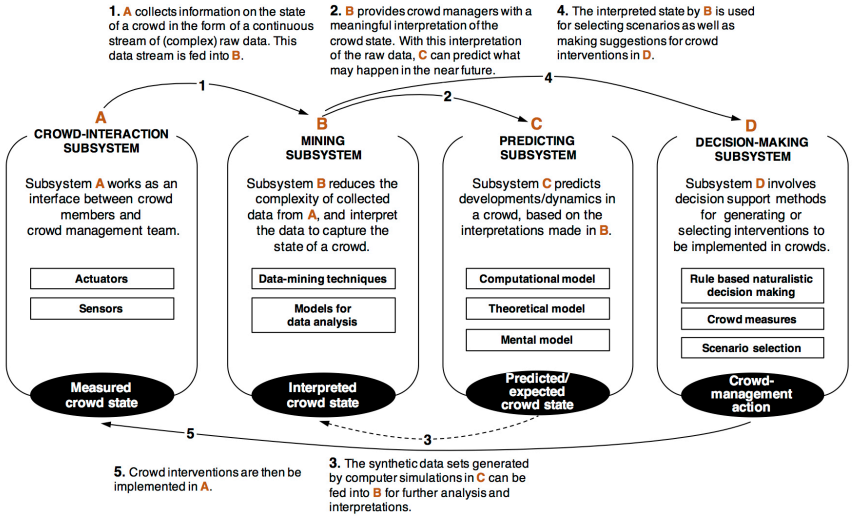


Figure 2.2. The Four subsystems of INCROWD and their interconnections (adapted from Wijermans et al., 2016)

By applying INCROWD to analyze the existing crowd management models found in the 237 articles, Wijermans et al. (2016) concluded that most models (89%) are computational and most models (94%) are still in development, and not yet mature enough to be applied in practical crowd management. A majority of the models in development belong to the predicting subsystem (77%), followed by mining subsystem models (13%). Only a few papers consider the crowd-interaction (5%) and decision-making subsystems (4%). Based on these findings, Wijermans et al. (2016) suggested several future directions: (1) focusing more on automatic crowd sensing and crowd data mining, (2) developing possible interventions for managing crowds towards a desired state, and (3) concentrating on collecting more data on individual crowd members, focusing on their emotions and behavior.

The last suggestion is in line with Berlonghi (1994) who stressed that psychological aspects of individual crowd members, such as emotions or moods must be assessed, because crowd members may be angry or aggressive due to tardiness, overnight waiting, or intense rowdiness. Always paying attention to the emerging tension between rivals may help ease the confrontations in time. This is nicely summarized by Bob Quintella, stating that:

"To keep management from crossing over into crowd control, one of the most important things to do is correctly assess the mood of the crowd" (Waddell, 1997).

2.3 UNDERSTANDING CROWD MANAGEMENT BASED ON CROWD EXPERT INTERVIEWS

Section 2.2 reviewed the state of the art of crowd management, presenting the strategies concerning managing crowds before and during events. It ended with stressing the importance of correctly assessing the emotions of crowds. To have a thorough understanding of the concerns in actual crowd management practice and to see whether these are similar to those described in the literature, interviews with crowd experts were conducted. This section presents the interviews with crowd experts who are actively involved in crowd management practice. The goal of the interviews was to find out whether the strategies found in the literature are widely applied in today's crowd management, and what the expectations of crowd experts are about improving the understanding of crowds.

2.3.1 Methods

The interviews took place in the summer of 2012. This section presents the selection of interviewees, the interview procedure and the methods for analyzing the collected data.

2.3.1.1 Interviewees

Many factors, such as types of crowd event, locations, visitor profiles, time of year, and weather, have an impact on the selection of crowd management strategies. To achieve variety, we approached ten organizations in the Netherlands that allowed us to cover a wide range of events and crowds, from daily emerging crowds during peak hours in train stations to crowds attending festivals. The ten chosen organizations were known for hosting and managing large crowds in the Netherlands or Europe. From each organization, we interviewed a senior professional with experience in dealing with large crowds. We called these professionals crowd experts (CEs). Separate interviews were conducted with each of the experts. The ten interviewees and their domain of expertise are summarized in Table 2.1.

Note that, even at one single location, e.g., a train station, crowd experts (CEs) may have different tasks. For example, CE 3 was a station manager whose primary task was to manage crowds at the station during weekday peak hours. On special days, like national celebration days or decisive football matches, large

crowds take trains to go to their destinations. It is also CE 3's task to take care of them. CE 10 also worked at a station, but he was specialized in crowd flow management. His main job was to monitor crowds with the aid of technologies, such as surveillance cameras, Bluetooth and Wi-Fi signals. An expert from an organization that was specialized in designing and building barriers for large events was also invited as an interviewee. This expert (CE 6) presented different perspectives and use cases of crowd management. Finally, the organization we label as "Security Company" differed from the other organizations due to their consultancy-oriented business model, and their experiences in managing a wide range of crowd events. They were experienced in delivering crowd management training and workshops, as well as providing consultancy and crowd management services on diverse crowd events.

Although the work contents of the approached crowd experts were not the same, the type of crowd they have managed fitted to our definition of a crowd as described in Chapter 1: "*A gathering of diverse individuals at the same physical location, at the same time, for some shared or different goals or interests*".

Table 2.1. The interviewees: Ten selected crowd experts (CEs).

Working contexts of the ten crowd experts (CEs)	Crowd size (Persons)	Crowd duration	Description
CE1. Indoor music festival	1000-2000	8 hours	Chief organizer of an annual indoor music festival, coordinating the preparation, registration, staff training, communication during the festival
CE2. Indoor conference	1000	12 hours	Chief organizer of an annual large indoor conference, coordinating the registration, communication, transportation, parking, catering etc.
CE3. Central train station	250,000	4 hours	Crowd manager of a central train station in a capital city, managing the crowds in daily situations and large events
CE4. Police	700,000	8 hours	Crowd manager involved with large crowds e.g., on a national festival
CE5. Security company	1000-100,000	Several hours to days	Head of a security company, providing consultancy and crowd management services on diverse crowd events
CE6. Barrier company	1000-100,000	Several hours to days	Head of a barrier company designing and building custom barriers for various types of crowd events as well as managing their layout
CE7. Outdoor music festival	60,000-100,000	3 days	Manager of an annual outdoor music festival, coordinating the site construction, ticketing, crowd flow control, transportation, parking, catering, etc.
CE.8 Stadium	55,000	4-5 hours	Crowd manager of a stadium, managing the crowds for various events, such as concerts and football matches
CE.9 Theme park	40,000-60,000	12 hours	Manager of a theme park, focusing on managing the daily crowd flows, queues and large crowds (e.g., crowds watching a music fountain) during holidays
CE.10 Central train station crowd flow management	180,000	12 hours	Crowd manager of a central train station, monitoring real-time crowd flows via video cameras, Bluetooth and Wi-Fi signals

2.3.1.2 Procedure

We conducted semi-structured interviews with crowd experts. The interviews addressed five main topics, including (1) (daily) operations and processes in managing crowds, (2) crowd characterization, (3) managing strategies and use of technologies, (4) feedback about current strategies and technologies, and (5) expectations about future strategies and technologies.

The reason why the interviews were called "semi-structured" is that they were well-prepared with goals and an outline of questions, but they did not strictly follow the question-answer pattern. The interviewees were encouraged to tell stories and give extra explanations about each topic (Remington & Tyer, 1979). We chose to conduct semi-structured interviews because they guarantee consistency in the topics that were addressed, but also allow the interviewees to diverge and provide their unique personal perspectives when necessary. This approach stimulates interviewees to share concrete stories about each topic rather than provide general and abstract information. It may raise new topic-related questions that can adequately elicit issues to compose a more comprehensive report (Remington & Tyer, 1979).

Each interview was scheduled around 1 to 1.5 hours at the workplace of the crowd expert and was recorded with a voice recorder. During the interviews, crowd experts were encouraged to write and sketch about the topics and show the interviewers around in their workplaces. For instance, the manager of the stadium took the interviewers to the central control room and explained how evacuations are executed in his everyday working environment. All the artifacts discussed in the interviews, for example, sketches, booklets, photos, or maps, were collected.

2.3.1.3 Data analysis

The voice recordings of the ten interviews were analyzed following four steps as suggested by Sanders and Stappers (2012): (1) transcription, (2) interpretation, (3) categorization, and (4) presentation.

(1) Transcription. The recorded interview conversations were transcribed into texts right after the interviews. The collected artifacts were used to aid the transcription process.

(2) Interpretation. After the transcription, a team of three researchers coded the texts of each interview as follows. First, each researcher read all the transcripts and independently selected the relevant paragraphs that matched the five main topics or raised some new interesting issues. Then, the team collaboratively grouped the overlapping choices into statement cards. In cases for which no consensus could be found, the researchers discussed whether to discard or to keep the paragraphs. A statement card consisted of a group of selected paragraphs cut out directly from the printed transcripts and a statement summarizing the paragraphs (see Figure 2.3-a). The three researchers generated 241 statement cards in total.

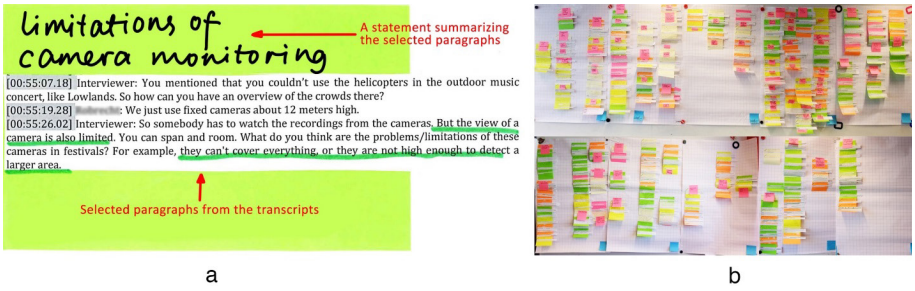


Figure 2.3. (a) An example of statement card; (b) The categorization of the statement cards (Martella, Li et al., 2017).

(3) & (4) Categorization and presentation. For Step 3 (Categorization), a fourth researcher joined the team. To categorize the statement cards, the four researchers followed a process resembling a bottom-up clustering process. Statement cards were grouped inductively into categories, and so were the resulting categories, when possible, until no more categories could be generated or grouped. The clustering was not directed by any pre-defined category, so category names emerged during the process. The session was carried out in a room with walls covered by magnetic whiteboards. A1-size white paper sheets were fixed on the wall with magnets. The statement cards with relevant information were put together on the same A1-size sheet. Statement cards from different crowd experts were made into different colors, making it possible to track back to the transcripts (Figure 2.3-b).

The categorizations of the 241 statement cards were summarized as a poster named "Crowd Management Narratives". Figure 2.4 is a simplified version of the poster. The complete version of the poster is presented in Appendix 1, visualizing the categories and a summary of the statements under each category. It also highlights a few selected quotes from the crowd experts, which are considered as relevant to certain categories. An interpretation of the poster is presented in the next section.

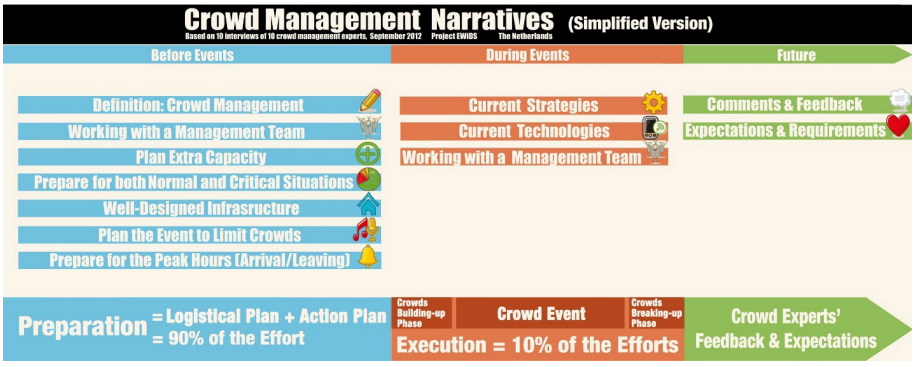


Figure 2.4. A summary of the statement cards categorization (simplified version).

2.3.2 Results

Three main categories were identified based on categorizing the 241 statement cards, namely “preparation before the events”, “execution during the events” and crowd experts’ “feedback and expectations for the future”. Each category consists of several sub-categories. For example, the second category “execution during the events” can be further divided into three sub-categories: “current strategies”, “current technologies” and “working with a management team”.

2.3.2.1 Before crowd events: Communication for preparation

Communication within the crowd management team. Before crowd events, the communication mostly happens face-to-face within the management team. For a successful crowd event, it is important that all the representatives of the management agencies (e.g., public transportations, stadiums, police, event organizer) sit together to prepare for the event.

Each representative in the crowd management team is assigned with specific tasks according to his or her expertise. For instance, the police are mainly responsible for the crowd control or riot control, ensuring crowd safety when things go wrong. Event organizers train all personnel (e.g., personnel for security, first-aid, catering) and coordinate tasks like looking after the number of tickets sold, the mobility plan and the layout of the event site including the position of barriers, entrances, exits, toilets, and food stands, etc. Train station managers are responsible for keeping the train moving, transporting and guiding crowds to the event. The barrier experts decide on the application of appropriate barriers and lead the construction of barriers on the event site. For instance, two types of barriers are widely applied, bone-structure barriers and line barriers (Figure 2.5). The bone-structure barriers are typically arranged in front of a stage at a concert and can effectively prevent the crowd members from the back pushing forward. They are surrounded by soft fences that can be easily pushed down or crossed over. The bone-structure barriers also allow people to enter and evacuate the event field from all directions. The line barriers which force people to queue in line can frequently be seen in many places, from airports to theme parks,

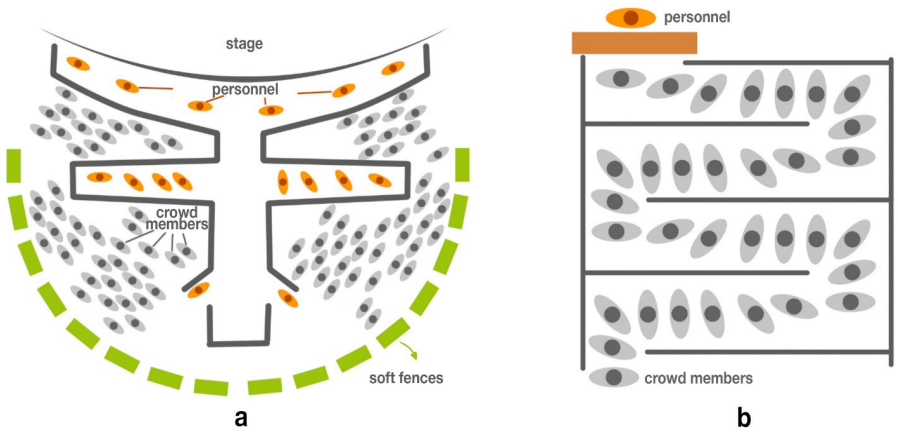


Figure 2.5. Two types of barriers: (a) the bone-structure barriers, and (b) the line barriers.

The main goal of the preparation is to allow the crowd to move freely and safely, but at the same time, to avoid certain dangerous or unpleasant situations caused by factors like uneven distribution of crowd members, obstructions and bottlenecks on the event site. The preparation starts with a definition of the desired behavior of crowd members. The crowd management team defines what behavior is proper in the context of a specific crowd event. This definition guarantees that the outcomes of all the decisions should eventually steer the crowd towards the desired behavior during the event. The content of preparation communicated in the management team consists of a series of what-if scenarios and strategies concerning how to respond to each scenario. These scenarios are typically constructed with the knowledge and insight of all the crowd management agencies and the aid of computer simulations. The scenarios are prepared for both normal and critical situations.

The CEs mainly discussed normal scenarios and only a few critical scenarios. Normal scenarios comprise strategies to manage crowds based on normal influential factors such as weather, visitor profiles, locations (e.g., indoor or outdoor), most crowded areas and peak hours. For example, CE 6 pointed out that if a long queue appears in front of a bar and blocks the path, barriers should be placed to make the crowd queue up in a different direction to free the path. Several CEs mentioned that, for an indoor event, the crowd size should be limited according to the number of emergency exits of that building. According to CE 1, in the Netherlands, the number of crowd members allowed in an indoor event is determined by the width of all the evacuation exits, which is 90 people per meter. That is to say, if an indoor event site has five evacuation exits with a total width of ten meters, then, the maximal crowd capacity of this site is 900 people. Critical scenarios deal with emergencies such as evacuation plans and crowd control.

Two categories of factors that influence the planning were identified in the interviews: internal factors and external factors. Related inquiries for each factor are presented in Table 2.2 and 2.3. These inquiries are typical questions

to be considered and decided by the management team during the preparation. Internal factors relate to the crowd itself, such as crowd size, density, mobility, noise, and visitor profiles. External factors include weather, the location of the event, the client (e.g., celebrities, singers, bands), government, personnel, and event type. Many of these factors reflect Challenger et al.'s (2010) crowd typology dimensions (see Chapter 1, Section 1.3.1). Duration of the event, start time, and event boundaries are typical external factors, while other dimensions such as the purpose of the crowd, event atmosphere, crowd membership, level of interaction, and size of group unit are related to the crowd itself (i.e., internal factors).

Table 2.2. Internal factors influencing crowd event planning.

Internal Factors	Inquiries
Crowd Size	Is the size of the crowds huge? Is it above 10,000 or below 1,000?
Density	Is the density of the crowds very high? Is it a jammed crowd or free-movement crowd?
Mobility	Are the crowds moving a lot or staying still?
Noise	Is the level of noise or emotion intensity in the crowds very high?
Visitor Profile	Do the visitors tend to be aggressive or peaceful? Are they experienced visitors? Are they in groups or individuals?

Table 2.3. External factors influencing crowd event planning.

External Factors	Inquiries
Weather	Will the weather influence the crowds/event a lot? Is it an indoor or an outdoor event?
Location	Is it an indoor or an outdoor event? Are there sufficient emergency exits? Are there spaces for parking or any public transportations around the location?
Client	Is there any celebrity who probably will cause chaos?
Government	What are the regulations from the government? Will any police present?
Personnel	What are the right personnel to hire?
Event Type	What is the event itself in terms of duration, activities? How is the historical level of conflicts? Is it a ticket-less event? Is the number of people in the crowds predictable? Are the crowds mostly standing or sitting?

Communication between the crowd management team and crowd members. The crowd management team also starts communicating with crowd members before events (Figure 2.1, Arrows A1 and A2). For example, the stadium managers ensure that the correct entrance is written on the ticket according to the seat number. Usually a few hours before the event, guidance is given at the exits of highways by using matrix display boards, suggesting people take the proper exit: "Do not take Exit A. Please take a detour to leave the highway at Exit B. It is easier to find a parking place and the entrance written on your ticket" (CE 8). Some event organizers communicate with the visitors via email beforehand

and encourage them to arrive earlier to avoid the peak registration hour. For example, CE 2 provided breakfast to conference visitors who came one hour earlier.

2.3.2.2 During crowd events: Communication and constant monitoring

During the event, communication is a powerful means to influence and steer the behavior of a crowd. Communication is used to keep the crowd informed about decisions made by the management team, and to support independent decisions by crowd members. Communication is also used within the management team to exchange information about monitored areas, to brief personnel about plan changes or actions to be taken.

Communication within the crowd management team. Communication within the team has different goals. First, it allows representatives in the team to share information about the state of the crowd, such as distributions of people in different areas, the formation of flows, warnings about anomalies, and logistical information. This type of information generally travels from the personnel observing crowd members from within the crowd to the crowd management team (Figure 2.1, Arrows C1 and C2). Then, it is processed and used for decision-making. Moreover, communication is needed to provide personnel in the crowd with actions to execute as the result of the decisions made by the management team. Finally, communication is used to coordinate actions among the personnel.

The communication within the team occurs through different channels and technologies, depending on the recipients (e.g., scouts), the crowd density, and the distance to cover. For example, for short ad-hoc communication between two people in a sparse area, mobile phones are sufficient. However, mobile phones have problems functioning in extremely dense crowds. As an illustration, CE 4 referred to C2000[11] communication network. As a replacement for mobile phones, C2000 supports communications between the police, ambulances or fire brigades in emergencies and dense crowds. Walkie-talkie and other radio-based communication tools can be used to broadcast information from one to multiple points at the same time. These instruments often support multiple channels, preventing a single channel from getting too busy or preventing some recipients from being overloaded with information. The following quote from CE 3 describes the communication within a management team:

"The conductor in the train can call the security center in Utrecht to inform about the over-crowded situation in Amsterdam Central Station. So, the security center can arrange this train to stop in another station of Amsterdam. Then, the passengers can be guided to take a metro to the center. You know, at that moment, all telephones are busy. It is crucial that the conductor can communicate with the security center. So far, we have not had severe problems with the communication. If there were problems, we had

11 C2000 is a closed (private) communication network and intended for use by the Dutch emergency and security. Designated users of the system are: Police, Fire department, Ambulance Services, etc.). Adopted from: https://nl.wikipedia.org/wiki/C2000, retrieved on October 12, 2015.

a command team with the police, the railway police and operational managers, sitting together to make decisions about the problems. If the telephones or walkie-talkies are still working, we can communicate with all the target locations."- CE 3

Communication between the management team and the crowd members. The communication between the management team and the crowd members consists of crowd density information in different areas, timely updates, schedules of public transportations, different path options and weather conditions. The role of communication here is to discourage the crowd to move towards certain areas of the event site and to persuade the crowd members to take different routes, sometimes also to suggest a longer detour that makes them spread more evenly over the event site.

Communication can be supported by tools such as screens, matrix display boards, barriers and signs. For example, different colors of balloons installed above the streets to help the individuals identify and follow different routes to their intended destinations (e.g., a route with red balloons or a route with blue balloons). Digital or matrix displays can be installed at the entrances to show the number of available spaces in a confined space. Lights can indicate directions and persuade individuals to move to an alternative entrance.

Most CEs recommended spreading these tools evenly across the event site to reach as many as possible crowd members and position them at outside places with a high capacity for large crowds so that these tools do not become obstacles. For example, big digital screens with train schedules are advised to be installed outside the train station hall. In this way, people will not stop to read the schedules in the station hall, which may block the crowd flow (CE 3). If the event allows, information about transportation and routes can be communicated to the crowd in advance through flyers, radio and television broadcasts, Internet sites and social media. CE 4 described their "balloon strategy" for guiding the crowd from the train station as follows:

"On the day of the event, we plan several routes from the central station to the city. We want to give the crowds an attractive route to the city. But it is not always the quickest way that you follow. We planned several routes this year marked with balloons of different colors: yellow, blue or orange, etc., to actively communicate with the crowds, advising them this was the fastest way to the city. We made sure in advance that there would not be big events on these routes. So, people would not get congested on these routes. There were only allowed small markets, not parties. When you were buying a train ticket going to Amsterdam, for example, you would get a flyer there. The flyer would suggest you take the blue route to the Museum Square." –CE 4

Constant monitoring. To well communicate with crowd members, constant monitoring of crowd situations is necessary. Information about crowd members is collected by personnel assigned to the crowd. They observe and profile crowd members and identify negative emotions or abnormal behaviors through their knowledge and insight based on training, experience and visual estimations (Figure 2.1, Arrow C1).

When technologies like CCTV systems are used, the recorded or real-time videos are monitored by experts in the control room (i.e., the crowd management team, Figure 2.1, Arrows B1 and B2). Automatic processing of the recorded video streams by the CCTV is still not wide-spread among crowd management practitioners and presents low accuracy for highly dense crowds. For example, the cameras can mistakenly count two or three persons as one when crowd density is high, largely influencing the accuracy of the estimation. UAVs (Unmanned Aerial Vehicles) equipped with cameras can fly over a crowd to detect target areas in detail, such as monitoring queues, spotting riots, and detecting abnormal situations. The remotely controlled UAVs provide valuable information, but mostly they are not legally permitted due to the risk imposed on the crowd, in case of malfunctioning (e.g., the UAVs may crash). Recently, social media, such as Twitter and Facebook, have been used by some crowd managers to monitor uses of specific keywords in crowds (CE 2). In this way, managers can detect abnormal situations and collect feedback from crowd members.

2.3.3.3 After crowd events: Expectations of crowd experts for the future

Concerning communication. After crowd events, the communication within the management team happens in the form of reflection on the preparation and execution of the strategies. The reflection will need to be documented to support the next event planning. Most crowd experts in the interviews expressed the need for reliable communication within the team and with the crowd members, especially in critical conditions. Current approaches are mostly human dependent and manually operated, which may cause information loss or overload. Crowd experts stressed the needs for more effective tools to support the direct communication with crowd members, especially allowing crowd members to express their feelings, emotions and (dis)satisfaction (Figure 2.1, dashed arrow).

Concerning monitoring. Crowd experts also articulated the need for reliable means to measure the state of the crowd in real-time for predicting critical conditions. The current strategy for monitoring large crowds is to assign scouts to patrol and observe within the crowds, in addition to the CCTV system which provides overviews. This strategy, however, is labor-intensive and prone to human errors. Current automatic approaches, like computational analysis of video streams or automatic counting based on mobile phone signals, do not yet operate well enough at extremely dense or large-scale crowds.

2.3.3.4 Stressing the distinctions between crowd management and crowd control

All experts emphasized the distinctions between crowd management and control, and in doing so are consistent with the literature (e.g., Abbott & Geddie, 2000; Berlonghi, 1995). The first distinction is related to the differences between crowd management, crowd control and riot control. The second distinction is

related to the two phases in crowd management, namely before and during a crowd event. As quoted from CE 5 & CE 8:

"Actually, there are four levels, in my point of view. The first is the preparation. Then we have the event. The third is crowd control. The last one is riot control. The first two parts take most of the efforts and they are what we focus on. The last two are backup strategies. We have to do 90% preparation, including everything on crowd management, crowd behavior, rules and distributing crowds are our tasks. Coordinating the stewards and the security personnel are also our tasks. Only when there is something concerning public order or incidents, the police step in and take over." – CE 8

"Our responsibility, which is actually crowd management, is the preparation. Preparation is quite complex. For example, the police are more on crowd control instead of crowd management. In my opinion, crowd control refers to the measures are taken when things go wrong. We call it riot control in extreme situations, including making arrests and keeping the public orders. Crowd management is everything you do in advance." – CE 5

In summary, there are four levels in dealing with crowds (see Figure 2.6). Level 1 is the preparation, which often starts at least half a year before a crowd event. Crowd experts come up with many possible scenarios (usually 20 to 30 scenarios) based on their experience and/or computer simulations of the crowd. Then, they prepare strategies for these scenarios. For example, they predict that there will be chaos in front of a bar, so they assign a sufficient number of security personnel and install enough barriers at that location. Level 2 is about the execution of the prepared strategies during the event. Crowd managers observe the crowd continuously through surveillance cameras and communicate with the scouts who are monitoring from inside the crowd. Once crowd managers identify something abnormal, they will check whether the situation fits any prepared scenario and use strategies based on their preparations. The first two levels are known as crowd management, accounting for 90% of the total effort and belongs to crowd managers' responsibility. Concerning the two levels of crowd management, 90% is preparation beforehand, and only 10% is real-time management during the event. The last two levels, namely crowd control and riot control, are crowd control measures; these happen only when the situation starts getting out of control. Police will step in and take the lead.

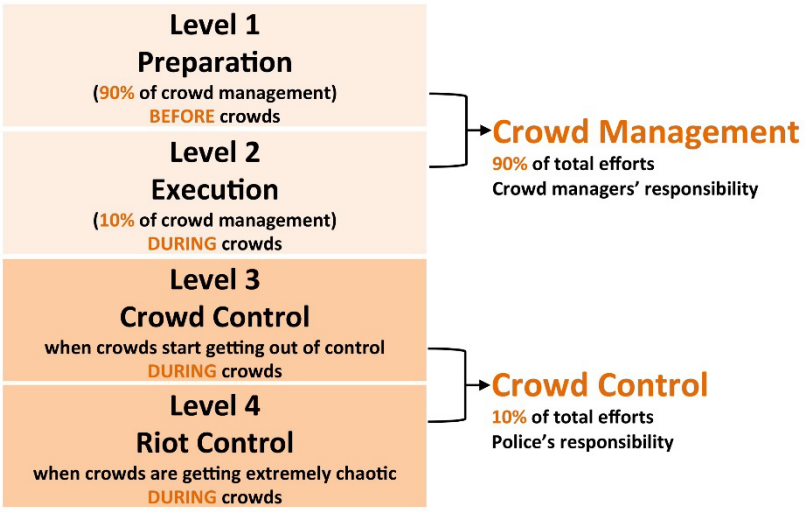


Figure 2.6. Four levels in dealing with crowds, developed based on crowd expert interviews.

2.3.3.5 Types of crowd situations classified by crowd experts

Overall, nine types of crowd situations were extracted from the interviews with the crowd experts. Figure 2.7 illustrates these crowd types: the dots represent crowd members, and the colors of the dots show levels of emotional arousal: blue dots stand for calm and quiet people, and red dots represent very active and excited ones. The arrows attached to the dots indicate directions of movements. The emotional arousal and movements of crowd members are based on the crowd experts' perception.

A remarkable finding from the interviews is that crowd experts suggested that each crowd event usually consists of several different crowd types during different periods or at different locations. They usually did not name a crowd event after the main activities within it, such as a music festival crowd, a theater crowd or a conference crowd. For example, during an outdoor music festival, crowd members may form four crowd types. At the beginning of the festival, crowd members are approaching the event field (Crowd Type 1 in Figure 2.7). During the festival, some people form queues, while others walk around, or stand in front of stages (Crowd Type 2, 4, and 9 in Figure 2.7). Similarly, on a crowded train station platform, people usually form two crowd types, namely Crowd Type 2 and 3 in Figure 2.7, because of queuing and arching.

Most crowd experts considered Crowd Type 1, "crowds approaching the event field" as a thorny problem in crowd management because most instruments for monitoring crowds are installed at the event site. Therefore, it is difficult to obtain an overview of the crowd when crowd members are approaching but have not arrived at the event site yet. This is the most unpredictable moment, no matter whether it happens before a conference,

a stadium event, or a festival. In contrast, crowds sitting in an auditorium or theater (Crowd Type 5) are usually well behaved, predictable and relatively easy to manage, because the level of emotional arousal of an auditorium crowd is relatively low (e.g., talking and making noise is not allowed during a performance), and the weather influence is small. In this case, the crowd stays predictable even if crowd size and density are large.

Crowd Type 6 represents crowd flows in a train station hall: people come and leave, and the level of their emotional arousal is low. Crowd Type 7 illustrates a typical crowd in a train, bus or airplane. This situation is comparable to Crowd Type 5 (an auditorium crowd), but people might be slightly more talkative than people sitting in an auditorium. The only difference between Crowds Type 4 and 8 is whether the event site has boundaries. The boundary of an outdoor event is not fixed (e.g., usually fences are installed as boundaries), while the buildings that host indoor events have fixed boundaries (e.g., walls). Consequently, evacuation plans for an indoor event are stricter than for an outdoor event.

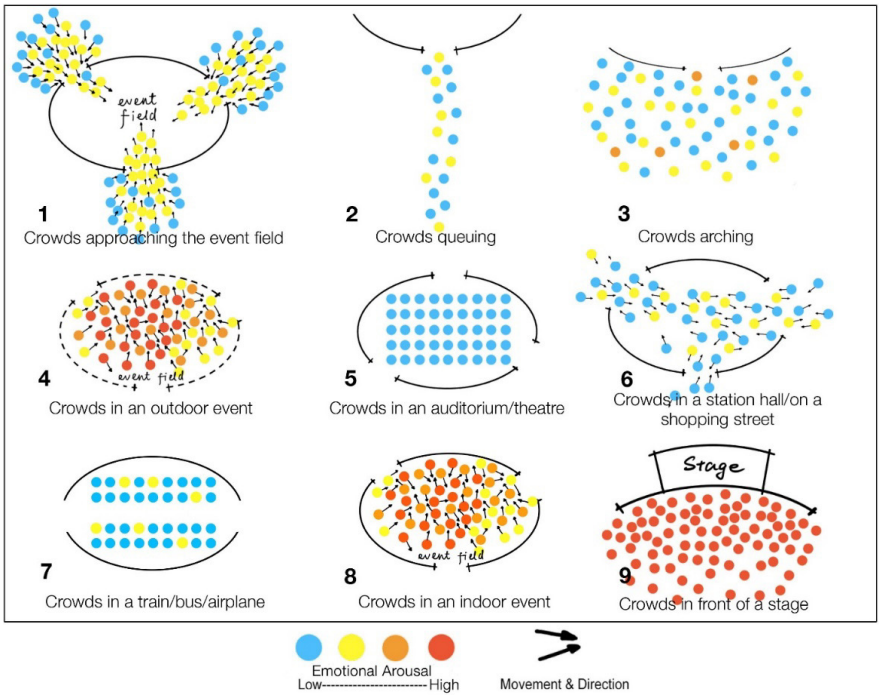


Figure 2.7. Nine crowd types summarized from the expert interviews. The dots represent crowd members, and the colors of the dots show levels of emotional arousal of crowd members (i.e., blue=calm or quiet; red=active or excited). The arrows on the dots indicate directions of movements of crowd members.

2.4 CONCLUSIONS

Most efforts in current crowd management practice are spent on thorough preparation before crowd events so that the need for interventions during crowd events can be minimized. However, crowd managers wish for more support in understanding and intervening in crowds in real time. Crowd managers realize that making real-time decisions about interventions to be implemented during crowd events becomes increasingly essential to crowd management. This requires a better understanding of crowd emotions and crowd behavior.

Figure 2.8 maps the insights from the interviews into the Wijermans et al. (2016)'s INCROWD framework. As shown in the figure, most statements from the interviews concern the Crowd-Interaction Subsystem. Interestingly, most of them concern indirect communication between crowd management team and crowd members. This underlines that current crowd management practice is still limited concerning direct communication with crowd members. Additionally, in practice monitoring emotions of crowd members is mainly taken care of by the (security) personnel who stay in crowds. This becomes cumbersome when the crowd size gets larger. To better understand crowds, technological support is needed in assessing emotions of crowd members based on profound insights into crowd emotions and behavior. The support for generating and selecting proper interventions (Decision-Making Subsystem) is also limited. So far, only scenario thinking has been applied, combined with a manual selection of interventions.

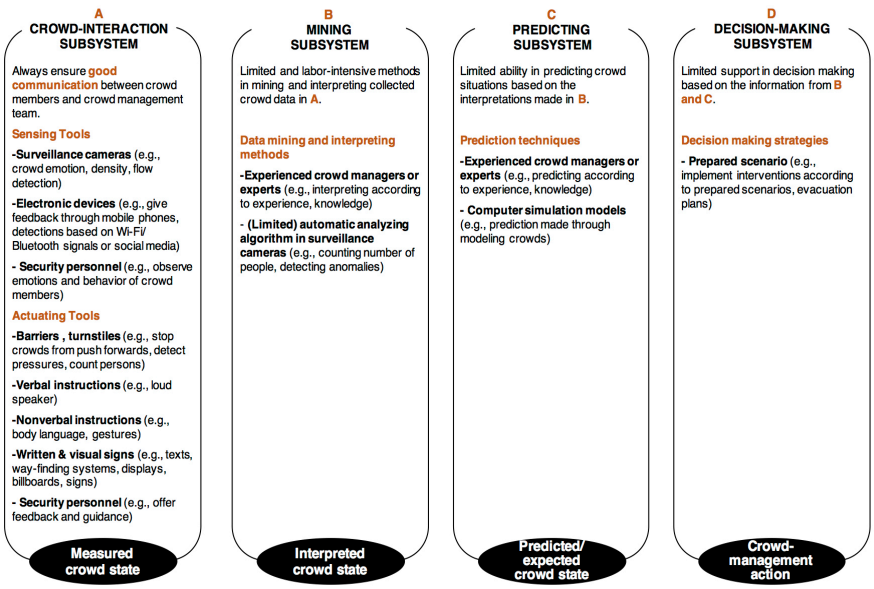


Figure 2.8. Mapping insights gained from the interviews about current crowd management practice in the INCROWD framework.

With respect to the three levels of understanding crowds, namely the crowd level, the group level and the individual level, we found that today's crowd management concerns all three levels (Figure 2.9). At the crowd level, the crowd managers monitor mainly the overall crowd density, distribution and flows. At the group level, they separate different profiles of crowd members (e.g., assigning a specific area for families with children, separating football fans of Team A from Team B). At the individual level, they hire security personnel to patrol in the crowd to detect individuals with suspicious behavior or negative emotions. However, it is evident from Figure 2.9 that most efforts have been concentrated on the crowd level and the group level. The strategies for understanding individuals in crowds are limited: by hiring security personnel and occasionally applying expensive and high-risk UAVs. In the future, crowd management should not only emphasize the efforts for preparations beforehand, mainly at the crowd level, but also flexible real-time strategies based on a better understanding of individuals in crowds. The goal is to enhance the direct communication between crowd management team and crowd members, thus enabling crowd managers to know in advance about what a situation is likely to develop into, from the detection or feedback obtained from crowd members, and to act as early as possible. Crowd managers would like to not only have an estimation of how soon an event site will reach its full capacity, but also how people feel in crowds. Understanding emotions of crowd members helps the crowd management team to predict crowd behavior and rapidly make decisions about what guidance should be given to crowd members to keep them updated, informed and satisfied.

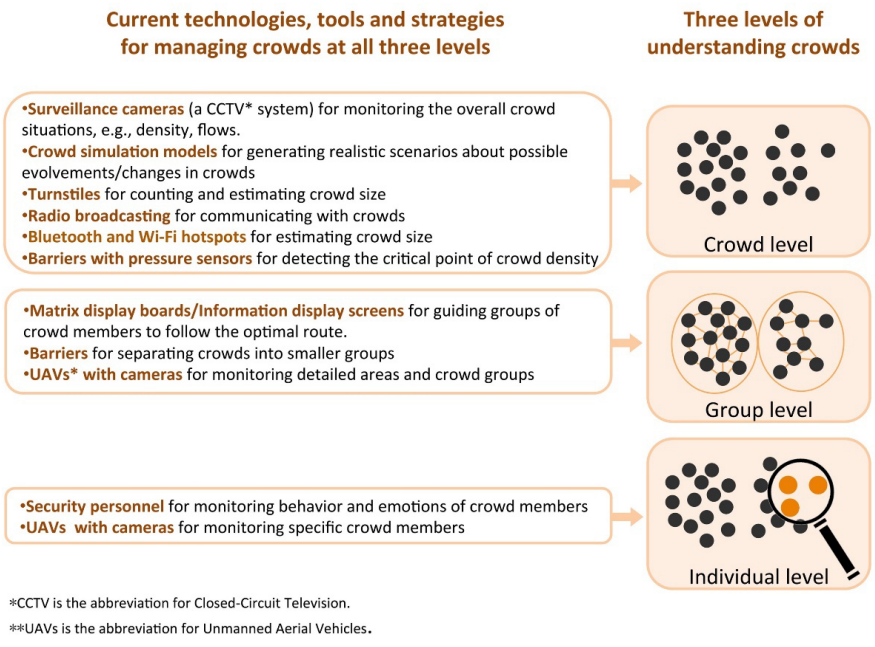


Figure 2.9. Current technologies, tools and strategies aiming at managing crowds at three levels.

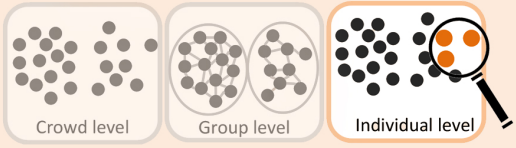
To approach crowds at the individual level, it is not sufficient to only monitor crowds externally with technologies that only give clues on density, flow or high-level crowd movement patterns. Crowd management should go into crowds, approaching crowd members locally and accurately measuring their emotions in time, realizing that emotions are widely considered in social psychology as influencers of behaviors. For example, positive emotions make people smile and behave enthusiastically. Negative emotions drive them to behave in a way that changes or improves their emotional states, such as running away to be not fearful, fighting to feel better (Isen, 1984, 1987). Understanding emotions of crowd members is a step toward better understanding and predicting crowd behavior.

"The world makes much less sense than you think. The coherence comes mostly from the way your mind works."

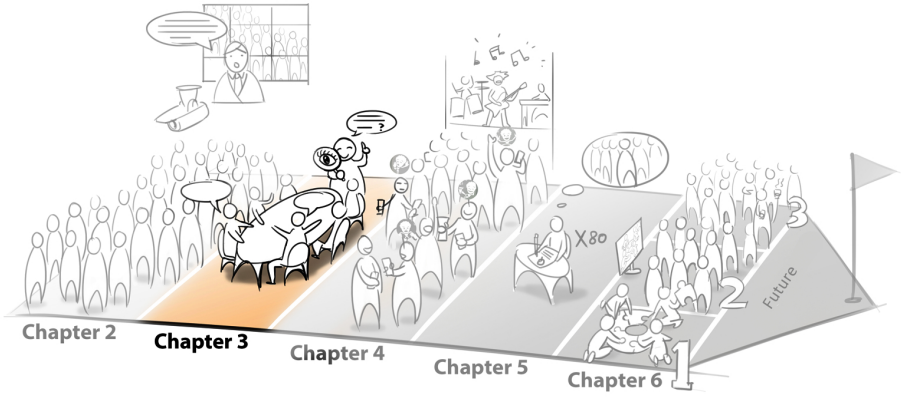
— Daniel Kahneman,
Thinking Fast and Slow

CHAPTER 3

Factors Contributing to Well-being in Crowds



Chapter 3 explores, from the individual level, what factors contribute to the well-being of crowd members through studies with ten crowd members. It concludes with a classification of two distinct crowd types, namely event crowds and non-event crowds. The factors concerning sustaining well-being are different in these two crowd types: crowd members in non-event crowds are more concerned about safety than those in event crowds. Safety does not contribute to but is an important consideration for obtaining well-being. In event crowds, relatedness, autonomy and competence are three prominent needs for sustaining well-being.



This chapter is written based on the following published articles:

- Li, J., de Ridder, H., Vermeeren, A., Conrado, C. & Martella, C. (2013). Designing for crowd well-being: Needs and design suggestions. In *Proceedings of the 7th International Conference on Planning and Design*, Tainan, Taiwan, pp. 373-382.
- Li, J., Vermeeren, A. & de Ridder, H. (2014). Designerly ways of exploring crowds. *International Journal of Cultural and Creative Industries, 2*(1), 4-17.

3.1 INTRODUCTION

The previous chapter presents interviews with ten crowd experts. From these interviews, it becomes clear that many crowd management strategies still heavily focus on preventing problems, such as keeping crowds moving smoothly to avoid bottlenecks and over-crowdedness. Ninety percent of the efforts in dealing with crowds are spent on thorough preparations beforehand. One of the important conclusions is that crowd experts begin to realize that only preparations before crowd events and continuously monitoring crowds during crowd events are not sufficient. Going into crowds and assessing crowd members' emotions is crucial for better understanding crowds, sustaining the well-being of crowd members and preventing crowd management from turning into crowd control. To support the well-being of crowd members, it is necessary to know, from their perspective, what factors are contributing to it.

In this chapter, we go one step further in understanding factors contributing to well-being in crowds by interviewing people who have experienced being in crowds. Ten participants were recruited with experience in being in outdoor events, public transportations and indoor events. Typical characteristics of these three crowds can be found in Table 3.1.

To be able to interpret the interviews, we will first discuss what is meant by "well-being in crowds". As far as we know, there is no literature about well-being in crowds. Section 3.2, therefore, starts with introducing background information about the definition of human well-being in general and the needs for sustaining well-being in life. It ends with a provisional definition of well-being in crowds. Section 3.3 describes two context mapping studies conducted with participants who had experience in large crowds. It aims at investigating the experiences and requirements for sustaining well-being in different crowd situations, from the perspective of crowd members. The results of the context mapping studies show the relations between needs fulfillment and well-being in different types of crowds. Section 3.4 concludes by introducing two distinct crowd types, namely event crowd and non-event crowd. It highlights the factors contributing to the well-being of crowd members in these two types of crowds and the main motivations for people to join a crowd.

Table 3.1. Comparison of the three selected crowd situations by Challenger et al. (2010)'s crowd typology dimensions

Crowd Typology Dimensions (Challenger et al., 2010)	Outdoor Event (e.g., festivals, sports events)	Public Transportation (e.g., train stations, airports)	Indoor Event (e.g., conferences, theaters, museums)
Purpose	Entertainment/Sports	Travel	Entertainment/learning
Duration	Medium[1]/Long term[2]	Transient	Medium/Long term
Start time	Fixed[3]/Variable[4]	NA[11]	Fixed/Variable
Event boundaries	Open boundaries/Fixed seat	Passing through	Fixed seat/Moveable
Event atmosphere	High[5]/Medium levels of conflict	Low levels of conflict	Non-existent conflict
Crowd membership identification	High[6]/Medium[7]	Low	Medium/Low
Level of interaction	High	Low	Medium/Low
Heterogeneity of membership	Medium	High[8]	Medium
Size of group unit	Mainly groups	Mixed[9]	Mixed
Amount of luggage	Medium[10]	Large	Non-existent

1 Medium term (duration): a few hours, usually three to six hours
2 Long term (duration): a day or several days.
3 Fixed (start time): e.g., a sports event with an opening and an end.
4 Variable (start time): e.g. a festival with a range of events.
5 High levels of conflict (event atmosphere): e.g., a football match.
Levels of conflict represent the tendencies that conflict is anticipated among crowd members, as a result of behavior at previous events.
6 High (crowd membership identification): e.g., football fans.
7 Medium (crowd membership identification): e.g., visitors to academic conferences.
8 High (heterogeneity of membership): crowd members with different purposes.
9 Mixed (size of group unit): e.g., some singles, some groups.
10 Medium (amount of luggage): e.g., bags and tents.
11 NA: Not Applicable

3.2 HUMAN WELL-BEING: A LITERATURE REVIEW

As stated in Chapter 1, human well-being is a complex concept which not only refers to the absence of (mental) illness but also concerns optimal experiences and functioning (Ryan & Deci, 2001). What defines optimal experiences and what constitutes a good life are, therefore, central topics in well-being research. Ryan and Deci's (2001) review of research on well-being shows that diverse theories have been formulated to measure and understand human well-being, among which two theories have raised most debate, namely those about subjective well-being and psychological well-being.

3.2.1 Subjective well-being and psychological well-being

The model of subjective well-being (SWB) proposed by Diener (1984, 1993, 2000), describes how people experience the quality of their lives and includes both emotional reactions and cognitive judgments. There are two components of SWB. One is Affect Balance and the other is Life Satisfaction. Affect balance, or hedonic balance is defined as the overall equilibrium between positive and negative affect, where positive affect is about experiencing pleasant emotions and moods and negative affect is about experiencing unpleasant, distressing emotions and moods (Steel et al., 2008). Life satisfaction concerns global judgments of one's life and satisfaction with specific life domains. This model is based on people's self-assessments of happiness and satisfaction with their current lives as well as long-term well-being. The assessments concern people's positive and negative emotional reactions to events, their moods, and include judgments they form about their life satisfaction, fulfillment, and satisfaction with domains such as marriage, social relationship and work (Diener et al., 2003). Concerning short-term well-being, Oishi et al. (2001) found that physical pleasure is an important indicator for short-term satisfaction, but it does not have a long-lasting influence on a general sense of well-being.

Around the same time, Ryff (1989) introduced his multidimensional model of psychological well-being (PWB). This model includes six distinct components of positive psychological functioning: (1) self-acceptance (positive evaluations of oneself and one's past life), (2) personal growth (a sense of continued growth and development as a person), (3) purpose in life (the belief that one's life is purposeful and meaningful), (4) positive relations with others (the possession of quality relations with others), (5) environmental mastery (the capacity to effectively manage one's life and surrounding world), and (6) autonomy (a sense of self-determination) (Ryff & Keyes, 1995). PWB focuses on a broad definition of well-being in terms of fully physical and psychological functioning (Ryff & Keyes, 1995). In this way, it includes issues like achieving happiness as well as meaningfulness (McGregor & Little 1998) and covers Ryan and Deci (2000)'s set of psychological needs to be fulfilled, such as competence, autonomy and relatedness.

In debates about SWB and PWB, SWB was challenged as being heavily focused on the subjective positiveness, which may fail to promote healthy living (Ryff & Singer, 1998). PWB was retorted by Diener et al. (1998) as a set of criteria for experts to assess well-being while SWB assessment allows people themselves to describe what is their optimal experience and what contributes to a good life. Despite these differences, SWB and PWB have in common that they both include two main perspectives in achieving well-being: the hedonic perspective (Kahneman et al., 1999) and the eudaimonic perspective (Waterman, 1993). The hedonic perspective on well-being focuses on happiness, especially on pleasure attainment and pain avoidance. The eudaimonic perspective focuses on meaning, human flourishing and self-realization. From the eudaimonic perspective, well-being is not only about subjective happiness, because not all achieved desires

or pleasure producing outcomes will be good for people or promote wellness. Waterman (1993) defined eudaimonia as a state of personal expressiveness. It occurs when people's life activities are most congruent with their deeply held values, and they are fully engaged in these activities. Involvement in these activities makes people feel alive and authentic, expressing their true-self. Waterman (1993) also demonstrated that the measures of personal expressiveness and hedonic enjoyment are strongly correlated, even though they indicate distinct types of experience. Personal expressiveness is more related to challenging and effortful activities promoting personal growth and development, whereas hedonic enjoyment is more associated with relaxation, happiness and staying away from problems.

3.2.2 Needs fulfillment and well-being

In his book *Motivation and Personality,* published in 1954, Maslow extensively discussed human needs and well-being. He postulated a hierarchy of five human needs, from lower-level needs to higher-level ones, namely (1) physiological needs (e.g., physical requirements for human survival and thriving), (2) safety needs (e.g., personal and financial security, safety and health versus accidents and illnesses), (3) needs for love and belongingness (e.g., maintain emotionally significant relationships such as friendship, intimacy and family), (4) needs for self-esteem (e.g., being accepted, respected and valued by self and others), and (5) needs for self-actualization (e.g., the realization of a person's full potential)(Figure 3.1-a). Maslow (1954) pointed out that the lower the need in the hierarchy, the more imperative it is for sheer survival, and the shorter gratification can be postponed. For example, people tend to be more desperate about lacking food and safety than about lacking respect. In this case, respect is a dispensable luxury compared with food and safety. Deprivation of higher-level needs does not lead to such desperate defense or emergency reaction as produced by the deprivation of lower-level needs. However, the gratification of the higher-level needs promotes more wellness, such as profound happiness, peacefulness and richness of inner life. Maslow's theory has also distinguished between "deficiency-motivated" needs and "growth-motivated" needs. Deficiency-motivated needs are enforced extrinsically by the social environment (safety, love and respect), whereas growth-motivated needs come from within the human and are about the need for constant betterment (self-actualization).

In most cases, satisfying the lower-level needs is a precondition for pursuing the higher-level needs. But there might be individual or cultural differences concerning the order of some needs. Maslow (1954), for example, admitted that in modern society, especially wealthy countries, needs for food and drinks are usually driven by appetite or pleasure rather than extreme hunger. Here, food is not the most urgent need anymore and therefore not the main precondition for people to pursue more delicate things.

Another vital framework about human needs fulfillment, motivation and well-being is Ryan and Deci (2000)'s self-determination theory (SDT). SDT supports three psychological needs that must be satisfied to foster self-motivation, social developments and well-being. The three needs are competence

(e.g., feel effective in activities, feel in control and experience mastery), autonomy (e.g., feel that one's activities are self-chosen and self-endorsed) and relatedness (e.g., want to interact with and be connected to others, experience caring and closeness). All three psychological needs are essential nutrients for human thriving. Hence, well-being can only be achieved by satisfying all three needs. Ryan and Deci (2000) used an analogy of a plant to specify this claim: a plant needs water, sunlight and specific minerals to thrive. The plant cannot survive when any one of these nutrients is missing. So, a society that allows people to develop competence but fails to nurture relatedness is supposed to lead to an inevitable impoverishment of well-being.

Sheldon et al. (2001) elaborated on the SDT theory and Maslow's theory in a more specific context, namely satisfying events. They aimed at figuring out what psychological needs are the most fundamental for humans in such context. They selected ten needs from a variety of psychological theories, including Maslow (1954)'s hierarchy of five needs and the three psychological needs of SDT. Sheldon et al. (2001) found that needs for love and belongingness in Maslow's theory are essentially equivalent to the needs for relatedness in Ryan and Deci's SDT theory because both address feelings of interpersonal connection and sense of affection with important others. At the same time, Sheldon et al. (2001) believed that autonomy and competence needs in the SDT theory are significantly different from Maslow's self-esteem and self-actualization needs. They phrased this difference as follows:

"Autonomy refers to a quality of self-involvement in momentary behavior, whereas self-actualization refers to a sense of long-term growth; competence refers to attaining or exceeding a standard in one's performance, whereas self-esteem refers to a more global evaluation of the self. Thus, we assessed these four needs separately." (Sheldon et al., 2001, p.326).

Therefore, Sheldon et al. (2001) identified seven needs based on the SDT theory and Maslow's hierarchy of needs, namely autonomy, competence, relatedness, physical thriving, security, self-esteem and self-actualization. They added three more needs: pleasure-stimulation (Epstein, 1990), popularity-influence and money-luxuries (Derber, 1979). The resulting ten needs selected by Sheldon et al. (2001) are listed in Table 3.2 with brief explanations.

Table 3.2. Ten psychological needs selected by Sheldon et al. (2001).

Ten needs	Explanations
Autonomy	Feel independent and self-decided
Competence	Feel capable and effective
Relatedness	Feel a sense of belongingness and closeness
Physical thriving	Feel healthy and well taken care of
Security	Feel safe and in control
Self-esteem	Feel respected and worthy
Self-actualization	Feel meaningful in life and capable of progressing toward the highest potentials
Pleasure-stimulation	Feel enjoyed and pleased
Popularity-influence	Feel popular and influential
Money-luxuries	Feel sufficiently wealthy and able to purchase most of the desirable things

Sheldon et al. (2001) conducted a series of studies across different time frames (i.e., last week, last month or last semester) and two distinct cultures (i.e., the U.S. and South Korean) to assess which needs are the fundamental ones contributing to a satisfying event. In their last study, they also included unsatisfying events. They found that autonomy, competence, relatedness and self-esteem emerged as the most salient psychological needs in every sample (see Figure 3.1-b). This result is highly consistent with Ryan and Deci (2000)'s self-determination theory. Viewing the results regarding the prioritization of the relative salience to the well-being of the participants, autonomy, security, self-actualization, pleasure-stimulation and physical thriving were positioned in the middle by Sheldon et al. (2001). Popularity-influence and money-luxuries were regarded as of little importance. In case of unsatisfying events, Sheldon et al. (2001) found that, in general, lack of autonomy, relatedness, competence and self-esteem were again of the highest priority, but here, lack of security became the fifth prominent feature of unsatisfying events.

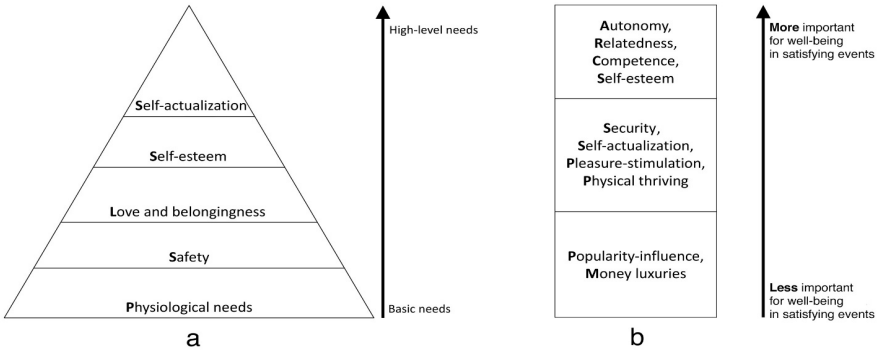


Figure 3.1. (a) Maslow's hierarchy of psychological needs, assuming that, in most cases, the satisfaction of the basic needs is a precondition for the satisfaction of the higher-level needs; (b) Sheldon et al.'s order of psychological needs, showing the prioritization of the needs contributing to well-being and happiness in satisfying events (the needs within each level are listed in no particular order).

Sheldon et al. (2001)'s ordering of needs was constructed based on the prioritization of the needs contributing to satisfying events and does not contain the precondition assumption of the hierarchy of needs proposed by Maslow (1954). So, popularity-influence and money-luxuries being are not listed at the bottom level for reasons of being the preconditions for higher level needs, but because they yielded rare importance in satisfying events. Overall, autonomy, competence, relatedness and self-esteem have demonstrated a positive impact on the well-being of people in satisfying events. However, the relative ordering of these needs varies from culture to culture. For example, Sheldon et al. (2001) found that South Korean participants cherished relatedness the most, whereas U.S. participants placed self-esteem on the top of the list.

The results of Sheldon et al. (2001)'s studies support Maslow's deficiency-growth distinction. Specifically, security needs became very prominent in unsatisfying events and served as a strong predictor of emotions in such events. Security needs must be taken care of before people search for other positive experiences. In the last study on satisfying and unsatisfying events, Sheldon et al. (2001) found that autonomy and relatedness have a less substantial impact on the emotions of people in unsatisfying events, which suggests that those two needs are more associated with obtaining "growth" than with avoiding "deficiency".

In conclusion, Sheldon et al. (2001)'s ordering of needs for satisfying events seems suitable for our study into crowd situations. We hypothesize that the needs contributing to well-being in crowds are the same as the top priority needs proposed by Sheldon et al. (2001). To achieve well-being in crowds, we claim that crowd members need to fulfill a variety of needs, in particular, autonomy, relatedness and competence. Furthermore, we think that security will not contribute to the improvement of well-being or positive experience in crowds, but that it will become a salient need when the crowd is getting out of control. The following section presents two context mapping studies that we conducted with people who have experience as crowd members.

3.3 UNDERSTANDING WELL-BEING IN CROWDS: TWO CONTEXT MAPPING STUDIES WITH CROWD MEMBERS

Section 3.2 provided a background for research on human well-being in general. Inspired by the distinction made by Sheldon et al. (2001) between satisfying events and unsatisfying events, we conducted studies to identify factors contributing to well-being both in attractive and unattractive crowds. We deliberately separated attractive and unattractive crowds, because we want participants to consider both positive and negative aspects of crowds, aiming at reducing the over-emphasis on the negativities in the literature (Reicher & Potter, 1985; Kazdin, 2000).

3.3.1 Methods

The studies were conducted in the form of context mapping sessions (Sleeswijk-Visser et al., 2005), which combined traditional focus groups (Morgan & Spanish, 1984) with generative techniques (Stappers & Sanders, 2002). The goal of the context mapping sessions was to map the overall experiences of people in crowds and to understand their expectations for sustaining well-being in crowds. The generative techniques enable participants to visualize their tacit knowledge through making collages or artifacts (Sleeswijk-Visser et al., 2005).

3.3.1.1 Participants

Two context mapping sessions were conducted with six and four participants, respectively. Both sessions had 50% male and 50% female participants. The age of the participants ranged between 22 and 38, with an average of 29. Participants varied in occupations (three master students, two PhD students, four researchers and one designer) and nationalities (Chinese, Dutch, New Zealander, Irish, and Mexican) and all had experience in both attractive and unattractive crowds, such as daily commuting crowds, shopping crowds, festival crowds and concert audiences.

3.3.1.2 Procedure

The context mapping sessions were conducted by following the three-step approach proposed by Sleeswijk-Visser et al. (2005) for contextmapping sessions. The three steps are (1) preparation and sensitizing the participants (e.g., with a designed booklet, Figure 3.2), (2) group sessions, and (3) analysis and communication.

(1) Preparation and sensitizing. Participants received a booklet with two sets of open-ended questions three days in advance to help them prepare for the group session. Each participant filled in the booklets individually. The first two pages of the booklet contain a brief introduction about the study, a how-to-use instruction, and a request to fill in demographic information about the participants. In the following pages of the booklet, participants were requested to think about attractive crowds as well as about unattractive crowds by answering the following two sets of questions:

(i) Pages 3-6: attractive crowds. What crowds attract you to join? Why do you want to join them? What do you do in an attractive crowd? Please visualize on the timeline in your booklet.

(ii) Pages 7-9: unattractive crowds. What crowds do you want to avoid? Why do you want to avoid them? What do you do in an unattractive crowd? Please visualize on the timeline in your booklet.

Figure 3.2 shows Pages 3-6 of the booklet, asking questions about attractive crowds. Page 3 (Figure 3.2-a) triggered participants to create a mindmap about "crowds that attract you joining". Following Buzan & Buzan's (2000) mindmap guidelines, instructions about brain-storming and making a mindmap were

provided at the beginning of the booklet: (1) draw branches, radiating outward from the center topic, e.g. crowds that attract me to join them; (2) add the crowd types coming across your mind to the mindmap following the branches; (3) write words on the branches as explanations; (4) wherever possible, add images to those words (make use of the 96 images in the appendix of your booklet); and (5) make sure that each element is connected to a branch. Page 4 (Figure 3.2-b) required participants to write down the reasons for joining the attractive crowd mentioned in the mindmap. After making the mindmap and giving the reasons for joining attractive crowds, participants were requested to visualize their activities in an attractive crowd on a timeline and highlight the positive and negative experiences with green and red dots, respectively. The positive or negative experiences refer to the moments in a crowd that made them feel positive (e.g., happy, relaxed) or negative (e.g., angry, bored). Figure 3.2-c gives participants an example of visualizing activities in crowds on a timeline. Page 5 (Figure 3.2-c) displays an example of how to visualize activities in crowds on a timeline as a preparation for the question "What do you do in an attractive crowd?" on Page 6 (Figure 3.2-d). The questions in (ii) are asked in the same way as the questions in (i) in the booklet, leaving out the example page about visualizing activities in crowds.

Participants were encouraged to visualize their answers to each question by using hand-drawings or the 96 pictures provided in the appendix of the sensitizing booklet. These pictures were selected from the internet for their ambiguity, enabling the participants to interpret them differently in crowd contexts. For instance, a bottle of fruit jam reminded a participant of a jammed crowd.

(2) Context mapping sessions. Two context mapping sessions were conducted. Each participant took part in only one of them. To reduce the possibility of dominant participants leading the group, two facilitators were present. Participants were asked to bring their booklets to the group session and to discuss the content with other participants. Each session took about 80 minutes. It started with 20-minute of peer discussions to compare their booklets, followed by 20-minute presenting the differences and similarities of their answers in the booklets. Later on, participants were instructed to do a 20-minute collage making to visualize their requirements and expectations in sustaining well-being in crowds (Figure 3.3-a) and ended with 20-minute presenting their collages (Figure 3.3-b).

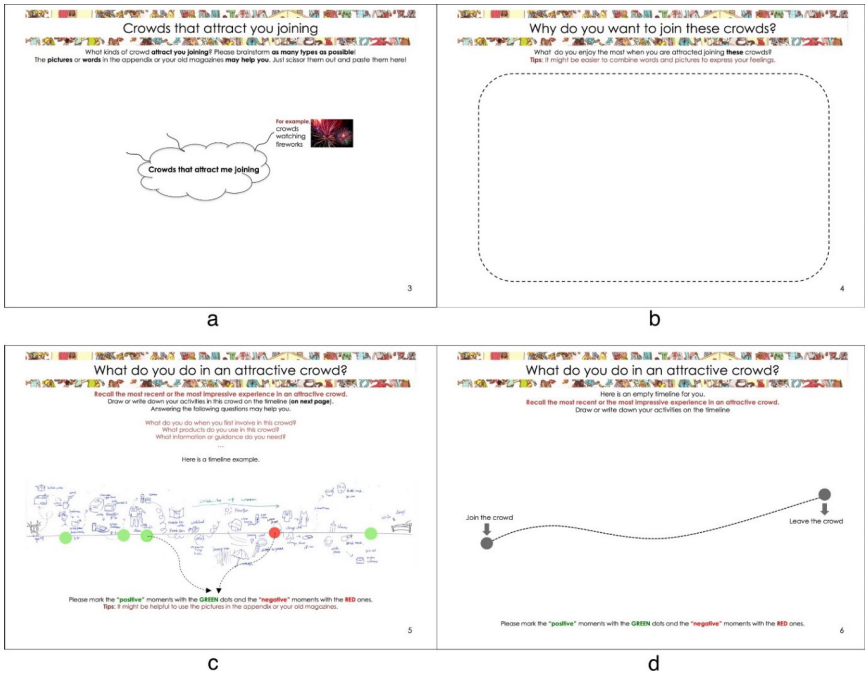


Figure 3.2. Four pages in the booklet: (a), (b), (d), asking questions about attractive crowds; (c) giving an example of how to visualize activities in crowds on a timeline with green and red dots indicating the positive and negative moment.

a b

Figure 3.3. (a) One context mapping session, participants were making collages to express their expectations for sustaining well-being in crowds, (b) one of the participants was presenting her collage.

(3) Analysis and communication. The analysis of the group sessions and the filled booklets followed the three steps guideline specified by Sleeswijk-Visser et al. (2005):

Step 1: Fixate on the data. All the booklets and collages were collected, and the sessions were videotaped and transcribed, as suggested by Rabiee (2004) to

establish “a trail of evidence”, allowing for verification. The goal of the analysis was to reduce data and search for patterns based on the questions asked in the booklet.

Step 2: Search and be surprised. A team of three researchers read through all the transcripts and booklets. Each researcher marked interesting contents in the transcripts and in the booklets with short explanation phrases based on subjective interpretations.

Step 3: Find patterns and create an overview. All the selected contents and the interpretations were compared and placed into five categories: (1) crowds that attract you to join them; (2) reasons for joining these crowds; (3) crowds that you want to avoid; (4) reasons for avoiding these crowds; and (5) requirements and expectations for sustaining well-being in crowds.

3.3.2 Results

Figure 3.4-3.6 show examples of data collected by the booklets, typically discussed in the first half of the context mapping session. These data illustrate attractive and unattractive crowds, reasons for joining or avoiding certain crowds and requirements for sustaining well-being in crowds from the perspective of crowd members. Figure 3.7 is a collage of well-being requirements made by one participant during the second half of the context mapping session. The results are summarized as follows into three categories: attractive and unattractive crowds, reasons to join or avoid a crowd, and requirements for sustaining well-being in crowds.

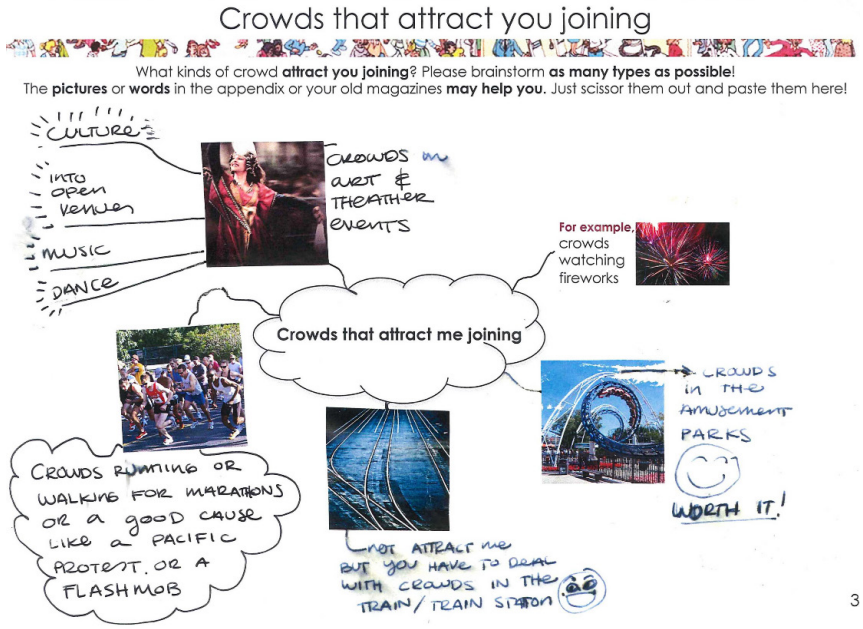


Figure 3.4. One page of booklet filled in by a participant, brainstorming about attractive crowds and presenting the results as a mindmap.

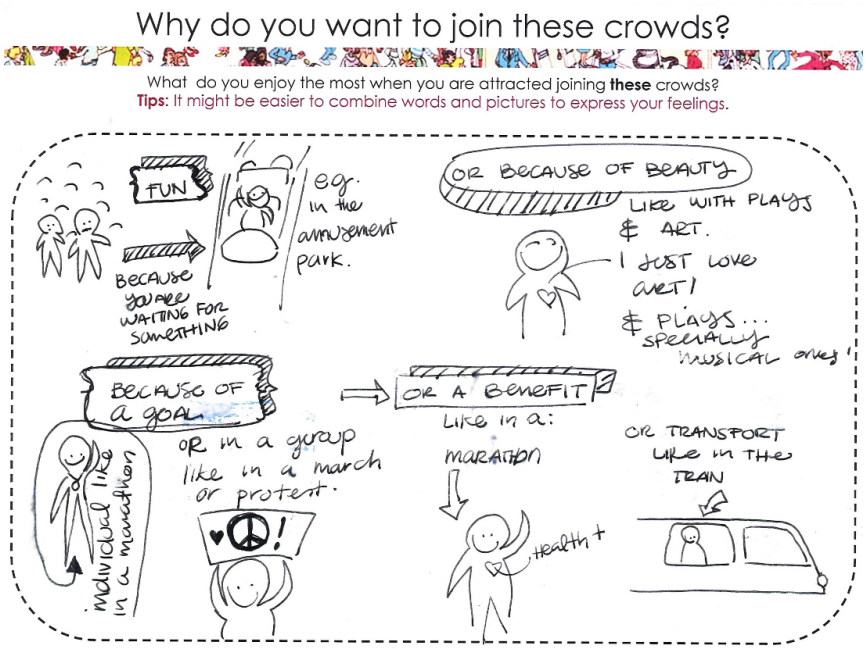


Figure 3.5. One page of booklet filled in by a participant, providing the reasons for joining attractive crowds.

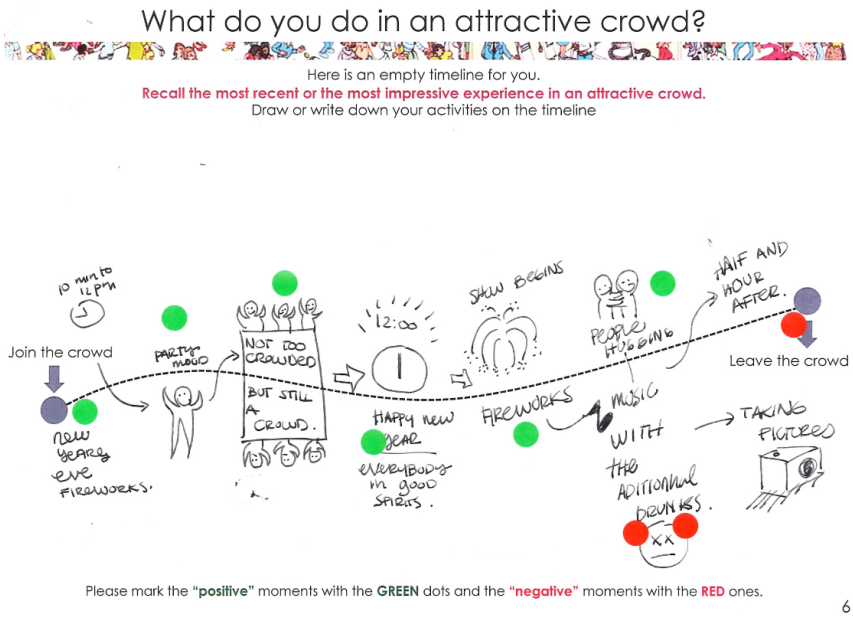


Figure 3.6. A participant visualized her activities in an attractive crowd, highlighted her positive (green dots) and negative (red dots) experiences.

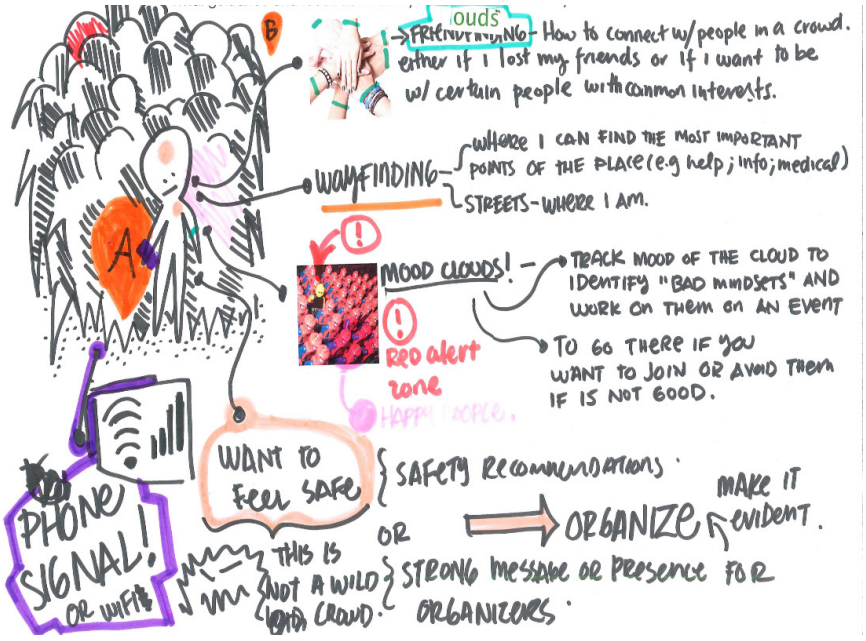


Figure 3.7. A collage made by one participant during the context mapping session, expressing her expectations and requirements for sustaining well-being in crowds.

3.3.2.1 Attractive crowds and unattractive crowds

From the responses of the participants, attractive crowds can be described as crowds attracting people to join them, such as crowds watching fireworks. Unattractive crowds usually make people uncomfortable, so they want to stay away from them, such as violent crowds. To get an overview of what crowds are considered attractive and unattractive, and what the participants experienced in these crowds, the mindmaps and the timelines were analyzed together.

Combining the answers in the ten booklets and the transcripts of the discussions during the two group sessions, we summarized a total of 46 attractive crowds and 37 unattractive crowds that were mentioned at least once. The participants used many unique labels to describe the crowds. Some labels were very specific, such as “crowds at an amusement park”, “crowds in a pub”, while other labels were quite general, such as “crowds doing things together”, “crowds that I can join in and benefit from”. Due to the inconsistency in labeling crowds, most of the attractive and unattractive crowds were only mentioned once or twice. However, in many cases, multiple “labels” of crowds mentioned by participants could be categorized into one general type. For example, three participants mentioned “a sports event” as an attractive crowd, while another participant labeled an attractive crowd as “marathon”. As a “marathon” is also a “sports event”, we grouped “sports event” and “marathon” together as one general type of attractive crowd, labeled as “sports events”, which was mentioned by a total of four participants.

Based on the new grouping of crowds, Table 3.3 and 3.4 present attractive crowds and unattractive crowds mentioned at least by two participants. As can be seen in Table 3.3, most of the attractive crowds are quite specific and event-related (e.g., theater crowd, festival), while unattractive crowds are mostly abstract and not related to specific events, but to problems in general. Notably, public transportation is regarded as both attractive and unattractive. Participants explained this dilemmatic situation as follows:

"I am usually not attracted to the crowds at the train station, but to a goal, [or] a destination." (Anonymous, personal correspondence, July 20, 2012).

"For some crowds, you have to join them to go somewhere, like the train station. However, there are other types of crowds, which you would love to or volunteer to join them. A fireworks crowd is one example that I enjoy a lot because of people cheering around me. It is about sharing the experience." (Anonymous, personal correspondence, August 7, 2012).

According to the explanations by the participants, it is the "goal" or "shared experience" that attracts people to join a crowd. One may think of going somewhere by public transportation, socializing with others, seeking knowledge in a conference or exhibition, or enjoying the activities. In contrast, frequently mentioned unattractive crowds (Table 3.4) are usually the situations in which people find it difficult to keep safe, to share experiences, or to obtain benefits.

Table 3.3. Attractive crowds mentioned at least twice based on the mindmaps in the booklets and the context mapping sessions, and whether they are event-related or not.

Mention frequency*	Attractive crowds	Involving events or activities? If yes, what are the events or activities?
6	Outdoor festivals or events	**Yes.** Singing, dancing programs, fireworks, carnivals, etc.
5	Friends or family gathering	**Yes.** Birthday party, housewarming, family dinner, etc.
4	Theater or cinema	**Yes.** Movies, dancing performance, drama, etc.
4	Public transportation	**No.** Usually having no specific activities except waiting and chatting.
4	Sports event	**Yes.** Marathon racing, watching football game, etc.
2	Art event	**Yes.** Appreciating the artworks, attending art shows, following art lectures, etc.
2	Knowledge seeking event	**Yes.** Going to academic conferences, attending technological exhibitions, etc.

*Mention frequency is the number of participants that at least mentioned it once.

Table 3.4. Unattractive crowds mentioned at least twice based on the mindmaps in the booklets and the context mapping sessions, and whether they are event-related or not.

Mention frequency*	Unattractive crowds	
5	Disordered and ill-disciplined crowds	**No.** Generally being described as problematic, not having specific events or activities.
4	Crowds of unfamiliar people or culture	**Yes.** It may have events and activities, but these are not interesting or even uncomfortable for some crowd members.
4	Violent and immoral crowds	**No.** Generally being described as problematic, not having specific events or activities.
4	Public transportation	**No.** Usually having no specific activities except waiting and chatting.
4	Shopping crowds for cheap goods	**Yes.** Shopping is an activity. It is enjoyable when it is not too crowded.
3	Noisy crowds	**No.** Focusing on the problem of noisiness, even if there are events/activities, they may not be enjoyable anymore.
2	Crowds under bad weather	**No.** Focusing on the poor weather condition, even if there are events/activities, they may not be enjoyable anymore.
2	Crowds on busy streets	**No.** Mostly walking or moving slowly.

*Mention frequency is the number of participants that at least mentioned it once.

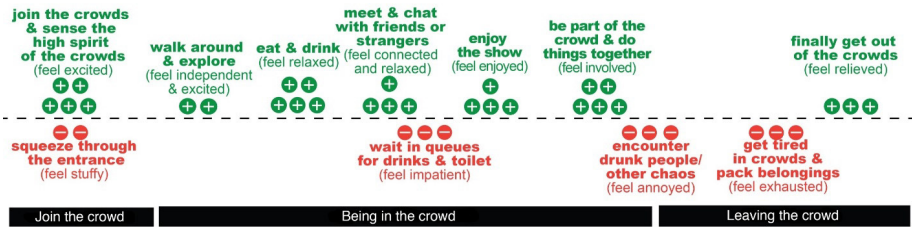


Figure 3.8. A summary of participants' timeline reports: positive experiences outnumbering negative ones in attractive crowds. General descriptions of the experiences are shown in bold texts and the corresponding feelings in small texts in brackets.

To understand the experiences in attractive and unattractive crowds, we analyzed the timelines for attractive and unattractive crowds separately. Figure 3.8 and 3.9 show the final results based on the sum of the visualized timelines of the participants. The first observation was that, in both cases, the timeline could be split into three parts, labeled "joining the crowd", "being in the crowd" and "leaving the crowd". In the first two parts of the attractive crowds, positive experiences (green dots) outnumber the negative ones (red dots), while positive

and negative experiences are almost equal in the "leaving the crowd" part (Figures 3.8). For the unattractive crowds, there were only negative experiences in the first two parts, while there were only positive experiences about leaving such crowd. They were relieved (Figure 3.9). Figure 3.8 and 3.9, in addition, show the specification of the experiences in terms of general descriptions as found in the booklets, and their corresponding feelings based on their discussions in the group sessions. The comparison of the two timelines suggests that attractive crowds are associated with mainly positive experiences and feelings, while unattractive crowds are associated with negative experiences and feelings. Since well-being is about balancing positive and negative experiences, our findings point out that the well-being of crowd members is supported in attractive crowds and threatened in unattractive ones.

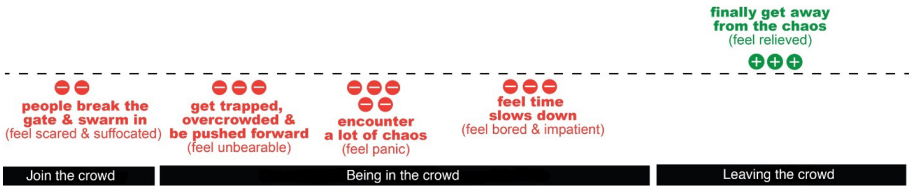


Figure 3.9. A summary of participants' timeline report: negative experiences dominate in unattractive crowds. General descriptions of the experiences are shown in bold texts and the corresponding feelings in small texts in brackets.

3.3.2.2 Reasons to join or avoid a crowd

The participants gave 30 reasons for joining attractive crowds and 30 reasons for avoiding unattractive crowds. Like with the labels of the attractive and unattractive crowds, the labels for similar reasons also varied among participants: many of the reasons were mentioned only once or twice, but they can be grouped. For example, "going with friends" and "going with family members" were grouped, since friends and family members are the persons that you are familiar and feel comfortable with. Reasons like "feeling of belonging to a group in crowds", "networking" and "socializing" were grouped because they are all about seeking for relatedness or belongingness in crowds. The new grouping helped generate main reasons for joining and avoiding a crowd. Table 3.5 shows the resulting reasons mentioned by at least two participants. Seeking relatedness with others (e.g., go with friends or family, feeling of belonging to a group), and being motivated to obtain pleasure or benefits from the crowd (e.g., look for fun and relaxation, waiting in queue for the gifts) are main reasons for joining a crowd. The lack of security or autonomy and low pleasure-stimulation are reasons for avoiding a crowd.

Table 3.5. Reasons for joining or avoiding a crowd mentioned at least twice. The last column shows the author's interpretation of the reasons for joining or avoiding a crowd in terms of Sheldon et al. (2001)'s ten psychological needs.

Mention frequency*	Reasons for joining attractive crowds	Corresponding psychological needs proposed by Sheldon et al. (2001)
7	Going with friends or family	Relatedness
6	Looking for fun and relaxation	Pleasure-stimulation
5	Feeling belonging to a group, networking and socializing	Relatedness
4	Joining for external goals, e.g., waiting in queue for gifts, take public transportation to somewhere	Pleasure-stimulation
4	Sharing positive experience and emotions	Relatedness
2	Joining for tasty food and drinks	Physical thriving
2	Joining because of curiosity	Pleasure-stimulation
2	Joining for supporting	Relatedness
2	Joining because of good atmosphere	Physical thriving, Security & Relatedness
2	Joining for knowledge and information	Competence
Mention frequency*	**Reasons for avoiding unattractive crowds**	**Corresponding psychological needs proposed by Sheldon et al. (2001)**
7	Having no control of the safety	Security
5	Easily getting trapped in jammed crowds	Autonomy & Security
4	Feeling bored	Pleasure-stimulation
4	Avoiding because of dirty and uncomfortable environment	Physical thriving & Security
3	Waiting for too long, receiving no information, getting bored	Autonomy & Pleasure-stimulation
3	Feeling annoyed, even suffocated	Autonomy & Security
2	Feeling unwelcomed/unappreciated	Relatedness & Self-esteem

*Mention frequency is the number of participants that at least mentioned it once.

Table 3.5 also shows the possible interpretation of the reasons in terms of Sheldon et al. (2001)'s psychological needs. The reasons for joining a crowd seem to be relatedness, pleasure-stimulation and physical thriving. The reasons for avoiding a crowd seem to be lack of security, autonomy and pleasure-stimulation. Interestingly, pleasure-stimulation is mentioned as a reason for both joining and avoiding crowds. In Sheldon et al. (2001)'s studies, considering relatively long-term timespans, pleasure-stimulation is not considered a high priority need for experiencing a satisfying event. However, they found different patterns of needs when participants reflected on long versus short periods of time, in their words:

"Self-actualization might be expected to be most salient within a more global frame of reference, whereas pleasure-stimulation might be most salient when a person considers short-term satisfaction." (Sheldon et al., 2001, p.333).

In our study, the mindmaps generated by the participants consisted of mostly short-term crowd experiences, for example, one-day festivals, watching shows

and commuting. This probably can explain why participants regarded pleasure-stimulation as a necessary need in crowds.

3.3.2.3 Requirements for sustaining well-being in crowds

The last 40 minutes of the context mapping session, participants were asked to make and present a collage to express their requirements and expectations in sustaining well-being in crowds. In total, the collages resulted in 36 requirements. Table 3.6 shows the main requirements after a similar regrouping as for the attractive and unattractive crowds and reasons for joining and avoiding a crowd. All ten participants mentioned that timely information and guidance is crucial to them, since it allows them to stay well-prepared for potentially dangerous situations, and to have a sense of control over the situations. Seven participants mentioned that safety is crucial in crowds. Furthermore, they would like to stay connected with others (e.g., family or friends), and to be involved in the crowd activities. These requirements are in line with Sheldon et al. (2001)'s needs for autonomy, competence, security and relatedness.

Table 3.6. The requirements mentioned at least twice. The last column shows the author's interpretation of the requirements for sustaining well-being in crowds in terms of Sheldon et al. (2001)'s ten psychological needs.

Mention frequency*	Requirements for sustaining well-being in crowds	Corresponding psychological needs proposed by Sheldon et al. (2001)
10	Stay well-informed, well-guided and well-prepared	Autonomy, Competence & Security
7	Stay connected with family or friends and feel involved in crowd activities	Relatedness
7	Feel safe	Security
6	Get familiar with the venue easily and quickly, proper way-finding tools, obvious meeting points	Autonomy & Competence
4	Free to escape from the crowds	Security & Autonomy
4	Have easily recognizable staff, giving guidance and supports	Security & Relatedness
3	Receive accurate information, e.g., waiting time	Autonomy
3	Have fewer or no queues	Competence & Autonomy
2	Ensure cleanness and hygiene	Physical thriving
2	Can communicate when the mobile phone stops working in crowds	Autonomy, Competence & Relatedness
2	Always be easy to get food and drinks	Physical thriving & Pleasure-stimulation
2	Know other crowd members' emotions	Relatedness

*Mention frequency is the number of participants that at least once mentioned this.

3.3.2.4 Relations between well-being requirements and reasons for joining or avoiding crowds

Table 3.5. and 3.6 respectively exhibit "reasons to join or to avoid a crowd" and "requirements for sustaining well-being in crowds" in terms of ten psychological needs proposed by Sheldon et al. (2001). Based on Table 3.5, we can assess how many times each psychological need was mentioned by the participants as a reason to join an attractive crowd or to avoid an unattractive crowd. Similarly, from Table 3.6, we can assess how many times each psychological need was mentioned by the participants as corresponding with requirements for sustaining the well-being in crowds. The resulting frequencies have been summarized in Table 3.7.

The table shows that three of the ten psychological needs have never been mentioned, namely self-actualization, popularity-influence and money-luxuries. Furthermore, self-esteem and physical thriving are hardly mentioned. The remaining five psychological needs (relatedness, competence, autonomy, pleasure-stimulation and security) can be used to connect requirements to sustain well-being with reasons to join or avoid crowds. Among the five needs, relatedness and pleasure-stimulation were mentioned as two main reasons to join attractive crowds (32 out of 40 in total). Relatedness was also frequently mentioned as a requirement for sustaining well-being, while pleasure-stimulation was not. This suggests that, in our study, relatedness is the only requirement for sustaining well-being in attractive crowds. The lack of security, autonomy, pleasure-stimulation was considered as the three main reasons to avoid unattractive crowds (37 out of 45 in total). Security and autonomy were also frequently mentioned as requirements for well-being in crowds, suggesting that, in our study, these two psychological needs are the requirements for sustaining well-being in unattractive crowds. Finally, Table 3.7 shows an exceptional role of competence in this study. It was often mentioned as a requirement for sustaining well-being, but almost never mentioned as a reason to join or avoid crowds.

Table 3.7. Summary of the results in Table 3.5 and 3.6.

Ten psychological needs proposed by Sheldon et al. (2001)	Importance to well-being in satisfying events in Sheldon et al. (2001)'s studies	Reasons to join attractive crowds*	Reasons to avoid unattractive crowds*	Requirements for sustaining well-being in crowds*
Relatedness	Important	20	2	15
Competence		2	0	21
Self-esteem		0	2	0
Autonomy		0	11	28
Pleasure-stimulation	Less important	12	7	2
Physical thriving		4	4	4
Security		2	19	25
Self-actualization		0	0	0
Popularity-influence	Least important	0	0	0
Money-luxuries		0	0	0

*The numbers in column 3, 4 & 5 are the mention frequencies of the ten needs.

3.4 CONCLUSION

This chapter suggests a new way of classifying crowds into two categories based on the presence of events, namely event crowds and non-event crowds. Since attractive crowds and unattractive crowds shared characteristics with event and non-event crowds, it is proposed that the requirements for sustaining well-being in attractive and unattractive crowds can be transposed to event and non-event crowds, respectively.

Table 3.3 and 3.4 present the most frequently mentioned attractive and unattractive crowds in context mapping sessions. The third columns of Table 3.3 and 3.4 describe the author's interpretation of whether the crowds involve events or activities. We observed that most mentioned attractive crowds are event-related or activity-related, while unattractive crowds usually have no desired activities or are simply described as problems. The public transportation, which usually has no specific activities or events, is regarded as an attractive and an unattractive crowd at the same time. Given these observations, we suggest a new way to classify crowds, namely event crowds and non-event crowds (see Figure 3.10). An event crowd is always event-based, where the goal of people is to enjoy performances or activities, to interact with others and to share experiences within the crowd (e.g., concerts, exhibitions, conferences, parties). A non-event crowd usually does not involve any activity or performance. People join the crowd not because they like the crowd or want to interact with others, but because they want to achieve some external goal or benefit (e.g., crowds at public transportation, crowds waiting in queues for free goods, crowds on a busy shopping street).

It is assumed that event crowds are overlapping with attractive crowds, most of which are well organized with exciting programs, encouraging people to interact with each other. Non-event crowds are not as attractive as event crowds but are not necessarily negative or full of problems. For instance, crowds at public transportation are typical non-event crowds. They can be attractive, because the trains or airplanes are means to reach the destination but can also be unattractive as they gather large crowds that bring inconvenience.

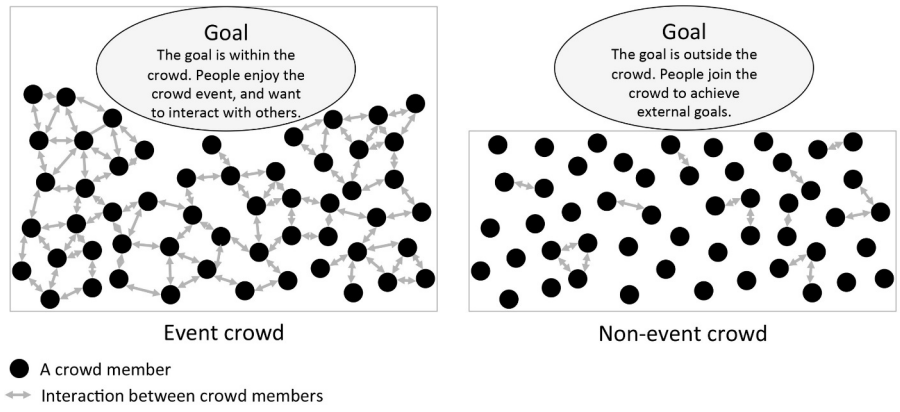


Figure 3.10. Event crowd and non-event crowd.

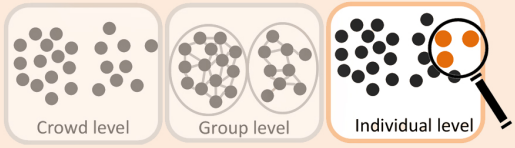
In conclusion, regardless the type of crowd, the most prominent requirements for sustaining well-being in crowds are autonomy, competence, relatedness and security. Self-esteem, which was important on Sheldon's list, is not necessary for well-being in crowds. Since attractive crowds and unattractive crowds shared characteristics with event and non-event crowds, respectively, we suggest that reasons to join attractive crowds and avoid unattractive crowds can be an indication for crowd members' well-being requirements in event and non-event crowds. In other words, we assume that, for event crowds, to sustain well-being, crowd members' needs for relatedness must be fulfilled. For non-event crowds, the need for security and autonomy is the top priority.

"Once you meet someone, you never really forget them."

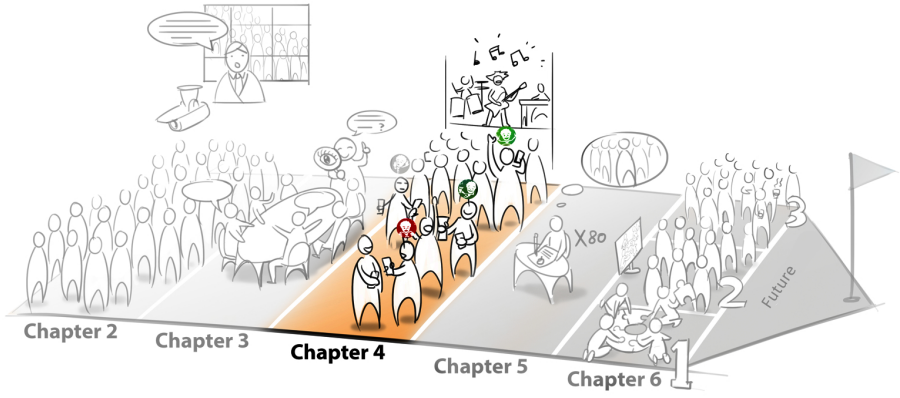
— Hayao Miyazaki,
Spirited Away

CHAPTER 4

Measuring Real-time Emotions in Crowds through Self-Reports: A Field Study



Chapter 4 focuses on the individual level and presents a field study in an indoor music festival with approximately 800 visitors, where approximately 10% of the crowd members used a playful smartphone application (i.e. EmoApp) to report their locations, their emotions and the perceived emotions of others in their proximity. From tracking the individuals using the EmoApp anonymously, we were able to sample the emotions at different locations of the festival. The collected information seemed to reflect the real situations: participants' movements, emotional changes and the activities at the festival were consistent with each other.



This chapter is an extended version of the following article:

Li, J., Erkin, Z., de Ridder, H. & Vermeeren, A. (2013). A Field Study on Real-time Self-Reported Emotions in Crowds. In *Proceedings of ICT OPEN*, Eindhoven, The Netherlands, 80-84.

4.1 INTRODUCTION

In recent years, crowd management has been increasingly gaining attention from both academia and practice as big cities are getting crowded, and events with a mass of people are prevalent. These phenomena are easily seen at public transportations and festivals. In a previous study presented in Chapter 2, we interviewed ten crowd experts, most of whom addressed the necessity for mechanisms that allow accurate estimation of crowd emotions for better crowd management. This observation is justified in several studies that clearly indicated that crowd emotion is contagious (Bartel & Saavedra, 2000; Hatfield et al., 1993; Le Bon, 1895; Lewis et al., 2010). This fact has severe implications since a well-behaved crowd can suddenly turn into an uncontrollable one due to a negative emotion spreading out. For example, the ceremony of the Dutch Dodenherdenking (Remembrance Day) in 2010 was disrupted by a person's loud scream, resulting in a panicked stampede among a crowd of 20,000 people. Positive emotions like excitement pass on in a spontaneous collaborative audience wave in the stadium of 1986 Mexico World Cup (Farkas et al., 2002). Emotion coordinates human behavior and psychological states (Nummenmaa et al., 2014). It is an important clue in social perception: emotion is a transient reaction to events that may impact an individual's well-being, so it usually results in immediate response and motivates people to behave adaptively (Lazarus, 1991). In other words, emotion serves as a predictor of human behaviors (Levenson, 1999). Perceiving other people's emotions, people can constantly judge their intentions and predict their behaviors to act accordingly. For example, most people would like to stay in a happy crowd and want to flee from a crowd when they sense negative emotions. Thus, it is crucial for crowd managers to understand crowd emotion in real-time to act appropriately.

To date, most research investigating the perception of emotions has concentrated on facial expressions (Adolphs, 2002; Sebe et al., 2007) and body language (McHugh et al., 2010; Schindler et al., 2008), which may work well in small crowds but might be difficult to distinguish in the distance or within a crowd of thousands of members. Besides, humans can conceal their emotions, which makes it even more difficult to perceive emotions merely by facial expressions and body language. As Levenson (1999) argued, apart from the core emotion system that responds automatically, there is also an emotion control mechanism. This mechanism can help preserve people's private feelings by altering their actual emotion expression into an unobservable one. Moreover, most crowd management teams are using video surveillance cameras (Li et al., 2013). Unfortunately, most surveillance cameras are not automated, and crowd managers must constantly examine the real-time crowd scenes on dozens of monitors to keep track of the situations. Besides, security personnel are hired to stay in the crowd to assist managers in detecting misbehaving crowd members (Abbott, 2000). All these methods are very inefficient and prone to human error especially when the crowd gets bigger.

Recently, some research teams have experimented with new ways of monitoring crowds. Gong et al. (2018) used social media data for estimating

crowd density in city-scale events. During Several crowd events in Amsterdam in 2015 and 2016, a combination of counting camera counting systems, Wi-Fi sensors, and GPS trackers was used to determine the crowd traffic state (Daamen et al., 2016). Yuan et al. (2016) developed a real-time prototype Crowd Monitoring Dashboard to collect, analyze and visualize the real-time data, as a means to estimate the state of the pedestrians in terms of their speed, density and flow. As we noticed that, all the recent technologies and experiments still tend to focus on monitoring crowds from an outsider's point of view, and pay attention to the density, flow of the crowds rather than understand the psychological needs of crowd members.

Instead of observing the crowd from the outside, the ideal case would be placing sensors on crowd members to measure their emotions automatically. Haag et al. (2004) trained computers to recognize emotions using multiple signals from many different bio-sensors. In their studies, a set of bio-sensors were attached to the subjects' body (e.g., jaw, chest, abdomen, fingers) to detect bio-signals including electromyography (i.e., muscle activity), electrodermal activity (i.e., skin conductivity), skin temperature, blood volume pulse (i.e., vasoconstriction and the heart rate), electrocardiogram (i.e., heart rate) and respiration (i.e., breathing rate). These bio-signals are often a good indicator for the level of stress as well as whether a person is facing conflict or non-conflict situations. For instance, high muscle tension often occurs under stress. A change in skin conductivity and temperature also indicates whether a person is under strain, anger or fear. A low heart rate can indicate a state of relaxation, whereas an increased heart rate can indicate a potential state of mental stress or frustration. Fast and deep breathing can indicate excitement such as anger or fear but sometimes also joy. Rapid shallow breathing can indicate tense anticipation including panic, fear or concentration. Slow and deep breathing indicates a relaxed resting state while slow and shallow breathing can indicate states of withdrawal, depression or calm happiness. Using a combination of bio-signals, Haag et al. (2004)'s studies trained a neutral network classifier based on the data collected from the subjects. The classifier obtained high recognition rates of emotional arousal and valence.

A disadvantage of bio-sensors is that they are complicated and intrusive since they require subjects to wear a set of cumbersome and invasive sensors on different parts of their body (e.g., Haag et al., 2004). These sensors are not comfortable to subjects in an optimized experiment setting. Applying them in crowd situations will make it worse. As an alternative to these intrusive bio-sensors, one may use non-intrusive sensors such as cameras for detecting emotions based on video recordings of people's face and body expressions, microphones for recording audio signals to recognize emotions in conversations, and infrared cameras for observing emotion changes on thermal image recordings (for an overview, see Gunes and Pantic, 2010). However, Gunes and Pantic (2010) mentioned that, due to the ethical issues, making recordings (e.g., cameras, microphones, infrared cameras and bio-sensors) should ask for subjects' permissions. As a result, subjects are aware of the recordings, which might influence the accuracy of emotion recognition. So, due to the complex nature of emotions and limits in the sensor technology, automatic emotion

recognition remains a challenge technically.

As an alternative, self-reporting is an effective way of assessing emotions. Nummenmma et al. (2014) applied the self-report method and found a universal topographical distribution of emotion-related bodily sensations among 701 participants of diverse cultural background. Reisenzein (2010) claimed that self-reports are the most direct and richest source of information about emotions, and emotion-related mental states. Our study intends to continue the self-reporting approach by encouraging crowd members to report their emotions via a smart device, such as a smartphone. From these self-reports, we would like to obtain a real-time dynamic map of crowd emotions to enable crowd managers to perceive the emotional changes rapidly.

In this chapter, we introduce a self-reporting tool to assess emotions in crowds. The tool is a self-report application working on smartphones. The reason why we choose the smartphone as the platform to run the self-report application is that most people have it and use it daily. It is a time- and cost-efficient way of collecting self-reporting data. Three steps are considered to design this application tool. First, we need to find out what emotions should be included and how to represent them on the interface of the application. Therefore, a literature review on emotion models is presented in Section 4.2. Then, we need to decide how to position these emotions on the interface that allows people to report intuitively. Finally, we need to think about the detail designs of the interface, such as graphics, colors, interactions.

Following the three steps, a self-report application *EmoApp* was developed to motivate crowd members to report their own emotion, real-time location and the perceived emotion of other crowd members in their proximity in a fast and non-intrusive manner. To test the reliability of the self-reported data, a field study was conducted in a music festival. The collected data have revealed many important aspects of crowd emotions such as the correlation between real-time emotional changes of the crowd members concerning the actual events. This experiment also provided very valuable insight into the further design of the self-report tool. This study is a first step toward measuring crowd emotion and capturing its changes.

The chapter is organized as follows: Section 4.2 provides an overview of emotion models relevant for designing the self-report application. Section 4.3 presents the design process of the self-report tool based on the emotion theories and user studies. Section 4.4 shows the methods and results of the field study at a festival. Section 4.5 discusses the lessons learned, points out the differences between “crowd emotions” and “emotions in crowds”, and presents the open issues. Finally, Section 5 concludes this chapter and suggests “action tendency” as a central topic in the next chapter.

4.2 EMOTION CLASSIFICATION: A LITERATURE REVIEW

Emotion coordinates human behavior and psychological states during survival-salient events and pleasurable interactions (Nummenmaa et al., 2014). It is an essential clue in social perception that guides people to form impressions of and make inferences about others. Emotion is a transient reaction to events that may impact an individual's well-being, so it usually results in immediate response and motivates people to behave adaptively (Smith & Lazarus, 1990). In other words, emotion serves as a predictor of human behavior (Levenson, 1999). Through perceiving others' emotions, people can constantly judge their intentions and predict their behaviors to act accordingly. For example, most people would like to stay in a happy crowd and want to flee from a crowd when they sense negative emotions. Thus, it is crucial for crowd managers to understand emotions in crowds in real-time to act appropriately.

Research on the classification of emotions is mainly based on two fundamental approaches. The first approach views emotions as discrete constructs whereas the second approach aims at grouping emotions on a dimensional basis.

4.2.1 Discrete emotions

Over the past centuries, researchers have proposed three to eleven emotions as primary or basic, all including fear, anger and sadness, and most including joy, love, and surprise (Kemper, 1987). Charles Darwin, Silvan Tomkins and Paul Ekman are three influential researchers in this field. In Charles Darwin (1872/1998)'s book *The Expression of the Emotions in Man and Animals*, he listed over 30 emotions and discussed them in seven categories. These categories are described separately in Chapter 7-13 of Darwin's book, covering the following emotions (1) low spirits, anxiety, grief, dejection, and despair; (2) joy, high spirits, love, tender feelings and devotion; (3) reflection, meditation, ill-temper, sulkiness and determination; (4) hatred and anger; (5) disdain, contempt, disgust, guilt, pride, helpless, patience, affirmation and negation; (6) surprise, astonishment, fear and horror; and (7) self-attention, shame, shyness, modesty and blushing. Following Darwin, Tomkins (1964) referred basic emotions as biologically based affects and proposed eight basic emotions ("primary affects") that have facial response controlled by an innate program. The eight basic emotions were all in pairs, in which two emotion labels represented the same category of emotion in low-intensity and high-intensity respectively. These emotion pairs are interest-excitement, enjoyment-joy, surprise-startle, distress-anguish, fear-terror, shame-humiliation, contempt-disgust and anger-rage.

Nowadays, for over 40 years, Paul Ekman (e.g., 1972, 1992, 1999 & 2011) is the leading authority for the "discrete" viewpoint advocated by Darwin (1872/1998) and Tomkins (1964). His main claim is the easiness to recognize certain emotions in others and ourselves. These emotions are described as "discrete" and "basic" because they are believed to be recognizable cross-culturally and to be

distinguishable by people's facial expressions and physiological processes. His most influential work revolved around basic emotions. In Ekman's article from 2011, he listed seven emotions that are universally recognizable: anger, fear, surprise, sadness, disgust, contempt and happiness.

Recently, Scarantino and Griffiths (2011) have found evidence that there are three ways to interpret the term "basic": conceptually basic, biologically basic and psychologically basic. Conceptually basic emotions are distinguishable in taxonomic categories. Rosch (1978) claimed that those basic-level taxonomic categories are the most abstract ones with shorter names. These short names can be expressed quickly by adults, are used most often by parents to teach their children and are first learned by children. Examples are chair, car, dog, table and so on. Biologically basic emotions have an evolutionary origin and distinctive biological markers. Ekman (1999) defined this biological basic-ness as adaptations which are evolved for dealing with "fundamental life tasks" such as facing a predator, pursuing goals, experiencing losses and so on. From a psychological perspective, basic emotions are defined by Ortony and Turner (1990) as the "primitive building blocks" of other non-basic emotions. In other words, basic emotions do not contain another emotion as a component.

4.2.2 Dimensional models of emotions

Contrary to the discrete view of emotions, dimensional models of emotions characterize all emotions by two or three dimensions (Robin & Talarico, 2009). Influential models are the circumplex model of affect (Russell, 1980), Plutchik (2003)'s psycho-evolutionary model of emotions, and the recent three-dimensional model developed by Lövheim (2012) based on the impact of three monoamines on controlling behaviors and emotions.

Russell (1980)'s *circumplex model of affect* suggests that emotions are distributed in a space with two dimensions: valence (e.g., positive versus negative) and arousal (e.g., active versus passive). The vertical axis represents the arousal dimension and the horizontal axis represents the valence dimension. Russell (1980) found that, in this space, eight affective or emotional states can be placed on a circle, in the following order (Figure 4.1-a): pleasure (0°), excitement (45°), arousal (90°), distress (135°), displeasure (180°), depression (225°), sleepiness (270°) and relaxation (315°). In a series of psychometric experiments, Russell (1980) connected 28 stimulus words to these eight states. These stimulus words were described as "words or phrases that people use to describe their moods, feelings, temporary states, affect, or emotions". Table 4.1 shows the results of one of these experiments using a sorting task. The frequencies of each category are more or less normally distributed with the highest frequency falling along the diagonal of the table, indicating that the ordering of emotions on a circumplex (Figure 4.1-a) is supported by this category-sort study.

Table 4.1 Frequency of placement of 28 words into eight categories, by Russell (1980). Copyright 1980 by the American Psychological Association. Re-used with permission.

Term	Category							
	Pleasure	Excitement	Arousal	Distress	Displeasure	Depression	Sleepiness	Contentment
Happy	21	8	2					5
Delighted	15	16	3					2
Excited	2	**29**	5					
Astonished		17	18	1				
Aroused		14	**21**	1				
Tense		8	18	9		1		
Alarmed		6	19	11				
Angry		5	**21**	5	3	2		
Afraid		2	11	22		1		
Annoyed		1	12	14	4	4		1
Distressed			4	**25**	5	2		
Frustrated		2	5	19	4	6		
Miserable				3	**23**	10		
Sad				10	6	19		1
Gloomy				2	11	22	1	
Depressed				4	7	**24**		1
Bored				3	2	14	17	
Droopy				1	1	8	26	
Tired					1	1	**34**	
Sleepy					1		32	3
Calm	4						3	29
Relaxed	6						4	26
Satisfied	3	1						**32**
At ease	7						3	26
Content	6	1						29
Serene	8	2						26
Glad	20	4						12
Pleased	**22**	2	2					10

In his psychoevolutionary model of emotions (Figure 4.2-a & b), Robert Plutchik (2003) identified eight primary bipolar emotions: joy versus sadness; anger versus fear; trust versus disgust; and surprise versus anticipation. In addition, each emotion can exist in varying degrees of intensity or levels of arousal. For example, rage is more intense in the family of "anger" while annoyance is less intense. Combining these two observations resulted in a cone-shaped three-dimensional surface of emotions, where the vertical axis represents the intensity of emotions. This model can outspread as a wheel in two dimensions. All other emotions, except the primary ones, are mixed or derivative states. That is, they occur as combinations, mixtures, or compounds of the primary emotions. For example, love equals to a combination of joy and trust, whereas submission is a mix of trust and fear.

4.2.3 Integrating discrete and dimensional models of emotions

Plutchik (2003) embraced both discrete and dimensional viewpoints in his model. He fully considered the eight basic emotions and derived a set of emotions that are in the same category with each basic emotion but differ in intensity. He also emphasized the similarity and bipolar nature among the basic emotions and showed the reason why basic emotions are called "basic" because other more complex emotions are actually a combination of the basic emotions.

Lövheim (2012)'s three dimensions "serotonin-noradrenaline-dopamine" are represented as three orthogonal axes, which form a cube of emotions. Through an extensive literature review, Lövheim (2012) has found much support to

prove that the serotonin axis (x-axis) represents self-confidence, inner strength and satisfaction. The noradrenaline axis (y-axis) is associated with activation, vigilance and attention. The dopamine axis (z-axis) is linked to reward, motivation and reinforcement. The eight pairs[12] of basic emotions proposed by Tomkins (1964) are placed at the eight corners of the cube (See Figure 4.1-b). In this way, Lövheim can connect discrete emotion models to dimensional models.

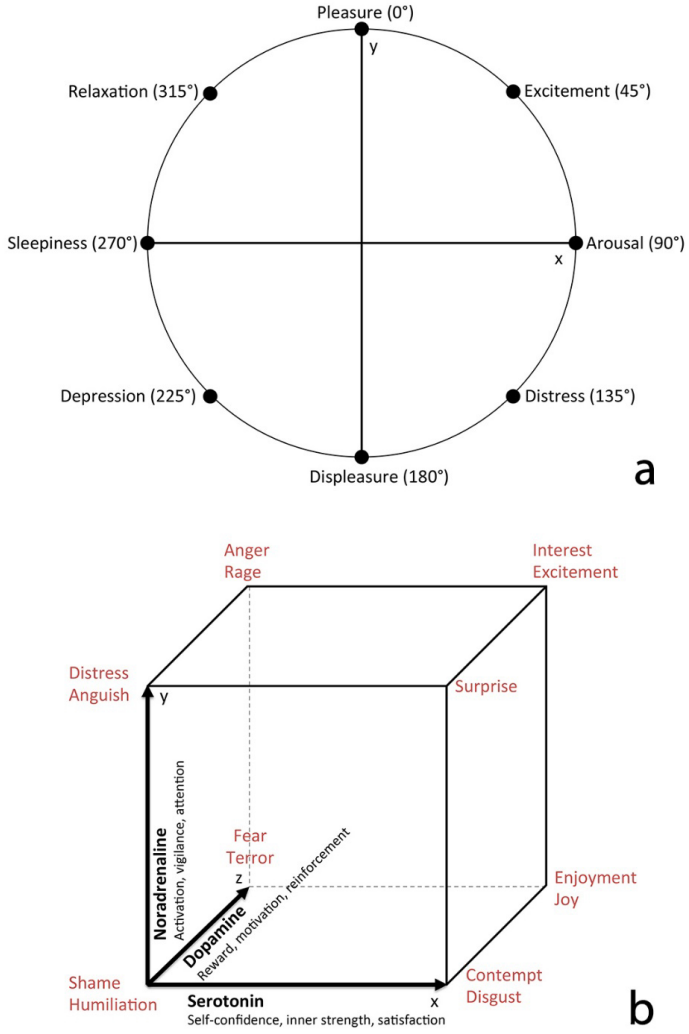


Figure 4.1. (a) Russell (1980)'s two-dimensional circumplex model (horizontal axis: valence, and vertical axis: arousal); (b) Lövheim (2012)'s emotion cube with Tomkins's eight pairs of emotions placed at the eight corners. Figure 4.1-a is illustrated based on the descriptions on p.1161 of the article Russell (1980); Figure 4.1-b is adapted from Lövheim (2012), p. 342, Copyright 2012 by Elsevier. Re-used with permission.

12 Lövheim only used "surprise" from Tomkins's "surprise-startle" pair, because he agreed with Ekman et al. (1985) that "startle" is a reflex, not an emotion. Therefore, he only selected "surprise" as a label.

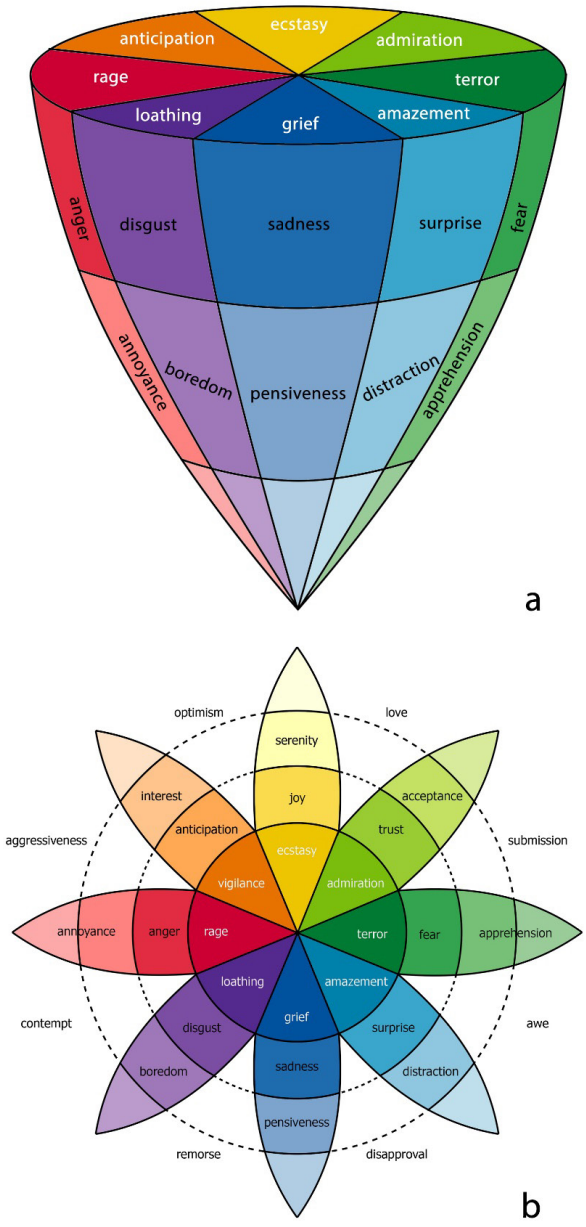


Figure 4.2. (a) Plutchik's three-dimensional psychoevolutionary model of emotions in a cone shape, and (b) the outspread version of Plutchik's model. Figure 4.2-a is adapted from Figure 4.1 on p. 63 in the book *Emotions in the practice of psychotherapy: Clinical implications of affect theories* (Plutchik, 2000), Copyright 2000 by the American Psychological Association. Re-used with permission. Figure 4.2-b is a theoretical graphic designed by Annette de Ferrari (Copyright owner) based on Plutchik's cone-shape emotion model. This figure originally appears on the front cover of the book *Emotions and Life: Perspectives from Psychology, Biology, and Evolution* (Plutchik, 2003). Re-used with permission.

4.3 DESIGNING AN APPLICATION TO MEASURE REAL-TIME EMOTIONS IN CROWDS

In order to design an application on the smartphone to allow crowd members to report their emotions directly, a number of questions have to be answered first: (1) what emotions should be included, (2) how to position these emotions on the interface allowing people to report intuitively, (3) how to fine-tune the interface, such as graphics, colors, and interactions. The first question will be answered using the literature of emotions (see Section 4.2), while the other two issues will be solved in two separate studies plus refining and detailing the interface to be used in a field study.

4.3.1 Emotion selection

Both Russell (1980)'s circumplex model of affect and Plutchik (2003)'s psychoevolutionary model represent emotions on a continuous circle. We decided to follow Russell and Plutchik to use a circular interface on the self-report application. The next decision was to simplify the self-reporting task by reducing the number of emotion labels. To this end, Russell (1980)'s valence and arousal dimensions were combined into four labels, namely positive-active, positive-passive, negative-active, and negative-passive. The connection of these labels with Russell's dimensions/categories can be found in Table 4.2, including the terms associated with these labels.

Table 4.2. The creation of emotion labels using Russell (1980)'s original data shown in Table 4.1. The table shows the terms associated with the valence and arousal dimensions from Russell (1980)'s model.

Label	**Term**	**Category**			
		Pleasure	Arousal	Displeasure	Sleepiness
Label 1: Positive-Active	Pleased	22	2		
	Happy	21	2		
	Delighted	15	3		
	Excited	2	5		
Label 2: Negative-Active	Angry		21	3	
	Annoyed		12	4	
	Distressed		4	5	
	Frustrated		5	4	
Label 3: Negative-Passive	Gloomy			11	1
	Bored			2	17
	Droopy			1	26
	Tired			1	34
	Sleepy			1	32
Label 4: Positive-Passive	Calm	4			3
	Relaxed	6			4
	At ease	7			3

4.3.2 Positioning emotions on a circular interface

A user study was conducted to determine the preferred positions of the four labels of emotions on a circular interface. Participants were students and employees of Delft University of Technology (n=140, 59 females and 81 males). The test material consisted of a drawing depicting a two-dimensional (2D) smartphone in real size with a circle on its screen to simulate the interface. Participants were asked to read the emotion terms in the four groups and indicate the most proper position on the circular interface for each emotion group (Figure 4.3).

Figure 4.3. The test to determine the preferred positions of the four emotion groups.

For analyzing purpose, the circle was split up into 16 segments of 22.5 degrees. Figure 4.4 shows the frequencies per segment and per emotion group. The first observation is that, in general, people preferred to use horizontal and vertical positions over the other positions (see Figure 4.4): 78% of the participants placed the positive-active emotions on the top position of the circle (Position 1), 43% placed the positive-passive emotions on Position 5, 43% placed negative-active emotions on Position 9, and 37% placed negative-passive emotions on Position 13. Note that, the latter was not so distinct as 29% of the negative-passive emotions were placed on Position 9 as well. The remainder of the responses were on the diagonals (Position 3, 7, 11 and 15).

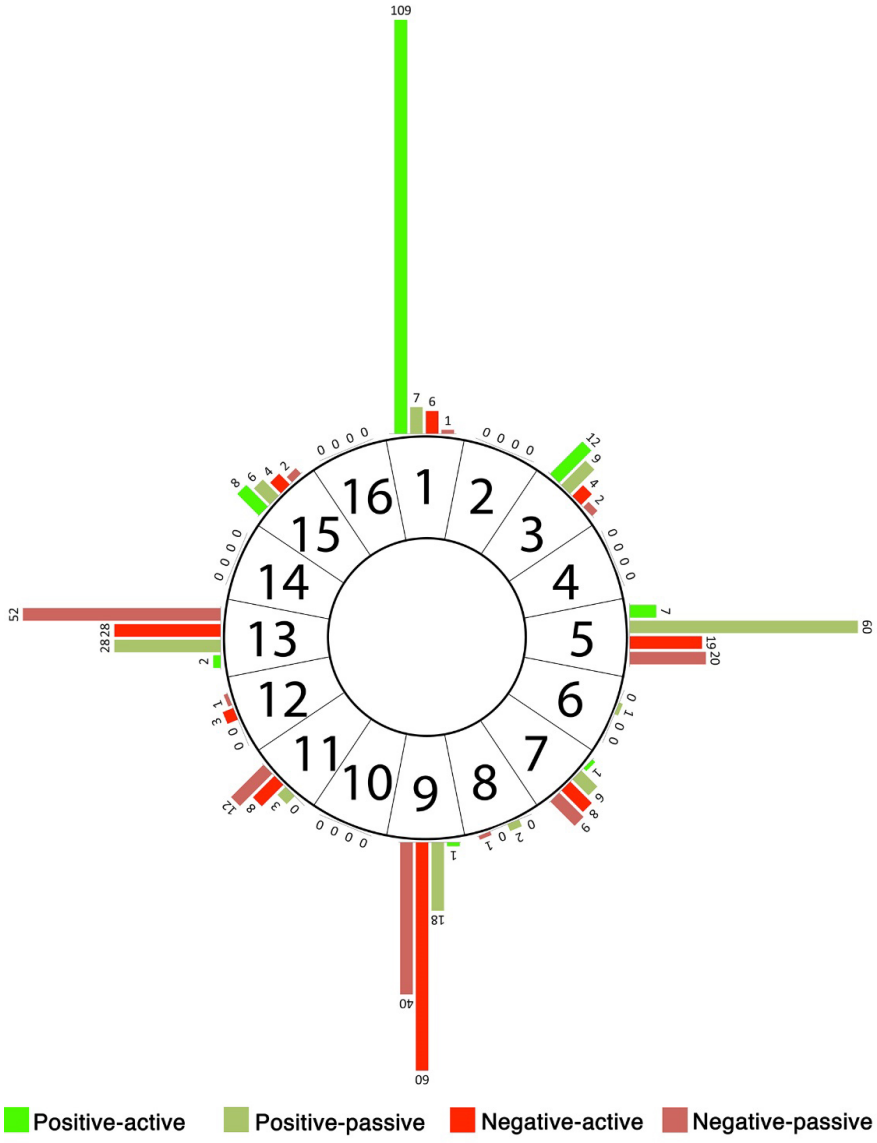


Figure 4.4. Emotion positions on a circular interface. The length of the bars indicates the number of participants placing one of the four emotion groups in each segment. For the relations between the four labels and the emotion terms, see Table 4.2.

4.3.3 Detail designs of the interface

The refining of the interfaces followed three requirements: (1) Usability. The interface design of *EmoApp* allows users to intuitively know how to operate it once they install it and have the report done in a few seconds. Here, intuitive use refers to the user's subconscious application of prior knowledge (Hurtienne & Blessing, 2007), like intuitively turning the tap head counter-clockwise to get tap water and sliding to unlock the smartphone. (2) Non-intrusiveness. Users

report via *EmoApp* with minimal effort, not interfering with their activities in crowds. (3) Attractiveness. *EmoApp* is aesthetically appealing to the users through a user-friendly interface and through providing rewards. Following the three requirements, a set of four emotion cartoon characters were designed and tested, along with appropriate background colors for each emotion type and a game-reward component.

Emotion Characters. Apart from defining the positions of emotions on the circular interface, we proposed to represent four types of emotions with cartoon characters (Figure 4.4-a). A software developments company *Shapers* (http://shapers.nl) assisted in designing and finalizing the emotion cartoon characters. To verify whether the designed characters conveyed the intended emotion types, a study was conducted with 82 participants from Delft University of Technology (39 females and 43 males). There were two tests for this study. The same 2D smartphone as in the emotion positioning study was included in both tests. The only difference between these two tests was the presence of the four groups of emotion words, the same as the words presented in the emotion positioning study (Figure 4.5).

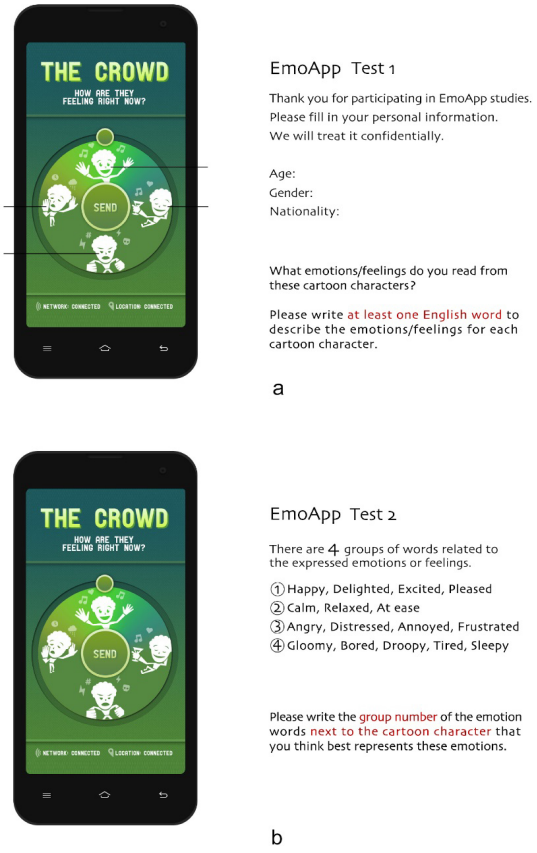


Figure 4.5 (a) Test 1: Describe the emotion conveyed by each cartoon character, (b) Test 2: Link emotions and cartoon characters. Participants gave answers to Test 1 before they could read Test 2.

In Test 1, participants were required to think about at least one English word to describe the emotion conveyed by each cartoon character (Figure 4.5-a). In Test 2, four groups of emotion words were already given. Participants were instructed to link each group of emotions to the cartoon character that they thought best represented these emotions (Figure 4.5-b). Each participant performed the two tests sequentially. They gave answers to Test 1 before they could read Test 2.

In Test 1, where the participants had to come up with emotion words, the accuracy in recognizing the emotions in the cartoon characters was high. 93% of the participants used happy, excited, joy, enthusiastic or cheerful to describe the character representing positive-active emotion. 82% were able to recognize the positive-passive character as relaxed or enjoyable. 96% could see anger and aggressiveness in the negative-active character. 90% identified bored, tired and sad emotions in the negative-passive character. The results of Test 2 were in line with those from Test 1. All participants correctly linked the four groups of emotion words to their corresponding cartoon characters. These results indicate that the cartoon characters are obvious in representing the four types of emotions. In conclusion, these cartoon characters were successfully designed to represent the four types of emotions.

Color. Different background colors were added under the four emotion cartoon characters to differentiate them. According to the "color and emotion" study by Naz and Epps (2004), green was highly associated with happiness and excitement. Blue stood for feelings of relaxation and calmness. Red had associations with fight and anger. Greenish yellow elicited the feeling of sickness. Accordingly, we applied green, blue, red and greenish yellow to highlight positive-active, positive-passive, negative-active and negative-passive emotions respectively. The cartoon character is highlighted with the corresponding background color when the user moves the small circular slide close to it (see Figure 4.6-b, c, d & e).

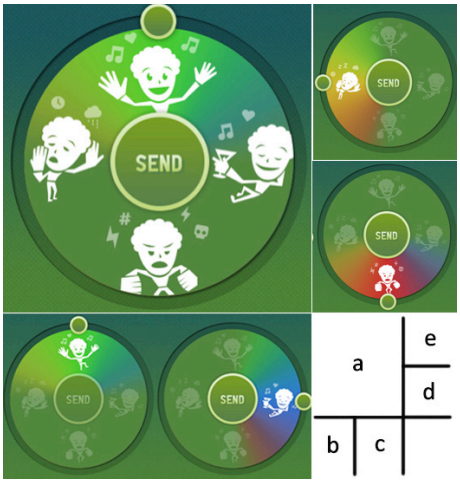


Figure 4.6. (a) Cartoon characters representing four types of emotions; (b), (c), (d), (e) Color association with each emotion type.

Game component. The reward is a key strategy in game design to attract people to participate (Hamari, & Eranti, 2011). Besides the appealing interface design, *EmoApp* users were rewarded with free drinks. The participants immediately received a free drink once they successfully installed *EmoApp*. A virtual glass would be gradually filled after each report (Figure 4.7). They could redeem the second free drink when Glass 1 was full after two reports. To fill Glass 2 and 3, the participants had to report three times each. Each participant could get maximally four free drinks. Additional reports were not rewarded.

Figure 4.7. The virtual glasses on the *EmoApp* interface: The left-hand screen shows the interface after one report, and the right-hand screen shows the interface after two reports, where they could redeem the second drink. To fill Glass 2 and 3, the participants had to report three times each. Each participant could get maximally four free drinks. Additional reports were not rewarded.

4.3.4 Emotion data collection by the *EmoApp*

Our goal was to collect emotion data from the crowd members without abruptly interfering with them. For this purpose, the following information was sent by each smartphone application to a central server: the smartphone ID, the location, the timestamp, the self-emotion, the perceived emotion of others. Here, the smartphone ID is a unique identifier of the smartphone. The location is the physical location of the participant. The timestamp is the digital recording of the time when the data were sent. The self-emotion is the real-time emotion of the participant. The perceived emotion of others is the emotion of other crowd members in proximity to that participant.

Requesting participants to report the perceived emotion of others is a way to correct deliberately reported false emotions. For example, Participant A feels frustrated, but he reports that he feels happy. At the same time, we receive reports from other participants in the proximity of Participant A, perceiving

negative emotions in other crowd members. From this, we may conclude that Participant A is probably not happy but angry. This mechanism was used to check false reporting.

The location of the participant was defined by two inputs: the participant's self-report on a festival map (Figure 4.8) and the Wi-Fi positioning system that measured the longitude and latitude of the participant with an accuracy of approximately 20 meters. Combining these two location inputs enabled the location to be more accurate, for example, by excluding participants who used *EmoApp* outside the festival. Timestamps on each participant's reports were not continuous since they only received a new notification 30 minutes after their previous report.

The water stage and the entrance square were outdoor areas of the festival. Each had a small stage, where music programs stopped at 00:30. The entrance square had a few food and drink stands, and sofas for visitors to rest. The other four locations were indoor areas. The largest stage was at the main stage area, where music program lasted until 06:00. Another indoor stage was located at i.d-kafee, where the program stopped at 04:15. The entrance hall had a photo booth, where visitors could shoot a group photo with friends. The studio had a lighting installation, where visitors could relax.

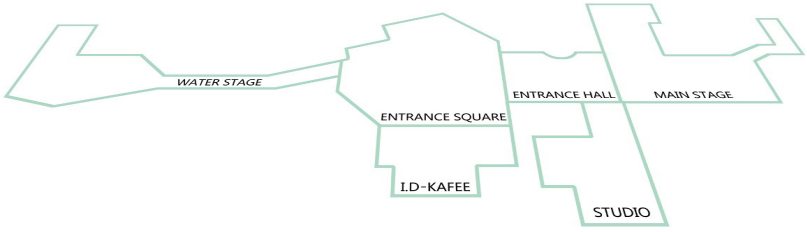


Figure 4.8. Six main locations on the festival map.

4.4 MEASURING EMOTIONS IN CROWDS: A FIELD STUDY AT A MUSIC FESTIVAL

To test whether *EmoApp* can measure (changes in) emotions in crowds and whether we can obtain a real-time emotion map based on the reports from crowd members, an experiment was conducted in a music festival with approximately 800 visitors. This section presents the methods and the results of this experiment.

4.4.1 Methods

The experiment was conducted in a summer music festival at the Delft University of Technology in 2013, which started at 9:00 pm on June 14 and ended next morning at 6:00 am.

Participants. 78 visitors of the music festival voluntarily used *EmoApp*, approximately 10% of the crowd. Due to the anonymity, the profile of the participants remained unknown.

Procedure. The procedure was as follows.

(1) Ten assistants handed out a flyer of *EmoApp* to as many as possible crowd members. The flyer provided installation instructions of the *EmoApp* and explanation of the four types of emotions, to help crowd members correctly read the emotions of each cartoon character. In the end, 78 visitors of the music festival used *EmoApp*.

(2) The participants downloaded and installed the application, which took around 30 seconds. After installation, they immediately received a free drink as a reward.

(3) The participant indicated his/her location on the first screen of *EmoApp*, being a simplified festival map consisting of six main locations: water stage, entrance square, entrance hall, i.d-kafee, studio and main stage (Figure 4.9-a). After clicking the "confirm" button, the participant received the second screen (Figure 4.9-b).

(4) The participant reported his/her emotion by moving the circular slide to an appropriate position on the circle. Then, he/she pushed the "send" button, after which the third screen appeared (Figure 4.9-c). On the third screen, he/she did the same action, but now for reporting the emotion of the surrounding crowds. After clicking the "send" button, the fourth screen appeared (Figure 4.9-d).

(5) The fourth screen shows a virtual glass and an indication how long it will take to report again. The virtual glass would be 50% filled after the first report, and 100% filled after the second report (Figure 4.9-d). In that case, participants could redeem the second free drink by swiping at the bottom of the screen. The swiping also occurs after the fifth report (Glass 2 is filled), and after the eighth report (Glass 3 is filled). They would receive another prompt (a vibration) to report 30 minutes after the previous one. The free drinks offer stopped at 3:00 a.m., if earlier, after the eighth report.

(6) Apart from the data collected from the *EmoApp,* the ten assistants also worked as observers during the experiment. They took notes of the observed crowd situations when crowds moved from one place to another. They managed to approach 21 visitors who had used the *EmoApp* during the festival and noted their feedback about the usability of the *EmoApp*.

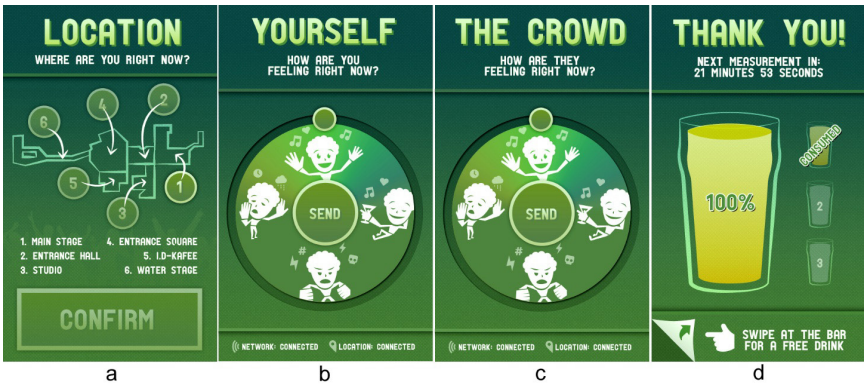


Figure 4.9. The four screens of the *EmoApp* interface.

4.4.2 Results

The results are divided into three parts. The first part concerns overall statistics of the collected reports. The second part is about transforming the emotion data into emotion maps. The third part presents the usability feedback from the *EmoApp* users.

4.4.2.1 Collected reports

We received a total of 306 valid reports during the festival (306 reports about self-emotions and 306 reports about perceived crowd emotions). Regardless the timestamps and locations of the collected reports, the number of reports participants gave throughout the festival varied from one to twelve times (Figure 4.10). Seventeen participants reported only once after installing the *EmoApp*. They received the first free drink to award their installation, but they did not manage to receive the second free drink. Thirty-one participants filled the Glass 1 and could receive the second free drink, but not the third one. Twenty-two participants filled Glass 1 and 2, so they got the third free drink. Eight participants managed to fill all the three glasses and receive the last free drink. Six of them continued reporting after the eighth report without free drinks reward.

Next, we look at the number of reports distributed over the six locations. Most of the emotion reports came from two locations: the entrance square and the main stage, which were the two most crowded locations in the festival based on the observations of the assistants (see Figure 4.11). The number of reports represented the crowd size to some extent, but not always. The two most crowded location indeed received the most reports. However, although the main stage was more crowded than the entrance square, the number of reports in the latter location was 44% more than the former one, because the entrance square was designed for relaxation, with many sofas, food stands and a small stage with relaxing music. Probably, people at the entrance square had more time playing with their mobile phones and reporting emotions. At the main stage, people

were actively engaged in dancing and singing with the bands, which may explain why the reports were fewer than the entrance square.

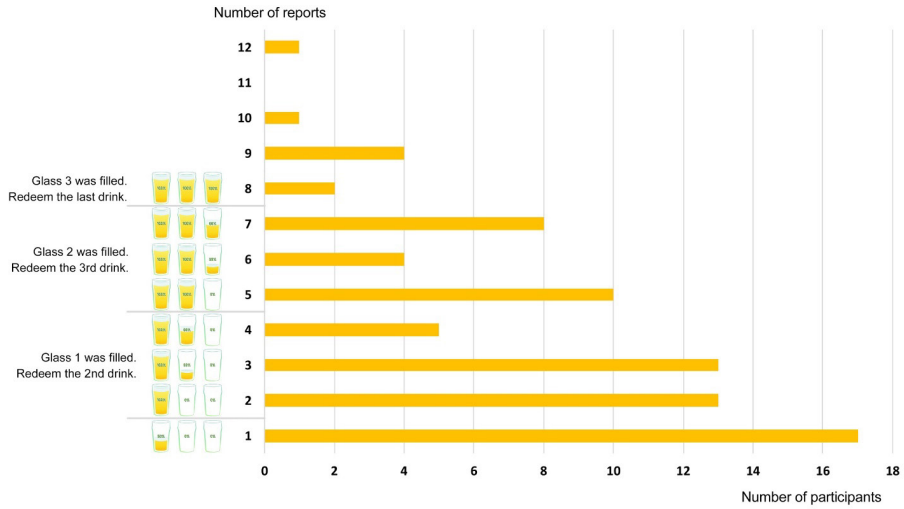


Figure 4.10. A varied number of reports participants gave throughout the festival.

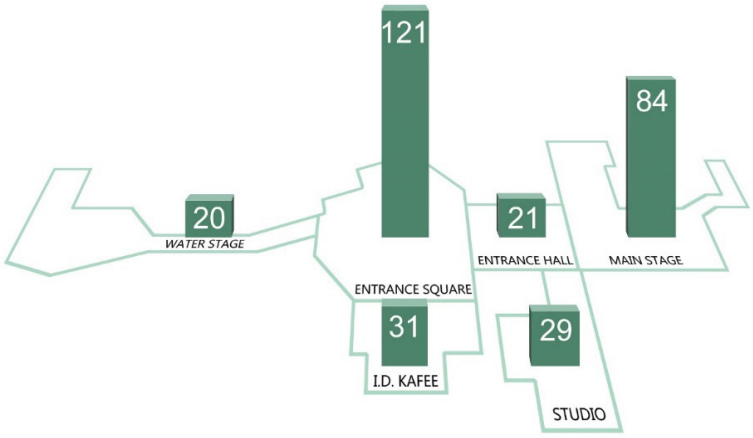


Figure 4.11. Amount of reports in six main locations of the festival.

Then, we divided the 9-hour festival into 18 half-an-hour time slots. The blue line in Figure 4.12 shows the total amount of reports of the six locations over time. The other two lines represent the two most crowded locations that yielded the most reports (i.e., the entrance square and the main stage). The peak moments last from 00:00 to 03:30, when the total amount of reports of the six locations exceeded 20 times each half an hour.

The number of reports reflected the activities in the locations. For example,

when programs on the entrance square stopped at 00:30, the number of emotion reports declined. Meanwhile, the main stage that still had programs received increasing reports, indicating that visitors moved from the entrance square to the main stage. This was in line with what the assistants had observed at the festival. Furthermore, there was a decrease of reports from 02:00 until 02:30 at the main stage, even though the programs were still on the stage. This decrease at the main stage and the increase at the entrance square could be explained by the spontaneous complaints from the visitors about the "bad" DJs on the main stage during 02:00-02:30.

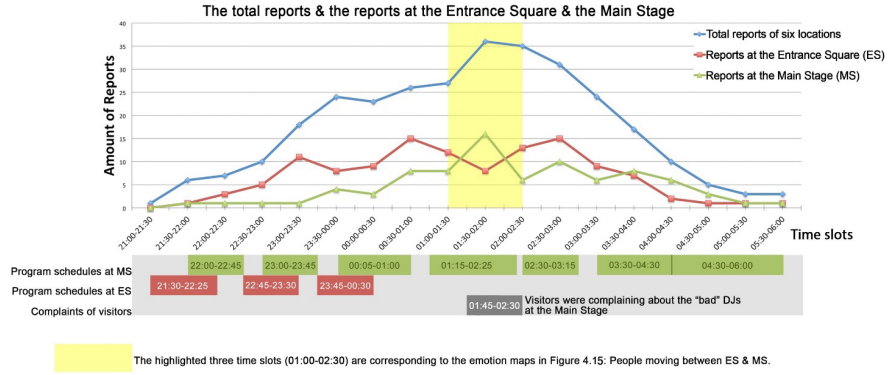


Figure 4.12. The number of reports over time: The total amount of reports of the six locations (blue), the number of reports at the entrance square (red) and the main stage (green).

4.4.2.2 Emotion maps.

The emotion data were collected from the participants by means of moving a slider around the emotion circle. The measured positions of the slider were not always at the positions where the cartoon characters are. This is in line with the data in Table 4.2, where terms within each label have different categorical weights. For example, both gloomy and tired are within Label 3, but gloomy weighs heavily on "displeasure", while tired weighs heavily on sleepiness. There were many emotions reported as in-between two emotion types. We classified the collected emotions into eight equal categories as shown in Figure 4.13: positive active (PA), positive neutral (PN), positive passive (PP), between PP and NA, negative active (NA), negative neutral (NN), negative passive (NP), and between NP and PA. Note that the two grey "segments" on Figure 4.13 are paradoxical, as they represent the emotion state between two distinct ones: positive-passive and negative-active states, as well as negative-passive and positive-active states. Nevertheless, we still received reports from these two categories. For "between NP and PA", 23 times (7.5%) of the perceived crowd emotion reports and 18 times (5.9%) of the self-emotion reports. This emotional state could be interpreted as tired and sleepy, but still slightly happy. "Between

PP and NA" was rarely reported by participants: only five times (1.6 %) of the perceived crowd emotions and two times (0.7%) of the self-emotions.

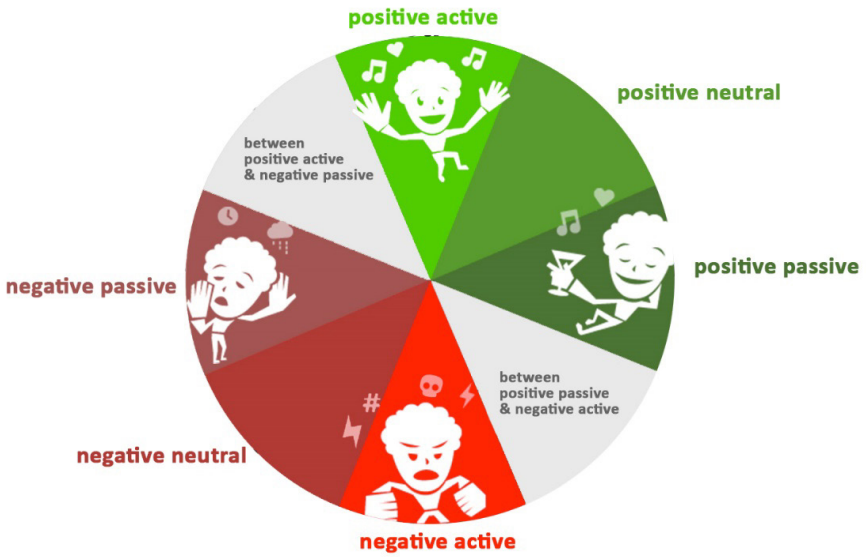


Figure 4.13. Received emotion reports in eight categories: positive active (PA), positive neutral (PN), positive passive (PP), between PP and NA, negative active (NA), negative neutral (NN), negative passive (NP), and between NP and PA.

To check the possibility of deliberately reported false emotions, we compared the self-emotion reports with the perceived crowd emotion reports, to see whether they are consistent. This is an attempt to see if the reported self-emotions were genuine. A Pearson's correlation analysis was performed to calculate whether the reported self-emotions and crowd emotions were highly correlated in terms of the eight categories suggested in Figure 4.13. The result indicates a significant positive correlation between the two variables, $r = 0.993$, $n = 8$, $p < 0.01$. Therefore, the reported self-emotions and emotions of other crowd members were highly correlated, and we concluded that most crowd members had reported real emotions.

Since reported self-emotions and reported crowd emotions were highly correlated, the results presented as follows mainly focus on self-emotions. We charted the eight categories of self-emotions into six locations every half hour. This created an emotion map of each time slot. Figure 4.14 shows an example of emotion maps based on reported self-emotions during three time slots (i.e., 01:00-01:30, 01:30-02:00, 02:00-02:30). From the emotion maps, possible movements of the crowds from one location to another can be deduced based on the number of reports received at each location. Based on the types of reported emotions, real crowd situations can be reflected. For instance, the number of reports increased at the main stage, while decreased at the entrance square during 01:30-02:00, which suggested that crowd members were increasingly

moving from the entrance square to the main stage because the main stage had music programs. Note that, although there were still DJs performing on the main stage, the number of reports decreased during 02:00-02:30, with a few negative emotions reported since 01:30. At the same time, the reports increased at the entrance square, which may suggest that people did not enjoy the DJs performances at the main stage (i.e., people complained the disappointing performances of DJs at the main stage during 01:45-02:30) and moved back to the entrance square. The emotion map mainly presents the valence of reported emotions (i.e., positive versus negative emotions). When negative emotions are increasing, crowd managers can zoom in to see what types of negative emotions (e.g., negative-active, negative-passive or negative-neutral emotions) are reported. For example, it can be seen in Figure 4.14, what categories of emotions constitute the main stage emotion reports during 01:00-02:00. For instance, negative-passive emotions indicate that this participant is bored and sleepy. He or she may need new stimulations or some rest, which may not lead to dangerous behavior. Negative-active emotions indicate that this participant is angry, which may result in dangerous behavior, such as fighting. Crowd managers need to pay extra attention when they spot negative-active emotions.

It is also possible to zoom into the level of individual participants. In this way, we were able to track their emotion changes in relation to their locations. Take two participants as examples during the three time slots (see Figure 4.15), Participant A moved from one location to another and had never stayed at one location longer than half hour during the three time slots. Participant B did not report during 01:00-01:30 and had stayed at the main stage since 01:30-02:00. The emotion of Participant A was positive at the entrance square and changed to neutral at the main stage during 02:00-02:30, then changed back to positive during 02:00-02:30 at the i.d-kafee. Participant B first felt positive. Then, His or her emotion changed to negative during 02:00-02:30 at the main stage. When zooming in, we can see that this negative emotion of Participant B is negative-active (e.g., angry). So, it is recommended that crowd managers should check, at that moment, what happened at the main stage.

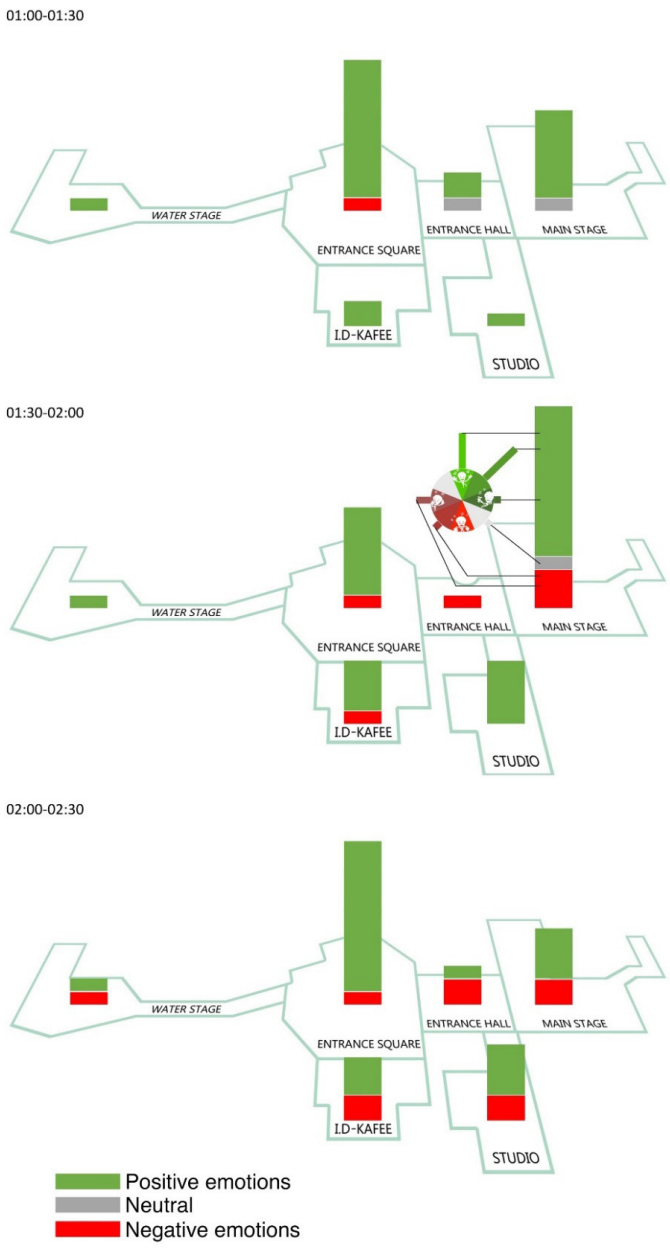


Figure 4.14. Reported self-emotion maps of three time slots. During 01:00-01:30, the entrance square received the most reports. Half an hour later, during 01:30-02:00, the main stage received the most reports. Afterward, during 02:00-02:30, the entrance square again received the most reports. The changes suggested that most crowd members moved between the entrance square and the main stage, following the music programs at these two locations. This map shows the valence of emotions (i.e., positive, neutral and negative). When negative emotions are increasing, crowd managers can zoom in to see what types of negative emotions are reported (see what categories of emotions constitute the main stage emotion reports during 01:00-02:00 as an example).

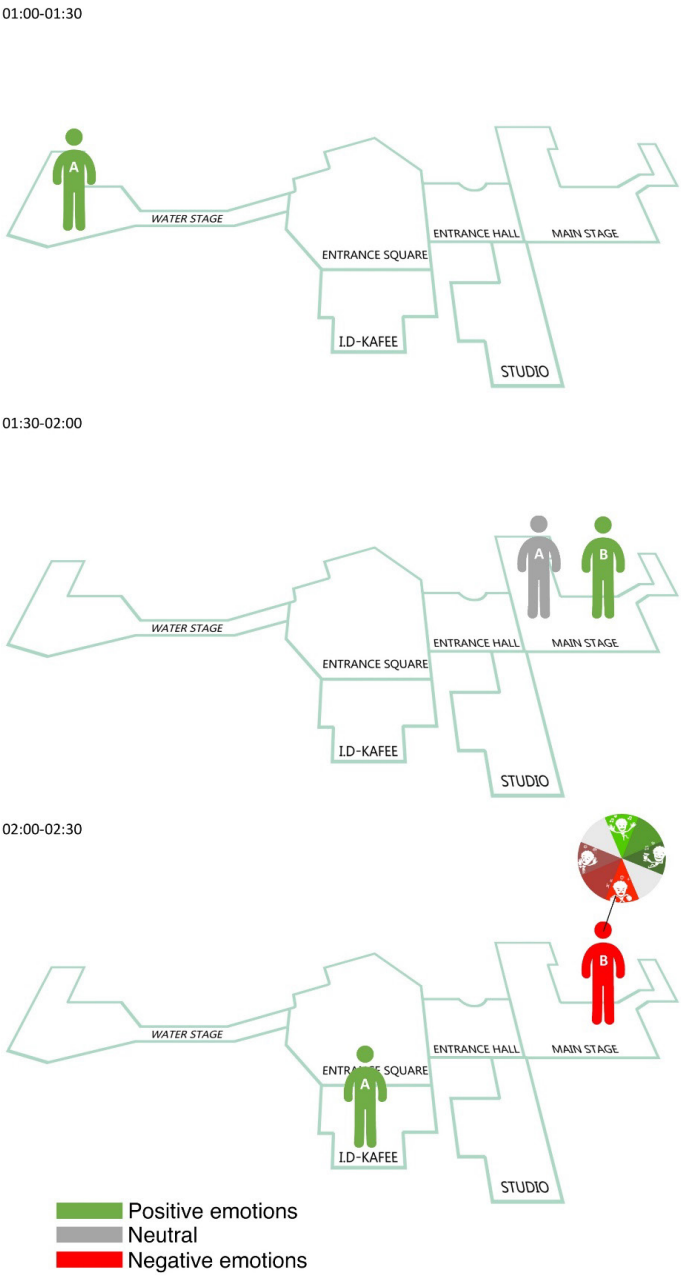


Figure 4.15. The reports and movements of Participant A and B are highlighted. When a negative emotion is reported by a participant, it is able to zoom in to see what negative emotion is (see Participant B at the main stage during 02:00-02:30 as an example). Negative-passive emotions indicate that this participant is bored and sleepy. He or she may need new stimulations or some rest, which may not lead to dangerous behavior. Negative-active emotions indicate that this participant is angry, which may result in dangerous behavior, such as fighting. Crowd managers need to pay extra attention when they spot negative-active emotions.

4.4.2.3 Usability feedback

The feedback notes from the experiment assistants were collected and categorized. Three themes emerged from the feedback provided by the 21 *EmoApp* users, namely (1) user interface design, (2) situation awareness and self-expression, (3) future improvement.

User interface design. All the 21 users were positive about the *EmoApp*. They found the circular interface is intuitive and easy to use. It only took them a few seconds to finish a self-report. The positioning of the emotions on the interface is reasonable and the cartoon characters are easily recognizable. All of them mentioned that the rewarding mechanism (i.e., the virtually filled beer glasses) worked well to motivate them to report.

Situation awareness and self-expression. 12 users (out of 21) pointed out that they felt more aware of the crowd situations in their proximity because they were triggered to check the emotions of other crowd members constantly. Six users mentioned that they were excited about being able to express their negative emotions and dissatisfaction about the disappointing DJ performances.

Future improvement. Nine users suggested usability improvement for the *EmoApp.* They pointed out the location reporting was not very easy at the beginning, especially when they were not familiar with the festival venue. They would like to have automatic positioning function within the app. Another suggestion mentioned by six users was to distinguish the interfaces for reporting self-emotions and perceived emotions of other crowd members, because the current identical interface easily confuse them.

4.5 DISCUSSION

The field study presented in this chapter is a step toward measuring emotions in crowds and capturing their changes. Although statistical data were collected, it is a rather qualitative study with interpretations based on comparing emotion data with human observations. In this section, we discuss the lessons learned from the *EmoApp* field study, explain the differences between the top-down and bottom-up approaches in the crowd emotion research, compare the positions of emotions in the *EmoApp* with literature and present open issues like the privacy protection, the reliability of self-report method and the accuracy of the positioning system.

4.5.1 Lessons learned

Framing effects. The *EmoApp* users were positive about the *EmoApp*. They felt more aware of the situations in their proximity and were excited about being able to express their dissatisfaction. Besides, the gradually filled virtual glasses felt like winning a game, which made them more excited than actually getting a free drink. This made us realized that the possible framing effect of this reward mechanism, which might bias the users' judgment of emotions (Tversky

& Kahneman, 1981), since they tended to be more positive because of the free drinks. Our solution at the field study was to give limited free drinks (maximum three), and the users can only receive one drink after a few reports. In this way, we tried to keep users motivated but reduce the framing influence of free drinks on their reports.

Mixed emotions. There were 76% of the emotion reports in the positive categories and 16% in the negative categories. The remaining 8% of the reports fell into the neutral emotion categories: the grey categories in Figure 4.13. This suggested that participants sometimes found themselves or other crowd members having mixed emotions. Several studies indicated that it is possible to be happy and sad at the same time (Hunter et al., 2008; Larsen et al., 2001; Williams & Aaker, 2002). These so-called bittersweet situations can make people feel mixed. For example, people have to leave the festival, so they feel sad; however, at the same time, they feel happy since they enjoy this festival very much. This probably can explain why the participants reported in this way.

The most crowded location did not always receive the most reports. Even though we could roughly estimate the crowd size of a location based on the number of reports, the location with the highest number of reports was not necessarily the most crowded location. For instance, the entrance square was much less crowded than the main stage, but we received 44% more reports at the entrance square. The possible explanation is that the entrance square had many sofas, food stands and less noisy than the main stage. Therefore, people felt more relaxed there and then tended to check their mobile phones and use the *EmoApp*. At the main stage, people were engaged with dancing and the performances on the stage, so the probability to play with their mobile phones and notice the prompts for reporting declined.

4.5.2 Crowd emotions and emotions in crowds

Very recently, there has been a growing interest in crowd emotions, which are mostly termed as collective emotions or group emotions (e.g., Von Scheve & Ismer, 2013; Hopkins et al., 2016; Van Kleef & Fischer, 2016). Von Scheve & Ismer (2013) proposed a definition of collective emotions as *"the synchronous convergence in affective responding across individuals towards a specific event or object"*. Straightforwardly, Bar-Tal et al. (2007) conceptualized collective emotions as "common feelings by members of a social unit as a result of shared experiences".

There are two perspectives in viewing collective emotions: *top-down* and *bottom-up*. The *top-down* approach considers a group or a crowd as an entity, which tends to influence their members by homogenizing their emotion and behavior. The *bottom-up* approach views collective emotions as the sum of the group members' emotions. It focuses on how group members' emotions shape the development of collective emotions (Barsäde & Gibson, 1998). In this chapter, we adopted the bottom-up approach: we collected emotion reports from individual crowd members to form an impression and estimation of the crowd emotions.

Von Scheve & Ismer (2013) suggested three dimensions for understanding what collective emotions are and how the emotional similarities are manifested in groups and crowds. First, physical proximity, for example, face-to-face interactions promotes emotional contagion among individuals. Second, shared culture and knowledge direct individuals to have similar emotional reactions and meanings towards an event. Third, group membership, self-categorization and shared social identity suggest the existence of group-based emotions. In addition to the three dimensions of collective emotions, Delvaux et al. (2016) found that emotional similarities do not always happen in crowds, because emotions are not always contagious. Emotions spread only when they contain information about the situation that is relevant to all crowd members. In other words, people do not blindly mimic emotions unless they want to affiliate themselves with the sender. For example, emotional mimicry is lower among members from two rival groups, or the sender is perceived as an out-group member (Weisbuch & Ambady, 2008).

As far as we know, no literature has summarized a list of crowd emotions as was done for individual emotions. Von Scheve and Ismer (2013) stressed that the proposed three dimensions do not presuppose that crowd emotions are qualitatively different from individual emotions. Most individual emotions, such as happy, angry, sad, anxious can be found in crowds as a shared emotion among crowd members. Some emotional feelings, such as feeling connected and feeling stuffy are typical in crowd situations (Li et al., 2014).

In this dissertation, the term “crowd emotions” and “emotions in crowds” respectively refer to the top-down and bottom-up approach proposed by Barsäde and Gibson (1998). Our focus is placed on the bottom-up approach: emotions in crowds.

4.5.3 Emotion positions

Russell (1980) created “direct circular scaling coordinates” for the 28 affect words as presented in Table 4.1. Figure 4.16-b shows a simplified version of the coordinates with the selected words for designing the *EmoApp* under four labels in Table 4.2. Figure 4.16-a is a simplified version of Figure 4.4, showing the two most frequently reported positions of each group of emotions. For the positive-active group (i.e., pleased, happy, etc.), it is clear that they should be placed at the top of the circle (90°). Going clockwise, Russell’s model would predict the appearance of positive-passive emotions (i.e., calm, relaxed, etc.) at 0° position in the *EmoApp*. For the other two groups, our positioning does not agree with Russell’s model. For these groups, they mainly varied between two positions. The negative-active group (i.e., angry, frustrated, etc.) was mainly at 270° and 180°, and so was the negative-passive group (i.e., gloomy, sleepy, etc.).

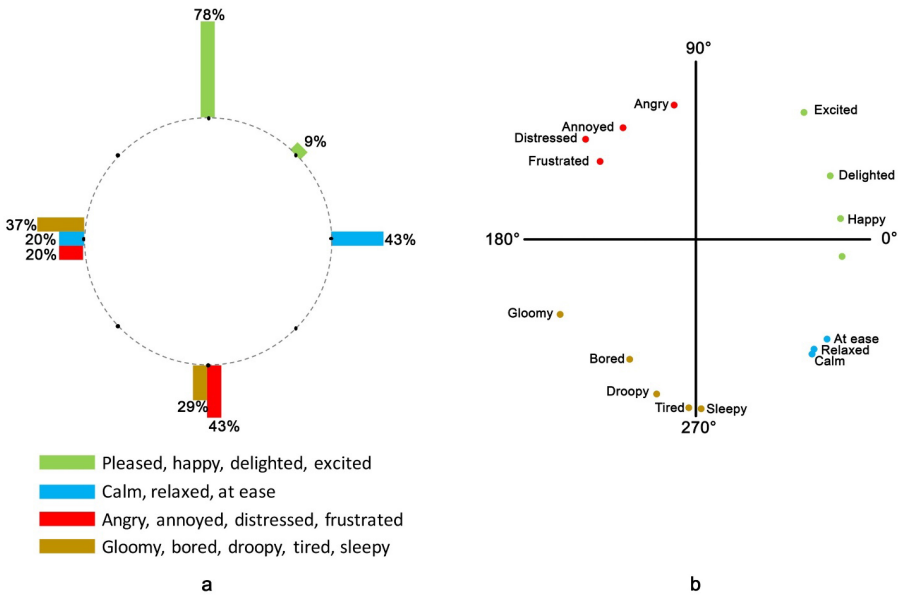


Figure 4.16. (a) The two most frequently reported positions of each group of emotions, (b) Russell's direct circular scaling coordinates (a simplified version with the selected affect words presented in Table 4.2).

To solve this disagreement, we plotted the eight categories of emotions into Russell (1980)'s valence-arousal dimensions. The resulting plot looks like a butterfly with the positive-active group at the upper-right position, the positive-passive group at the bottom-right position, the two neutral groups at the origin, the negative-active group at the top-left position, and the negative-passive group at the bottom-left position (Figure 4.17). The positioning of the two neutral groups at the origin is in line with a diagram that is often used to valuing the physical environment by the dimensions "*pleasure* and *arousal*", where the center is assumed to represent conditions which people experience as harmonious (Bakker et al., 2014). A possible explanation for the butterfly scheme is that the participants made their judgment in two steps. First, they assessed whether they felt positive, neutral or negative. Second, they expressed their level of activeness (i.e., active, neutral, passive). Harmony is a state when the levels of valence and arousal are both neutral. The circular interface of *EmoApp* allows participants to express their "harmonious" state.

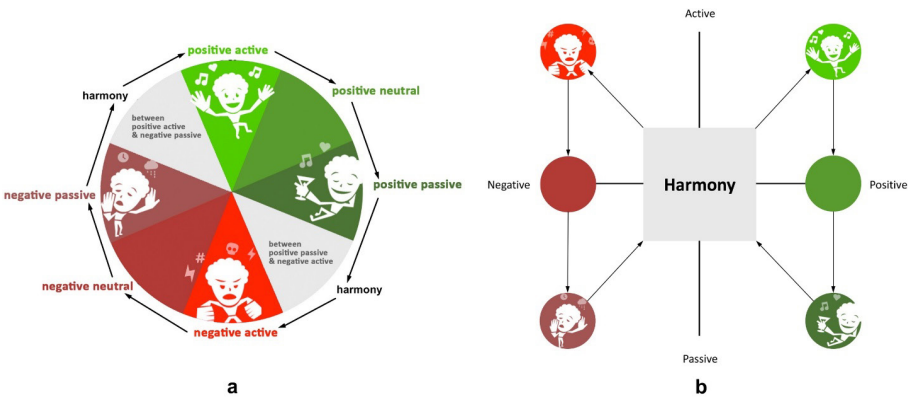


Figure 4.17. Moving clockwise from positive-active emotions along the circular interface in the *EmoApp* (a) forms a butterfly-shaped model in Russell's valence-arousal dimensions (b). The two neutral categories (in gray color) in (a) are placed at the origin of the valence-arousal dimensions as a state of "harmony" (Bakker et al., 2014).

4.5.4 Open issues

The frequency of self-reports. To be non-intrusive, *EmoApp* only prompted users to report every 30 minutes. This frequency may not be sufficient to make *EmoApp* useful in an emergent situation, such as the described example of the Dutch Dodenherdenking (Remembrance Day) in 2010 at the beginning of Chapter 1. In that situation, the time between the "loud scream" and the "panicked stampede" was no longer than a couple of seconds. It is questionable whether crowd members would have time to take out their phones and use *EmoApp* in such an extreme case. Further research is needed to investigate other psychological states of crowd members, such as action tendency (Frijda et al., 1989), which can be a step further in predicting crowd behavior. If the action tendency of the "loud screamer" could be identified in advance, the crowd managers probably could have stopped this incident.

Privacy concerns and limitations of self-report. Since *EmoApp* can track participants' locations by the Internet positioning system and the Global position system (GPS), both during and after the events, many of them were concerned that *EmoApp* would invade their privacy. Moreover, the participants were worried about the identity linking could damage their privacy if they reported something negative. This concern is especially true when the event involves political or personal issues like demonstration where some people want to stay anonymous and conceal their opinions. This invasion in privacy can bring another problem: it increases the chance that users send false data in the self-reports. Fan et al. (2006) pointed out that, there are often "inaccurate responders" and "jokesters" in self-report studies. The former provides false responses due to confusions, while the latter gives intentional false responses due to fun or privacy concerns. Reisenzein (2010) also stated that self-reported emotion is subject to voluntary control, resulting in deliberate suppression and falsification. However, Reisenzein is not convinced that these limitations are serious obstacles to use self-reports in human-computer interactions. He

suggested seeing them as one source of measurement error, which is less severe than other measurements, such as wearable sensors. He also advised using a comprehensive system, i.e., a combination of measurement methods to correct the possible biases of self-reports (Reisenzein, 2010). In the field study of this chapter, our solution to prevent false self-reports is to request participants to report both their own emotions and the perceived emotions of others in their proximity. Ideally, suppose the majority of crowd members have the *EmoApp* to report and most of them will not deliberately gave false reports, the inaccurate reports of some crowd members will be ruled out by comparing their self-reported emotions and the emotions reported by other crowd members about them.

A solution to resolve privacy-related considerations is to conceal privacy-sensitive data of the users from the data collector. Notice that in our study, the statistical data are mostly considered rather than individual data. Therefore, solutions that hide the individual data from the data collector can be deployed. One such approach is to use cryptography-based solutions (Lagendijk et al., 2013). In that approach, the privacy-sensitive data is kept hidden from the data collector by means of encryption. As the collector does not have the decryption key, it cannot access the content. However, using cryptographic protocols and with the help of decryption key owner, the data collector can still process the encrypted data to gather statistical information. While this approach provides privacy protection by hiding the sensitive data from the data collector, it requires more computational resources since computations are performed on the encrypted data. We leave such a privacy-preserving emotion detection mechanism as future work.

Location Accuracy. Having a more precise emotion map is another goal of our future work, which requires improving the accuracy of the positioning systems. The systems we applied in this study could achieve a maximal accuracy of 20 meters indoor, which would drop dramatically to 700 meters when the participants were outside. Due to this inaccuracy, the participants were asked to indicate their locations on the *EmoApp*, which introduced an additional step in the application, reducing the speed of each report.

Accurate location information is necessary particularly for crowd management in real time: the organizers and security personnel can detect the accurate locations of the incidents and react to them as quickly as possible. However, determining the exact location of individuals with current devices is technologically challenging. If that becomes feasible, then we face another issue: knowledge of exact locations can threaten privacy. As in the case of privacy-preserving emotion report, a mechanism that conceals the exact location of the individuals might be necessary. This introduces a dilemma, which requires substantial research in the future.

4.5.5 How can crowd managers use the *EmoApp* data

Combining with the location information, the self-reported emotions by crowd members form a series of emotion maps that continuously update in real time.

The scenarios visualized in Figure 4.18 and 4.19 explain how these emotion maps assist crowd managers in predicting and steering crowd behavior. Once crowd managers identify negative emotions at certain locations, they can zoom in to see what constitute these negative emotions (i.e., how many negative-active, negative neutral and negative-passive are reported). If there are increasingly negative-active emotions reported, they should assign security personnel to observe the situation. They can further zoom in to see "who" have reported these negative-active emotions. To protect the privacy, the real identities of the visitors are hidden, but crowd managers can track their registration numbers to observe their emotional changes. If their emotions stay negative-active for a while, crowd managers can further intervene with the help of security personnel. In this way, crowd managers are well prepared by having a real-time overview of what is happening in crowds and intervening when necessary.

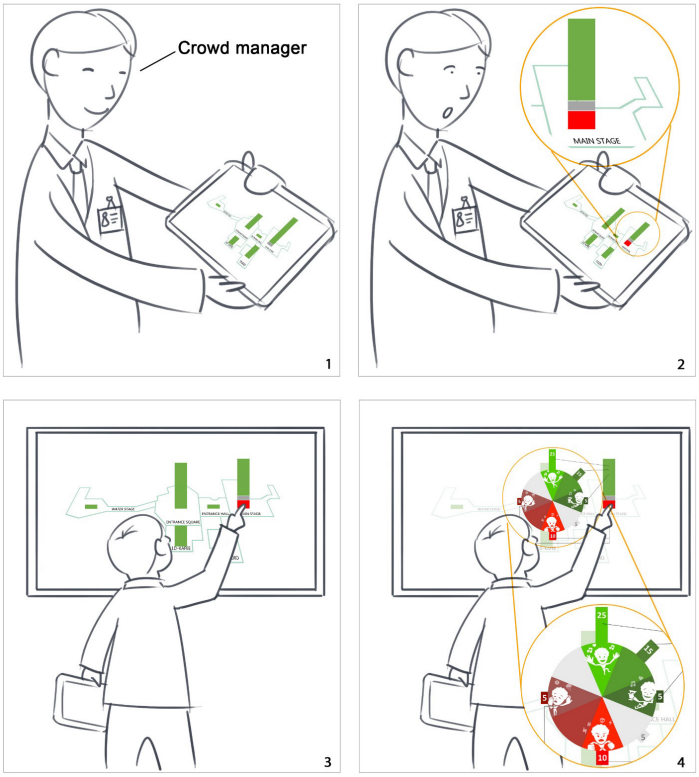


Figure 4.18. Emotion map scenario, Part 1: (1) The crowd manager is watching a real-time emotion map of a festival crowd on a tablet. The emotion reports from the crowd members are visualized as bar charts on the map of the festival. Positive emotions are in green. Negative emotions are in red. Neutral emotions are in gray. At the moment, no negative emotions are appearing on the map. (2) Suddenly, the crowd manager receives a notification (a vibration) on the tablet, reminding the manager to check the negative emotions on the emotion map. (3) The crowd manager clicks at the location (the main stage) where negative emotions appear. (4) The crowd managers can see which categories of the emotions are reported at the main stage. He notices that there are suddenly ten negative-active emotions reports (e.g., angry, frustrated).

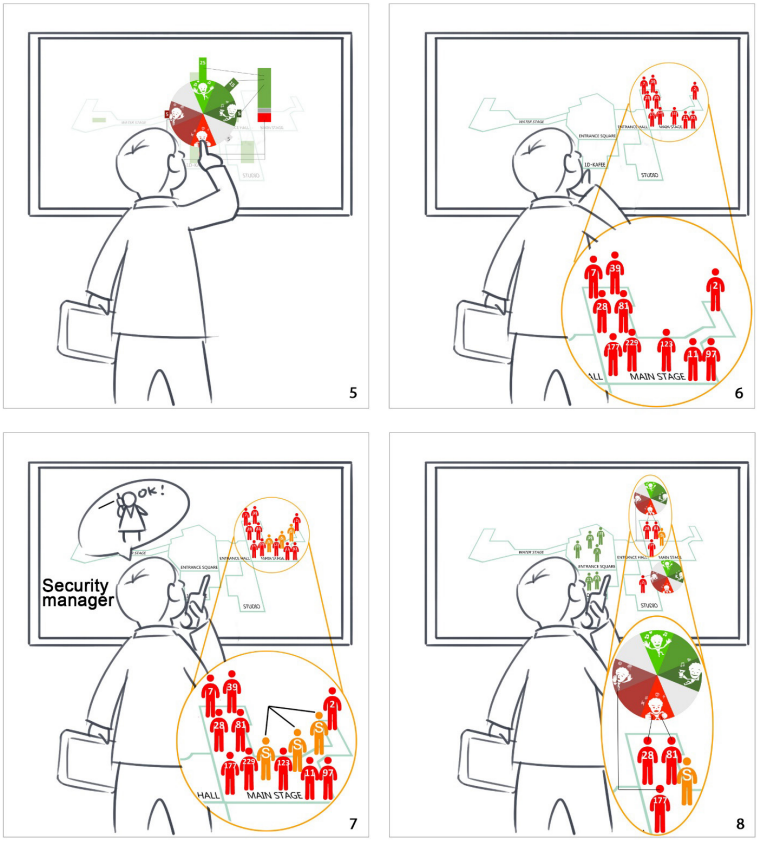


Figure 4.19. Emotion map scenario, Part 2: (5) The crowd manager clicks at the negative-active emotion to see who reported them. Due to privacy protection, the visitors remain anonymous. (6) The crowd manager sees the registered number of the visitors who reported the negative-active emotions, but he cannot know their real identity. (7) The crowd manager calls the security manager, asking him to pay particular attention to the main stage area. So, the security manager immediately assigned three security personnel to the main stage. (4) The crowd manager continues observing the emotional changes of the ten visitors who reported negative-active emotions. He can follow them on the emotion map, to see where they are moving to and how their current emotions are. He notices that almost all the ten visitors' emotions have changed into either positive or negative-passive, but Visitor 28 and 81 are continuously reporting negative-active emotions for a while. So, crowd manager calls the security manager to check the exact location where the two visitors probably are and find out what the problem is.

4.6 CONCLUSION

Three questions were asked before designing and testing the *EmoApp*: (1) what emotions should be included, (2) how to position these emotions on the interface allowing people to report intuitively yet efficiently, (3) how to fine-tune the interface to allow the requirements "usability, non-intrusiveness

and attractiveness" to be fulfilled. The *EmoApp* we developed was based on the answers to these questions. In addition to Russell (1980)'s valence-arousal model, we incorporated two neutral groups which seem to agree with the concept of "harmony" (Bakker et al., 2014).

From the timestamp on each emotion report, we found that, in most cases, the time gap between reporting self-emotion and emotions in crowds was only a few seconds. Thus, we could conclude that most of the participants had reported quickly. The participants largely accepted the circular interface and the free-drink rewards and found the *EmoApp* useful and accessible. A few of them continued reporting even after the free drink offer stopped at 3:00 a.m. The collected data seemed to reflect the real situations at the festival. For instance, the reported self-emotions and perceived emotions in crowds are highly related. Notably, participants' movements and emotional changes were consistent with the activities at the festival. When we received some spontaneous complaints from the visitors about the unsatisfactory performance at the main stage around 2:00 a.m., negative emotions had increasingly shown on the emotion map since then. This observation suggested that a majority of participants reported their real emotions.

This study tried to measure the valence and arousal dimensions of emotional experience in crowds. As suggested by Bakker et al. (2014), a third scale "dominance" should be included to have a complete measurement of human experience. Dominance is behavior-related, referring to the feeling of control and influence over a person's surroundings and the extent to which the person feels restricted in his or her behavior (Mehrabian & Russell, 1974; Mehrabian, 1996). It is humans' conative response on how they act on their feelings and thoughts (Bakker et al., 2014). Therefore, the study presented in the next chapter (Chapter 5) will investigate the conative responses of crowd members, for example, action tendencies (Frijda et al., 1989), as a step further in predicting crowd behavior.

“人生不能像做菜，把所有材料準備好了才下鍋。”

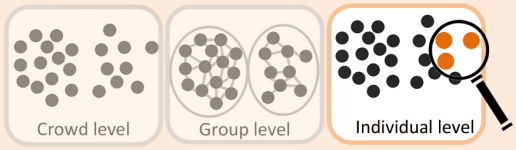
— 李安 《飲食男女》

"Life is not like the *mise en place* before cooking. Life is spontaneous. You will never be fully prepared for it."

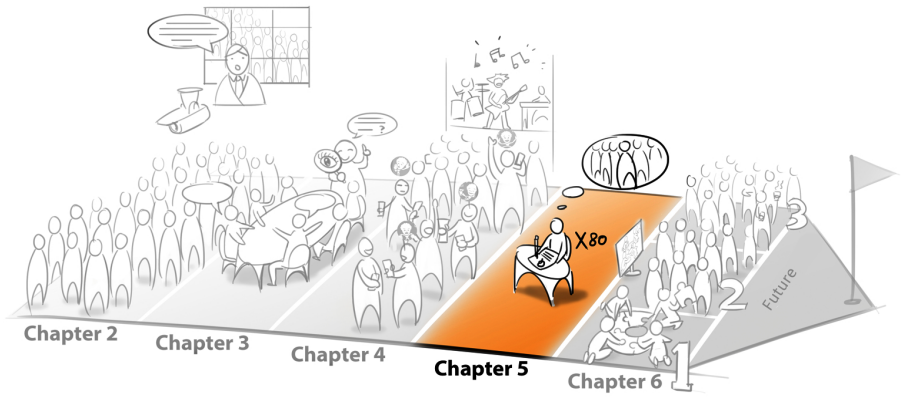
— Ang Lee, *Eat Drink Man Woman*
translated by Jie Li

CHAPTER 5

Emotions and Action Tendencies in Event and Non-Event Crowds



Chapter 5 explores another psychological aspect, from the individual level: the action tendency of crowd members, which is believed to predict crowd behavior more directly than emotions. It investigates the relation between crowd emotional feelings and action tendencies based on the recalled crowd experiences of the subjects. It defines a set of typical crowd emotional feelings, and demonstrates relations between the typical emotions and the typical action tendencies in crowds. We concluded that people generally feel more curious, excited, connected and happy in event crowds than in non-event crowds. When they feel positive, they tend to have positive action tendencies, whether in event or non-event crowds. This study is one step further in predicting crowd behaviors.



This chapter is an extended version of the published article:

Li, J., Cai, R., de Ridder, H., Vermeeren, A. P., & van Egmond, R. (2014). A study on relation between crowd emotional feelings and action tendencies. In *Proceedings of the 8th Nordic Conference on Human-Computer Interbehavioral: Fun, Fast, Foundational* (pp. 775-784). ACM.

5.1 INTRODUCTION

In Chapter 4, we have shown that real-time emotional experiences in crowds can be measured on two dimensions: valence (feeling positive versus feeling negative) and arousal (feeling active versus feeling passive). For a more complete measurement and a richer understanding of human experiences, Mehrabian (1996) proposed to include a third "dominance" dimension next to Russell's two-dimensional circumplex model (Russell, 1980), with dominance defined as "a feeling of control and influence over one's surroundings". The opposite is submissiveness, the extent to which a person feels restricted in his or her behavior. Recently, also Bakker et al. (2014) suggested to include a behavior-related third dimension. They introduce it to measure human's conative responses, which reflect how humans would act on their thoughts and feelings. This chapter aims at understanding conative responses of crowd members and how these responses are related to their emotions. To do so, we adopt the concept of "action tendencies" as proposed by Frijda et al. (1989). We see a better understanding of such a behavior-related dimension of emotions as a step toward predicting the behavior of crowd members. This is in line with Scherer (2005) who also pointed out that action tendencies are the motivational part of emotion. For crowd managers, it may be more interesting to know these motivational parts of emotions than knowing the emotions themselves.

In Chapter 3, two types of crowds were introduced, namely event crowds and non-event crowds. An event crowd is always event-based, where the goal of people is to enjoy performances or activities, to interact with others and to share experiences within the crowd (e.g., concerts, exhibitions, conferences, parties). A non-event crowd usually does not involve any activity or performance. People join the crowd not because they like the crowd or want to interact with others, but because they want to achieve some crowd-external goal or benefit (e.g., crowds at public transportation, crowds waiting in queues for free goods, crowds on a busy shopping street). As a result, differences in emotions and action tendencies are expected in event and non-event crowds. This is the focus of the studies in this chapter.

This chapter is organized as follows. Section 5.2 is a literature review about the relation between emotions and action tendencies. Sections 5.3 present a series of studies, aimed at (1) selecting action tendencies that are relevant for crowd situations, (2) identifying emotional feelings in crowds, and (3) exploring the relations between the typical emotional feelings and action tendencies in crowds. This chapter ends with Section 5.4, in which the main conclusions are presented, as well as a possible way to extend the *EmoApp* (see Chapter 4) with reporting action tendencies. Section 5.4 also describes a design case about a future airplane interior, separating the zones of an airplane into event zones (active zones) and non-event zones (non-active zones) and raising a question about whether a non-event crowd can be affected by an event crowd through emotional contagion.

5.2 EMOTIONS AND ACTION TENDENCIES: A LITERATURE REVIEW

In the field of social psychology, the relation between emotions and behavior has been abundantly studied. There are two main theories about this relation (Baumeister et al., 2007 & 2010). The first theory holds that emotion causes behavior directly. To illustrate this with two frequently used examples: when facing dangerous predators, fear causes one to run away; when facing an enemy, anger drives one to fight (Russell, 2003). Through this mechanism, our ancestors who had emotions like fear and anger could survive, protect and gain resources. The alternative theory holds that emotions do not cause behavior directly. There are far fewer types of emotions than types of behaviors. Therefore, emotions are not specific enough to directly cause specific behavior (Schwarz & Clore, 2007). From this, it has been suggested that emotions function as an inner feedback system. Emotions tend to fully arise after the behavior, prompting the person to reflect on the behavior and its consequences. It is not rare to see people describing their panic and fear after a narrow escape from a dangerous event. Through reflection, it is possible that the person learns useful lessons for the future. For instance, if the person learns that doing yoga makes him happy, he probably will continue this exercise to sustain his feeling of happiness. When a person feels guilty about his selfish behavior, he might amend this by offering more help, which probably will change his guiltiness into more positive emotional outcomes.

Baumeister et al. (2007) explained their viewpoint on the term *behavior* and introduced two types of emotional phenomena (i.e., *automatic affect and conscious emotion*). They pointed out that, in psychology, the broadest usage of the term *behavior* includes emotion and cognition. However, they "wish to reserve the term *behavior* to refer to physical actions, as distinct from both cognition and emotion". Subsequently, they explained what automatic affect and conscious emotion are. *Automatic affect* arises quickly, possibly within a small fraction of a second, may not be able to awake a person's conscious experience and generally involves little arousal. It is a rapid "twinge of feeling" that tells something is good or bad, to approach or to avoid, and that dissipates almost immediately. Baumeister et al. (2007) suggested that *automatic affect* is the emotional process that informs and guides behavior by providing brief and direct information such as "The tiger is bad, I must avoid". Consequently, the person has already run away when the predator is recognized (Smith et al., 2003), far before the conscious emotion of fear is fully developed (Baumeister et al., 2007). Compared to *automatic affect, conscious emotion* is considered a full-blown, subjectively felt experience with psychological arousal. Conscious emotions, such as fear, do not cause a person to run away, because it is too slow and too complicated to guide behavior directly. To illustrate this: if fear is the drive for flight behavior, the person must first recognize the dangerous predator, which gives the physiological arousal. Then, the bodily arousal triggers cognitive processing in the brain, and the person recognizes the bodily state as fear. This recognition initiates a motor response that results in the flight behavior. According to

Baumeister et al. (2007), this process takes at least seconds and even minutes, and at the same time, the person is continuously exposed to danger. If the behavior is directly guided by conscious emotion, our ancestors might not have been able to survive. Conscious emotions such as fear would have been phased out during evolution.

In general, *conscious emotion* indirectly influences behavior and does not cause behavior directly. It stimulates reflection and learning and enables a person to have more *automatic affects* in the future. For example, after the narrow escape from the tiger, the person feels fear for a long time when he thinks of it. Therefore, next time, when he is in the forest again, his *automatic affects* would provide him with "flight" signals even due to a subtle noise in the grass. Baumeister et al. (2007, 2010) do not deny that *conscious emotions* can directly cause people to have facial and vocal expressions such as cry, smile or make different kinds of facial expressions. Some extreme emotions may even urge people to behave in a self-destructive way, but even then, such conscious emotions may lead to a positive outcome. For example, Isen (1984, 1987) pointed out that negative emotions may drive a person to act in a way to improve his emotional state. Manucia et al. (1984) found that sad people tend to help others more to in fact cheer themselves up.

5.2.1 A component process model of emotions

Scherer (1987, 2001, 2005) proposed a component process model, which defines emotion as an episode that consists of five interrelated "component processes": (1) cognitive component (appraisal), (2) neurophysiological component (bodily symptoms), (3) motivational component (action tendencies), (4) motor expression component (facial and vocal expression) and (5) subjective feeling component (emotional experience). Emotions occur when changes in all the component processes become coordinated and synchronized for a short period, driven by the appraisal processes (i.e., an evaluation of external or internal stimuli relevant to major concerns of a person).

According to Scherer (2005), main characteristics of *emotions* can be summarized as follows. Emotions are elicited by external stimulus events (e.g., thunderstorms, the behavior of other people or animals, one's own behavior) or internal stimulus events (e.g., physiological changes, memories, images that come to our mind). These eliciting events of emotions must be relevant to our major concerns since we generally do not get emotional about things or people we do not care about. Given the relevance of the eliciting event, which may disrupt our current flow of behavior, most of our subsystems (e.g., central nervous system, neuroendocrine system, and autonomic nervous system) must synchronize to prepare for actions. However, emotions are not stable states, because they are undergoing constant modifications due to the changes of new information and re-evaluations. Therefore, emotions constantly prepare adaptive action tendencies and their motivational underpinnings. Emotions have a substantial effect on emotion-consequent behavior, often interrupting ongoing behavior sequences and generating new goals and plans. Due to the importance of emotions for triggering behavioral adaptation, the intensity of emotions is

assumed to be relatively high, costing energy to prepare for actions. Therefore, the duration of emotions must be relatively short, not to consume too much energy.

Scherer (2005) also discussed feelings in relation to emotions. *Feeling,* as one component in Scherer's component process model, refers to the subjective emotional experience component, presumed to have an important monitoring and regulation function. Feelings reflect the total pattern of cognitive appraisal as well as motivational and somatic response patterning that underlies the subjective experience of an emotional episode. There is no consensus about whether feelings should be synonymous with, or separable from, emotions (Scherer, 2005; Baumeister et al., 2007; Lowe & Ziemke, 2011). As Prinz (2005) stated, "when emotions are felt, the feeling is the emotion: the emotion is a conscious perception of a patterned change in the body." In the study of this chapter, we instruct our participants to recall crowd experiences, and necessarily, these collected experiences must be consciously remembered. Therefore, we decide to interpret their responses as *emotional feelings* (Lowe & Ziemke, 2011) *in crowds*.

5.2.2 Action tendencies

An important concept in Scherer (2005)'s model is regarding "action tendencies" as a motivational component. Nico Frijda, a Dutch psychologist, suggested that human emotions serve to promote tendencies to undertake actions that are appropriate in certain circumstances (Frijda, 1986). The tendencies, which are widely called action tendencies (Arnold, 1960), are present prior to the execution of behavior and are independent of the behavior.

Relation between action tendency and action. Action tendencies are action readiness states to execute different actions having the same intent: the intent to change from an actual situation as perceived, to a desired situation (Frijda, 1986). Many different behaviors can manifest after a given emotion-relevant event (Kreibig et al., 2010). For instance, in response to angering or fearful events, people can execute behavior like flight, attack or cry out, or completely hold the behavior in abeyance as some readiness or tendency. Such tendency might be released as actions when the appropriate opportunity comes, or when the inhibition is weakened. It might also dissipate if the situation resolves. However, no matter what action is executed (e.g., flight, attack, crying out or suppression), they share the same intent, the intent of seeking protection, withdrawal, deploying force and so on, to change the current situation (Frijda, 1986).

Furthermore, appetitive behaviors (e.g., approach, watch, open up, body contact) and defensive behaviors (e.g., withdraw, go against, submit, detach) may be alternately elicited during a given emotional event (Frijda, 2010). Gray (1982) proposed two types of neural systems, namely behavioral activation system (BAS) and behavioral inhibition system (BIS). The BAS is related to appetitive behaviors and approach tendencies, whereas the BIS is for defensive behavior and withdraw tendencies. The relation between action tendency and

overt behavior is not merely feedforward but complexly dynamic. For example, Schauer and Elbert (2010) postulated a cascade of "Freeze-Flight-Fight-Fright-Flag-Faint" behaviors in response to a fearful event, where, as we can see, BAS and BIS systems are alternately activated. A tendency of active coping (BAS) may lead to an appetitive behavior. For example, I want to fight to increase the chance of survival (a tendency of active coping). So, I approach the opponent and fight (appetitive behavior). However, after a few seconds, the appetitive behavior may result in a tendency of inhibition (BIS). For example, I approach and fight (appetitive behavior), but the opponent is too strong. I want to flight (a tendency of inhibition).

Relation between action tendency and emotion. Action tendency is an essential component in emotional experience, which differentiates one kind of emotional experience from another (Frijda et al., 1989). Emotions are defined by Arnold (1960) as "felt action tendencies", because, as she argues, felt action tendencies characterize emotional experience, making it richer than and differentiating it from mere feelings of pleasantness or unpleasantness. Action tendencies characterize different emotions. Nevertheless, Frijda et al. (1989) identified no one-to-one correspondences between action tendencies and emotions. In their two studies, Frijda et al. (1989) extensively investigated the accuracy of emotion predictions by action readiness terms. They found that action readiness performs well in predicting emotions like *shyness, disgust, despair, anxiety, anger, rage, rebellious, sorrow, shame, enthusiasm, warm-feeling,* and *enterprising*. The positive emotions, *pride, relief, happiness* and *enthusiasm* all show the action tendencies of *exuberant* and *approach*. Further, action readiness can also help distinguishing more subtle emotions. For instance, *sorrow,* unlike *sadness,* strongly implied the *interruption* of behavior and desires to *approach* and *be with.* The truly negative states *anger* and *rage* scored differently from *annoyance* and *contempt. Anger and rage* implied *antagonistic* tendencies whereas *annoyance* and *contempt* involved only *boiling inside*. Frijda et al. (1989) also found that the seven basic emotions (i.e., *joy, sorrow, disgust, surprise, contempt, anger,* and *fear*) proposed by Ekman (1992) were not more predictable by action readiness than the other emotions. Furthermore, hardly any action readiness term can distinguish the emotions that are often considered complex. As in contrast to the basic emotions, these complex emotions include *jealous, regret, distrust, disappointment,* and so on. For these complex emotions, the corresponding action readiness terms are mostly *don't want* or *attending*.

The studies conducted by Frijda et al. (1989) provided us with an overview of action tendencies and their relations with emotions and behavior. In the following section, a series of studies are presented to investigate the possible relations between emotions and action tendencies in crowds.

5.3 EXPERIMENTAL STUDIES

This section presents a series of four studies. The first study identified action tendencies in crowd situations based on the 29 action readiness terms defined by Frijda et al. (1989). The second study collected frequently evoked emotions in crowd situations. The third study categorized these emotions, resulting in

13 typical emotional feelings in crowds. The last study explored the relations between the typical emotional feelings and action tendencies in crowds.

5.3.1 Study 1: Identifying action tendencies in crowds

Frijda et al. (1989) proposed a list of 29 action readiness terms and studied their relations with 32 emotions. In this section, a study is conducted to identify action tendencies from Frijda (1989) et al.'s list that have a high probability to occur in crowd situations.

5.3.1.1 Participants and procedure

Forty-three people of mixed nationalities participated in this study (25 females and 18 males, average age 30). Thirty-seven of them were employees or students of Delft University of Technology. The other six were employees of different companies.

They were asked through an online questionnaire to recall all kinds of crowd situations they had experienced and indicate on a 5-point scale (1 = do not match at all, and 5 = match extremely well), to what extent each of the 29 action readiness statements from Frijda et al. (1989), match any of the crowd experiences they had. The participants were allowed to recall multiple experiences but only rated each action tendency with one score according to one experience in a crowd. In this way, we aimed for collecting action tendencies that are typical for crowd situations in general.

5.3.1.2 Results

According to the ratings of the 43 participants, the means of 11 action readiness terms were higher or equal to 3.00. The means of 15 terms fell between 2.00 and 3.00 and three terms were below 2.00. We selected the 11 terms that were rated higher than 3.00 as the action tendencies with a high probability of occurrence in crowd situations. These are: *attending* (M = 3.65, SD = .87), *helping* (M = 3.56, SD = 1.14), *laughter* (M = 3.51, SD =1.10), *excited* (M = 3.42, SD = 1.12), *be with* (M = 3.35, SD = 1.17), *distance* (M = 3.35, SD = 1.07), *exuberant* (M = 3.35, SD = 1.13), *protection* (M = 3.26, SD = 1.14), *avoidance* (M = 3.07, SD = 1.08), *don't want* (M = 3.00, SD = 1.23), and *rest* (M = 3.00, SD = 1.20). The descriptions of the 11 action tendency terms are presented in Table 5.1.

The 14 terms that fell between 2.00 and 3.00 are *interrupted, submitting, approach, boiling inwardly, preoccupied, reactant, rejection, in command, disinterest, blushing, helplessness, shutting off, disappear from view, inhibition, and apathy.* The three terms that were below 2.00 were *giving up, crying* and *antagonistic.* The 11 action tendencies with a score above 3.00 are selected to be used in the last study of this chapter, exploring the relation between emotional feelings and action tendencies in crowds.

Table 5.1. Eleven action tendencies (from Frijda et al. (1989)'s list) that are typical for crowd situations in general.

Action Tendencies	Description
Attending	I wanted to see things well, to try to understand them, or I paid attention.
Helping	I wanted to help someone, to take care of someone.
Laughter	I laughed, had to laugh, or wanted to laugh.
Excited	I was excited, restless, could not sit still.
Be with	I wanted to be or stay close with others.
Distance	I wanted to keep something or someone out of my way, to keep it at a distance.
Exuberant	I wanted to move, be exuberant, sing, jump, undertake things.
Protection	I wanted to protect myself from someone or something.
Avoidance	I wanted to have nothing to do with something or someone, to be bothered by it as little as possible, to stay away.
Don't want	I wanted something or someone not to be so, not to exist.
Rest	I felt at rest, thought everything was ok, felt no need to do anything.

5.3.2 Study 2: Frequently evoked emotional feelings in crowds

The goal of Study 2 is to collect emotional feelings that frequently occur in crowds and compare them with the 39 daily emotions suggested by Scherer (2004).

5.3.2.1 Participants and procedure

A total of 110 people of various nationalities participated in this study (63 females and 47 males, average age 25). Two versions of online questionnaires were used, both including a collage of diverse crowd situations. Version 1 consists of a collage of crowd situations that are considered as attractive (see Chapter 3), and Version 2 focuses on crowd situations that are considered as unattractive (see Chapter 3). Fifty-five participants were randomly selected to answer Version 1, which asked them to recall experiences in crowds within the past 12 months and name as many as possible positive emotional feelings evoked in those situations. In contrast, the other 55 participants answered Version 2, recalling negative emotional feelings. All of the participants were Master students of the Delft University of Technology, who were highly educated with high proficiency in English. They were asked to name the emotional feelings in English. All the participants were interviewed after they provided the list of emotional feelings, to help us clarify the intended meaning of some ambiguous terms. For example, "warm" does not necessarily mean physical warmth or high temperature but could also mean "warmth in your heart".

5.3.2.2 Results

We collected 376 negative terms and 324 positive terms from two questionnaires. We eliminated the repeated terms, and only kept one term if two terms had the same stem (e.g., happy & happiness, angry & anger, etc.). Thus, the list was reduced to 107 positive and 127 negative terms, among which 91 terms (40 positive and 51 negative terms) were mentioned at least by two participants, and 35 terms (13 positive and 22 negative terms) were mentioned at least by four participants. These 35 terms are listed in Table 5.2. The full list of 107 positive and 127 negative terms is presented in Appendix 2.

Table 5.2 shows the terms mentioned by at least four participants. The terms highlighted in grey overlap with Scherer (2004)'s list of 39 daily emotions (i.e., they appear both in our collected list of emotional feelings in crowds and Scherer's list). Only two positive and eight negative emotional feelings in crowds overlap with Scherer (2004)'s daily emotions. This suggests that emotional feelings in crowds are quite different from daily emotions.

Table 5.2. Positive and negative terms mentioned at least by four participants. The highlighted terms appear on Scherer (2004)'s daily emotion list.

Positive Terms (Crowd Emotional Feelings)		Negative Terms (Crowd Emotional Feelings)	
Bustling	Relaxed	Angry	Frustrated
Cheerful	Secure	Annoyed	Helpless
Cozy	Sharing	Anxious	Hot
Enthusiastic	Smiling	Awkward	Irritated
Excited	Togetherness	Being ignored	Lonely
Happy	Warm	Bored	Nervous
Joyful		Breathless	Smelly
		Confused	Stressful
		Disappointed	Tired
		Disgusted	Uncomfortable
		Fearful	Worried

The collected answers were not just representing pure emotions, but covering a wider range of terms, such as bodily feelings (e.g., sweating, feel breathless), crowd spirits (e.g., feel connected, sense of belongingness), action tendencies (e.g., wish to escape, want to go home) etc. Probably, it is difficult for participants to differentiate emotions and feelings. For instance, when a participant wrote down sweating as a negative emotion, he probably felt unpleasantly warm or might feel disgusted at strangers' sweat. Sweating might be a good summary of his mixed emotions or feelings. In this thesis, "emotional feeling" is used to describe emotional experiences in crowds.

5.3.3 Study 3: Categorizing emotional feelings in crowds

The goal of Study 3 is to categorize the collected 107 positive and 127 negative emotional feelings in crowds. Based on the categorization, we expect to find a set of representative emotional feelings that are specific in crowds.

5.3.3.1 Participants and procedure

Eight master students of mixed nationalities (five females and three males) from Delft University of Technology participated in this study. They were divided into two groups: 2 females and 2 male students were in Session 1, and the other four students (three females and one male) were in Session 2. The two sessions took place separately, but the procedure was the same. Each of the collected crowd emotional feelings was printed on a 2cm×8cm white paper in Font Calibri (Size 60) and black color. The four participants in each session were firstly asked to categorize the 107 positive terms together and then categorize the 127 negative ones. They were encouraged to discuss with each other during the 90-minute session.

5.3.3.2 Results

For the validity of comparison, only categories with at least five terms of emotional feelings were considered. With this criterion, participants in Session 1 came up with six positive categories (A1-A6) and eleven negative ones (C1-C11). Participants in Session 2 had five positive categories (B1-B5) and nine negative ones (D1-D9). Every positive category from Session 1 was compared to every positive category from Session 2, so were the negative categories in the two sessions. For each comparison, we counted the number of emotional feelings that were in both categories. Table 5.3 shows the number of overlapping positive emotional feelings between categories generated in Session 1 and 2. For instance, Category A1 of Session 1 has 24 emotional feelings in common with Category B1 of Session 2. In other words, these 24 emotional feelings were considered as similar by participants in two sessions. The number of overlaps above five is highlighted in Table 5.3. There are eight pairs of categories that have at least five overlapped emotional feelings (i.e., A1-B1, A2-B2, A5-B3, A3-B2, A6-B4, A3-B3, A4-B2, and A7-B1). The emotional categories (A1-A7, B1-B5, C1-C11, D1-D9) are presented in Appendix 3.

Based on the eight groups of overlapping emotional feelings, one out of each group was selected to represent those emotional feelings in that group. The eight selected emotional feelings are *feel connected, excited, relaxed, happy, curious, pleased, enthusiastic* and *feel warm (psychologically)*. *Happy* and *pleased* are combined and named as "happy", because "happy" and "pleased" are closely placed in Russell (1980)'s valence-arousal dimension. *Excited* and *enthusiastic* are also combined and named as "excited" since they are both positive and highly aroused emotional feelings. In the end, a total of six typical positive emotional feelings were identified. The descriptions of the typical positive emotional feelings are presented in Table 5.4

Table 5.3. Comparing the six categories of POSITIVE emotional feelings in Session 1 (A1-A6) and five categories of POSITIVE emotional feelings in Session 2 (B1-B5). The table shows the number of overlapping positive emotional feelings between two compared categories (e.g., A1 and B2 have 24 positive emotional feelings in common). The number of overlaps above five is highlighted.

		Seven categories of Session 1						
		A1 (27*)	**A2** (22)	**A3** (14)	**A4** (12)	**A5** (12)	**A6** (10)	**A7** (9)
Five categories of Session 2	**B1** (35)	**24**	2	0	1	1	1	**5**
	B2 (31)	0	**16**	**7**	**6**	0	2	0
	B3 (16)	0	0	**6**	1	**8**	0	1
	B4 (15)	3	0	0	3	0	**6**	3
	B5 (8)	0	4	1	0	3	0	0

* The number in the bracket under the category name (e.g., A1) indicates the number of emotional feelings in that category.

Table 5.4 Six typical positive emotional feelings in crowds and descriptions.

	Six typical positive emotional feelings in crowds and descriptions
Feel Connected	Feeling connected in crowds is an experience of belongingness or togetherness.
Excited	Being excited in crowds is an experience of feeling elated, eager or enthusiastic.
Relaxed	Feeling relaxed in crowds is an experience of being calm, comfortable, secure and mentally free.
Happy	Feeling happy in crowds is an experience of being cheerful, pleased and having pleasure.
Curious	Feeling curious in crowds is an experience of being interested in something and having a desire to explore.
Feel warm (psychologically)	Feeling warm in crowds is an experience of feeling touched and being cared by people.

Table 5.5 shows the comparisons between categories of negative emotional feelings from the two sessions. In both Session 1 and 2, negative emotional feelings were grouped into more categories than the positive emotional feelings. The categories of negative emotional feelings are less consistent than the categories of positive ones. For the categorizations of the positive emotional feelings, all categories of Session 2 except B5, have at least five emotional feelings in common with categories in Session 1. In contrast, for the categorizations of negative emotions, many categories in two sessions did not

share at least five emotional feelings in common (e.g., five categories C5, C8, C9, C10 and C11 in Session 1 and three categories D4, D8 and D9 in Session 2). As a result, negative categories had a smaller number of emotional feelings than the positive categories, and the number of overlaps between negative categories was also smaller than positive ones.

Table 5.5. Compare the eleven categories of NEGATIVE emotional feelings in Session 1 (C1-C11) and nine categories of NEGATIVE emotional feelings in Session 2 (D1-D9). The table shows the number of overlapped negative emotional feelings between two compared categories (e.g., C2 and D1 have seven negative emotional feelings in common). The number of overlaps above five are highlighted.

		11 categories of Session 1										
		C1 (17*)	**C2** (15)	**C3** (15)	**C4** (14)	**C5** (12)	**C6** (9)	**C7** (9)	**C8** (9)	**C9** (6)	**C10** (5)	**C11** (5)
9 categories of Session 2	**D1** (23)	1	**7**	2	**5**	1	0	2	2	0	0	3
	D2 (16)	**6**	0	0	0	4	0	0	3	1	2	0
	D3 (16)	**5**	1	0	**5**	1	0	1	0	0	0	0
	D4 (16)	2	4	1	1	0	2	0	1	0	2	1
	D5 (15)	0	1	2	1	2	1	**5**	0	1	0	1
	D6 (13)	0	1	**7**	0	1	1	0	0	2	0	0
	D7 (10)	0	1	0	1	2	**5**	0	1	1	0	0
	D8 (9)	3	0	0	2	1	1	0	2	0	0	0
	D9 (7)	0	0	3	0	0	0	0	0	0	1	0

For the negative emotional feelings, eight emotional feelings were selected to represent the overlapped ones in two sessions, namely *alert, angry, feel stuffy, feel small, anxious, shy, confused* and *bored*. *Shy* and *feel small* are combined and named as "feel small" since they both expressed similar experience as unconfident, feeling inferior, etc. Table 5.6 presents the seven typical negative emotional feelings in crowds and their descriptions.

The six positive and seven negative emotional feelings were visualized into cartoon characters (see Figure 5.1-a and 5.1-b), which were used in Study 4 in Section 5.3.4. These visualizations aim at capturing the essence of the typical emotional feelings in crowds, which can be further developed and implemented in self-report tools. Note that, cartoon characters representing happy, relaxed, angry and bored are taken from the *EmoApp* (see Chapter 4). The other cartoon characters are drawn in a similar style with these four.

Table 5.6 Seven typical negative emotional feelings in crowds and descriptions.

	Seven typical negative emotional feelings in crowds and descriptions
Anxious	Feeling anxious in crowds is an experience of being nervous or worried about something, or even being panicking about unexpected incidents.
Feel stuffy	Feeling stuffy in crowds is an experience of being trapped in an unpleasantly warm and limited space, where there is not enough fresh air.
Angry	Being angry in crowds is an experience of feeling strong dislike or impatience or being irritated about something or somebody.
Feel small	Feeling small in crowds is an experience of being overwhelmed by the scene, feeling unconfident to interact with others, or feeling ignored or oppressed.
Alert	Being alert in crowds is an experience of being over-exposed, receiving too much attention or being cautious about threats.
Confused	Feeling confused in crowds is an experience of being helpless, disoriented, and not knowing what is happening or what to do.
Bored	Being bored in crowds is an experience of feeling tired, indifferent or impatient because you lose interest in something or have nothing to do.

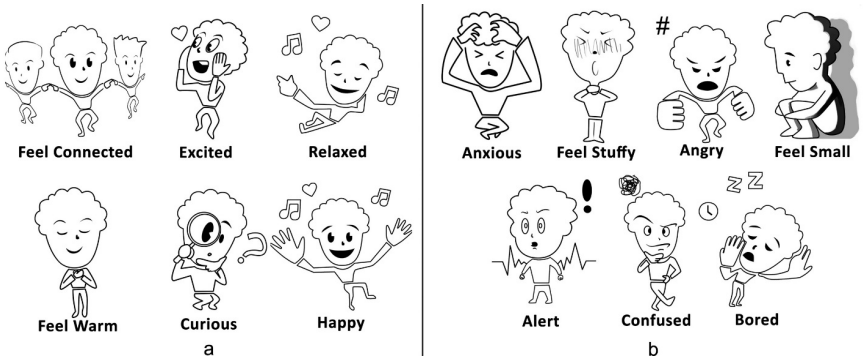


Figure 5.1. (a) Six representative positive emotional feelings, and (b) seven representative negative emotional feelings in crowds.

5.3.3.3 Discussion

This study reduced the list of 107 positive and 127 negative emotional feelings to a representative set of six positive and seven negative emotional feelings in crowds. Russell (1980)'s emotion dimensions (valence-arousal) cannot fully explain the categorization results of Session 1 and 2. For example, in one category of Session 1, participants grouped satisfied, pleased, cheerful, and passionate together. However, in Russell's valence-arousal dimension, satisfied and pleased are placed at the lower level of arousal than cheerful and passionate. Schimmack & Reisenzein (1997) proposed an episodic model to explain how

people judge the similarity of emotions. The episodic model assumes that people mainly judge the similarity of emotions based on their memories. That is to say, emotions that tend to co-occur in memory will be judged as similar, whereas emotions that co-occur infrequently or even exclude each other will be judged as different. The episodic model can explain some of the categorizations of emotional feelings in the two sessions, such as the differentiation made between "feel connected" and "feel warm (psychologically)". People may first feel warm and cared by others before they have a sense of belongingness to the group.

Four out of the 13 typical emotional feelings, namely *happy*, *relaxed*, *angry* and *bored* are the four main emotions measured by the *EmoApp* (see Chapter 4), respectively representing positive-active, positive-passive, negative-active and negative-passive emotional states. Participants of the *EmoApp* study did not only report these four main types of emotions, they also reported in-between emotional states, such as positive-neutral (i.e., positive in valence and neutral in arousal), negative-neutral (i.e., negative in valence and neutral in arousal) and harmony (i.e., neutral in both valence and arousal). Looking at the other nine emotional feelings in crowds, we discover that some of them, in fact, could represent those in-between emotional states. For instance, *feel connected* could be positive-neutral. *Confused* could be negative-neutral. Apart from the emotional feelings that fit into *EmoApp's* measurement, other emotional feelings like *feeling warm (psychologically), feeling stuffy, feeling small* are unique in crowd situations.

5.3.4 Study 4: Relations between emotional feelings and action tendencies in crowds

The goal of the final study is to investigate the relation between action tendencies and emotional feelings under two different crowd conditions, namely the event and the non-event crowd (see chapter 3).

5.3.4.1 Participants and procedure

Eighty people of mixed nationalities (44 females and 36 males, average age 24) participated in this study. Four versions of questionnaires were used:

Version 1, positive emotional feelings in event crowds;
Version 2, positive emotional feelings in non-event crowds;
Version 3, negative emotional feelings in event crowds; and
Version 4, negative emotional feelings in non-event crowds.

Participants randomly selected a version to answer. For each version of the questionnaire, 20 participants were recruited. The structure of the questionnaire will be explained based on the example of Version 1. The questionnaire first explained the definition of an event crowd in texts, showed a collage of typical event crowds, and asked participants to recall and write down as many as possible event crowds they have ever been in. Then, a cartoon character of one positive emotional feeling, visualized in Figure 5.1, was presented, followed by a short description of this emotional feeling. For example, "Feeling connected

in crowds is an experience of belongingness or togetherness". Three questions were asked below the cartoon character:

(1) Have you ever felt connected in any event crowd? (If the answer is yes, write down this event crowd, and go to Question 2. If the answer is no, this emotion intensity will be recorded as "0" in intensity and go to next page.)

(2) Please indicate how intense you felt connected in this event crowd (on a 5-point scale, 1 = very slightly, 5 = extremely).

(3) When you felt connected in this event crowd (that you mentioned in Question 1), please indicate on a 5-point scale, to what extent the following 11 statements matched your experience (0= do not match at all, 1= slightly match, 2= somewhat match, 3= moderately match, 4= very much match, and 5 = match extremely well).

The 11 statements in Question 3 are the selected 11 typical action tendencies as shown in Table 5.1. Each participant repeatedly answered the above three questions for each emotional feeling of a selected version of the questionnaire (see Appendix 4 for one version of the questionnaire).

5.3.4.2 Results

For Question 1 and 2, we gave ordinal values 0 to 5 to the felt intensity (0 = not at all, which means answer "no" in Question 1; 1 = very slightly, 2 = somewhat, 3 = moderately, 4 = very much, and 5 = extremely). Contingency analysis was applied to examine the relationships between types of emotional feelings and their intensity distributions in both event and non-event crowds. Significant associations were found for both positive and negative emotional feelings and their intensity distributions in two types of crowds (positive emotional feelings: χ^2 (55) =106.6, p<.0001; negative emotional feelings: χ^2 (65) =151.1, p<.0001). Figure 5.2 and 5.3 are mosaic plots in JMP software program to represent the contingency tables (Hartigan & Kleiner, 1981; Friendly, 1994). In both Figure 5.2 and 5.3, the x-axis represents the same emotional feelings in both event and non-event crowds, next to each other. The proportions on the y-axis at right represent the overall proportions of the emotional intensity from 0 to 5. The scale of the y-axis at left shows the response probability, with the whole axis being a probability of one (representing the total sample).

As can be seen in Figure 5.2, the intensity of six positive emotional feelings in both event and non-event crowds were compared. The redder the color is, the stronger the intensity of the emotional feeling is. The bluer the color is, the weaker the intensity of the emotional feeling is. In general, people feel more *curious, excited, connected*, *warm* and *happy* in event crowds than in non-event crowds. *Excited* is the most intense emotional feeling in event crowds, where 100% of the participants reported they were moderately to extremely excited. The intensity of *relaxed* has no difference in event and non-event crowds. *Feel warm is* the most absent emotional feeling in both event and non-event crowds. 40% of the participants reported that they did not *feel warm* in event crowds, but another 40% said they felt this very much in event crowds. 50% did not feel warm in non-event crowds. 35% of the participants did not feel *happy* in non-event crowds. In contrast, all participants felt *happy* in event crowds, 65% of whom felt

very or extremely happy.

Figure 5.3 illustrates the intensity of seven negative emotional feelings in both event and non-event crowds. Participants tend to have a higher intensity of *angry, confused* and *feel stuffy* in non-event crowds than in event crowds. *Confused* is the most absent emotional feeling in event crowd, where 75% of the participants did not feel confused at all. In contrast, in non-event crowds, 70% of the participants felt moderately or very confused. *Alert* is the most common emotional feelings in crowd situations. All participants felt *alert* in both event and non-event crowds. *Feel stuffy* is the most intense emotional feelings in non-event crowds, where 75% of the participants felt very or extremely stuffy. 70% of the participants felt moderately or very stuffy in event crowds. Many participants (55%) reported that they did not *feel small* in both event and non-event crowds. The intensity of *anxious* is about the same in event and non-event crowds.

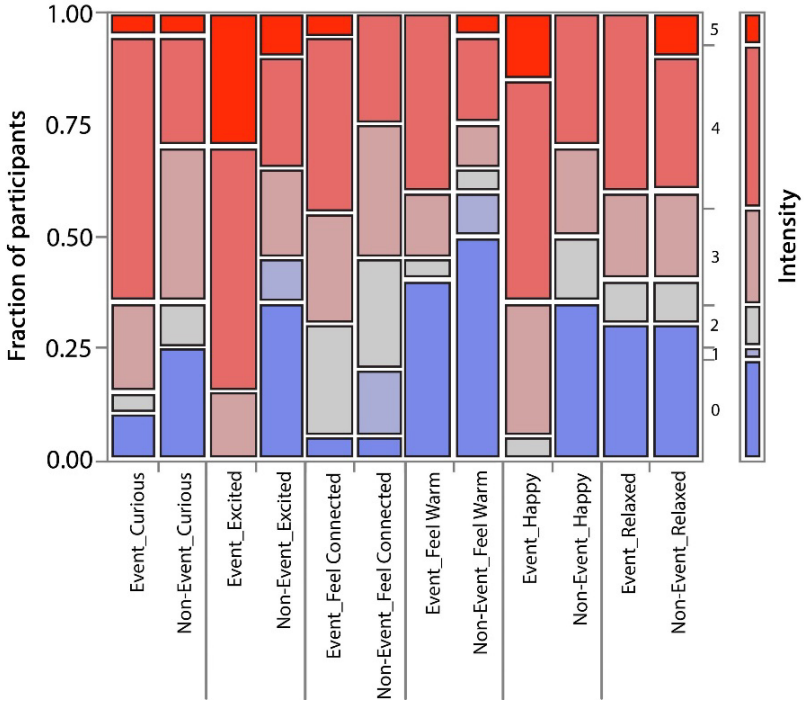


Figure 5.2. The felt intensity of positive emotional feelings in both event and non-event crowds. The x-axis shows the positive emotional feelings in both event and non-event crowds. The y-axis represents the intensity of emotional feelings, 0 = not at all (answer "no" in Question 1), 1 = very slightly, 2 = somewhat, 3 = moderately, 4 = very much, and 5 = extremely, and the fraction of participants who gave one of the intensity score.

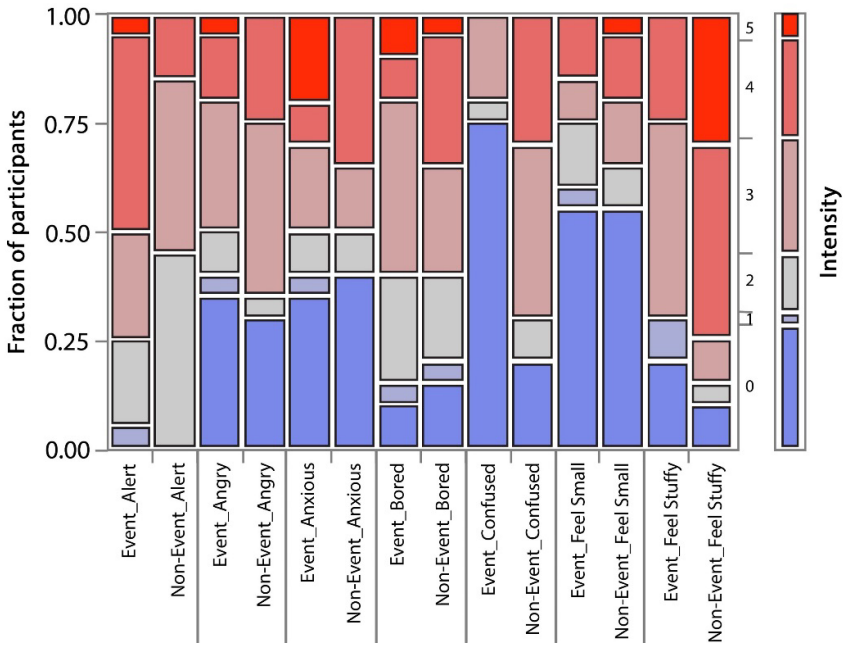


Figure 5.3. The felt intensity of negative emotional feelings in both event and non-event crowds. The x-axis shows the negative emotional feelings in both event and non-event crowds. The y-axis represents the intensity of emotional feelings, 0 = not at all (answer "no" in Question 1), 1 = very slightly, 2 = somewhat, 3 = moderately, 4 = very much, and 5 = extremely, and the fraction of participants who gave one of the intensity score.

For Question 3, we conducted two-way hierarchical clustering analyses to generate heat maps that show the relation between emotional feelings and action tendencies in both event and non-event crowds. We differentiated the intensity of each emotional feeling with "strong" or "weak" labels based on the 1 to 5 ordinal values (1, 2 and 3 = weak, 4 and 5 = strong). Figure 5.4 shows the relation between positive emotional feelings and action tendencies in event crowds. Since *excited* is both an emotional feeling and an action tendency, for differentiation, we decided to use "*excited (AT)*" to represent action tendency in the following paragraphs.

As can be seen in Figure 5.4, action tendencies are mainly clustered into three groups, and positive emotional feelings are clustered into two. The action tendencies are independent of positive emotional feelings in event crowds. *People do not have action tendencies like* protection, distance, avoidance *and* don't want *when they feel positive in event crowds (blue area in the graph). Be with, laughter, attending* is connected with all positive emotional feelings regardless of the intensity of them. *Excited (AT), exuberant* are connected with almost all the positive emotional feelings except *feeling warm (weak) and relaxed (strong). Feeling warm, happy (weak)* and *relaxed* is strongly connected with *rest.* Interestingly, the connections between *helping* and all the positive emotions are relatively weak.

Perhaps people do not want or do not feel the need to help others when they feel positive in an event crowd.

Figure 5.5 shows the relation between positive emotional feelings and action tendency in non-event crowds. Action tendencies are clustered into three groups, and positive emotions are clustered into two. *When people feel positive in non-event crowds, they have higher action tendencies to help others than in event crowds.* Similar to event crowds, *people do not have action tendencies like* protection, distance, avoidance, *and* don't want *when they feel positive in non-event crowds. Curious, feel connected* and *feel warm* (regardless of intensity) are connected with *be with, helping* and *attending. Happy (strong)* and *excited (strong)* are quite strongly linked with *be with, attending, excited (AT), exuberant,* and *laughter. Relaxed* is connected with *rest.*

Figure 5.6 and 5.7 show the relation between negative emotional feelings and action tendencies in event and non-event crowds respectively. In Figure 5.7, *be with* and *attending* are quite strongly connected with *alert (strong), anxious (strong), angry (strong)* and *feel small*, and somewhat connected with *alert (weak), anxious (weak) and confused (weak)* in non-event crowds. *Negative emotional feelings are not necessarily linked to negative action tendencies like avoidance or distance. Alert (strong), anxious (strong), angry* and *feel stuffy* are strongly connected with *protection, distance avoidance* and *don't want*. In Figure 5.7, *alert* and *feel small* are strongly connected with *protection* and *attending*, and somewhat connected with *avoidance* and *distance*. *Angry*, *anxious (weak)* and *feel stuffy* are connected with *avoidance, distance* and *don't want*. It is interesting to see that *anxious (strong)* does not strongly link to any action tendency except slightly connecting with *excited (AT)*, *exuberant* and *attending*, but *anxious (weak)* is quite strongly connected to *be with, protection, attending, avoidance, distance* and *don't want*.

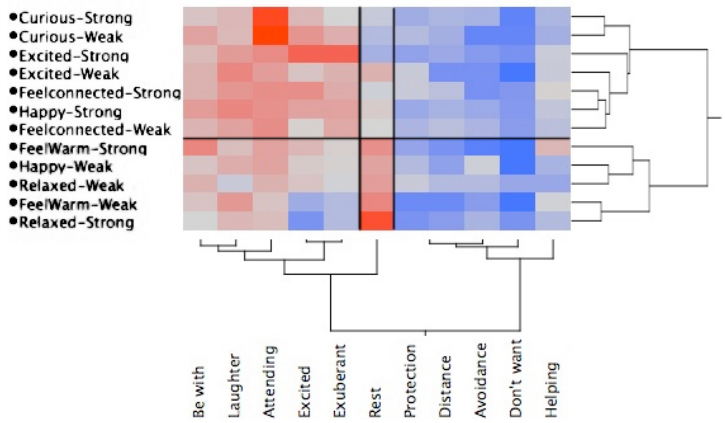


Figure 5.4. The heat map shows the relation between POSITIVE emotional feelings (Y-axis) and action tendencies (X-axis) in EVENT crowds (highly saturated red color = strong linkage, grayish colors = moderate linkage, highly saturated blue color = no linkage; the thick black lines indicate the separation of the clusters.).

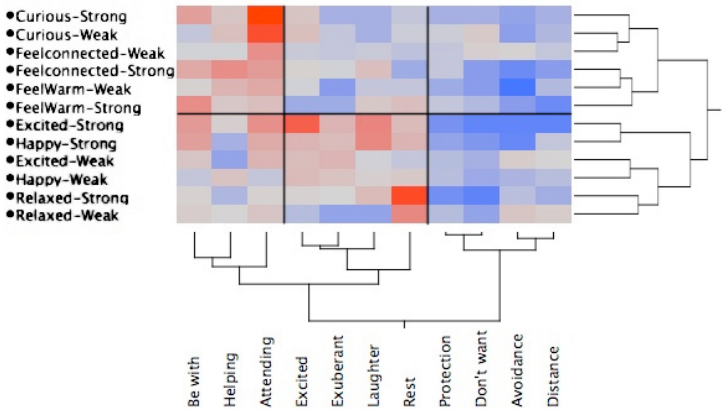


Figure 5.5. The heat map shows the relation between POSITIVE emotional feelings (Y-axis) and action tendencies (X-axis) in NON-EVENT crowds (highly saturated red color = strong linkage, grayish colors = moderate linkage, highly saturated blue color = no linkage; the thick black lines indicate the separation of the clusters.).

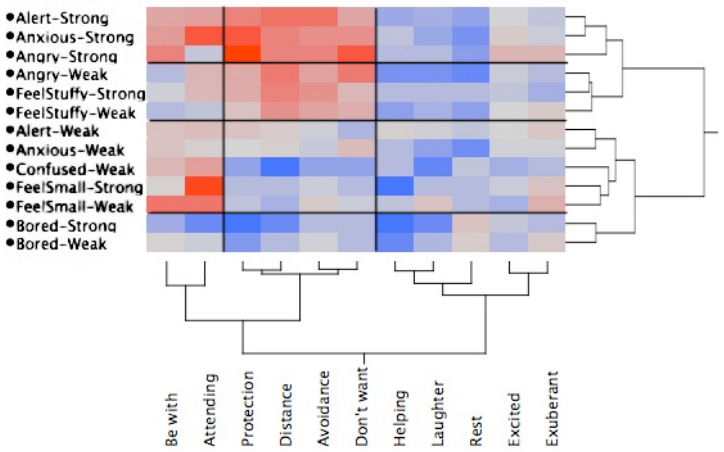


Figure 5.6. The heat map shows the relation between NEGATIVE emotional feelings (Y-axis) and action tendencies (X-axis) in EVENT crowds (highly saturated red color = strong linkage, grayish colors = moderate linkage, highly saturated blue color = no linkage; the thick black lines indicate the separation of the clusters.).

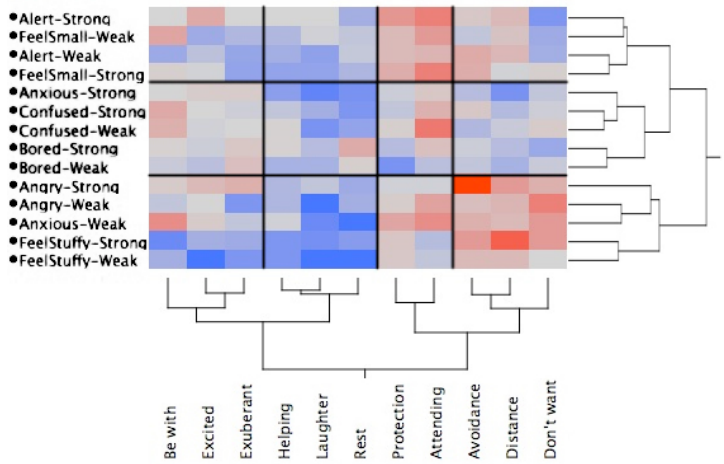


Figure 5.7. The heat map shows the relation between NEGATIVE emotional feelings (Y-axis) and action tendencies (X-axis) in NON-EVENT crowds (highly saturated red color = strong linkage, grayish colors = moderate linkage, highly saturated blue color = no linkage; the thick black lines indicate the separation of the clusters.).

5.3.4.3 Discussion

In Scherer (2005)'s component process model, "action tendency" is the motivational component of an emotion episode, and "emotional feeling" is the subjective experience component. Here, we tried to identify the relation between emotional feelings and action tendencies. The goal is to provide crowd managers with richer information about emotional experiences and the underpinned motivations (action tendencies) of crowd members. Study 4 found that people in different crowds tend to have different emotions. For example, people generally feel more positive in event crowds than in non-event crowds. Even having the same emotions, crowd members might behave differently in event crowds compared to non-event crowds. We found that, when people feel positive in non-event crowds, they tend to help others. However, when they feel positive in event crowds, they tend to enjoy themselves and do not help others, or they may feel it is not necessary to help others in such a positive event crowd because no one is in trouble. When crowd members feel negative, it does not necessarily mean that they will behave dangerously. They might be bored and want to look for new stimulations, or they might be angry and want to leave for a while. Since negative emotions do not necessarily result in dangerous behavior, it is more interesting for crowd managers to understand the motivations (action tendencies) underlying the emotions of crowd members than only knowing their emotions. In this way, crowd managers can better predict crowd behavior and sustain the well-being of crowd members.

5.4 SUMMARY

We developed a set of 13 emotional feelings in crowds (study 2 and 3), being six positive and seven negative ones, and investigated the relation of the 13 emotional feelings with 11 action tendencies that we had identified as having a strong chance of occurrence in crowd situations (study 1). The 13 typical emotional feelings in crowds were different from Scherer (2004)'s list of 39 daily emotions. Some frequently elicited emotional feelings in crowds, such as *togetherness*, *warm (psychologically), bustling, awkward,* and *breathless* are not typical daily emotional feelings. Therefore, this chapter suggests a set of typical emotional feelings in the context of crowds to be used to measure emotional experiences of crowd members, as an extension to the use of dimensional emotion models (e.g., Russell (1980)'s valence-arousal emotion dimensions are applied in the *EmoApp* in Chapter 4).

We also found that some emotional feelings were absent in specific crowd types. For example, *confused* was not felt in event crowds. However, *confused* was quite a typical negative emotional feeling in non-event crowds, since 70% of the participants felt it moderately or very much.

Over half of the participants did not *feel small* in both event and non-event crowds, but the participants who felt small were always in a crowd situation with a lot of strangers, e.g., attending a conference, traveling alone in a metro with strange people, or in a crowd consisting of an overwhelming number of people. Another possible explanation could be that *feel small* is related to personality. For example, introverted people who are more susceptible and sensitive to possible punishment or threats (Gray, 1970), often tend to feel small than extroverted people.

In general, people feel more curious, excited, warm (psychologically), connected and happy in event crowds than in non-event crowds. Negative emotions do not necessarily lead to negative action tendencies. For example, *be with* and *attending* are quite strongly connected with *alert (strong), anxious (strong), angry (strong)* and *feel small*, and somewhat connected with *alert (weak), anxious (weak)* and *confused (weak)* in non-event crowds*. When people feel positive, no matter what crowd type it is (event or non-event), they tend to behave positively. When people feel positive in non-event crowds, they have higher action tendencies to help others than in event crowds.* Another interesting finding is that differences in intensity of anxiety were connected with quite different action tendencies. *Strong anxiety usually led to excitement.* People could not sit still. They want to move and interact with others to release the anxiety. *Weak anxiety made people want to stay with others and protect themselves from threats.*

5.5 CONCLUDING REMARKS

The results of the studies suggest two main conclusions. The first conclusion is people in an event crowd tend to have overall better experience than those in a non-event crowd. The second is measuring both emotions and action tendencies is a way to enrich the understanding of crowd members.

5.5.1 Better experiences in event crowds

The relations between emotions and types of crowds suggest that crowd members tend to have better experiences in event crowds than in non-event crowds. Given the main difference between event and non-event crowds is the existence of interesting or meaningful activities, we infer that introducing such activities to a non-event crowd can potentially change it to an event crowd and improve the experience of its crowd members. This strategy has already been applied by some crowd managers. For instance, the King Cross station in London placed several pianos in the station hall with a label "Play Me", attracting many passersby to play music. The waiting crowds in the stations responded positively to these small, surprising musical events. Another example of positively influencing a non-event crowd is the Dutch theme park *Efteling*. A unique waiting path is built right under the track of a wooden roller coaster. When crowds are queuing on the path, they have different angles of views as they move on step by step. Instead of waiting outside and being far away from the roller coaster, crowds are staying closer to the roller coaster while they are queuing and having the thrilling experience of "seeing the trains going down at 75 kilometers per hour" before on ride. The waiting crowds like the design of this unique path, because they feel that they are distracted from the dull waiting experience.

These two examples show the positive influence of introducing exciting activities or nice distractions to a non-event crowd. The same idea can be applied to future design cases. For example, an interior design project for a future aircraft named "Blended Wing Body (BWB)" applied the strategy of introducing events and activities to a non-event crowd (Wang, Li & Vink, 2014). Current airplane interior designs force passengers to sit in rows, with limited mobility and limited motivation to interact with each other. The space division of the new BWB airplane interior abandons the current concept of classes (i.e., economic class, business class and first class). Instead, it introduces a concept of dividing the aircraft space into "active zones" and "inactive zones". Metaphorically speaking, the aircraft is like a city. The active zones are located at the center of the airplane, like the city center, with public spaces, diverse activities and people who want to network with others. Passengers who stay in the active zones form an event crowd. The inactive zones are located at the periphery, with private seats and sleeping cabins. Passengers are mainly individuals or in small groups in the inactive zones. Passengers can reserve their seats in different zones for different periods. For example, a passenger can book a seat in the active zone for the first three hours and move to the sleeping cabin for the next three hours. In this future visional project, the authors tried to envision how a non-event crowd like passengers on current airplanes can be changed to an event crowd.

The concept provides flexible choices to passengers, who can enjoy activities in an event crowd (the active zone) and have a good rest in the inactive zone when needed. This project also raises the question about emotional contagion between passengers: whether the positive emotions of the event crowds pass on to other passengers in the inactive zones, attracting them to join the activities and improving the overall onboarding experience in the end. Further tests are needed to see how emotional contagion happens. This will be a topic in Chapter 6.

5.5.2 Measuring emotions and action tendencies

The results of this chapter suggest that, for anticipating problems in crowds, measuring emotions may not be enough, because we found that negative emotions do not always lead to negative behavior. One implication would be that, for example, the *EmoApp* (see Chapter 4) could be extended with the function of reporting both emotions and action tendencies. Figure 5.8 illustrates a possible way to do so. The 13 emotional feelings in crowds and the 11 action tendencies are included in the self-report tool for crowd members. Crowd members report their emotions along with their action tendencies through the self-report. The reports from crowd members assist the crowd manager in better understanding the crowd and providing guidance and help when needed. For instance, a person in a conference reports via a tool that he *feels small* and tends to want to see things well and to interact with others (*attending*). Conference organizers or crowd managers could help him connect with others.

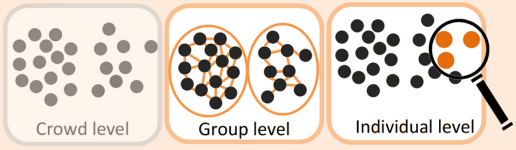
Figure 5.8. An extended self-report tool with the function to report both emotions and action tendencies, supporting the communication between crowd managers and crowd members.

"Just follow your heart and keep smiling."

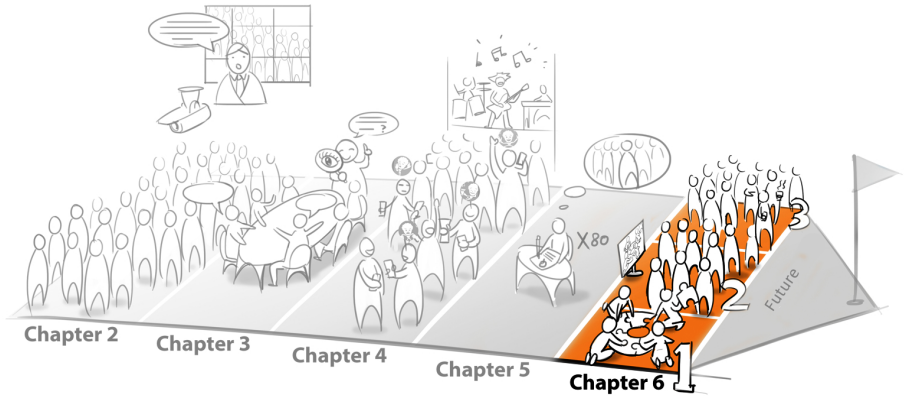
— Hayao Miyazaki,
Kiki's Delivery Service

CHAPTER 6

Emotions and Action Tendencies in Three Different Types of Crowds



Chapter 6 presents a lab experiment, from the individual level and the group level, and aims at investigating whether emotional contagion effects exist between different groups in a crowd. The three lab conditions respectively simulate three types crowds, namely an event crowd, a spectator crowd and a non-event crowd. The experiment also adopted a network of RFID sensors to investigate whether the sensor data can reflect the emotional experiences and the behavior of crowd members. The findings suggest that, changing a non-event crowd to an event crowd can bring more positive emotional experiences to the crowd members. However, the existence of a contagion effect was supported only by the number of reported positive emotional feelings for the spectator crowd being between those for the event and non-event crowds. Based on the sensor data, no significant or systematic differences were observed between the three crowds.



6.1 INTRODUCTION

Engaging in enjoyable activities (e.g., play, entertainment, or having nice food, etc.) is central to positive and meaningful experiences, and the accumulation of positive experiences is crucial to sustaining well-being (Lyubomirsky, 2007; Desmet and Hassenzahl, 2012). As concluded in Chapter 5, people tend to feel more curious, excited, connected and happy in event crowds than in non-event crowds[13], because an event crowd usually involves attractive activities. This raises the question how to change a non-event crowd with members not feeling positive to an event crowd. The feelings of the crowd members appear relevant because when people are feeling positive, no matter whether they are in an event or non-event crowd, they tend to behave positively. In that case, no intervention seems required.

So far, we have assumed that, in an event crowd, all crowd members are actively involved in the event. However, many crowd events have shown that a crowd is not necessarily homogenous. For example, at a music festival, it is usually the case that not all crowd members are actively participating in the activities. Some of them are standing in front of a stage, singing and dancing with the artists on the stage (the event crowd). The others may stand further away, not actively engaged with the performances on the stage, but just watching the live recordings of the performances on the screens next to the stage (the spectators). There might even be crowd members who are not interested in the current event but are waiting for other events to come (the non-event crowd).

We have found that crowd experts generally consider "crowds approaching the event site" a very critical moment. Crowd managers usually experience difficulties in predicting the size, flows and behavior of the crowds when they are approaching the event site from all directions, which for them is a typical non-event crowd situation. During this period, crowd members might get trapped in traffic jams, queue for a long time at the entrance and become impatient. Similarly, the studies with ten crowd members also pointed out that non-event crowd situations like "squeezing through the entrance" and "waiting in queues" are very negative experiences in crowds. Two examples of positively influencing non-event crowds are the "street pianos" and the special waiting path at the *Efteling* theme park. These two examples were introduced at the end of Chapter 5 (See Section 5.5.1) to demonstrate the positive influence of introducing interesting activities or nice distractions to a non-event crowd. However, when the crowd size is getting (extremely) large, it is unrealistic to expect that they will immediately influence the whole crowd. An interesting alternative would be that crowd managers influence only a selected number of groups within the crowd (e.g., engaging a waiting crowd with a funny activity) and that, when these crowd members become positive, their positive emotions spread like seeds to the rest of the crowd. In other words, when other crowd members watch the selected group playing happily, their emotions may start getting better as well According to emotional contagion theory (Fischer et al., 1990; Hatfield et al., 1993), this should

13 Please refer to Chapter 3, Section 3.4 for a definition about event and non-event crowds.

be possible.

The objective of this chapter is to gain a better insight into this emotional contagion effect and its possible implications on crowd behavior. To this end, we set up a study in which we investigated differences between three types of crowd situations, namely, event crowd, spectator crowd, and non-event crowd. Three lab experiments were set up to simulate the three types of crowd situation. The goal is to learn about possible differences regarding emotions, action tendencies, and grouping behavior by investigating the influence of being active in an event, being a spectator or just waiting. The overall question is whether the event crowd is the most positive crowd and whether the spectator crowd is more positive than the non-event crowd, predicted to be the least positive crowd.

Ideally, one should measure the possible impact of introducing activities as well as contagion effects on the crowd members' experiences in real time and on the spot. Unfortunately, most assessment tools are rather obtrusive and affect the outcome of the measurements. Therefore, alternatives had to be searched for. In the present study, we opted for a non-obtrusive retrospective approach: crowd members reported their experiences (emotions and action tendencies) right after instead of during the experiments. Video cameras registered the crowd activities during the whole session. In an attempt to link these self-reports with some real-time measure of the crowd members' behavior, the crowd members were requested to wear a so-called proximity sensor (Martella et al., 2014). This sensor can measure crowd members' relative positions, which basically tell who is close to whom in crowds without absolute positions of the crowd members. Based on the sensor data, time-varying proximity graphs could be constructed for each type of crowd. We took two measures from the proximity graphs, namely the averaged connectivity rate over time and the number of groups within the crowd, and we are interested in the question of whether it makes sense to look for relations between the self-reported experiences (emotional feelings and action tendencies) and the two measures derived from the sensor data? The following Figure 6.1 illustrates the rationale for investigating these possible relations. The two blue question marks are the explored relations in this chapter: (1) Are the changes in the connectivity rate over time related to the changes in emotional feelings and action tendencies? (2) Are the changes in the number of groups in the crowd related to the changes in emotions and action tendencies?

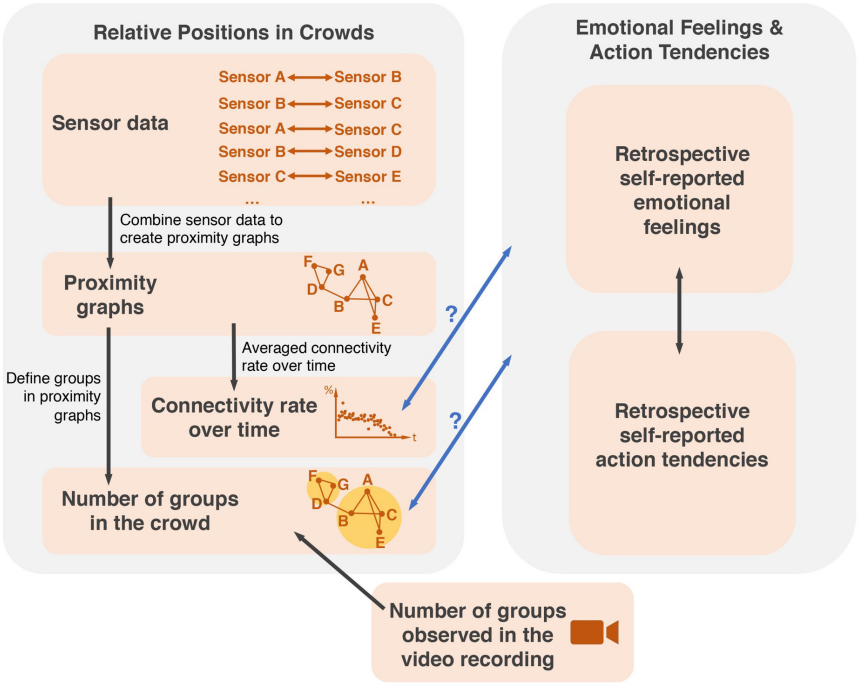


Figure 6.1. The rationale for investigating the possible relations between the self-reported experiences (emotions & action tendencies) and the measures (connectivity rate over time and number of groups) extracted from the sensors.

The chapter is organized as follows. Section 6.2 introduces the theory about emotional contagion. Section 6.3 starts with describing the experimental study that compares the three crowd types, including descriptions of the participants, experiment setup, procedure and details about the three types of crowds. Subsequently, the working principles of the sensors are explained, and some expected outcomes are presented. In the remainder of Section 6.3, the results of this study are presented as follows: Part 1 mainly concerns the retrospective judgments of the emotional feelings and action tendencies, and a comparison between the emotion-tendency relations observed in this chapter and those in Chapter 5. Part 2 is about the time-varying proximity graphs derived from the output of the proximity sensors. Section 6.4 reflects on the findings in this chapter, including the relations between the sensor data and the emotion data.

6.2 EMOTIONAL CONTAGION

Emotional contagion refers to the tendency of a person to automatically mimic and synchronize expressions, vocalizations, postures, and movements with those of another person's and, consequently, to converge emotionally. Emotional states can be transferred to others via emotional contagion, leading them to

experience the same emotions as those around them (Fischer et al., 1990). Researchers believe that awareness of the existence of emotional contagion may help us better understand group behaviors, for example, how Martin Luther King spread a message of love to the world, or how people in crowds behave (Hatfield et al., 1993).

Emotional contagion research has shown that emotional contagion most often occurs automatically and unconsciously based on physiological responses, such as mimic other persons' expressions (e.g., Hatfield et al., 1994; Neumann and Strack, 2000). Barsäde (2002) used a metaphor of "walking mood inductors" to describe how people continuously influence the moods, the judgments and the behaviors of others. Mehrabian (1972) claimed that words are the least important in understanding emotions, for which nonverbal cues are primary. These nonverbal cues include facial expressions, vocal feedback, and body language. Hatfield et al. (1992) found that the emotional experiences of participants tend to be affected by the facial expressions they adopt and suggested that participants' emotions are shaped by feedback from other person's posture and movement. When people produced facial expressions of fear, anger, sadness, or disgust, they were more likely to feel the emotion associated with those specific expressions (Laird and Bresler, 1992). Ilgen and Klein (1988) stressed that direct interpersonal contact is important for the transmission of emotions in groups due to the importance of these nonverbal cues. However, recently, Kramer et al. (2014) investigated the evidence of emotional contagion through social networks. They claimed that, on social networks, in-person interaction (i.e., face-to-face) and nonverbal cues are not strictly necessary for emotional contagion. The observation of others' positive experience can already contribute to the positive experience of oneself. Kramer et al. (2014) suggested that crowd management today can speed up or even increase the impact of the positive emotional contagion using social media.

In our study, emotional contagion was investigated by providing a group who was instructed to wait for a videotape to watch. The videotape recorded another group of people playing a game. It is expected that, through positive emotional contagion, people who are watching others enjoying the activity will feel more positive than having nothing to do but waiting. The study is described in Section 6.3.

6.3 EXPERIMENTAL STUDY ON COMPARING THREE CROWD TYPES

This section presents three separate lab experiments, respectively simulating an event crowd, a spectator crowd and a non-event crowd. It aims at learning about the differences in terms of emotions, action tendencies and grouping behavior in the three crowd conditions. Participants were asked to report their emotions and action tendencies on a questionnaire right after the experiments. In addition to the self-reports, a network of wearable proximity sensors was applied to measure the relative positions of crowd members in real time. The

idea is to investigate the linkage between the sensor data and the emotions of the crowd members. Two questions are addressed for the study: (1) What are the differences between the three crowds concerning emotion and behavior? (2) Can the sensor data reflect the emotion and behavior of the crowd members?

6.3.1 Methods

The three experiments were separately conducted in the PEL lab, located in the Faculty of Industrial Design Engineering, the Delft University of Technology. The event crowd and the spectator crowd experiments were scheduled from 13:00-14:00, and 16:00-17:00 respectively, on March 17, 2015 GMT[14] +1:00. The non-event crowd experiment was scheduled from 13:00-14:00 on March 18, 2015 GMT+1:00.

6.3.1.1 Participants

For each experiment, we invited 25 participants, roughly equal in genders. In the end, 17 participants (11 females and 6 males, with average age of 22) came to the event crowd experiment (Crowd 1); 18 participants (13 females and 5 males, with average age of 23) came to the spectator crowd experiment (Crowd 2); and 20 participants (9 females and 11 males, with average age of 22) came to the non-event crowd experiment (Crowd 3). All the 55 participants were either bachelor or master students of Delft University of Technology.

6.3.1.2 Experiment setup

Each experiment took about 30 minutes, including a 20-minute lab experiment and a 10-minute questionnaire. Figure 6.2 illustrates the setups of the 20-minute experiments, simulating the three crowd situations: the event crowd (Crowd 1), the spectator crowd (Crowd 2), and the non-event crowd (Crowd 3).

According to official guidelines concerning a safe crowd, the crowd density should not exceed 20 people per 10 square meters (Health and Safety Executive, 1999). The room for the experiments is approximately 35 square meters, which meets the safety requirement.

14 GMT stands for “Greenwich Mean Time”.

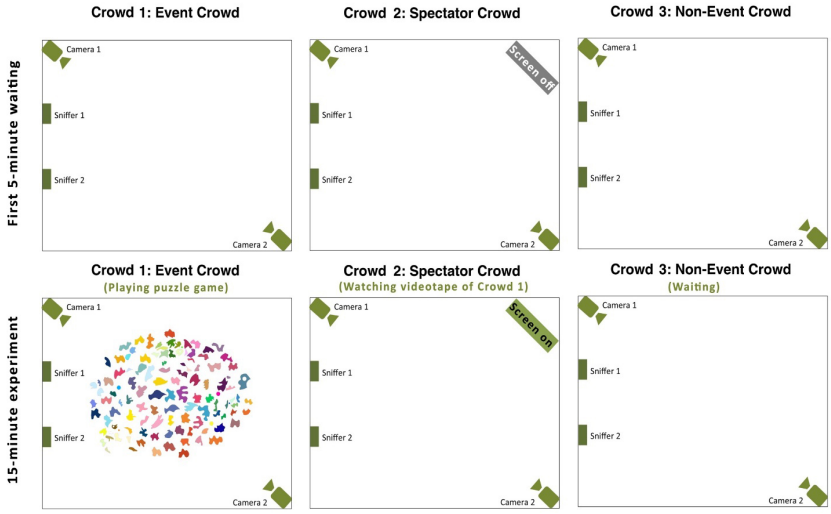


Figure 6.2. Setups of the three lab experiments, respectively simulating the event crowd, the spectator crowd and the non-event crowd. Row 1 indicates the situations in the first 5-minute waiting. Row 2 indicates the situations in the subsequent 15 minutes.

Equipment. In the PEL lab, two cameras were installed at two corners of the ceiling to record the experiments. Camera 1 was fixed. Camera 2 was adjustable, which could move along the wall where two sniffers were. For the Crowd 2 experiment, a 70-inch screen was placed at a corner of the room and was only used after the first 5-minute waiting. It was used for playing the videotape of Crowd 1.

Puzzles. A 2m×2m jigsaw puzzle, designed by the author and made of wooden boards, was applied in the Crowd 1 experiment (Figure 6.3). For the Crowd 1, right after the first 5-minute waiting, the experimenter brought in the puzzles, and the crowd members started playing.

Figure 6.3. The 2m×2m jigsaw puzzle played by Crowd 1.

Proximity sensors and sniffers. All the participants were asked to wear an RFID (Radio-Frequency Identification) sensor that can detect other sensors typically within a range of 1.5 to 2 meters. Each sensor has an associated unique identifier, for example, "ML", and periodically broadcasts its identifier "ML" to be received by the other sensors within the range of 1.5 to 2 meters. Two sniffers were placed on the wall where the Camera 1 was. The two sniffers could scan, observe and record the message transmissions among sensors in the lab. During the experiments, we only counted the mutual connections. In other words, the message transmissions between two sensors must be reciprocated to be counted as a connection. For example, during a certain period (i.e., typically one second), if ML sees MT, and MT also sees ML, then we consider this to be a connection between these two sensors.

Participants were all wearing the sensor in front of their chests. Therefore, the typical detection range of the sensor was not a 360° circular, but an approximately 150° sector in front of the participant (see Figure 6.4-a). Thus, when all the participants are facing each other, forming a circle-like group (Figure 6.4-b), the connectivity rate is higher than when they are forming several small groups (Figure 6.4-c). When crowd members were forming lines, for instance, when they are standing in front of a screen or a stage, sensors can only detect others who are next to them. However, sensors cannot detect the ones that are in front of or behind them, because the human body blocks the sensor signals (Figure 6.4-d).

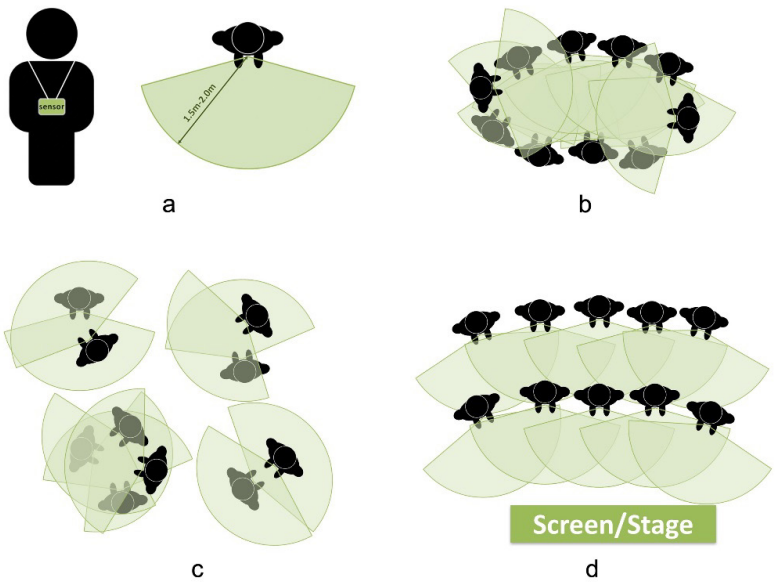


Figure 6.4. (a) The typical detecting range of a sensor is 1.5m-2.0m; (b), (c) and (d) exhibit different ways of grouping: (b) circle-like grouping, (c) grouping into small groups, (d) grouping in front of a screen or a stage. It is expected that (c) and (d) will have lower connectivity than (b). These three types of grouping are expected to represent the grouping behavior in an event crowd, a non-event crowd and a spectator crowd, respectively.

Based on the detections of the data transmissions among the sensors, we could extract the proximity information spatiotemporally from the crowd, in other words, to know who was close to whom during a period. The extracted proximity information forms a series of time-varying proximity graphs, representing real-time dynamic connections between sensors. Usually, a screenshot of the proximity graphs is taken to analyze how the sensors are connected within three seconds. However, the extracted information did not contain any location information (e.g., the absolute positions of the individuals), or information about distance or angle of the detection. Although the information collected from the sensors was limited, the evolving series of the proximity information could be used to correlate patterns of proximity with various aspects of crowd behavior, such as grouping, queuing or continuously moving (Martella et al., 2014). In the present study, we took two measures from the proximity graphs, namely the connectivity rate and the number of groups within the crowd. For further details, see Section 6.3.6.

6.3.1.3 Procedure

The 20-minute experiment. Each experiment lasted 20 minutes. The first 5 minutes of the three crowds were the same, which worked as a control period. Participants were all waiting, and they were not informed about the exact waiting time. When the 5-minute waiting was over, the experimenter brought in a puzzle for Crowd 1, turned on the screen and played the video for Crowd 2 and informed Crowd 3 that "We are waiting for more people to come" (see Figure 6.5). During the 15-minute experiment, Crowd 1 and 2 were doing their activities, while Crowd 3 was told halfway that something went wrong and "We are calibrating the sensors".

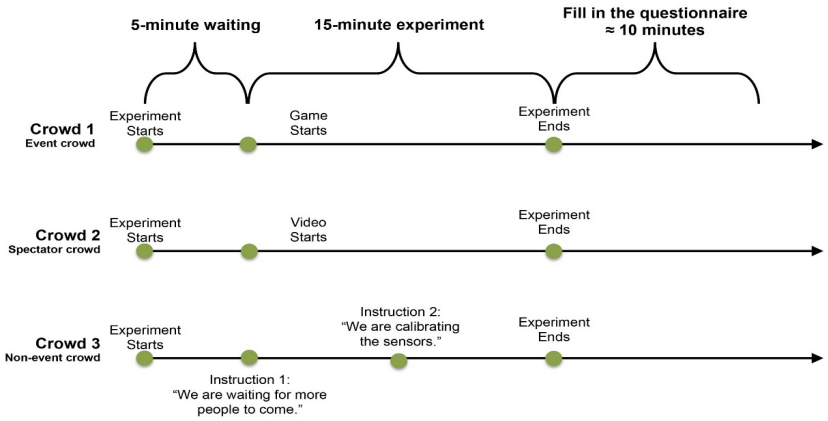


Figure 6.5. The procedure of the three experiments.

The 10-minute questionnaire. Six typical positive and seven typical negative crowd emotional feelings were used for measure emotions of the participants (see Chapter 5, Section 5.3.3), and 11 selected action tendencies from Frijda's (1989) list were used to measure their intended behavior (see Chapter 5, Section 5.3.1). Right after the experiment, participants were asked to recall and report their emotional feelings and action tendencies on a timeline, following the four-step instructions:

Step 1: Write down your emotional feelings on your timeline. How did you feel during different periods of the experiment? Please indicate on your timeline, using the six positive and seven negative crowd emotional feelings.

Step 2: Indicate the intensity of your emotional feelings. Please indicate how intense did you feel each emotion, on a 1-5 scale (1=very slightly, 2=somewhat, 3=moderately, 4=very much, and 5=extremely).

Step 3: Write down your action tendencies on your timeline, linked to your emotional feelings. Please reflect, when you were feeling this emotion, what did you tend to do (using the 11 action tendencies)? Please write down your action tendencies, linked to that emotion.

Step 4: Indicate the intensity of your action tendencies. Please indicate the intensity of each action tendency, on a 1-5 scale (1=very slightly, 2=somewhat, 3=moderately, 4=very much, and 5=extremely).

Figure 6.6 provides an example of reported emotional feelings and action tendencies on a timeline. The questionnaire for the event crowd experiment (Crowd 1) was presented in Appendix 5 as an example.

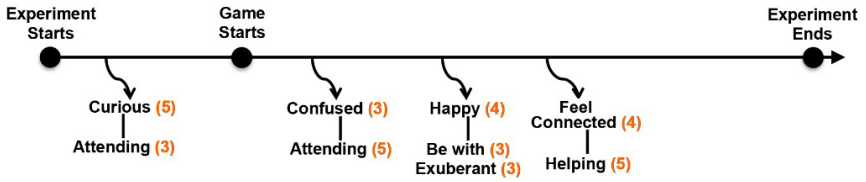


Figure 6.6. An example of reported emotional feelings and action tendencies on a timeline. The terms at the first row are reported emotional feelings (i.e., curious, confused, happy and feel connected). The terms of the second row are reported action tendencies that are connected to specific emotional feelings in the first row. The number in color orange indicates the intensity of that emotional feeling or action tendency (1=very slightly, 2=somewhat, 3=moderately, 4=very much, and 5=extremely).

6.3.2 Sensor data transformation

Two sniffers had recorded the message transmissions among sensors in the three experiments. Each sniffer generated a log file every three seconds to store the messages. The contents of each log file depended on the number of message transmissions detected by the sniffer during the specific three seconds. All the

recorded messages contained two strings of information: one was the timestamp, and the other represented the detected data transmission between sensors at that time, both in human-unreadable formats.

During the experiment of Crowd 1 (the event crowd), Sniffer 1 had generated 1599 log files and Sniffer 2 had 1193. In Crowd 2 (the spectator crowd), Sniffer 1 had 1078 log files and Sniffer 2 had 1037. In Crowd 3 (the non-event crowd), Sniffer 1 had 1241 files and Sniffer 2 had 1232. The log files of two sniffers were combined for each experiment and were translated into a readable format with four columns of information. Figure 6.6 shows one second of the recorded and translated sensor data of Crowd 1. The first column represents the timestamps in the format of Unix Time[15]. For example, the first line, "1426594412.0" means 1426594412.0 seconds since Thursday, 1 January 1970. If this number is converted into a human- readable format, it is 17 March 2015, 13:13:32 GMT+1:00 in the Netherlands. All the data were sorted according to the order of timestamps in the first column. The second column shows the labels of the senders, which were the sensors that had sent the messages and had been observed by at least one sniffer. The numbers in the third column represent the total rounds of message sending by the sensor at that moment. The fourth column represents the detected neighbors of the sender. For example, in Figure 6.6 (Line 1), this was the 729th message that had been sent by sender TD since it had been turned on, and sender TD had detected six sensors (i.e., ML, N4, QB, QH, RP and SV) as its neighbors at that moment. If no sensor labels are shown in the square brackets in the fourth column, it means that, at that moment, the sender did not see any neighbor.

During the experiments, both sniffers sometimes detected the same piece of information. For instance, in Figure 6.7, the message on Line 4 is the same as the one on Line 3, both saying that R2 is sending out its 601st message and claiming to see the other eight sensors as its neighbors. We ignored the repeated messages while analyzing the data. Another fact about the sensors is that all sensors send out messages regularly, about twice per second. However, not all signals were picked up by the sniffers. In Crowd 1, about 85% of the messages were picked up by at least one sniffer. The pick-up rates in Crowd 2 and 3 were 77% and 67%, respectively. The differences were probably caused by the positions of the participants in the experiment room. In Crowd 1, participants were playing a game in the center of the room, being closer to the sniffers. So, the sniffers could scan and record more messages in Crowd 1. In the other two crowds, participants were more scattered and further away from the sniffers.

15 Unix Time defined the time as the number of seconds that have elapsed since 00:00:00 Coordinated Universal Time (UTC), Thursday, 1 January 1970, not counting leap seconds. This explanation is given on Wikipedia, retrieved on 30 June, 2016: https://en.wikipedia.org/wiki/Unix_time

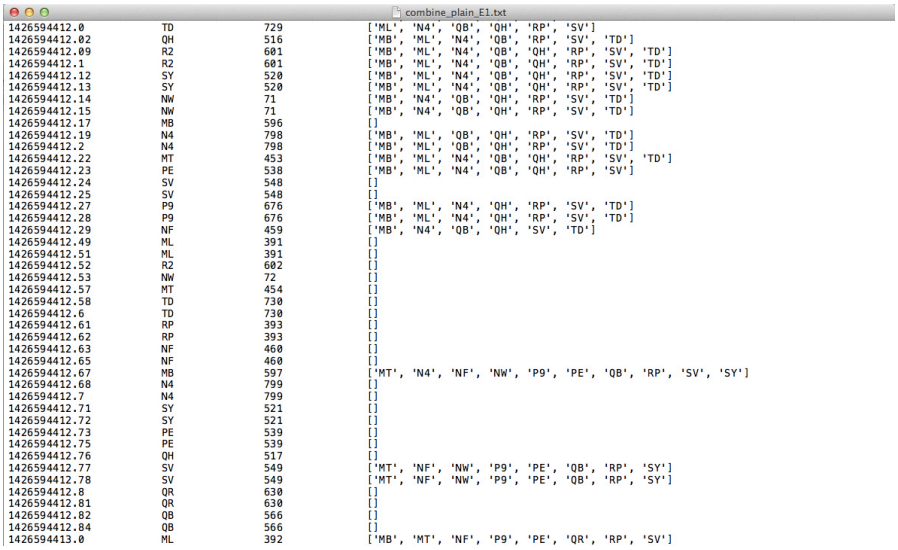


Figure 6.7. One second of the recorded and translated sensor data of Crowd 1. The first column represents the timestamps in the format of Unix Time. All the data were sorted according to the order of timestamps in the first column. The second column shows the labels of the message senders. The numbers in the third column represent the total rounds of messages sending by the sensor at that moment. The fourth column represents the detected neighbors of the sender.

6.3.3 Expected outcomes

The first 5-minute waiting. Since all the three crowds were waiting during the first five minutes, we expected that, during this period, no significant differences would be identified among the three crowds regarding emotions and grouping behavior.

Emotions during the 15-minute experiment. In Chapter 5, we concluded that people generally feel more positive in event crowds than in non-event crowds. Therefore, during the 15-minute experiment, the participants in Crowd 1 were expected to experience the most positive emotions, while the participants in Crowd 3 experience the most negative emotions. The valence of the emotions of Crowd 2 was supposed to be in-between Crowd 1 and 3 because Crowd 2 were watching the game playing of Crowd 1. It is expected that positive emotional contagion would happen between Crowd 1 and 2, making Crowd 2 more positive than Crowd 3.

Grouping and connectivity rate during the 15-minute experiment. We predicted that, during the 15-minute experiments, most participants in Crowd 1 would be forming a circle-like group, who were playing the puzzle game and staying around the puzzle. The participants might spontaneously divide into three groups, each group taking care of one big fish in the puzzle. The participants in Crowd 2 were expected to form lines in front of the screen. Crowd

3 was predicted to consist of several small groups of 2 to 4 persons through the whole period. Due to the sensitivity of the proximity sensors (see Section 6.3.1.2), Crowd 1 was expected to have the highest connectivity rate and the fewest number of groups during the 15-minute gaming (mainly three groups around the puzzle). Crowd 2 was supposed to experience a decrease in connectivity rate, and an increase in the number of groups when participants were forming lines in front of the screen. Crowd 3 was predicted to have the lowest connectivity rate and the largest number of groups during the 15 minutes.

Figure 6.8 illustrates the expected outcomes about emotions and grouping behavior in the three crowds at two different periods (i.e., the first 5-minute waiting and the 15-minute experiment).

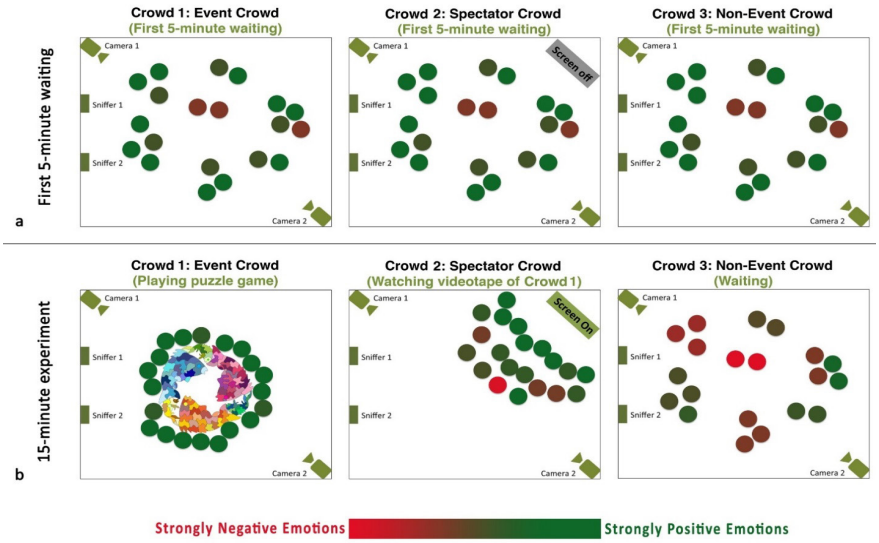


Figure 6.8. Expected outcomes: (a) During the first five minutes, all the three crowds were waiting. We predicted that no significant differences were identified among the three crowds in terms of emotions, grouping behavior, and connectivity rate; (b) during the 15-minute experiment, we predicted that Crowd 1 had the highest connectivity rate, with the fewest number of groups. The participants in Crowd 1 were forming a circle-like group, and they were experiencing the most positive emotions. The connectivity rate of Crowd 3 was the lowest among the three crowds. The participants in Crowd 3 were forming the most number of small groups, and their emotions were the most negative. The connectivity rate and the valence of the emotions of Crowd 2 were expected to be in-between Crowd 1 and Crowd 3. When the participants in Crowd 2 were forming lines in front of the screen, the connectivity rate was expected to drop.

6.3.4 Results part 1: Emotional feelings

Based on the received emotion data reported on every participant's timeline, we first compared the total number of reports. Figure 6.9 shows the sum of positive and negative emotional feelings reported in the three crowds during the "pre" period and the 15-minute experiment. Since three crowds had a

different number of participants (17, 18 and 20 participants in Crowd 1, 2 and 3, respectively), we corrected the number of reports by equation

$$n_{ci} = \frac{N_{max}}{N_i} \times n_i$$

(n_{ci}= the corrected number of reports; n_i= the original number of reports; N_{MAX} = the maximum number of participants across the three crowds, ; N_{MAX}=20; n_i=number of participants in the specific crowd, n_1=17, n_2=18, n_3=20).

Figure 6.9 suggests that during the waiting time the number of emotional reports did not change much while during the experiment the number of reports systematically decreased from event via spectator to non-event crowd. That is, for the 15-minute experiment, the event crowd was the most active crowd in reporting emotional feelings, which yielded the largest number of reports compared to the other two crowds. As illustrated in Figure 6.9, the number of reported emotional feelings (both positive and negative) of the event crowd was 85.8, the most as compared to the spectator crowd (68.8) and the non-event crowd (58.0). This effect of crowd type was supported by the outcome of a three-way mixed ANOVA, with time (pre vs post) and type of emotional feeling (positive vs negative) as within-subjects variables and type of crowd (event, spectator and non-event) as between-subjects variable. The test of between-subjects effects indicated a significant effect of crowd type: $F(2,107) = 7.16$, $p = 0.001$, partial eta squared = 0.12). The test of within-subjects contrasts yielded significant effects for emotional feelings ($F(1,107) = 6.01$, $p = 0.02$, partial eta squared = 0.05), for time x emotional feelings ($F(1,107) = 228.92$, $p < 0.001$, partial eta squared = 0.68), and for time x emotional feelings x crowd type ($F(2,107) = 50.63$, $p < 0.001$, partial eta squared = 0.49).

To investigate whether the three crowds were comparable, a two-way mixed ANOVA was conducted to examine the influence of the independent variables (type of emotional feelings and crowd type) on the number of reported emotional feelings in the three crowds during the "pre" period (the 5-minute waiting). The type of emotional feelings is a within-subject variable, including two levels (positive and negative). The crowd type is a between-subjects variable, including three levels (event, spectator, and non-event). The main effect for the type of emotional feelings showed a significant difference, as determined by $F(1, 52) = 11.84$, $p < 0.01$, indicating that crowd members reported more positive emotional feelings than negative emotional feelings across the three crowds. The main effect for crowd type also showed a unexpected significant difference ($F(2, 52) = 4.20$, $p < .05$), indicating that the number of reported emotional feelings was different in the three crowds during the "pre" period. A post hoc test (Turkey HSD) revealed that this significant difference in the reported number of emotional feelings was caused only by the relatively high number of negative emotional feelings reported in the spectator crowd. Hence, it may be assumed that the three crowds are comparable.

Next, the number of reports was analyzed per type of emotional feeling, first the positive emotions and then the negative ones. A two-way mixed ANOVA was conducted to examine the influence of two independent variables (time and crowd type) on the number of reported positive emotional feelings. Time is a within-subjects variable with two levels (pre and post). Crowd type is a between-subjects variable with three levels (event, spectator, non-event). The interaction and main effects were all significant. The main effect for time yielded $F(1, 52) = 19.78$, $p < 0.001$, partial eta squared = 0.28, indicating a significant increase from the "pre" to the "post" period. The main effect for crowd type yielded $F(2, 52) = 21.81$, $p < 0.001$, partial eta squared = 0.46, indicating significant differences between the event, the spectator, and the non-event crowd. The interaction effect (time × crowd type) was also significant, $F(2, 52) = 9.74$, $p < 0.001$, partial eta squared = 0.72. The post-hoc test (Turkey HSD) confirmed that the number of emotional feelings reported in the event crowd was significantly higher than the spectator ($p < 0.01$) and the non-event crowd ($p < 0.001$). The spectator crowd had significantly more reports of positive emotional feeling than the non-event crowd ($p < 0.05$). As can be seen in Figure 6.9, the interaction effect is due to the changing number of reports per crowd type in the "post" period while those in the "pre" period did not change across the three crowds.

Another two-way mixed ANOVA was conducted on the influence of the same two independent variables (time and crowd type) on the number of reported negative emotional feelings. None of the effects were significant except for the time variable. The main effect for time yielded $F(1, 52) = 51.63$, $p < 0.001$, partial eta squared = 0.50, indicating a significant difference between the "pre" and the "post" period. Crowd members gave more negative reports in the "post" period than the "pre" period. The main effect for crowd type was not significant ($F(2, 52) = 2.73$, $p = 0.07$, partial eta squared = 0.10). The interaction effect (time × crowd) was also not significant ($F(2.52) = 2,58$, $p = 0.09$, partial eta squared = 0.09).

Figure 6.10 shows the comparison of emotional feelings of the three crowds in details. During the "pre" period, we see the same pattern across the three crowds, with *curious* as the most reported emotional feeling. The spectator crowd reported slightly more negative emotional feelings in the "pre" period than the other two crowds, including *anxious, bored* and *feel stuffy*, which were mostly absent in the event crowd and the non-event crowd. During the "post" period, *feel connected* and *excited* were the two most reported positive emotional feelings in the event crowd, and the most reported negative emotional feeling of the event crowd was *confused*. However, in the "post" period of the spectator and the non-event crowd, *excited* and *feel connected* were rarely reported, while *bored* was the most reported. As shown in Figure 6.10, in the event crowd, the number of reported negative emotional feelings in the "post" period is 28.2, most of which is the emotion *confused* (15.3).

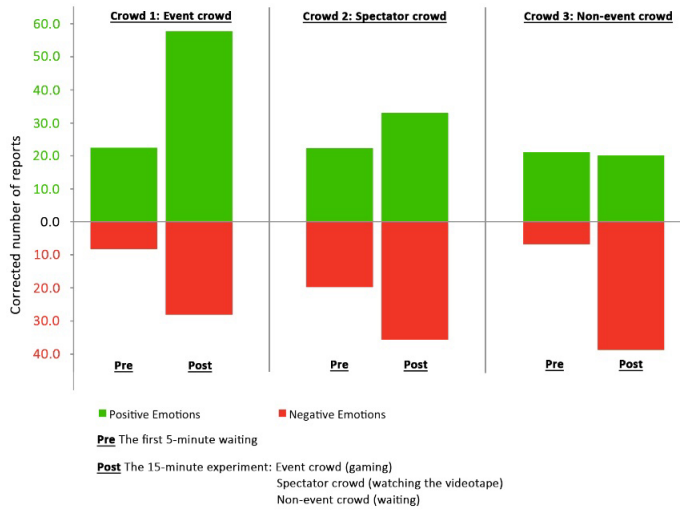


Figure 6.9. The overall number of emotional reports in the three crowds. The number is corrected by the equation presented at the beginning of Section 6.3.4.

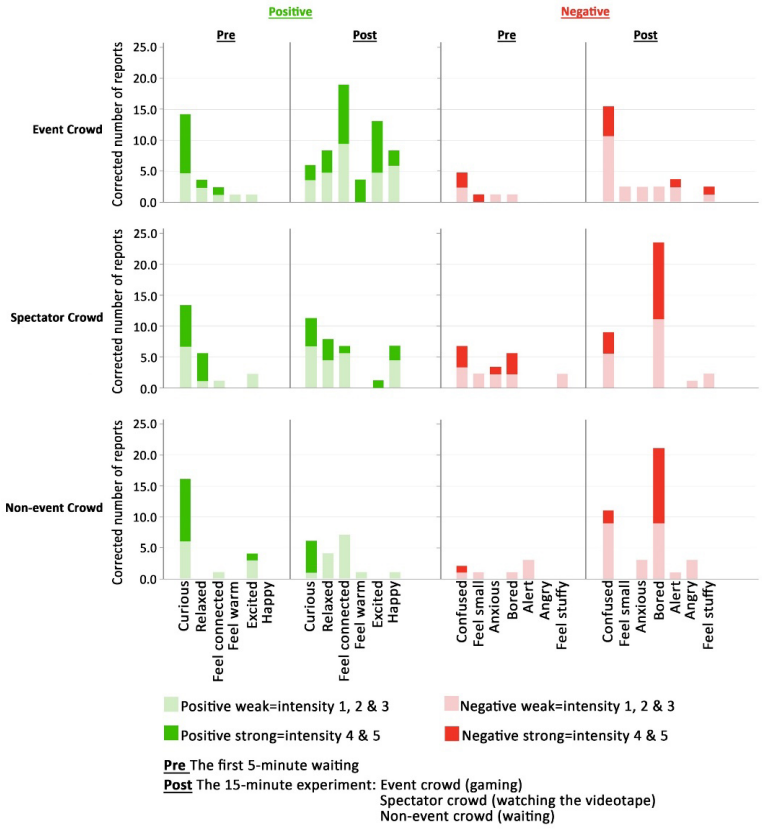


Figure 6.10. Corrected number of emotional reports in the three crowds for each emotional feeling.

Figure 6.9 illustrates the six crowd situations in which we wanted to observe differences in terms of emotions. We labeled the six crowd situations as event_pre, event_post, spectator_pre, spectator_post, non-event_pre and non-event_post, respectively. Label "pre" stands for the first 5-minute waiting period, and "post" stands for the 15-minute experiment. Labels "event", "spectator and "non-event" stand for the three crowds, respectively. So, for example, "event_pre" stands for the first 5-minute waiting in the event crowd, "event_post" represents the 15-minute gaming in the event crowd, and so forth.

The method "complete linkage" [16] of the hierarchical clustering analysis (Field, 2009) was applied to calculate the similarity of these six situations concerning emotional patterns, with consideration of both negative and positive emotions. As illustrated in Figure 6.10, emotional patterns can be viewed as the number of reports distributed over each emotion. For instance, by visual inspection, the negative emotional patterns of spectator_post and non-event_post are quite similar, both receiving more reports on *confused* and *bored* than the other negative emotions.

Table 6.1 shows the correlations of the emotional patterns in the six situations. Figure 6.11 is a dendrogram based on the hierarchical clustering analysis, which visually represents the similarities. The horizontal axis of the dendrogram represents the distance or dissimilarity among the situations and their clusters. The vertical axis represents the six situations. As can be seen in Table 6.1, emotional patterns in event_pre, spectator_pre and non-event_pre are similar. The correlations between event_pre and spectator_pre (0.912), event_pre and non-event_pre (0.895), and spectator_pre and non-event_pre (0.776) are all significant at the 0.01 level (2-tailed). They are closely clustered in the dendrogram (Figure 6.11). The results indicate that, during the first 5-minute waiting, the emotional patterns in the three crowds exhibited high similarity.

High similarity can also be identified between spectator_post and non-event_post, which are significantly correlated (0.910) and closely clustered in the dendrogram. In contrast, the emotional patterns of event_post were very different from the spectator_post and the non-event_post, which indicates that, during the 15-minute experiment, the emotional patterns of the spectator crowd and the non-event crowd were similar, but the emotions of the event crowd were quite different from the other two crowds.

16 Complete linkage, also known as the furthest neighbor or maximum method, defines the distance between two groups as the distance between their two farthest-apart members. This method usually yields clusters that are well separated and compact.

Table 6.1. Correlation matrix of the six crowd situations.

Correlations

		Event _pre	Event _post	Spectator _pre	Spectator _post	Non-event _pre	Non-event _post
Event _pre	Pearson Correlation	1					
	Sig. (2-tailed)						
Event _post	Pearson Correlation	.207	1				
	Sig. (2-tailed)	.497					
Spectator _pre	Pearson Correlation	.912**	.104	1			
	Sig. (2-tailed)	.000	.734				
Spectator _post	Pearson Correlation	.356	.142	.557*	1		
	Sig. (2-tailed)	.232	.644	.048			
Non-event _pre	Pearson Correlation	.895**	.084	.776**	.234	1	
	Sig. (2-tailed)	.000	.784	.002	.442		
Non-event _post	Pearson Correlation	.223	.138	.443	.910**	.077	1
	Sig. (2-tailed)	.464	.654	.129	.000	.802	

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

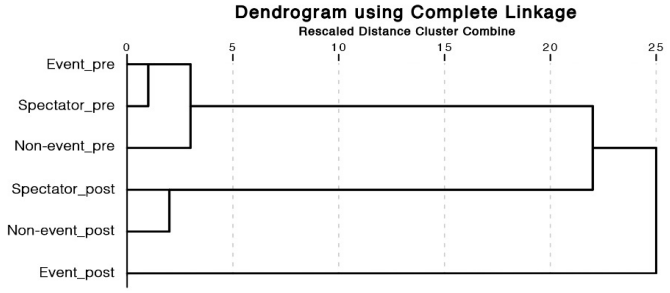


Figure 6.11. Dendrogram showing the similarity of the emotions (including both positive and negative emotional feelings) in the six crowd situations. During the first five minutes, the emotions of the event, the spectator and the non-event crowd were similar. During the 15-minute experiment, the emotions of the spectator and the non-event crowd were similar, but the emotions of the event crowd were quite different from the other two crowds.

In summary, this subsection compares two aspects of the reported emotional feelings between the three crowds. The first is the number of reported emotional feelings and the second is the emotional patterns. For the first aspect, during the "pre" period, the number of positive emotional feelings was not different between the three crowds, while the number of negative emotional feelings was reported more in the spectator crowd than in the other two crowds. During the

"post" period, the event crowd reported more positive emotional feelings than the spectator crowd and the non-event crowd. The spectator crowd also reported more positive emotional feelings than the non-event crowd. The number of negative emotional feeling did not show significant differences between the three crowds during the "post" period. For the second aspect, during the "pre" period, no differences in emotional patterns were found between the three crowds. During the "post" period, the emotional pattern of the spectator crowd is similar to that of the non-event crowd. The emotional pattern of the event crowd is different from that of the other two crowds.

6.3.5 Results Part 2: Comparison of action tendencies

Action tendencies were reported as connected to emotional feelings, forming emotion-tendency pairs. Participants were provided with a list of 13 emotional feelings and 11 action tendencies. However, not all types of emotional feelings or action tendencies were reported during the experiments. During "pre" periods (the first 5-minute waiting), the mostly reported emotion-tendency pair was *curious-attending*. During the "post" periods (the 15-minute gaming, video watching or waiting), a total of 29 emotion-tendency pairs were reported at least twice in one of the crowds. Figure 6.12 illustrates the frequencies of these 29 emotion-tendency pairs in the form of three heat maps. The y-axis and x-axis, respectively, show the eight emotional feelings and the nine action tendencies covered by the 29 emotion-tendency pairs. The emotional feelings and action tendencies in orange color are negative. Those in green are positive. The reddish colors on the heat maps represent "frequently reported pairs", while the gray cells represent no reports.

By pure visual inspection of the heat maps in Figure 6.12, the patterns of Crowd 1 are different from those of Crowd 2 and 3. In Crowd 1, tendencies like *attending*, *be with and helping,* were frequently reported as connected with positive emotional feelings like *feel connected, excited, curious* and *relaxed*. Action tendencies like *don't want* and *avoidance* do not exist in Crowd 1. In Crowd 2 and Crowd 3, *bored-rest*, *bored-don't want* were frequently reported.

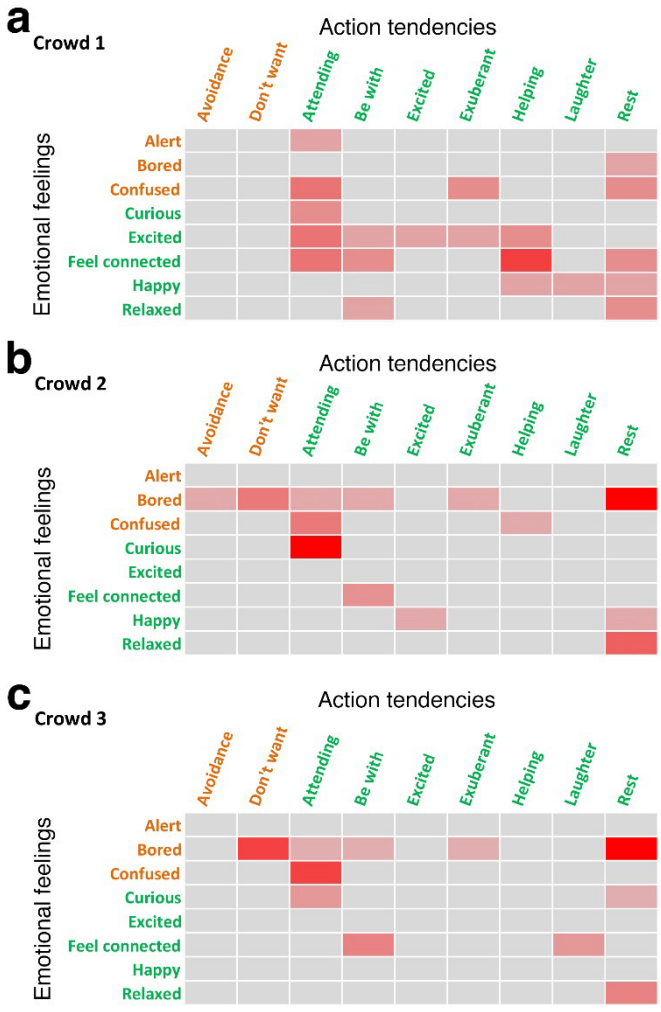


Figure 6.12 The Heat maps show the frequencies of the emotion-tendency pairs reported in the three crowds during the "post" periods: (a) Crowd 1, (b) Crowd 2 and (c) Crowd 3. The y-axis represents the emotional feelings, and the x-axis represents the action tendencies as connected with the emotional feelings on the y-axis. The emotional feelings and action tendencies in orange color are negative. Those in green are positive. The reddish colors on the heat maps represent "frequently reported pairs". The empty cells on the heat map represent no reports. The heat map patterns of crowd 2 and 3 are similar as compared to crowd 1.

In Chapter 5, Section 5.3.4, relations between crowd emotional feelings and action tendencies (i.e., emotion-tendency relations) were identified, both in event crowds and non-event crowds. The results were presented in the form of heat maps. The study in Chapter 5 was conducted based on the recalled crowd experience of the participants, while in this Chapter, the emotional feelings and action tendencies were reported right after the experiment. We would like to examine whether the emotion-tendency relation identified in these three

experiments are comparable to those in Chapter 5. We found that most emotion-tendency pairs reported in this chapter were consistent with those collected in Chapter 5. Some differences were identified and described as follows:

Positive emotional feelings in event crowds. The event crowd in this chapter was the 15-minute gaming in Crowd 1. We compared the emotion-tendency pairs collected in Crowd 1 during the gaming period with those reported according to the recalled event crowd experience in Chapter 5. As shown in Figure 6.13, the y-axis represents the relation of positive emotion and action tendency that was reported both in the 15-minute gaming of Crowd 1 and the event crowds in Chapter 5. The x-axis represents the strength of the action tendencies for given related emotional feelings (1=very slightly, 2=somewhat, 3=moderately, 4=very much, and 5=extremely). The "strong" and "weak" attached to the emotional feelings indicated the intensity of that emotional feeling reported by participants. The definitions of the "strong" and "weak" labels were the same as in Chapter 5: "strong" represents the intensity score 4 and 5, and "weak" represents the intensity score 1-3.

As for the event crowd, the strength of action tendencies for given related emotions was close to those in Chapter 5, except the tendency *helping* (Figure 6.13). The possible explanation is that the puzzle game itself induced participants to collaborate and to help each other. In a general event crowd (e.g., music festival), it is not necessary for people to help others, especially when most people are enjoying themselves and feeling positive.

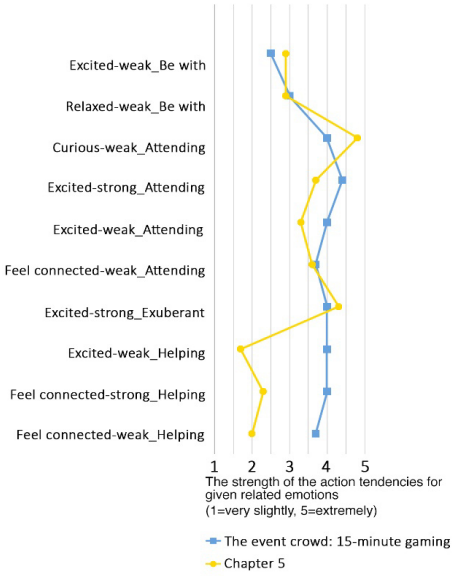


Figure 6.13. Compare the relation between POSITIVE emotional feelings and action tendencies in the EVENT crowd: The 15-minute gaming of the event crowd (rating right after the experiment) vs. event crowds in Chapter 5 (rating based on memories in the past 12 months). The x-axis represents the strength of action tendencies for given related emotional feelings. The y-axis shows the common emotion-tendency pairs in this chapter and Chapter 5.

Positive emotional feelings in non-event crowds. Since the three crowds in this chapter all began with a 5-minute waiting, and waiting is typically a non-event situation, the first 5-minute reports of the three crowds were combined and compared with the ratings for non-event crowds in Chapter 5. The emotion-tendency pairs that were at least reported twice in the three experiments were selected. In the waiting periods of the three crowds (non-event situations), when people reported *curious*, *feel connected* (weak) and *excited* (weak), the strength of the action tendency *be with* was higher than people who recalled their non-event crowd experience in Chapter 5. Regarding action tendency of *attending*, when people felt *curious* in the three crowds, they were less *attending* than the people reported based on recalled experience in Chapter 5 (Figure 6.14).

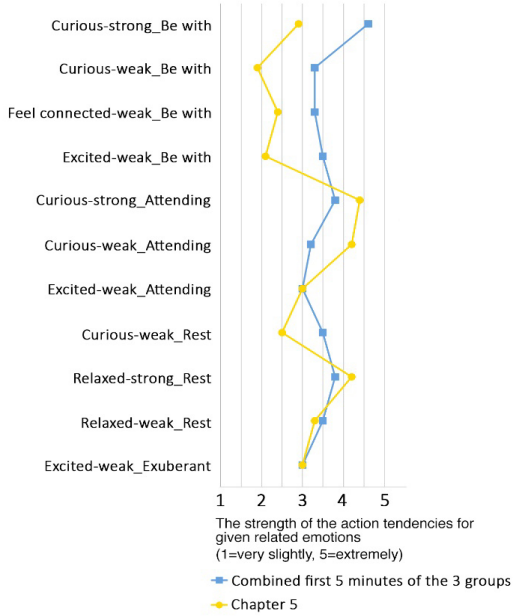


Figure 6.14. Compare the relation between POSITIVE emotional feelings and action tendencies in NON-EVENT crowds: The first 5 minutes of the three crowds (rating right after the experiments) vs. the non-event crowds in Chapter 5 (rating based on memories in the past 12 months). The x-axis represents the strength of action tendencies for given related emotions. The y-axis shows the common emotion-tendency pairs in this chapter and Chapter 5.

Negative emotional feelings in event crowds. Both in the experiment of this chapter and Chapter 5, negative emotional feelings were rarely reported in event crowds, except several cases of *Alert* (weak) and *confused* (weak) reports, which were connected to action tendency *attending*.

Negative emotional feelings in non-event crowds. People tended to feel less negative during the 5-minute waiting (the non-event crowd situations), as compared to the non-event crowd experience recalled in Chapter 5. The possible explanation is that people who came to the three lab experiments tended to feel

safer than staying in their remembered non-event crowds. Furthermore, they only waited for five minutes. Probably, they felt less threaten and bored, so the negative tendencies such as *protection, avoidance, distance* and *don't want* were absent during the first 5-minute waiting, and the strength of the tendencies such as *be with* and *rest* was higher than those in Chapter 5. However, when participants kept on waiting for another 15 minutes in the non-event crowd (Crowd 3), *bored* (strong) that connected to *don't want* tendency started to show up in the reports. In Chapter 5, negative tendencies like *protection, avoidance, distance* and *don't want* were frequently reported and were connected to emotional feelings such as *alert, angry, feel stuffy*.

6.3.6 Results Part 3: Analysis of the proximity graphs

The transformed sensor data enabled us to extract the number of mutual connections[17] per second and compare the connectivity rate of the three crowds. Based on the frequency of mutual connections among sensors, it is possible to perform hierarchical clustering analysis to see the grouping behavior (e.g., who was close to whom most of the time) and compare the grouping behavior extracted from the sensor data with that recorded by the two cameras in the experiment.

6.3.6.1 Comparison of connectivity rate

During the experiments, every participant was wearing a sensor, hanging in front of their chest. In Crowd 2, a sensor (Labeled RA) was placed on the screen. We noticed that, in all three experiments, a sensor, labeled as RS had failed. Thus, in the end, sixteen sensors were effective in Crowd 1, eighteen sensors in Crowd 2 (including RA attached to the screen) and nineteen sensors in Crowd 3. The state of all the effective sensors being mutually connected with each other was named as the state of full connectivity (100% connectivity rate). Under this state, Crowd 1 would have 120 connections, Crowd 2 would have 153 connections and Crowd 3 would have 171 connections (calculated by , being the number of effective sensors).

As illustrated in Figure 6.15-6.17, every second, the number of mutual connections was calculated into connectivity rate (in percentage, y-axis) and plotted against the timestamps (in seconds, x-axis). The green fitting curve was calculated based on the *median filter*, which is an effective method that can, to some extent, distinguish out-of-range isolated noise (MATLAB documentation, 2016). Specifically, the median filter replaces a data point by the median, instead of the average, of all surrounding data points in the neighborhood. We defined this neighborhood as 30 data points on the connectivity plot, that is 15 data points before the data point that would be replaced, and 15 data points after it.

17 As defined earlier in this Chapter (see Section 6.3.1.2): The connection between two sensors must be reciprocated to be counted as a mutual connection. For example, during a certain time period (i.e., typically one second), sensor ML sees sensor MT, and MT also sees ML, then we consider there is a mutual connection between these two sensors.

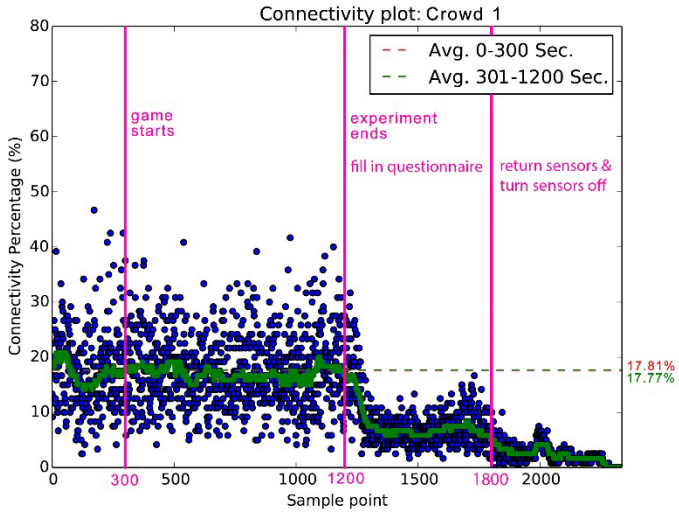


Figure 6.15. Connectivity rate plot (Crowd 1: The event crowd). The red dashed line indicates the average connectivity rate during the first 5 minutes. The green dashed line indicates the average connectivity rate during the 15-minute experiment.

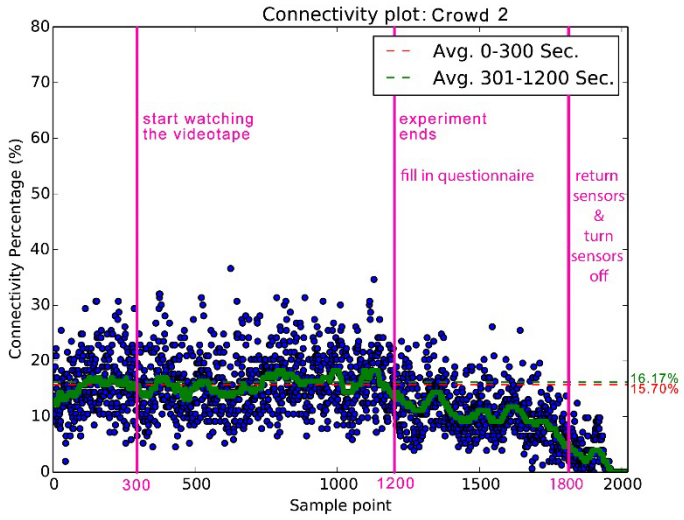


Figure 6.16. Connectivity rate plot (Crowd 2: The spectator crowd). The red dashed line indicates the average connectivity rate during the first 5 minutes. The green dashed line indicates the average connectivity rate during the 15-minute experiment.

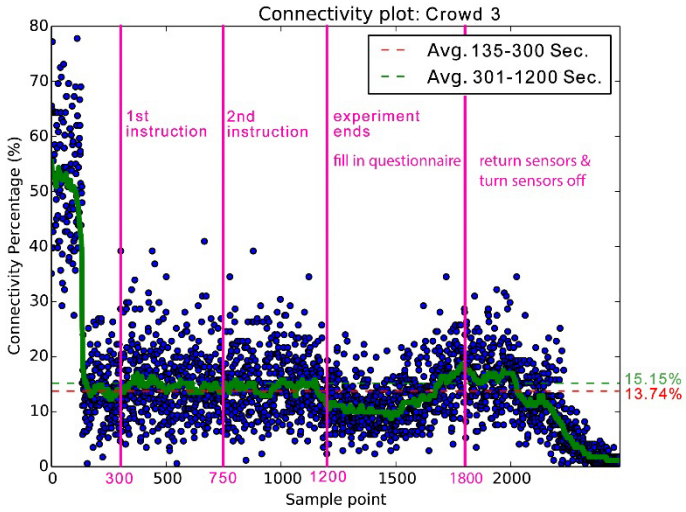


Figure 6.17. Connectivity rate plot (Crowd 3: The non-event crowd). The red dashed line indicates the average connectivity rate during the second half of the first 5 minutes (between 135-300 seconds). The green dashed line indicates the average connectivity rate during the 15-minute experiment.

The fitting curve assists in observing changes in the connectivity rate. The first 5 minutes (300 seconds) of all the three crowds were supposed to be the same since participants were all waiting during this period. As shown in Figure 6.15, the connectivity rate of Crowd 1 during this waiting period firstly experienced a small decrease and then increased to the average rate (17.81%). Crowd 2 increased gradually to the average rate (15.70%) and stayed stable (Figure 6.16). However, we noticed that, at the beginning of the measurements for Crowd 3, the connectivity rate was rather high, around 50%, followed by a sudden drop at 134th second towards the averaged connectivity rate established between 135-300 seconds and being 13.74% (Figure 6.17).

We investigated the cause of this change of Crowd 3 by inspecting the video recordings. As we discussed in Section 6.3.1.2, participants were all wearing the sensor in front of their chests. Therefore, the typical detection range of the sensor was not a 360° circular, but an approximately 150° sector in front of the participant. We noticed that, during the first 135 seconds, most participants in Crowd 3 were standing closely, forming a circle-like group, and mostly facing each other instead of turning their backs on others. This circle-like grouping behavior explained the high connectivity rate at the very beginning. Between 135 and 300 seconds, participants in Crowd 3 were forming groups of 3-4 persons. Probably, this was the cause of the sudden decrease in the connectivity rate. Inspecting the video recordings of Crowd 1 and Crowd 2, we did not see similar changes from a circle-like group to several groups: participants had already separated into groups with 2-4 persons at the very beginning.

If we observe the overall trends from 301s to 1200s (the 15-minute period)

of the three crowds, the green median filter curves were flattening out on all the three plots (Figure 6.15-6.17), which indicated no dramatic changes in the connectivity rate in all three crowds. During the 15 minutes (301s to 1200s), the average connectivity rate of the event crowd (Crowd 1), the spectator crowd (Crowd 2) and the non-event crowd (Crowd 3) was 17.77%, 16.17% and 15.15%, respectively. Figure 6.18 illustrates the box plot of the connectivity rate in the three crowds, comparing the maximum, the minimum, the first quartile, the median and the third quartile value. The differences in connectivity rate of the three crowds were minor. Crowd 1 was slightly higher than the other two crowds, and Crowd 3 had the lowest connectivity rate.

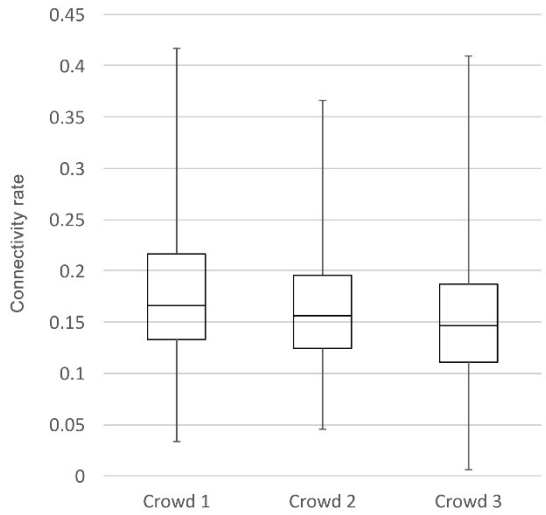


Figure 6.18. Box plot of the connectivity rate in the three crowds during the 15-minute experiment (301s~1200s), comparing the maximum, the minimum, the first quartile, the median and the third quartile value of the connectivity rate in the three crowds.

When the experiments ended, and participants started filling in questionnaires, the connectivity rate of all the three crowds showed a decrease, especially Crowd 1 and Crowd 2. From the video recordings, we have seen that participants all moved to the walls of the lab, where tables and chairs were provided for them. Most of them were facing the walls while filling in the questionnaire, so the sensor signals were mostly blocked, resulting in a decrease in connectivity rate.

After participants finished the questionnaire, they were requested to return the sensors to a box and turned the sensors off. The increase of connectivity rate around the 1800th second in Crowd 3 was due to the participants returning the sensors to the box without switching them off immediately. Unlike the Crowd 1 and Crowd 2, many participants in Crowd 3 forgot to switch off the sensors. So, many sensors stacking in a small box resulted in the increase of connectivity.

6.3.6.2 What does connectivity rate say about grouping behavior

On average, if the number of crowd members stays constant, the more groups a crowd has, the smaller each group is. It is assumed that connections only exist within groups, that is, all the members within the same group are connected with each other but are not connected with other crowd members outside the group. Based on this assumption, the following trends may be observed:

(1) The more groups a crowd has, the lower the chance of having a high connectivity rate.

(2) The more unconnected individuals a crowd has, the lower the connectivity rate will be.

These two observations can be illustrated by the following example: Suppose there is a crowd of ten persons. A group in a crowd should have a minimum of two persons. In other words, an individual is not counted as a group. This ten-person crowd will at most have five groups. In this case, each group has two persons. Appendix 6 shows all the grouping possibilities and the corresponding theoretical connectivity rate of this ten-person crowd. If this crowd has five groups, and each group consists of two persons, the theoretical connectivity rate is then 11.11%. If it has four groups, the possible theoretical connectivity can range from 8.89% to 20.00%. If it has one group, the possible theoretical connectivity rate can range from 2.22% to 100.00%. Therefore, we infer that the fewer groups a crowd has, the higher connectivity rate it can reach (Figure 6.19).

Figure 6.19 illustrates the theoretical grouping and possible connectivity rate of a 10-person crowd. As the dashed line indicates, the same connectivity rate can lead to many grouping possibilities. For instance, two, three and four groups can all result in 20% connectivity rate. Link this insight to the studies in this chapter, the three experiment crowds had very similar connectivity rate during the "post" period, ranging from 10-20%, but their groupings can be very different from each other. Since no differences were identified among the three crowds in terms of the connectivity rate, the possible differences of grouping behavior in the three crowds were investigated in the following subsection.

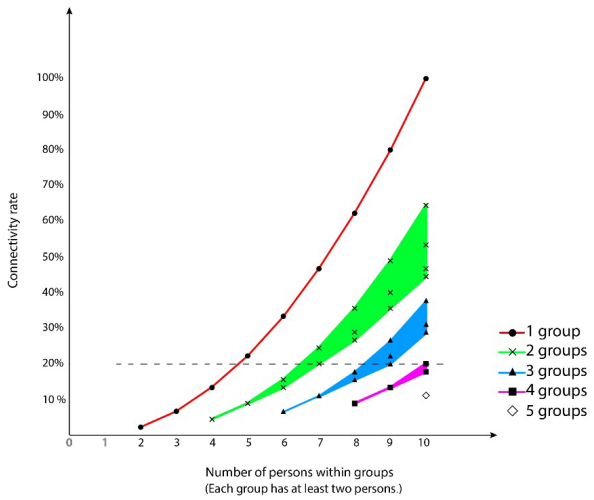


Figure 6.19. Theoretical grouping and possible connectivity rate of a 10-person crowd. The fewer groups a crowd has, the higher connectivity rate it can reach. Some of the connectivity rates are difficult to infer how the actual grouping is organized. For example, the dashed line indicates that, when the connectivity rate is 20%, there are three possibilities of the grouping: ten crowd members may form 2, 3 or 4 groups. When the connectivity rate is 100%, there is only one possibility in grouping: the ten persons form a big 10-person group.

6.3.6.3 Comparison of grouping behavior in the video recordings

The video recordings of the three crowds (both Camera 1 and 2) were observed, and differences in grouping behavior can be found. When crowd members did not change their groupings during a period in the video recordings, constant changes on the proximity graphs were still observed, which might be caused by people's body movements, such as suddenly turning aside. In Figure 6.20-6.22, corresponding proximity graphs were compared next to the screenshots of video frames, which exhibit certain trends of the grouping behavior.

Crowd 1. During the first 5-minute waiting, participants in Crowd 1 were forming groups of 2-4 persons. Their main activity was chatting (Figure 6.20-a). During the gaming, the same as we predicted, they were forming three groups, divided by the "three fishes" in the puzzle. They were forming a circle-like pattern and surrounding the puzzles (Figure 6.20-b). From the proximity graphs of Crowd 1, the grouping behavior cannot be seen as clearly as in the video recordings. Due to the physical closeness, all the crowd members tended to connect with each other. During the gaming, crowd members seemed to form two groups on the proximity graph. The possible explanation for the inconsistency between the proximity graph and the video recordings is the sensitivity of the RFID sensors used in the experiments. In some periods, participants who were in the same group were not necessarily connected. For instance, when two participants were playing the puzzle game in the same group, they were kneeling on the floor, shoulder to shoulder. Their body positions may block most of the data transmissions between the two sensors hanging in front of their chests. So,

even though they were in the same group, no connections were built between their sensors. In other periods, participants of Group 1 may well connect with participants of Group 2 who were physically close to them. For example, some sensors in Group 1 happened to fall into the detection range of a few sensors in Group 2, if some participants of the two groups were close to each other, and their body positions did not block the sensor signals. This probably can explain why absolute divisions between groups cannot be seen on the proximity graph.

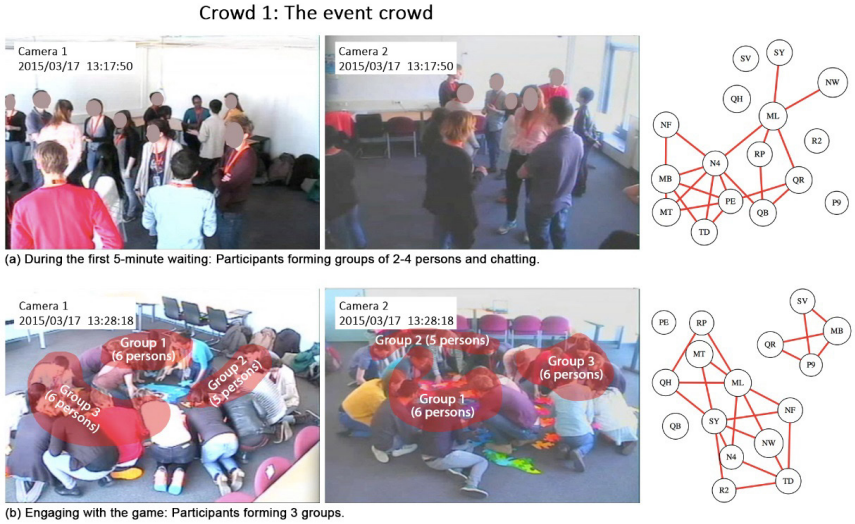


Figure 6.20. Grouping behavior in the event crowd: (a) During the first 5-minute waiting versus (b) Engaging with the game.

Crowd 2. During the first 5-minute waiting, participants in Crowd 2 were also forming groups of 2-4 persons like Crowd 1. Their activities were quite relaxed. Some of them were sitting down on the floor or doing yoga. When they were watching the videotape (Figure 6.21-b), they were indeed forming lines in front of the screen as what we predicted in Figure 6.8-b. After a few minutes, they lost interest in the videotape, and returned to the state of the grouping of 2-4 persons and chatting (Figure 6.21-c). In the experiment of Crowd 2, Sensor RA was attached to the screen. As shown in the proximity graph in Figure 6.21-a, during the waiting, no crowd members were connected with RA. When the video was turned on, they were forming two lines in front of the screen. Crowd members standing in the first line were probably the ones that are connected with RA on the proximity graph (Figure 6.21-b). The other unconnected crowd members were probably standing in the second line. When crowd members lost interest in the video, they moved away from the screen. We observed that RA became unconnected again (Figure 6.21-c). This suggests that fixating sensors to immovable objects can help identify movements of crowd members on proximity graphs.

Crowd 3. The grouping behavior of participants in Crowd 3 did not change throughout the 20 minutes. They were always in groups and chatting. The proximity graphs also did not show dramatic changes in the number of connections and groups (Figure 6.22).

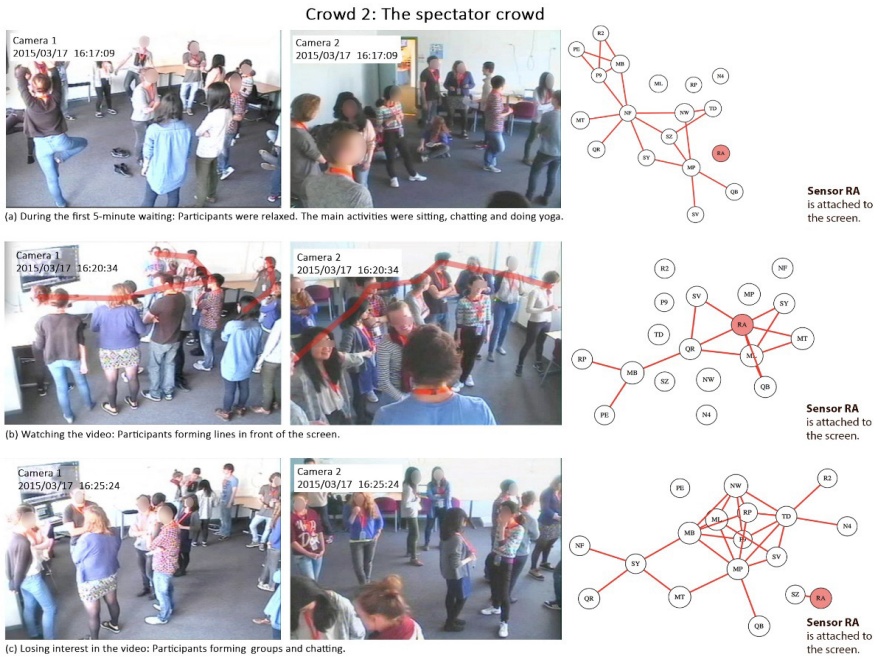


Figure 6.21 Grouping behavior in the spectator crowd: (a) During the first 5-minute waiting, (b) Watching the video, and (c) Losing interest in the video.

Figure 6.22. Grouping behavior in the non-event crowd: (a) During the first 5-minute waiting, (b) After the 1st instruction, and before the 2nd instruction, and (c) After the 2nd instruction.

In summary, the grouping behavior observed from the video cameras was consistent with the expected outcomes. Participants in Crowd 1 were mainly forming three groups during the 15-minute gaming. When participants in Crowd 2 were watching the videotape, they were indeed forming lines in front of the screen. The grouping behavior of participants in Crowd 3 did not change throughout the experiment. They were continuously chatting, and the borders between groups were not clearly divided. The patterns of grouping behaviors in proximity graphs were not as apparent as the ones observed in video recordings, because of the physical closeness of the crowd members. Even if they were not in the same group, they still had high chance to connect with each other in such a small experiment lab. The fixated Sensor RA in Crowd 2 was helpful in identifying the movements of crowd members on the proximity graphs.

Visually inspecting the proximity graphs was not sufficient for seeing the divisions between groups in crowds, nor for identifying the differences between the three crowds. Therefore, we decided to explore the hierarchical clustering based on the sensor data to see whether it can reveal the potential differences between the grouping behavior in the three crowds.

6.3.6.4 Comparison of grouping behavior through hierarchical clustering

Hierarchical clustering analysis. To extract grouping information, a hierarchical clustering analysis was conducted (MATLAB documentation, 2016b). The input for the hierarchical clustering analysis is the distance between sensors. Typically, the sensors used in the experiment can detect other sensors within a range of 1.5 to 2.0 meters. If two sensors are close to each other within this range, then at least one sensor should see the other more frequently than the sensors that are further away from each other. If at least one sensor frequently sees the other sensor, the probability that the two sensors are in the same group and close to each other is high. For calculating the distance between two sensors, we first considered the total amount of reports of both sensors. The sensor that had more reports than the other during that period was considered to be more "active". Then we took the reports of this active sensor to define the distance: the more frequently this active sensor sees the other sensor, the smaller the distance between them is. More precisely, the distance was defined as follows:

A and B are two different sensors. During one period, if A has reported a total of N_a times ($N_a \neq 0$), among which A has seen B as its neighbor for N_{ab} times; and B has reported a total of N_b times ($N_b \neq 0$), among which B has seen A as its neighbor for N_{ba} times.

If $N_a > N_b$ ($N_a \neq 0$ and $N_b \neq 0$), the distance between A and B is $N_a - N_{ab}$, otherwise the distance is $N_b - N_{ba}$.

If $N_a \neq 0$ and $N_b = 0$, then the distance is $N_a - N_{ab}$.

If $N_b \neq 0$ and $N_a = 0$, then the distance is $N_b - N_{ba}$.

If $N_a = 0$ and $N_b = 0$, then the distance is 10000, which is big enough to indicate

the large distance.

The 20-minute sessions of the three crowd conditions were divided into time frames. Each time frame had the length of 30 seconds and the time difference between each frame was three seconds. For instance, Crowd 1 started at March 17 2015, 13:13:30 GMT+1:00. So, the first 30-second time frame was 13:13:30-13:14:00, the second frame was 13:13:33-13:14:03, the third frame was 13:13:36-13:14:06, and so on. So, each 20-minute session consisted of 391 time frames. The reason for defining time frames in this manner is to smooth out the sudden changes in the sensor data due to the sensitivity of the sensors. The hierarchical clustering was conducted within each time frame. The result of a hierarchical clustering was in the form of a dendrogram. In a dendrogram, the height of the U-lines indicated the distance between the clusters (y-axis). The number of clusters can be determined by drawing a horizontal line at a certain cut-off value and counting the number of lines that the horizontal line intersects. The number of sensor clusters is expected to reflect the number of groups in the crowd (MATLAB documentation, 2016a). A series of dendrograms were generated based on the 391 time frames. There is a rule of thumb to determine the number of clusters in a dendrogram, which sets 70% of the maximum distance as the cut off value (MATLAB documentation, 2016a). Applying this 70% rule, the number of groups in the crowd can be determined.

Figure 6.23 shows the overall plots of the number of groups in the three crowds during the 20-minute experiment. The trend lines (red dashed lines) were calculated based on the "moving average" of 20 data points. The number of groups varies but not dramatically. Most of the time, there were four or five groups in each crowd. One noticeable change can be seen at the beginning of the non-event crowd (0s-134s). During the first 134 seconds, there was only one group in the non-event crowd, much fewer than in the other periods of the non-event crowd and in the other two crowds. As we observed from Figure 6.17, during that same period, the connectivity rate was unusually high, since participants were forming one big circle-like group. Thus, figure 6.23-c provides a consistent explanation for the high connectivity rate in Figure 6.17.

Figure 6.24 is the box plot comparison of the number of groups during the 15-minute period. The differences between the three crowds were minor. Crowd 1 (the event crowd) had the fewest groups, and Crowd 3 (the non-event crowd) had the most groups. For Crowd 1, the median value is four groups (the same as the first quartile value), and the mean is 4.48 groups. For Crowd 2 (the spectator crowd) and Crowd 3, the median value is five groups (the same as the third quartile value). The mean values for Crowd 2 and 3 are 4.56 and 4.70 groups. In other words, based on the box plots no differences in the number of groups were identified.

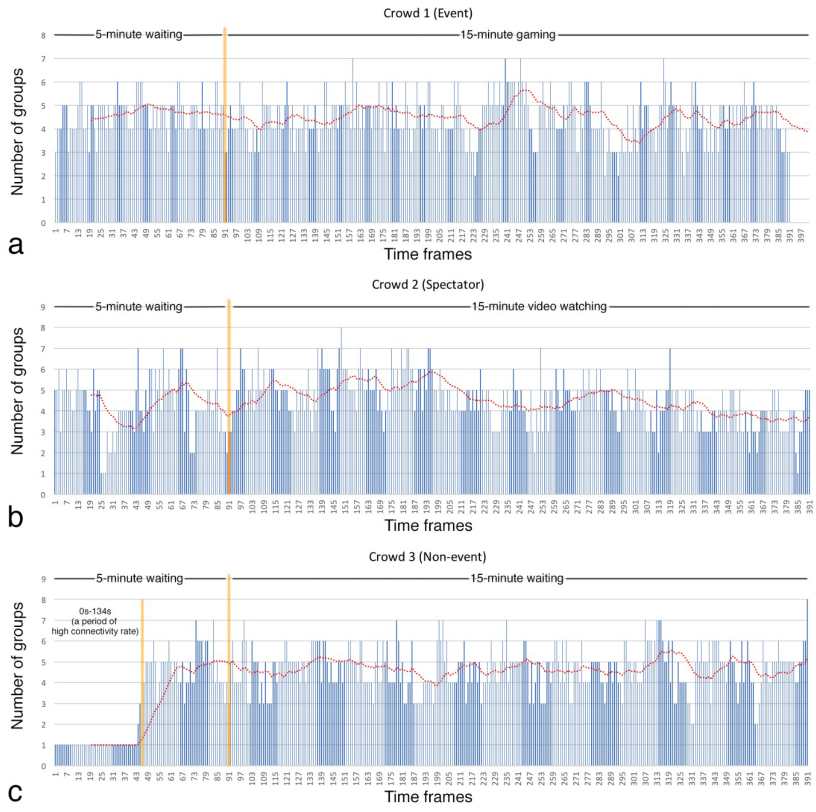


Figure 6.23. Number of groups plots: (a) Event crowd, (b) spectator crowd and (c) non-event crowd. At the beginning (the period of 0s-134s) of the non-event crowd, there was only one group in the crowd, which explained the unusually high connectivity rate in Figure 6.16. The red dashed trend lines were generated according to the "moving average" of 20 data points.

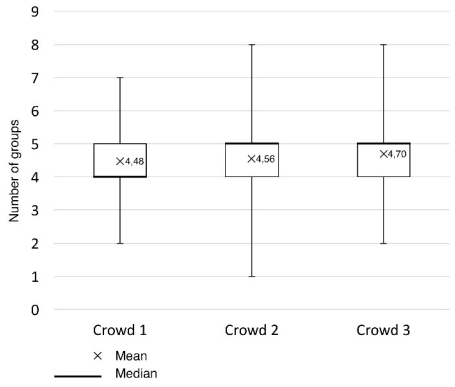


Figure 6.24. Box plot of the number of groups in the three crowds during the 15-minute experiment. For Crowd 1, the median value is the same as the first quartile value. For Crowd 2 and 3, the median value is the same as the third quartile value.

In summary, the sensor data did not provide strong evidence for our expected outcomes. We expected to see that, during the 15-minute, Crowd 1 would have the highest connectivity rate and fewest number of groups, while Crowd 3 would have the lowest connectivity rate and the greatest number of groups. Crowd 2 would be in-between Crowd 1 and 3. However, the results of the sensor data analysis show that there were only slight differences between the three crowds regarding the connectivity rate and the number of groups. Another finding is that forming a big circle-like group can result in a high connectivity rate, which was reflected at the very beginning period of Crowd 3.

6.4 DISCUSSION

Three outcomes were expected in this chapter (see Section 6.3.3):

(1) During the first 5-minute waiting, no differences would be identified among the three crowds in terms of the emotional feelings, the connectivity rate, and the grouping behavior.

(2) During the 15-minute experiment, Crowd 1 was expected to be the most positive crowd, reporting the greatest number of positive emotional feelings and least number of negative emotional feelings. Crowd 3 would be the opposite of Crowd 1, and Crowd 2 would be more positive than Crowd 3, but less positive than Crowd 1.

(3) Crowd 1 was expected to have the highest connectivity rate and the fewest number of groups during the 15-minute gaming (mainly three groups around the puzzle). Crowd 2 was supposed to experience a decrease in connectivity rate, and an increase in the number of groups when participants were forming lines in front of the screen. Crowd 3 was predicted to have the lowest connectivity rate and the largest number of groups during the 15 minutes.

Our findings were mostly consistent with the first expected outcome. The number of positive emotional feelings was the same in the three crowds during the waiting time. The same holds for the negative emotional feelings except that Crowd 2 reported slightly more negative emotional feelings than the other two crowds, due to reporting more *bored* and *confused*. This, however, does not seriously harm our main conclusion that the three crowds were comparable. With respect to the connectivity rate and the number of groups, again, the three crowds were similar. For example, the number of groups always varied between four and five, provided that the first 134 seconds in Crowd 3 was not taken into account. During that period, a high connectivity rate (around 50%) was observed, probably due to the fact that participants were gathering close to each other and forming a circle-like crowd, showing that the sensors were operating as intended.

Our findings were partly consistent with the second expected outcome. During the 15-minute experiment, the number of positive emotional feelings

reported in Crowd 2 was in between that for Crowd 1 and 3, with Crowd 1 having the highest number. In contrast, the negative emotions did not differ among the three crowds. From this, we expected that the positive and negative emotional pattern of Crowd 2 would be similar to that of Crowd 1, but it turned out to be similar to that of Crowd 3. Hence, the emotional contagion effect is demonstrated in the number of reported emotional feelings but not in the pattern of emotional feelings.

Finally, our overall findings were not consistent with the third expected outcome. No significant differences were found either in the connectivity rate or the number of groups of the three crowds. However, meticulously inspecting the grouping behavior in the video recordings, differences could be identified between the crowds. For instance, in Crowd 1, there were fewer groups when participants were playing the puzzle game than during the waiting period. In Crowd 2, when participants were standing in lines and watching the video, they separated into more groups as compared to the waiting period. In Crowd 3, the number of groups did not exhibit obvious changes throughout the 15 minutes. (for further details, see the additional analysis at the end of this chapter).

In Chapter 5, we conducted studies based on the recalled crowd experience of the participants and found that people felt more *curious, excited, connected* and *happy* in event crowds than in non-event crowds. This finding is consistent with the observations in this chapter (Chapter 6): the event crowd (Crowd 1) indeed felt more positive than the non-event crowd (Crowd 3). Chapter 5 and this chapter both found that *confused* was a frequently reported negative emotional feeling in non-event crowds. Studies in Chapter 5 identified that *confused* was generally not felt in event crowds. However, in the study of this chapter, *confused* was often reported in the event crowd, which happened typically at the end of the jigsaw puzzle. The possible explanation is that participants just finished the game and were feeling *confused,* wondering what the next step would be. Apart from *confused*, the other negative emotional feelings were mostly absent in the event crowd in both studies of Chapter 5 and this chapter.

6.4.1 The Spectator Crowd: Emotions and Expectations

We predicted that the emotional feelings of the spectator crowd (Crowd 2) would be similar to those reported in the event crowd (Crowd 1). However, we found that, during the 15-minute experiment, the patterns of the emotional feelings reported in the spectator crowd were similar to those in the non-event crowd, even though the spectator crowd had reported a larger number of positive emotional feelings. This could have been caused by the expectations of the participants in the spectator crowd: the video was possibly not as interesting as they had expected.

The subjective desire to achieve a goal and the expectation that the goal will be reached, have been proposed by Price and Barrell (1984) as two critical experiential dimensions in predicting emotions. When a discrepancy between the expectation and the actual stimulus exists and is noticed, it may lead to experiences that are in contrast with the expectation (Wilson et al.,

1989). Reflecting about the spectator crowd, participants might have had high expectations of having some interesting activities to play during the experiment. However, they ended up watching the videotape of Crowd 1. The discrepancy between their expectations and the actual activity was probably noticed by many participants, evoking experiences that were contrary to their expectations, which may have resulted in reporting more negative emotions. In the studies of this chapter, the spectator crowd was only connected to the event crowd through a video display. Future research is suggested to allow the spectator crowd and the event crowd to stay at the same physical location. This is expected to have stronger emotional contagion effects between the two crowds than when they are separated into two locations.

6.4.2 The relation between the sensor data and the emotion reports.

In this chapter, we tried to apply a network of sensors to identify trends in crowds. Probably due to the limited features of the sensors, the relation between the sensor data and the emotions could not be clearly established, even though some trends did exist. For instance, when participants were playing the game (an event crowd), they indeed formed fewer groups and had increasingly more positive emotions as compared to the waiting period (a non-event crowd). We also noticed that the number of groups might be related to the activities in the crowd. There were three fishes in the puzzle, so we saw participants forming three groups during the puzzle game. If there had been five fishes, participants might spontaneously have been divided into five groups. Further research is needed to clarify the relations between emotions and the sensor data (preferably more advanced sensors, e.g., sensing the location of each crowd member or sensing the emotions of the participants).

6.5 SUMMARY AND CONCLUSION

In conclusion, Crowd 1 (the event crowd) is different from the other two crowds (Crowd 2: spectator crowd; Crowd 3: non-event crowd), in terms of emotional feelings and action tendencies. The patterns of emotional feelings and action tendencies of Crowd 2 and Crowd 3 are alike. There are some indications for a positive emotional contagion effect since Crowd 2 reported a larger number of positive emotional feelings than Crowd 3. However, no significant differences could be found between the three crowds concerning the connectivity rate and the number of groups calculated based on the sensor data. As a consequence, no potential relations could be identified between the sensor data and the self-reported experiences (emotional feelings and action tendencies). A very weak indication of relation seems to exist between the number of groups and the experiences of crowd members: the event crowd that reported the most positive emotional feelings tended to have less number of groups than the other crowds. Yet, we believe that the relation between automatically collected data through technologies and self-reports is a valuable research direction for the future and

calls for further research into human-centered sensor technologies.

The emotions and behavior of Crowd 1 and Crowd 3 were close to what we have predicted. Crowd 2 was partly out of our expectation. The emotional contagion could be identified by looking at the number of reported positive emotional feelings between Crowd 1 and Crowd 2 but did not happen with other measures we employed. Some experimental conditions may have reduced the observed degree of emotional contagions, namely the absence of co-presence at the same physical location, the possibly not-so-interesting content of the introduced activity and the way that emotions were measured afterward and not in real time. In future studies, these factors should be considered.

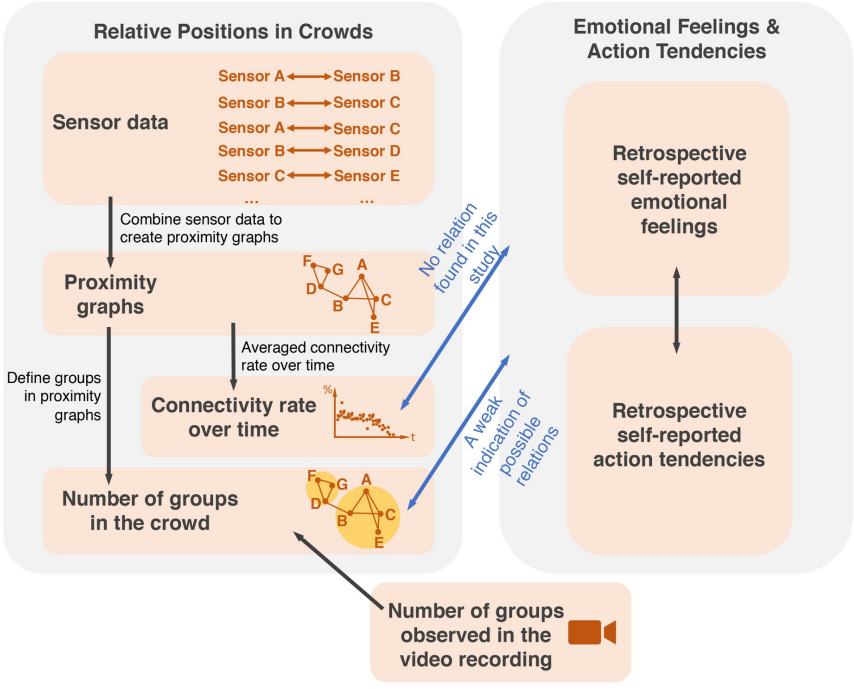


Figure 6.25. The relation between automatically collected data through technologies and self-reports is a valuable research direction for the future.

ADDITIONAL ANALYSIS: COMPARING GROUPINGS OF CHARACTERISTIC PERIODS

The overall grouping comparison yielded no differences between the three crowds. However, when zooming in to some characteristic periods, changes are observable in terms of grouping behavior in the three crowds. We selected a total of eight characteristic periods from the three crowds by observing the camera recordings, in which clear differences in number of groups could be identified in the recordings. The selected characteristic periods are the moments when participants were following the instructions and forming the type of crowd as expected. For example, Crowd 2 did not watch the video recording for 15 minutes. In fact, they only watched it for about two minutes (i.e., forming a spectator crowd for two minutes) and then started to move away from the screen, and became a sort of non-event crowd again. Crowd 1 did not form three crowds at the beginning of the puzzle game. They started with moving around, searching for correct puzzle pieces. These periods were deliberately picked out for comparison, because participants were indeed doing the activity as instructed. In the comparison of these characteristic periods, it was expected that the differences in grouping identified on the camera recordings could also be seen in the hierarchical clustering. The selected characteristic periods are of 1.5-minute length, consisting of 21 time frames. These characteristic periods (P1-P8) are highlighted in Figure 6.26 and listed as follows:

Crowd 1

P1: Before the game (during the 5-minute waiting period)

P2: Engaging with the game

Crowd 2

P3: Before turning on the video (during the 5-minute waiting period)

P4: Watching the video

P5: Losing interest in the video

Crowd 3

P6: Before the 1st instruction [18] (during the 5-minute waiting period)

P7: After the 1st instruction, and before the 2nd instruction (during the 1st half of the 15-minute experiment)

P8: After the 2nd instruction [19] (during the 2nd half of the 15-minute experiment)

18 As can be seen in Figure 6.5, at the end of the 5-minute waiting period of Crowd 3, the 1st instruction "We are waiting for more people to come" was given.

19 In Figure 6.5, the 2nd instruction "We are calibrating the sensors" was given halfway of the 15-minute experiment in Crowd 3.

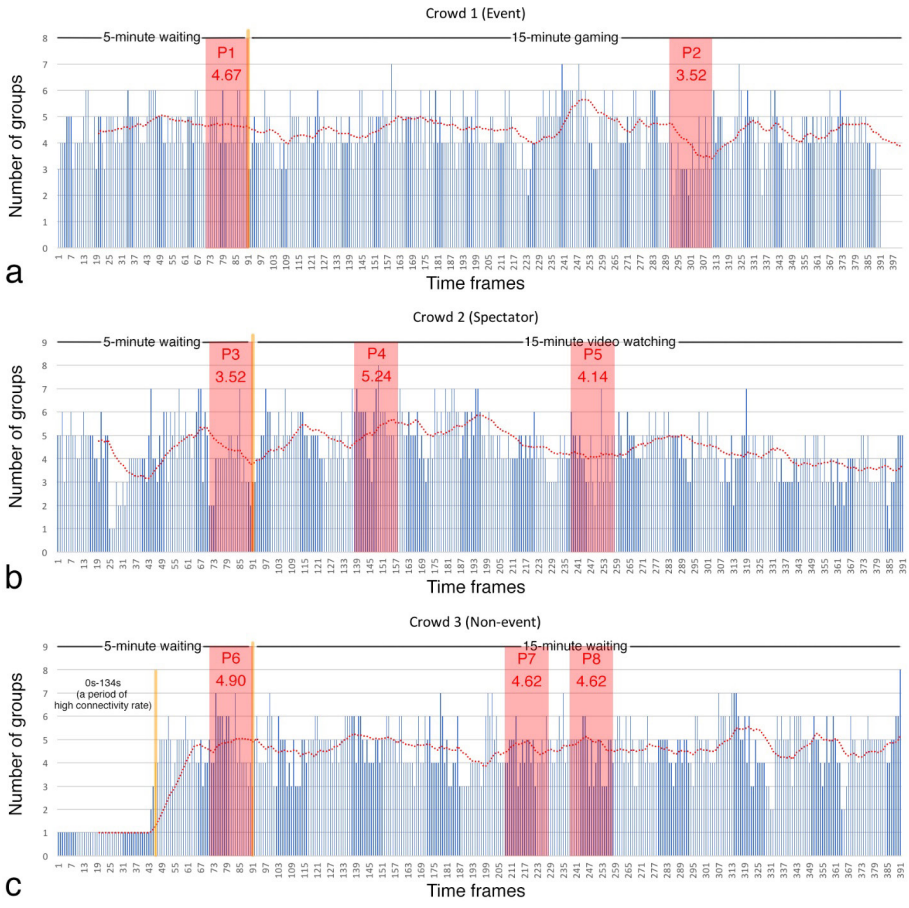


Figure 6.26. The eight characteristic periods (P1-P8) were highlighted in translucent red color. The red number indicates the average number of groups in the crowd during that characteristic period.

For Crowd 1, when the crowd was engaging with the puzzle game (P2), it was an event crowd. Much fewer groups were identified. It mostly had three groups. In contrast, before the puzzle game, it was a non-event crowd (P1), which had mostly four or five groups. There was a statistically significant difference between P1 and P2 of Crowd 1 as determined by one-way ANOVA (Figure 6.25), $F\ (1,40) = 14.472,\ p < .001$. The number of groups before gaming was significantly higher ($M= 4.67\pm0.91$) than during gaming in P2 ($M=3.52\pm1.03$).

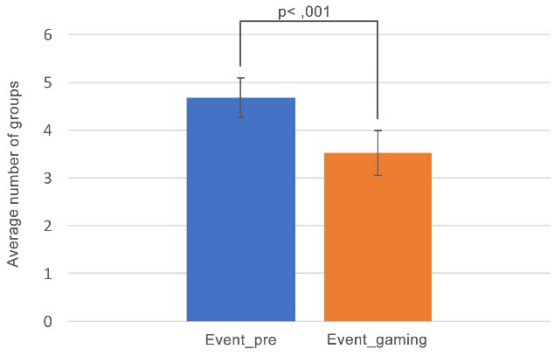


Figure 6.27. Compare the average number of groups during the two characteristic periods in the event crowd. The p value indicates that, when crowd members were playing the game, they formed significantly fewer groups than when they were waiting.

Crowd 2, before turning on the video, was a non-event crowd (P3). It had mostly three or four groups. When participants were watching the video, the number of groups increased (P4), due to the gathering of participants in front of the screen. They were standing in lines in front of the video. In this situation, the sensors can only detect others who stand next to them but cannot detect the ones who stand in front of or behind them, because the human body blocks the sensor signals. When participants lost interest in the video (P5), they moved away from the screen. The average number of groups dropped. One-way ANOVA yielded statistically significant differences among the three periods of Crowd 2 (Figure 6.26), $F\ (2,60) = 15.927,\ p < .001$. A Tukey post hoc test revealed that the number of groups before turning on the video was statistically significantly fewer $(M=3.52\pm1.03,\ p < .001)$ compared to that during the video watching $(M=5.24\pm1.00)$. When participants were losing interest in the video, the number of groups was also statistically significantly fewer ($M=4.14\pm0.96,\ p < .01$) compared to the "video watching" moment. There was no statistically significant difference in the number of groups between "before turning on the video" and "losing interest in the video" ($p > .05$).

For Crowd 3, the number of groups did not differ among the three periods, all having five or six groups. One-way ANOVA indicated no statistically significant difference among the three characteristic periods of Crowd 3 (Figure 6.27), $F\ (2, 60) = .615,\ p > .05$.

The selected characteristic periods are the moments when participants were doing the activity and forming the type of crowd as intended. Differences could be identified between these periods, which suggests that a better experimental design in future research could lead to differences. For example, having the spectator crowd stay together with the event crowd in the same physical space or letting crowd 1 play a game that is more interesting to watch.

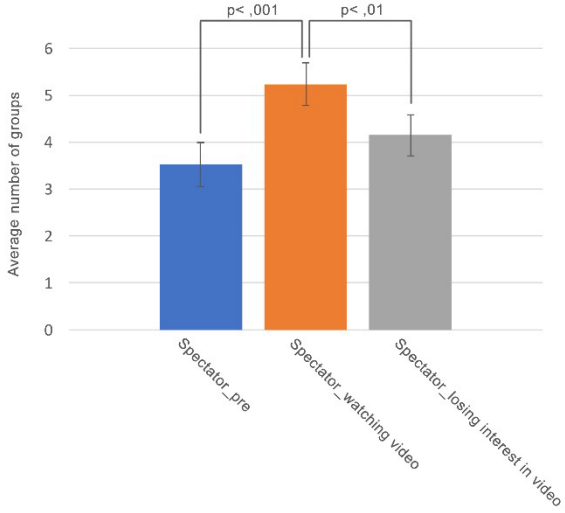


Figure 6.28. Compare the average number of groups during the three characteristic periods in the spectator crowd. The p value indicates that, when crowd members were watching the video, they formed significantly more groups than the other two moments.

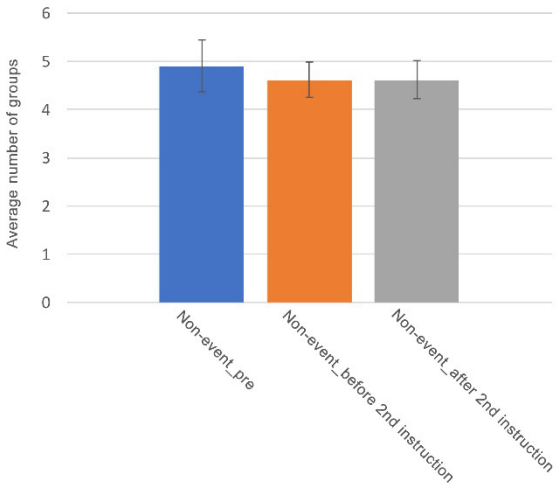


Figure 6.29. Compare the average number of groups during the three characteristic periods in the non-event crowd. No significant differences were found.

"Life is pain

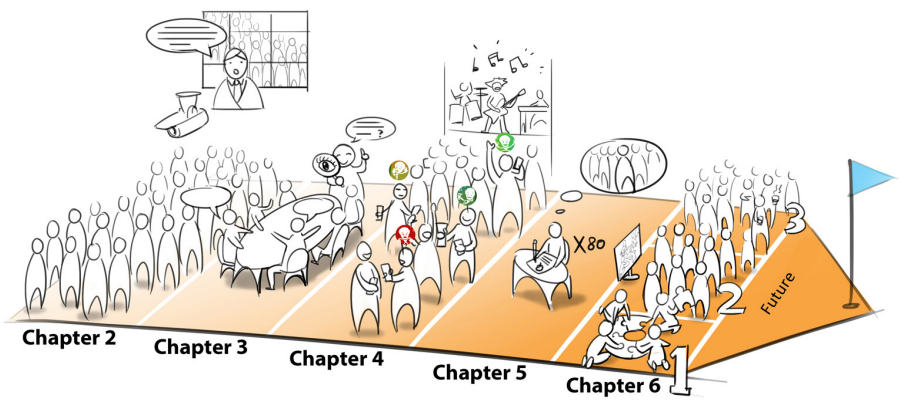
au

chocolat."

— Anonymous

CHAPTER 7

General Discussion and Conclusion



The goal of this thesis is "to contribute to a better understanding of crowds from the perspective of individual crowd members' experiences". The two parts of this thesis address two main themes:

- The state-of-the-art of crowd research and crowd management practices (Part 1, Chapter 1 &2)
- The three aspects of individual crowd members' experiences: well-being, emotional experiences and action tendencies (Part 2, Chapter 2-6).

For understanding the state of the art (Part 1), we reviewed an extensive collection of literature in the past decades and did a series of field interviews with crowd experts. We identified three levels of understanding crowds that are defined both in literature and crowd management practice, namely the crowd level, the group level and the individual level. By monitoring crowds from the outside, current crowd management practices mainly focus on understanding crowds at the crowd level and the group level. However, crowd managers indicated that more support is needed at the individual level. A better understanding of experiences of individual crowd members, such as their emotions, is considered to be important in understanding and predicting crowd behavior. For understanding the three aspects of individual crowd members' experiences (Part 2), we conducted (1) context mapping studies with crowd members to gain insights into the factors contributing to the well-being in crowds; (2) a field study as a trial to assess emotions in crowds using a smartphone application; (3) a questionnaire study and a lab experiment to investigate emotions and action tendencies in crowds and their relations. Below, we address the reason why understanding crowds at the individual level is important.

7.1 THE IMPORTANCE OF UNDERSTANDING EXPERIENCES OF INDIVIDUAL CROWD MEMBERS

The beginning of the introduction chapter described how two crowds with similar characteristics showed distinct behavior when facing disturbances. The crowd members in *the annual National Remembrance Day (Dodenherdenking)* became scared and ran away uncontrollably when hearing the screaming of one man. Many of them got trampled and were reluctant to participate in the event again. In contrast, crowd members in the *Pinkpop* festival stayed calm in a thunderstorm and continued celebrating afterward.

From an individual crowd members' point of view, two illustrations are presented in Figure 7.1 and 7.2 to compare the two situations. When the crowd members started to perceive something strange (i.e., a suspicious person or a coming thunderstorm), they became alert and tended to protect themselves and avoid the situation. One of the facts that could have caused the differences in these two crowds is that crowd managers of the *Pinkpop* festival could provide

crowd members with guidance when the thunderstorms were forecasted (Figure 7.2). However, managers in the Remembrance Day were not able to do so, because no tools could assist them in identifying the suspicious person in advance (Figure 7.1).

The differences in the behavior of the two crowds formed the inspiration of this thesis. It aims at understanding the emotional experiences and resulting action tendencies of individual crowd members. Suppose the changes in the emotional experiences and action tendencies of crowd members could have been identified in time on the Remembrance Day (e.g., some people became *alert*, *angry* or *anxious,* and they tended to *protect* themselves and *avoid* the situation), this would have offered buffering time for crowd managers to react to these negative "seeds" beforehand and can even stop the suspicious person.

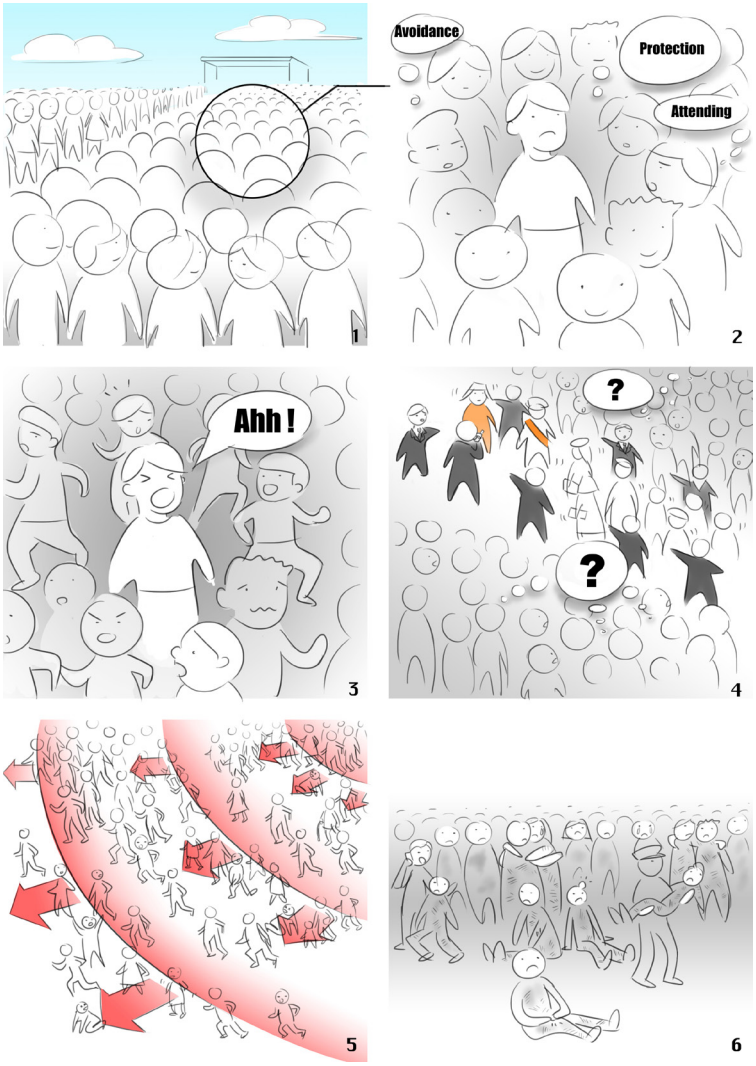


Figure 7.1 Crowds reacted on a suspicious scream on the National Remembrance Day.

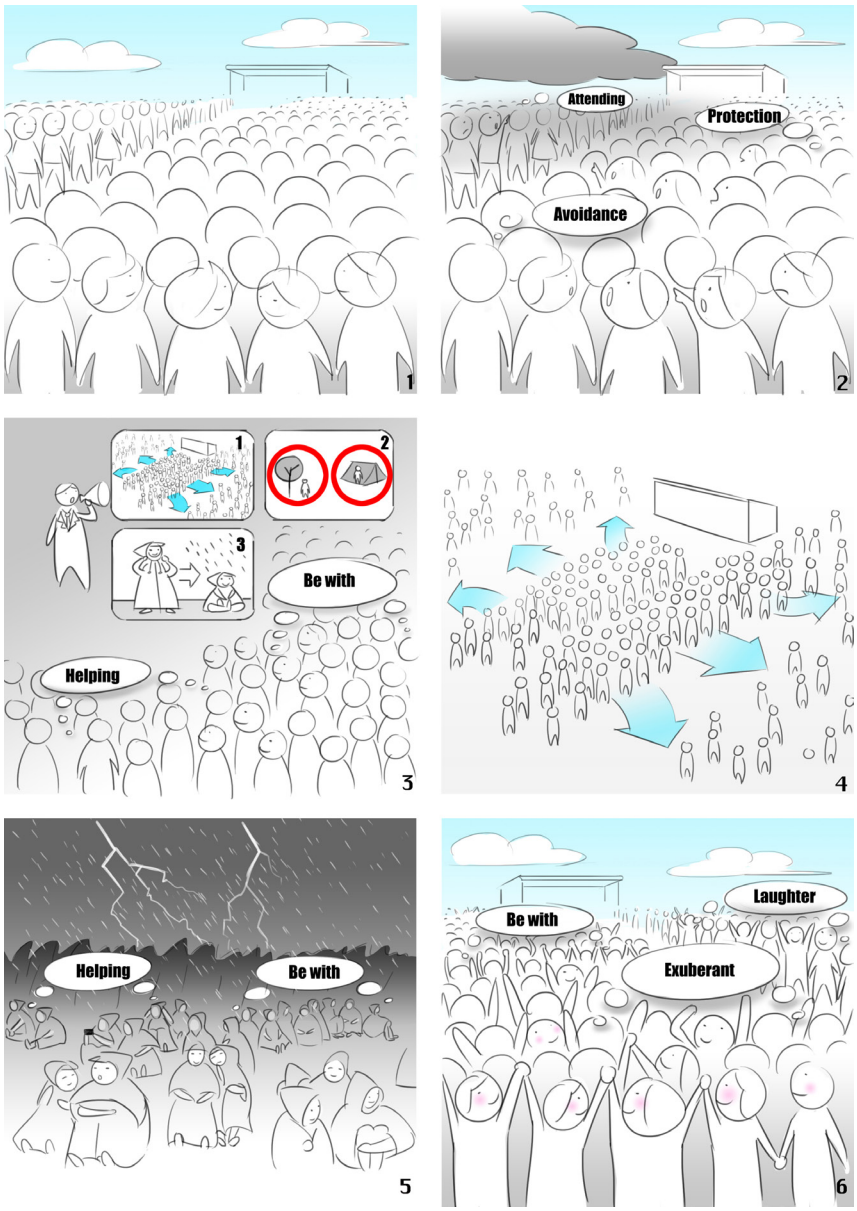


Figure 7.2 Crowds reacted on the thunderstorms on the *Pinkpop* festival.

7.2 ANSWERS TO THE RESEARCH QUESTIONS

In Section 1.4.1, five research questions were proposed that were addressed in Chapter 2-6. We revisit the research questions and summarize the findings as follows.

7.2.1 At what levels do crowd experts understand crowds?

Crowd experts distinguish between crowd management and crowd control. According to the experts, crowd control is not necessary if crowd management succeeds. Within crowd management two main stages can be identified: (1) the preparations before the crowd events, and (2) the execution of the prepared strategies during the crowd events. The preparations usually take 90% of the total efforts in crowd management, which generally start well ahead of the crowd events (e.g., half a year to one year). Crowd managers, such as event organizers, are mainly responsible for crowd management with their thorough preparations of scenarios covering a wide range of possible sudden occurrences, and considerations of various factors before the crowd events: internal factors (i.e., crowd size, density, mobility, noise, and visitor profiles), external factors (i.e., weather, location, client, government, personnel and event type). Their strategies during crowd events involve continuously monitoring the crowd situations, guiding and persuading crowd members to behave in certain ways. Crowd control strategies are executed only when crowds start getting out of control (crowd control level) or when crowds are getting extremely chaotic (riot control level). The police are allowed to execute intransigent or even violent measures if necessary. In this thesis, the focus is to contribute to a better understanding of crowds for crowd management, thus to prevent crowd management from crossing over into crowd control.

Crowd experts refer to three levels of understanding crowds for crowd management, namely crowd level, group level and individual level. The work of crowd managers involves all three levels. For instance, at the crowd level, they monitor the overall crowd density, distribution and flows; at the group level, they separate different profiles of crowd members (e.g., assigning a specific area for families with children, separating football fans of Team A from Team B); at the individual level, they hire security personnel to patrol in the crowd to detect crowd members displaying suspicious behavior or with negative emotions. However, we have found that the strategies concerning the individual level are limited.

In the future, crowd management will need more support on getting in touch with individual crowd members and developing flexible real-time strategies based on a better understanding of them. For example, in addition to having an estimation of how soon an event site will reach its full capacity, crowd managers would like to know how crowd members feel and what behavior they tend to show. The individual level of understanding crowds offers the crowd management team an additional layer of information on top of the information obtained from the crowd and the group level, allowing them to better understand and even predict behavior of crowd members, and to make decision more rapidly about what guidance should be given to the crowd members to keep them updated, informed and satisfied.

7.2.2 What factors influence the experience and well-being of individual crowd members?

In Chapter 2, it became clear that crowd managers need to get in touch with individual crowd members, to better understand the crowd situations and to sustain the well-being of crowd members. In chapter 3 the first step was taken to explore individuals' experiences in crowds and to identify factors contributing to the sustained well-being of individuals in crowds.

Along with understanding individuals' needs to sustain well-being in crowds, two distinct crowd types emerged from the discussions, namely event crowds and non-event crowds. An event crowd is always event-based, where people enjoy performances or activities, and want to interact and share experiences with others within the crowd (e.g., concerts, exhibitions, conferences, parties). A non-event crowd usually does not involve any activity or performance. People join the crowd not because they like the crowd or want to interact with others, but because they want to achieve some crowd-external goal or benefit (e.g., crowds at public transportation, crowd waiting in queues for free goods, crowds on a busy shopping street). Generally speaking, non-event crowds are not as attractive as event crowds, but they are not necessarily problematic. For instance, crowds at public transportation are typical non-event crowds. Crowd members often consider them as enjoyable experiences, because the trains or airplanes are means to reach a destination, but they may also be annoying as they gather large crowds that bring inconvenience.

The well-being factors are different in event crowds and non-event crowds. In event crowds, relatedness (i.e., feeling a sense of belongingness and closeness), autonomy (i.e., feeling independent and self-decided) and competence (i.e., feeling capable and effective) are three prominent needs for sustaining well-being. In non-event crowds, crowd members are more concerned about safety than in event crowds. Safety does not contribute to but is an important consideration for obtaining well-being.

7.2.3 How to obtain emotion data in crowds? How to use the emotion data to predict the crowd behavior?

Chapter 4 focused on measuring emotions of crowd members. A playful and non-intrusive mobile phone application *EmoApp* was designed for collecting self-reported emotions from crowd members and was tested in an event crowd (i.e., a music festival). The main circular interface represents the pleasure and arousal dimensions of emotional experiences (Russell, 1989). Two ways of emotion reporting were included in the application: crowd members were requested to report the emotions of themselves as well as the emotions of other crowd members around them. The results showed that the two ways of emotion reports did not differ from each other.

Many users complimented *EmoApp* on its playful interface. They found the *EmoApp* useful and accessible. The free-drink rewards largely encouraged them to report emotions but did not necessarily bias them towards reporting

only positive emotions. For example, they reported negative emotions when they were disappointed with the performances on the stage. The collected information seemed to reflect the real situations: participants' movements, emotional changes and the activities at the festival were consistent with each other. For instance, we have observed that, due to an unsatisfied performance on the main stage, many participants left the stage and moved to the outside square and meanwhile reported negative emotions.

7.2.4 What are emotions and action tendencies in crowds? What are the relations between emotions and action tendencies?

Next to emotions, Chapter 5 included a behavior-related element in understanding crowds: eleven crowd-specific action tendencies derived from the list of action readiness terms proposed by Frijda et al. (1989). The eleven action tendencies are "*be with, protection, avoidance, attending, distance, don't want, helping, excited, exuberant, laughter*, and *rest*". The descriptions of the eleven action tendencies are presented in Section 5.3.1, Table 5.1.

Based on the studies in Chapter 5, we found that people feel more *curious, excited, connected* and *happy* in event crowds than in non-event crowds. Negative emotions were not found to be necessarily connected with negative action tendencies. For example, *be with* and *attending* are quite strongly connected with *alert*, *anxious*, *angry* and *feel small*, and somewhat connected with *alert*, *anxious* and *confused* in non-event crowds. We also found that when people feel positive, no matter whether they are in an event or a non-event crowd, they tend to behave positively. When people feel positive in non-event crowds, they tend to help others more than in event crowds.

7.2.5 What are the emotions and action tendencies in three different crowds?

Chapter 2 to 5 were devoted to understanding crowds at the individual level, which covered three aspects: well-being, emotional experiences and action tendencies. We have noticed that a crowd is not a homogeneous entity. A crowd usually consists of different (social) groups. Emotional contagion effects may exist at the group level (between two groups within the same crowd) or at the crowd level (between two crowds). Chapter 6 investigated possible differences between three crowd types, namely the event crowd (i.e., a crowd making a puzzle), the spectator crowd (i.e., a crowd watching the event crowd making the puzzle) and the non-event crowd (i.e., a crowd just waiting), aiming to identify whether the crowd types influence specific emotions and behavior of crowd members.

We found that the event crowd is different from the spectator and the non-event crowd, in terms of expressed emotions and action tendencies. The patterns of emotions and action tendencies of the spectator and the non-event crowd are alike. There are some indications for a positive emotional contagion effect,

since the spectator crowd reported more positive emotional feelings than the non-event crowd. However, no significant differences could be found between the three crowds in terms of the connectivity rate and the number of groups calculated based on proximity sensor data. As a consequence, no clear relations could be identified between the self-reports (emotions and action tendencies) and the connectivity rate extracted from the sensor data. There seems to be a very weak, but interesting suggestion for a relation between number of groups and the experiences: the event crowd that reported most positive emotions tended to have somewhat less number of groups than the other crowds. Further investigation is needed employing more advanced human-centered sensor technologies.

The emotions and behavior of the event and the non-event crowd were close to what we had predicted. In the spectator crowd, however, they differed from our expectation. Only a weak indication of emotional contagion between event and spectator crowd was found. Some factors were identified that, in our study, may have had a negative impact on (registering) emotional contagion, namely the absence of co-presence at the same physical location, the weak content of the introduced activity (e.g., it is not interesting enough to watch or to attract people to join) and the way that emotions are measured (e.g., in real-time or afterward). In future studies, these factors should be considered.

7.3 LIMITATIONS

This thesis adopted a series of mixed methodologies with the goal of understanding well-being needs, emotional experiences and action tendencies of crowd members. The methodologies include (1) context mapping, (2) semi-structured field interviews, (3) field study with a real-time self-report tool, (4) retrospective self-reported questionnaire and (5) a lab experiment with retrospective self-reported questionnaires and proximity sensors. We are aware of four potential limitations to the studies in this thesis.

Using numbers in qualitative research. Context mapping is a core qualitative research method applied frequently in the field of user-centered design research to understand users and their day-to-day context (Sleeswijk-Visser et al., 2005). We adapted this method to understand the well-being needs of crowd members by guiding them to think extensively about their crowd experiences and instructing them to fill in a prepared probe (a booklet) individually before gathering them to have in-depth discussions in group sessions. The purpose of such group sessions is to allow participants building upon each others' ideas, thus to reach possibly latent knowledge that may be difficult to obtain in individual interviews (Sleeswijk-Visser et al., 2005). While analyzing the data, we used "mention frequency" to prioritize certain topics discussed in the context mapping sessions. It makes sense to count how frequently a participant mentioned a topic in their booklets, since these booklets were independently filled in by every participant. However, it may be controversial to determine "mention frequency" in their group discussions,

because participants may influence each other. The topics in a group session may be biased towards the opinion of a dominant participant or socially favorable situations (Smithson, 2000). To prevent our group sessions getting restricted to a narrow opinion, two trained facilitators guided the group sessions with techniques such as collage making, peer booklet review and presentations to ensure all participants' ideas were equally addressed.

Becker (1970) pointed out that in qualitative research quantitative claims are frequently made in verbal form, using terms such as *many, often, typically, sometimes*, and so on. He argued that numbers have the value of making such claims more precise and coined the term quasi-statistics for simple counts of things to support terms such as some, usually, and most. Similarly, determining "mention frequency" is suggested by Morgan and Krueger (1998), and Stewart et al. (2007) to interpret focus group data. Since a context mapping group session is essentially a focus group session with generative techniques (e.g., collage making, Sleeswijk-Visser et al., 2005), we counted "mention frequency" to obtain a better idea what needs are prominent for sustaining well-being in crowds. Our context mapping was the very initial explorative study towards understanding the well-being needs of crowd members. We are fully aware of the limitations of the generalizability of the results. Future research is needed to validate the findings.

Panel conditioning. Our self-reported questionnaire repeatedly asked participants to link different emotions with possible action tendencies. Such repetitions are believed to influence user' opinion as they get more knowledgeable through the information gained from the repetitions (Sturgis et al., 2009) and can be both positive and negative. Positively, because panel conditioning can increase the quality of reporting, since participants have improved understanding of the questionnaire and the surveying procedure. Negatively, because it decreases in data quality because participants have learned to answer certain questions in a way that would avoid follow-up questions (Sturgis et al., 2009). To minimize these potential positive and negative influences of panel conditioning, the order of the emotions in our questionnaire was randomized.

Retrospective self-reporting. We asked participants to recall positive and negative emotional experiences in crowds based on their crowd experiences in the past twelve months. The idea is to encourage participants to recall as many types of crowd events as possible and to reflect extensively on the associated emotional experiences within those events. Due to the limited time span of the study, it was almost impossible to request every participant to go to multiple types of crowd events and report their real-time experiences. So, the retrospective self-report questionnaire was adopted, which is believed to be cost- and time-efficient (Beckett et al., 2001). However, as noted by many researchers, potential biases are likely to happen in retrospective self-reports, such as the frequency, intensity, and changes-over-time of the experiences (e.g., Schwarz, 2007). Beckett et al. (2001) found that the data quality deteriorates as the length of the recall period increases. Keeping the recall period short is the strategy applied in the current study. The twelve months length was decided as

the benchmark for our participants to reflect on their emotional experiences in the most recent crowd events while their memories were reasonably fresh. We are aware of the potential biases of their self-reports. For instance, they may omit some less salient experience in their memories which may be interesting or important for us as researchers.

7.4 FUTURE RESEARCH DIRECTIONS

This thesis focuses on understanding crowds mainly at the individual level and how changes in emotions and behavior of individual crowd members can be used as an indicator and maybe even as a predictor of changes in crowd behavior. The ideal scenario would be to collect data from individual crowd members from various sources in real time, such as their locations, emotions and action tendencies. These sources of data could then be processed together to form a crowd map on which crowd density and flows of movement are visualized with a layer of emotion and action tendency on top of it. In this way, crowd management teams may not only see and prevent over-crowdedness, but may also intervene in time when negative emotions and action tendencies are observed. For example, if we reflect on the *Dodenherdenking* event introduced at the beginning of this thesis, we may presume that if the anxiety of crowd members who were nearby the suspicious person could have been reported or measured in time, crowd managers would have had time to intervene.

In this thesis data from individual crowd members were collected in two main ways. One was self-reporting done by crowd members. The other was the measurement done by wearable proximity sensors. As illustrated in Figure 7.3, the *EmoApp* had successfully collected self-reported emotions (happy, relaxed, angry and bored) and locations (six predefined areas at the festival) from crowd members in real time. The lab experiment requested crowd members to report their emotions and action tendencies based on an extended list of thirteen crowd-related emotions (six positive and seven negative emotions) as well as a list of eleven crowd-related action tendencies. Due to the long lists as compared to the simple valence-arousal emotion model in the *EmoApp*, the self-reports in the lab experiment had to be done right after the experiment (non-real time). Meanwhile, proximity sensors were applied in the lab experiment to capture physical closeness of crowd members real time, from which potentially interesting variables such as connectivity rate and number of groups could be identified. Unfortunately, the sensors could not identify the locations of individual crowd members.

The *EmoApp* study was successful in relating the reported emotions to the location-changing behavior of crowd members. In the lab experiment, we tried to relate the self-reports to sensor data, and to translate the insights obtained from the individual crowd members to an understanding at the group level. It proved to be possible to identify differences between self-reported emotions and action tendencies of different group situations (event, spectator and non-event), but the relations between the sensor data and the self-reported data could not be established since the sensors could not deliver crowd-differentiating parameters. This may have been caused by the limited capability of the sensors, but this

cannot exclude the possible negative impact of the non-real-time nature of the self-reports.

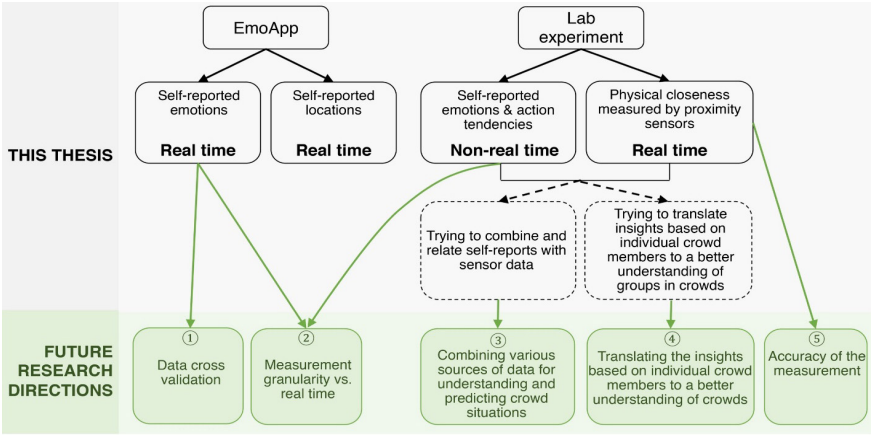


Figure 7.3. Five future research directions based on this thesis. For details, see text.

To continue the research as described in this thesis, some future directions are recommended. So far, there is hardly any ground truth about measured crowd experiences. Researchers are experimenting with a variety of methods to collect data from crowd members (e.g., Duives et al., 2018; Gong et al., 2018). So, the first future research direction will be the cross comparison and validation of multiple sources of data to obtain a more comprehensive picture of crowds and crowd experiences. For instance, Yuan et al. (2016) cross-compare three algorithms for real-time pedestrian state estimation, based on the empirical data collected from the SAIL2015 event. Second, we see a trade-off between measurement granularity and real-time measurement, especially in case of self-reports. Given the requirement to be non-obtrusive, the more granular data we request crowd members to report, the more difficult it will be to do this in real time. Further research is needed to identify which data are necessary to collect. Would only collecting action tendencies be sufficient to predict crowd situations? Third, more research is needed on how to combine various sources of (big) data collected at the individual level as a basis for a better understanding at the crowd level. How to combine all data to create an overview of crowd situations? Fourth, further research could focus on how to use changes in emotions and behavior at the individual level for a better prediction of behavior at the group and the crowd level and eventually translate them into effective behaviors-steering strategies. How does emotional contagion effects happen between groups and how do they influence the behavior of a crowd? Last but not least there is a need for improving the accuracy of measurements. How to accurately retrieve information from crowd members in a non-intrusive and even automatic way? To do so, technological support is necessary in terms of better sensors and better real-time data processing and visualizing techniques.

In solving the above issues, new issues will be raised as well, such as privacy protection and ethical considerations. For example, how can we protect the privacy of crowd members? How can we prevent the knowledge about crowds being used in an unintended way? A possible solution to resolve privacy-related considerations is to conceal privacy-sensitive data of the crowd members from the data collector by means of encryption (Lagendijk et al., 2013). In such cases the data collector can process the encrypted data only statistically. However, such an approach raises new questions such as efficiency of processing the encrypted privacy-sensitive data (Erkin et al., 2014).

In addition to privacy protection, ethical issues may arise in processing, dissemination and interpretation of datasets obtained from crowd members. National governments and international agencies (e.g., the European Commission and the Global Research Council) have devoted considerable attention and resources to develop guidelines for big data production, dissemination and re-use. The guidelines particularly emphasize the importance of considering issues of privacy, confidentiality, intellectual property and security (e.g., European Commission, 2016). Leonelli (2016) suggested that ethical training is needed to encourage critical thinking and ethical reflection among researchers involved in data processing practices. This thesis focuses on non-threatening crowd situations that mainly involve crowd management strategies. Experiments were conducted following a standard ethical procedure, with full respect for participants' safety, health and privacy. Further research should also be done under a thorough consideration of ethics of crowd members.

Understanding crowds is a very complex task. Despite the issues mentioned above, approaching crowds at the individual level is a promising future direction. It is expected to enhance the understanding of crowds in many ways. For instance, the knowledge of individual crowd members can help improve the accuracy of crowd simulation models. The changes in crowd members' emotions, especially the negative ones, can help crowd managers spot possible threats in time. The accumulation of individual data enables crowd management teams to get an overview of crowd situations and predict crowd behavior before things get out of control.

7.5 CONCLUSION

The main contribution of this thesis is to understand crowds at the individual level. We approached individual crowd members with a series of studies adopting mixed methodologies, and obtained insights into their well-being needs, emotional experiences and action tendencies in different types of crowds. Empirically, this thesis contributes to the improvement of current crowd management practices by emphasizing the importance of individual level of crowd research and set out the groundwork for the follow-up studies. Next, the thesis proposes a new way of defining crowd typology based on the presence of events or activities in crowds (i.e., event crowds and non-event crowds). The well-being needs are distinct in different types of crowd. A sense of

belongingness is the prominent need for event crowds, while safety guarantee is the priority in non-event crowds. This thesis also introduces a new tool to sample emotions in crowds. The tool is a graphical, playful, easy-to-use smartphone application for collecting self-reported emotions of crowd members and the perceived emotions of others. Apart from well-being needs and emotional experiences, the investigations into action tendencies and their relations with emotional experiences provide a richer picture of understanding and predicting crowd behavior. Methodologically, this thesis follows a designerly way of doing research (e.g., research through design, Zimmerman et al., 2007): using graphical sensitizing booklet and collage making techniques to gather data in context mapping studies; designing *EmoApp* as a means to assess emotions in crowds; visualizing crowd emotions to allow crowd members report emotions intuitively. In addition to the empirical and methodological contributions, the design iteration of the *EmoApp* followed three requirements, namely intuitiveness, non-intrusiveness and attractiveness, which shed light on the development of future emotion assessment tools. We strongly believe understanding crowds at the individual level is the future of crowd research and crowd management practices.

REFERENCES

Abbott, J. L., & Geddie, M. W. (2000). Event and venue management: Minimizing liability through effective crowd management techniques. *Event Management*, 6, 259–270.

Adolphs, R. (2002). Neural systems for recognizing emotion. *Current Opinion in Neurobiology, 12*(2), 169–177.

Alghamdi, A. (1993). Crowd control model with a management information system approach for command and control. *DAIA, 53(8),* 2995.

Allport, F. (1924). *Social Psychology*. Boston: Houghton Mifflin, p. 295.

Arnold, M. B. (1960). *Emotion and personality. Volume I: Psychological aspects*. New York: Columbia University Press.

Atallah, L., & Yang, G. Z. (2009). The use of pervasive sensing for behaviour profiling—a survey. *Pervasive and Mobile Computing, 5*(5), 447-464.

Bakker, I., van der Voordt, T., Vink, P., & de Boon, J. (2014). Pleasure, arousal, dominance: Mehrabian and Russell revisited. *Current Psychology, 33*(3), 405-421.

Bandini, S., Rubagotti, F., Vizzari, G., & Shimura, K. (2011, September). A cellular automata based model for pedestrian and group dynamics: motivations and first experiments. In *International Conference on Parallel Computing Technologies (pp. 125-139)*. Springer, Berlin, Heidelberg.

Barsäde, S. G., & Gibson, D. E. (1998). Group emotion: A view from top and bottom. *Research on managing groups and teams, 1*, 81-102.

Barsäde, S. G. (2002). The ripple effect: Emotional contagion and its influence in group behavior. *Administrative Science Quarterly, 47*, 644-675.

Bartel, C. A., & Saavedra, R. (2000). The collective construction of work group moods. *Administrative Science Quarterly, 45*(2), 197-231.

Bar-Tal, D., Halperin, E., & De Rivera, J. (2007). Collective emotions in conflict situations: Societal implications. *Journal of Social Issues, 63*(2), 441-460.

Baumeister, R. F., Vohs, K. D., DeWall, C. N., & Zhang, L. (2007). How emotion shapes behavior: Feedback, anticipation, and reflection, rather than direct causation. Personality and Social Psychology Review, 11(2), 167-203.

Baumeister, R. F., DeWall, C. N., Vohs, K. D., & Alquist, J. L. (2010). Does emotion cause behavior (apart from making people do stupid, destructive things). In Agnew, C. R., Carlston, D. E., Graziano, W. G., & Kelly, J. R. (Eds.) *Then a Miracle Occurs: Focusing on Behavior in Social Psychological Theory and Research,* 12-27. New York: Oxford University Press.

Becker, H. S. (1970). Field work evidence. In H. Becker, *Sociological work: Method and substance* (pp. 39-62). New Brunswick, NJ: Transaction Books.

Beckett, M., Da Vanzo, J., Sastry, N., Panis, C., & Peterson, C. (2001). The quality of retrospective data: An examination of long-term recall in a developing country. *Journal of Human Resources*, 593-625.

Berlonghi, A. (1994). *The special event risk management manual (rev. ed.).* Dana Point, CA: Berlonghi.

Berlonghi, A. E. (1995). Understanding and planning for different spectator crowds. *Safety Science, 18(4),* 239-247.

Brown, R. W. (1954). *The Handbook of Social Psychology*. Lindzey, G. (ed.), Chapter Mass Phenomena, 833-876. Addison-Wesley, Cambridge, MA.

Bouvier, E., Cohen, E., & Najman, L. (1997). From crowd simulation to airbag deployment: particle systems, a new paradigm of simulation. *Journal of Electronic imaging, 6*(1), 94-107.

Buzan, T. & Buzan, B. (2000). *The mindmap book*. Millennium edition. London: BBC Worldwide Limited.

Canetti, E. (1962). Crowds and power. Macmillan.

Challenger, R., Clegg, C.W., Robinson, M.A., & Leigh, M. (2010). *Understanding crowd behaviors (volume 1): Practical guidance and lessons identified.* Published by TSO (The Stationery Office), London.

Couch, C. J. (1968). Collective Behavior: An Examination of Some Stereotypes. *Social Problems, 15*(3), 310-322.

Daamen, W., Yuan, Y., Duives, D., & Hoogendoorn, S. P. (2016). Comparing three types of real-time data collection techniques: counting cameras Wi-Fi sensors and GPS trackers. In *Proceedings of Pedestrian and Evacuation Dynamics,* 2016.

Darwin, C. (1872/1998). *The expression of the emotions in man and animals (3rd edition).* London: Harper Collins.

Dee, H. M., & Velastin, S. A. (2008). How close are we to solving the problem of automated visual surveillance?. *Machine Vision and Applications, 19*(5-6), 329-343.

Delvaux, E., Meeussen, L., & Mesquita, B. (2016). Emotions are not always contagious: Longitudinal spreading of self-pride and group pride in homogeneous and status-differentiated groups. *Cognition and Emotion, 30*(1), 101-116.

Derber, C. (1979). *The pursuit of attention: Power and individualism in everyday life.* Oxford, UK: Oxford University Press.

Desmet, P. M. A. & Hassenzahl, M. (2012). Towards happiness: Possibility driven design. In M., Zacarias & J.V. de Oliviera (eds.), Human Computer Interaction: The Agency Perspective. Springer-Verlag Berlin Heidelberg.

Diener, E. (1984). Subjective well-being. *Psychological Bulletin, 95*(3), 542-575.

Diener, E. (1993). Assessing subjective well-being: Progress and opportunities. *Social Indicators Research, 31*, 103-157.

Diener, E., Sapyta, J. J., & Suh, E. (1998). Subjective well-being is essential to wellbeing. *Psychological Inquiry, 9*, 33-37.

Diener, E. (2000). Subjective wellbeing: The science of happiness and a proposal for a national index. *American Psychological Association, 55*: 34-43.

Diener, E., Oishi, S., & Lucas, R. E. (2003) Personality, culture, and subjective well-being: Emotional and cognitive evaluations of life. *Annual Review of Psychology, 54*, 403-425.

Dombroski, M., Fischhoff, B., & Fischbeck, P. (2006). Predicting emergency evacuation and sheltering behavior: A structured analytical approach. *Risk Analysis, 26*(6), 1675–1688.

Drury, J., Reicher, S. & Stott, C. (2003). Transforming the boundaries of collective identity: From the 'local' anti-road campaign to 'global' resistance?". *Social Movement Studies 2*, 191–212.

Duives, D. C., Daamen, W., & Hoogendoorn, S. P. (2013). State-of-the-art crowd motion simulation models. *Transportation research part C: emerging technologies, 37*, 193-209.

Duives, D. C., Daamen, W., & Hoogendoorn, S. P. (2018). Monitoring the Number of Pedestrians in an Area: The Applicability of Counting Systems for Density State Estimation. *Journal of Advanced Transportation*, 2018.

El Ali, A., Stratmann, T. C., Park, S., Schöning, J., Heuten, W., & Boll, S. C. (2018). Measuring, Understanding, and Classifying News Media Sympathy on Twitter after Crisis Events. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems* (p. 556). ACM.

Erkin, Z., Li, J., Vermeeren, A. P., & de Ridder, H. (2014). Privacy-preserving emotion detection for crowd management. In International Conference on *Active Media Technology (pp. 359-370)*. Springer International Publishing.

Ekman, P. (1972). Universal and cultural differences in facial expressions of emotions. In J. K. Cole (Ed.), *Nebraska symposium on motivation, 1971* (pp. 207-283). Lincoln: University of Nebraska Press.

Ekman, P. (1992). An argument for basic emotions. *Cognition & emotion, 6*(3-4), 169-200.

Ekman, P. (1999). Chapter 3. Basic emotions. In T. Dalgleish & M. Power (Eds.), *Handbook of Cognition and Emotion* (pp.45-60). John Wiley & Sons Ltd., Chichester, England.

Ekman, P., & Cordaro, D. (2011). What is meant by calling emotions basic. *Emotion Review, 3*(4), 364-370.

Ekman, P., Friesen, W. V., & Simons, R. C. (1985). Is the startle reaction an emotion?. *Journal of personality and social psychology, 49*(5), 1416-1426.

Epstein, S. (1990). Cognitive-experiential self-theory. In L. A. Pervin (Ed.), *Handbook of personality: Theory and research* (pp. 165-192). New York: Guilford Press.

Epstein, J. (2002). Modeling civil violence: An agent-based computational approach. In *Proceedings of the National Academy of Sciences, Vol. 99*, pp. 7243-7250.

European Commission. (2016). *Open innovation, open science, open to the World.* Brussels, Belgium: European Union Publication. Available at: http://bookshop.europa.eu/en/open-innovation-open-science-open-to-the-world-pbKI0416263/ (retrieved on March 6, 2018).

Fan, X., Miller, B. C., Park, K.-E., Winward, B. W., Christensen, M., Grotevant, H. D., & Tai, R. H. (2006). An exploratory study about inaccuracy and invalidity in adolescent self-report surveys. *Field Methods 18*(3), 223–244.

Farahmand, K. (1997). Application of simulation modeling to emergency population evacuation. In *Proceedings of the 1997 Winter Simulation Conference*, 1181-1188.

Farkas, I., Helbing, D., & Vicsek, T. (2002). Social behaviour: Mexican waves in an excitable medium. *Nature, 419*(6903), 131-132.

Festinger, L. (1962). *A theory of cognitive dissonance (Vol. 2)*. Stanford, Califorlia: Stanford University Press.

Field, A. (2009). *Discovering statistics using SPSS (3rd edition)*. London: SAGE Publications.

Filingeri, V., Eason, K., Waterson, P., & Haslam, R. (2017). Factors influencing experience in crowds–The participant perspective. *Applied ergonomics, 59*, 431-441.

Fischer, K. W., Shaver, P. R. & Carnochan, P. (1990). How emotions develop and how they organize development. *Cognition and Emotion*, 4(2), 81-127.

Franke, T., Lukowicz, P., & Blanke, U. (2015). Smart crowds in smart cities: real life, city scale deployments of a smartphone based participatory crowd management platform. *Journal of Internet Services and Applications, 6*(1), 27.

Fredrickson, B. L. (1998). What good are positive emotions?. *Review of General Psychology, 2*, 300–319.

Fredrickson, B. L., & Joiner, T. (2002). Positive emotions trigger upward spirals toward emotional well-being. *Psychological science, 13*(2), 172-175.

Friendly, M. (1994). Mosaic displays for multi-way contingency tables. *Journal of the American Statistical Association, 89*(425), 190-200.

Frijda, N. H. (1986). *The emotions. Studies in emotion and social interaction (pp.69-82)*. Press syndicate of the University of Cambridge.

Frijda, N. H., Kuipers, P., & Ter Schure, E. (1989). Relations among emotion, appraisal, and emotional action readiness. *Journal of personality and social psychology, 57*(2), 212.

Frijda, N. H. (2010). Impulsive action and motivation. *Biological psychology, 84*(3), 570-579.

y Gasset, J. O. (1993). *The revolt of the masses*. New York: WW Norton & Company. Originally published in 1930.

Gong, V. X., Yang, J., Daamen, W., Bozzon, A., Hoogendoorn, S., & Houben, G. J. (2018). Using Social Media for Attendees Density Estimation in City-Scale Events. *IEEE Access, 6,* 36325-36340.

Gray, J. A. (1970). The psychophysiological basis of introversion-extraversion. *Behaviour Research and Therapy, 8*(3), 249-266.

Gray, J. A. (1982). *The Neuropsychology of Anxiety: An Enquiry into the Functions of the Septo-hippocampal System*. New York, NY: Clarendon Press/Oxford University Press.

Gunes, H. & Pantic, M. (2010). Automatic, dimensional and continuous emotion recognition. *International Journal of Synthetic Emotions 1*(1), 68-99.

Haag, A., Goronzy, S., Schaich, P., & Williams, J. (2004). Emotion recognition using bio-sensors: First steps towards an automatic system. In *Tutorial and research workshop on affective dialogue systems* (pp. 36-48). Springer, Berlin, Heidelberg.

Hamari, J., & Eranti, V. (2011). Framework for designing and evaluating game achievements. In *Proceedings of DiGRA 2011: Think Design Play, 115*(115), 122-134.

Hatfield, E., Cacioppo, J. T. & Rapson, R. L. (1992). Primitive emotional contagion. In *Emotions and Social Behavior: Review of Personality and Social Psychology*, 14, 151-177. M. S. Clark, Ed. Sage, Newbury Park, CA.

Hatfield, E., Cacioppo, J. T., & Rapson, R. L. (1993). Emotional contagion. *Current directions in psychological science, 2*(3), 96-100.

Hatfield, E., Cacioppo, J. T. & Rapson, R. L. (1994). *Emotional contagion*. Cambridge University Press, New York, USA.

Hartigan, J. A., & Kleiner, B. (1981). Mosaics for contingency tables. In *Computer science and statistics: Proceedings of the 13th symposium on the interface* (pp. 268-273). Springer, New York, NY.

Health and Safety Executive. (1999). *The event safety guide (2nd edition): A guide to health, safety and welfare at music and similar events.* The Office of Public Sector Information, Information Policy Team, Kew, Richmond, Surrey TW9 4DU.

Health and Safety Executive (2000). *Managing crowds safely: A guide for organisers at events and venues*. © Crown copyright 2000. Available: http://www.hse.gov.uk/pubns/books/hsg154.htm, retrieved on Feb. 11, 2015.

Helbing, D., & Molnar, P. (1995). Social force model for pedestrian dynamics. *Physical review E, 51*(5), 4282.

Helbing, D., & Molnar, P. (1998). Self-organization phenomena in pedestrian crowds. *arXiv preprint cond-mat/9806152*.

Helbing, D., Farkas, I., & Vicsek, T. (2000). Simulating dynamical features of escape panic. *Nature, 407*(6803), 487–490.

Helbing, D., Buzna, L., Johansson, A., & Werner, T. (2005). Self-organized pedestrian crowd dynamics: Experiments, simulations, and design solutions. *Transportation Science, 39*(1), 1–24.

Helbing, D., & Mukerji, P. (2012). Crowd disasters as systemic failures: Analysis of the Love Parade disaster. *EPJ Data Science, 1(1),* 1-40.

Henderson, L. F. (1971). The statistics of crowd fluids. *Nature, 229,* 381–383.

Hoogendoorn, S. P., & Bovy, P. H. (2004). Pedestrian route-choice and activity scheduling theory and models. *Transportation Research Part B: Methodological, 38*(2), 169-190.

Hopkins, N., Reicher, S. D., Khan, S. S., Tewari, S., Srinivasan, N., & Stevenson, C. (2016). Explaining effervescence: Investigating the relationship between shared social identity and positive experience in crowds. *Cognition and Emotion, 30*(1), 20-32.

Hunter, P. G., Schellenberg, E. G., & Schimmack, U. (2008). Mixed affective responses to music with conflicting cues. *Cognition and Emotion 22*, 327–352.

Hurtienne, J., & Blessing, L. (2007). Design for intuitive use-testing image schema theory for user interface design. In *Proceedings of International Conference on Engineering Design*, ICED'07, Paris, France, 386–397.

Idrees, H., Saleemi, I., Seibert, C., & Shah, M. (2013). Multi-source multi-scale counting in extremely dense crowd images. In *Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition* (pp. 2547-2554).

Ilgen, D. R. and Klein, H. J. (1988). Organizational behavior. *Annual Review of Psychology*, 40, 327-351.

Johansson, A., Helbing, D., Al-Abideen, H. Z., & Al-Bosta, S. (2008). From crowd dynamics to crowd safety: a video-based analysis. *Advances in Complex Systems, 11*(4), 497-527.

Kahneman D., Diener E., & Schwarz N., eds. (1999). *Well-Being: The Foundations of Hedonic Psychology.* New York: Russell Sage Found.

Kallus, N. (2014). Predicting crowd behavior with big public data. In *Proceedings of the companion publication of the 23rd international conference on World Wide Web companion* (pp. 625-630). International World Wide Web Conferences Steering Committee.

Kazdin, A. E. (2000). *Encyclopedia of psychology.* Washington, D.C.: American Psychological Association, pp. 374–377. ISBN 1-55798-650-9.

Kemper, T. D. (1987) How many emotions are there? Wedding the social and the autonomic components. *American Journal of Sociology 93*, 263–289.

Kenny, J. M., McPhail, C., Waddington, P., Ijames, S. Farrer, D.N., Odenthal, D., Heal, S., & Taylor, J. (2001). *Crowd behavior, crowd control, and the use of non-lethal weapons (Technical report).* University Park: Pennsylvania State Applied Research Laboratory.

Kramer, A. D. I., Guillory, J. E. & Hancock, J. T. (2014). Experimental evidence of massive-scale emotional contagion through social networks. *Proceedings of the National Academy of Sciences,* 111 (24), 8788-8790.

Kreibig, S. D., Gendolla, G. H., & Scherer, K. R. (2010). Psychophysiological effects of emotional responding to goal attainment. *Biological psychology, 84*(3), 474-487.

Laird, J. D. & Bresler, C. (1992). The process of emotional feeling: A self-perception theory. In *Emotion: Review of Personality and Social Psychology*, 13, 213-234. M. Clark, Ed. Sage, Newbury Park, CA.

Lagendijk, R., Erkin, Z., & Barni, M. (2013). Encrypted signal processing for privacy protection. *IEEE Signal Processing Magazine 30*(1), 82-105.

Larsen, J. T., McGraw, A. P., & Cacioppo, J. T. (2001). Can people feel happy and sad at the same time?. *Journal of Personality and Social Psychology 81*, 684–696.

Lazarus, R. S. (1991). *Emotion and adaptation*. Oxford University Press on Demand.

Levenson, R. W. (1999). The intrapersonal functions of emotion. *Cognition & Emotion, 13*(5), 481-504.

Le Bon, G. (1895). *The Crowd. A Study of the Popular Mind*. Batoche Books, Kitchener, Canada, 2001.

Lea, M., & Spears, R. (1991). Computer-mediated communication, de-individuation, and group decision making. *International Journal of Man-Machine Studies, Special Issue on CSCW and Groupwar, 39*, 283–301.

Lee, R. S. C., & Hughes, R. L. (2007). Minimisation of the risk of trampling in a crowd. *Mathematics and Computers in Simulation, 74*, 29-37.

Leonelli, S. (2016). Locating ethics in data science: responsibility and accountability in global and distributed knowledge production systems. *Philosophical Transactions of the Royal Society A, 374*: 20160122. http://dx.doi.org/10.1098/rsta.2016.0122

Lewis, M., Haviland-Jones, J. M., & Barrett, L. F. (Eds.). (2010). *Handbook of emotions*. Guilford Press.

Li, J., de Ridder, H. Vermeeren, A., Conrado, C., & Martella, C. (2013). Designing for crowd well-being: Current designs, strategies and future design suggestions. In *Proceedings of 5th International Congress of International Association of Societies of Design Research, IASDR'2013*, Tokyo, Japan, 2278–2289.

Li, J., Erkin, Z., de Ridder, H., & Vermeeren, A. (2013a). A Field Study on Real-time Self-reported Emotions in Crowds. In *Proceedings of ICT OPEN*, Eindhoven, The Netherlands, 80-84.

Li, J., Cai, R., de Ridder, H., Vermeeren, A. P., & van Egmond, R. (2014). A study on relation between crowd emotional feelings and action tendencies. In *Proceedings of the 8th Nordic Conference on Human-Computer Interaction: Fun, Fast, Foundational* (pp. 775-784). ACM.

Lövheim, H. (2012). A new three-dimensional model for emotions and monoamine neurotransmitters. *Medical hypotheses, 78*(2), 341-348.

Lowe, R., & Ziemke, T. (2011). The Feeling of Action Tendencies: On the Emotional Regulation of Goal-Directed Behavior. *Frontiers in Psychology, 2* (346), 1-24.

Lyubomirsky, S., King, L. A., & Diener, E. (2005). The benefits of frequent positive affect: Does happiness lead to success?. *Psychological Bulletin, 131*, 803-855.

Lyubomirsky, S. (2007). *The how of happiness: A scientific approach to getting the life you want.* Penguin Press, New York, NY, USA.

Mackay, C. (2002). *Extraordinary Popular Delusions and the Madness of Crowds*. Barnes & Noble (originally published in 1841).

Manucia, G. K., Baumann, D. J., & Cialdini, R. B. (1984). Mood influences on helping: Direct effects or side effects?. *Journal of Personality and Social Psychology, 46*(2), 357.

Martella, C., van Steen, M., Halteren, A., Conrado, C., & Li, J. (2014). Crowd textures as proximity graphs. *Communications Magazine IEEE*, *52*(1), 14-121.

Martella, C., Li, J., Conrado, C., Vermeeren, A. (2017). On current crowd management practices and the need for increased situation awareness, prediction, and intervention. *Safety Science 91*, 381-393.

Martella, C. (2017). *Crowd textures: From sensing proximity to understanding crowd behavior*. PhD Thesis. Vrije Universiteit Amsterdam.

Maslow, A. H. (1954). *Motivation and personality (2nd Edition)*. Haper & Row Publishers, New York, Evanston and London.

MATLAB documentation (2016). *1-D median filtering.* Available at http://nl.mathworks.com/help/signal/ref/medfilt1.html, retrieved on October 19, 2016.

MATLAB documentation (2016a). *Dendrogram.* Available at https://nl.mathworks.com/help/stats/dendrogram.html, retrieved on October 19, 2016.

MATLAB documentation (2016b). *Hierarchical clustering.* Available at http://nl.mathworks.com/help/stats/hierarchical-clustering.html, retrieved on October 19, 2016.

McGregor, I., & Little, B. R. (1998). Personal projects, happiness, and meaning: on doing well and being yourself. *Journal of personality and social psychology, 74*(2), 494-512.

McHugh, J. E., McDonnell, R., O'Sullivan, C., & Newell, F. N. (2010). Perceiving emotion in crowds: the role of dynamic body postures on the perception of emotion in crowded scenes. *Experimental brain research, 204*(3), 361-372.

McPhail, C. (1991). *The myth of the madding crowd*. Walter de Gruyter, Inc., New York.

Mehrabian, A. (1996). Pleasure-arousal-dominance: A general framework for describing and measuring individual differences in temperament. *Current Psychology, 14*(4), 261-292.

Mehrabian, A., & Russell, J.A. (1974). *An approach to environmental psychology.* Cambridge, MA: M.I.T. Press. (deleted)

Momboisse, R. (1967). *Riots, Revolts and Insurrections.* Springfield, IL: Charles C. Thomas Publisher.

Morgan, D. L., & Spanish, M. T. (1984). Focus groups: A new tool for qualitative research. *Qualitative Sociology, 7*(3), 253-270.

Morgan, D. L., & Krueger, R. A. (1998). *Analyzing and reporting focus group results (Vol. 6)*. Sage.

Naz, K. A. Y. A., & Epps, H. (2004). Relationship between color and emotion: A study of college students. *College Student J, 38*(3), 396.

Neumann, R. & Strack, F. (2000). Mood contagion: The automatic transfer of mood between persons. *Journal of Personality and Social Psychology*, 79, 211-223.

Nummenmaa, L., Glerean, E., Hari, R., & Hietanen, J. K. (2014). Bodily maps of emotions. *Proceedings of the National Academy of Sciences, 111*(2), 646-651.

Nye, R. A. (1975). *The origins of crowd psychology: Gustave LeBon and the crisis of mass democracy in the third republic*. London: Sage.

Oishi, S., Schimmack, U., & Diener, E. (2001). Pleasures and subjective well-being. *European Journal of Personality, 15*(2), 153-167.

Ortony, A., & Turner, T. J. (1990). What's basic about basic emotions?. *Psychological review, 97*(3), 315.

Park, R. E., & Burgess, E. W. (1924). *Introduction to the Science of Sociology*. University of Chicago Press, Chicago.

Pentland, A. (2014). *Social physics: How good ideas spread-the lessons from a new science*. Penguin Press.

Plutchik, R. (2000). *Emotions in the practice of psychotherapy: Clinical implications of affect theories*. Washington, DC, US: American Psychological Association.

Plutchik, R. (2003*). Emotions and life: Perspectives from psychology, biology, and evolution*. Washington, DC, US: American Psychological Association.

Postmes, T., & Spears, R. (1998). Deindividuation and antinormative behavior: A meta- analysis. *Psychological Bulletin, 123*(3), 238-259.

Price, D. D., & Barrell, J. J. (1984). Some general laws of human emotion: Interrelationships between intensities of desire, expectation, and emotional feeling. *Journal of personality, 52*(4), 389-409.

Prinz, J. (2005). Are emotions feelings?. *Journal of Consciousness Studies, 12*(8-10), 9-25.

Rabiee, F. (2004). Focus-group interview and data analysis. *Proceedings of the Nutrition Society, 63*, 655-660.

Reicher, S. (1982). The determination of collective behaviour. In H. Tajfel (Ed.), *Social identity and intergroup relation*s. Cambridge, UK: Cambridge University Press, and Paris: Maison de Sciences de l'Homme.

Reicher, S. (1984). The St Paul's "riot": An explanation of the limits of crowd action in terms of a social identity model. *European Journal of Social Psychology 14,* 1–21.

Reicher, S. (1987). Crowd behaviour as social action. In J. Turner, M. Hogg, P. Oakes, S. Reicher, & M. Wetherell, *Rediscovering the social group: A self-categorization theory.* Oxford, UK: Blackwell.

Reicher, S. (1996). The battle of Westminster: Developing the social identity model of crowd behaviour in order to explain the initiation and development of collective conflict. *European Journal of Social Psychology, 26*(1), 115-134.

Reicher, S. (2001). The psychology of crowd dynamics. In *Blackwell handbook of social psychology: Group processes*, 182-208. Oxford, England, UK: Blackwell Publishers.

Reicher, S., & Potter, J. (1985). Psychological theory as intergroup perspective: A comparative analysis of "scientific" and "lay" accounts of crowd events. *Human Relations, 38*(2), 167-189.

Reisenzein, R. (2010). Broadening the Scope of Affect Detection Research. *IEEE Transactions on Affective Computing 1*(1), 42-45.

Remington, M., & Tyer, P. (1979). The social functioning schedule: A brief semi-structured interview. *Social Psychiatry, 14*, 151-157.

Rice, R. E., & Katz, J. E. (2003). Comparing Internet and mobile phone usage: Digital divides of usage, adoption, and dropouts. *Telecommunications Policy, 27*(8-9), 597-623.

Rosch, E. H. (1978). Principles of categorization. In E. Margolis & S. Laurence (Eds.), *Concepts: Core readings* (pp. 189–206). Cambridge, MA: MIT Press.

Runkel, S., & Pohl, J. (2012). Crowd management als Planungsaufgabe: eine sozialgeographisch Perspektive auf Masse und Raum bei Großveranstaltungen. *Geographische Zeitschrift, 100*(4), 189-207.

Russell, J. A. (1980). A circumplex model of affect. *Personality and Social Psychology 39*(6), 1161–1178.

Ryan, R. M., & Deci, E. L. (2000). Self-determination theory and the facilitation of intrinsic motivation, social development, and well-being. *American psychologist, 55*(1), 68-78.

Ryan, R. M., & Deci, E. L. (2001). On happiness and human potentials: A review of research on hedonic and eudaimonic well-being. *Annual review of psychology, 52*(1), 141-166.

Ryff, C. D. (1989). Happiness is everything, or is it? Explorations on the meaning of psychological well-being. *Journal of personality and social psychology, 57*(6), 1069.

Ryff, C. D., & Keyes, C. L. M. (1995). The structure of psychological well-being revisited. *Journal of personality and social psychology, 69*(4), 719-727.

Ryff, C. D., & Singer, B. (1998). The contours of positive human health. *Psychological inquiry, 9*(1), 1-28.

Sanders, E. B.-N., & P. J. Stappers. (2012). *Convivial Toolbox*. Amsterdam: BIS Publishers.

Saxena, S., Brémond, F., Thonnat, M., & Ma, R. (2008). Crowd behavior recognition for video surveillance. In *Advanced Concepts for Intelligent Vision Systems*, pp. 970-981. Springer Berlin Heidelberg.

Scarantino, A., & Griffiths, P. (2011). Don't give up on basic emotions. *Emotion Review, 3*(4), 444-454.

Schauer, M., & Elbert, T. (2010). Dissociation Following Traumatic Stress. *Zeitschrift für Psychologie/Journal of Psychology, 218*(2), 109-127.

Scherer, K.R. (1987). Toward a Dynamic Theory of Emotion: The Component Process Model of Affective States. *Geneva Studies in Emotion and Communication* 1, 1–98.

Scherer, K.R. (2001). Appraisal Considered as a Process of Multi-Level Sequential Checking. In K.R. Scherer, A. Schorr and T. Johnstone (eds.). *Appraisal Processes in Emotion: Theory, Methods, Research*, pp. 92–120. New York and Oxford: Oxford University Press.

Scherer, K. R. (2004). Ways to study the nature and frequency of our daily emotions: Reply to the commentaries on" Emotions in everyday life. *Social Science Information, 43*(4), 667-689.

Scherer, K. R. (2005). What are emotions? And how can they be measured?. *Social science information, 44*(4), 695-729.

Schimmack, U., & Reisenzein, R. (1997). Cognitive processes involved in similarity judgments of emotions. *Journal of Personality and Social Psychology, 73*(4), 645-661.

Schindler, K., Van Gool, L., & de Gelder, B. (2008). Recognizing emotions expressed by body pose: A biologically inspired neural model. *Neural networks, 21*(9), 1238-1246.

Schwarz, G., & Mosler, H. (2005). Investigating escalation processes in peace support operations: An agent-based model about collective aggression. In *Proceedings 3rd Annual Conference of the European Social Simulation Association (ESSA)*, 191–197.

Schwarz, N. (2007). Retrospective and concurrent self-reports: The rationale for real-time data capture. *The science of real-time data capture: Self-reports in health research,* 11-26.

Schwarz, N. & Clore, G. L. (2007). Feelings and phenomenal experiences. In E. T. Higgins & A. Kruglanski (Eds.*), Social psychology: Handbook of basic principles*. New York: Guilford.

Schreiber, M. (2010). *Group relations at crowd events*. Ph.D. thesis, Jacobs University Bremen.

Schroff, F., Kalenichenko, D., & Philbin, J. (2015). Facenet: A unified embedding for face recognition and clustering. In *Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition* (pp. 815-823).

Sebe, N., Lew, M. S., Sun, Y., Cohen, I., Gevers, T., & Huang, T. S. (2007). Authentic facial expression analysis. *Image and Vision Computing, 25*(12), 1856–1863.

Sheldon, K. M., Kasser, T., Elliot, A. J., & Kim, Y. (2001). What is satisfying about satisfying events? Testing 10 candidate psychological needs. *Journal of Personality and Social Psychology*, *80*(2), 325-339.

Sime, J. D. (1983). Affiliative behaviour during escape to building exits. *Journal of Environmental Psychology, 3*, 21–41.

Sime, J. D. (1999). Crowd facilities, management and communications in disasters. *Facilities, 17*(9/10), 313-324.

Sleeswijk-Visser, F., Stappers, P. J., van der Lugt, R., & Sanders, E. B. N. (2005). Contextmapping: Experiences from practice, *CoDesign: International Journal of CoCreation in Design and the Arts, 1*(2), 119-149.

Smith, C. A., & Lazarus, R. S. (1990). Emotion and adaptation. In *Handbook of personality: Theory and research*, Pervin, L. A. (Ed). New York, NY, US: Guilford Press, pp.609-637.

Smithson, J. (2000). Using and analysing focus groups: limitations and possibilities. *International journal of social research methodology, 3*(2), 103-119.

Stappers, P. J., & Sanders, E. B.-N. (2002). Generative tools for context mapping: Tuning the tools. In *Proceedings of 3rd International Conference on Design & Emotion*, Loughborough, UK.

Steel, P., Schmidt, J., & Shultz, J. (2008). Refining the relationship between personality and subjective well-being. *Psychological bulletin, 134*(1), 138.

Stewart, D. W., Shamdasani, P. N., & Rook, D. W (2007) Analyzing focus group data. In *Applied Social Research Methods: Focus groups* (pp. 109-133). Thousand Oaks, CA: SAGE Publications, Ltd.

Still, G. K. (2000). *Crowd Dynamics*. PhD Thesis, University of Warwick, UK.

Stott, C., & Drury, J. (2000). Crowds, context and identity: dynamic categorization processes in the "poll tax riot". *Human Relations, 53*(2), 247–273.

Sturgis, P., Allum, N., & Brunton-Smith, I. (2009). Attitudes over time: The psychology of panel conditioning. *Methodology of longitudinal surveys,* 113-126.

Surowiecki, J. (2005). *The wisdom of crowds*. Anchor.

Tajfel, H. (1978). *Differentiation between social groups.* London: Academic Press.

Tomkins, S. S., & Mc Carter, R. (1964). What and where are the primary affects? Some evidence for a theory. *Perceptual and motor skills, 18*(1), 119-158.

Tosin, A. (2014). Multiscale crowd dynamics modeling and theory. In *Collective Dynamics from Bacteria to Crowds* (pp. 157-177). Springer Vienna.

Tsouros, A. D., & Efstathiou, P. A. (2007). *Mass gathering and public health: Experience of the Athens 2004 Olympic Games.* World Health Organization 2007.

Triandis, H. C. (1987). Theoretical framework for mass psychology. *Contemporary Psychology, 32* (2), 123–124.

Turner, R.H., Killian, L.M. (1957). *Collective Behavior*. Englewood Cliffs, NJ: Prentice-Hall, page 547.

Turner, R. H., & Killian, L. M. (1972). *Collective Behavior (2nd Ed.).* Englewood Cliffs, NJ: Prentice-Hall, page 435.

Turner, J. C., Oakes, P. J., Haslam, S. A., & McGarty, C. (1994). Self and collective: Cognition and social context. *Personality and social psychology bulletin, 20*, 454-454.

Tversky, A., & Kahneman, D. (1981). The framing of decisions and the psychology of choice. *Science 211 (4481)*, 453-458.

Ulicny, B., & Thalmann, D. (2001). Crowd simulation for interactive virtual environments and VR training systems. In M. Magnenat-Thalmann and D. Thalmann (Eds.), *Computer Animation and Simulation,* pp.163-170. New York: Springer.

Van Kleef, G. A., & Fischer, A. H. (2016). Emotional collectives: How groups shape emotions and emotions shape groups. *Cognition and Emotion, 30*(1), 3-19.

Versichele, M., Neutens, T., Delafontaine, M., & Van de Weghe, N. (2012). The use of Bluetooth for analysing spatiotemporal dynamics of human movement at mass events: A case study of the Ghent Festivities. *Applied Geography, 32*(2), 208-220.

Von Scheve, C., & Ismer, S. (2013). Towards a theory of collective emotions. *Emotion Review, 5*(4), 406-413.

Van Steen, M. (2010). *Graph theory and complex networks: An introduction.* Amsterdam. ISBN-10-9081540610.

Waddell, R. (1997). Quintella talks crowd management: Director Bob Quintella of Oakland Coliseum, California [On-line]. *BPI Communications.* Available: http://business.highbeam.com/53/article-1G1-19560301/quintella-talks-crowd-management, retrieved on Feb. 11, 2015.

Wallace, E., & Diffley, C. (1988). CCTV control room ergonomics. Published by Police Scientific Development Branch of the Home Office, Publication, (14/98).

Wang, Y., Li, J. & Vink, P. (2014). The future aircraft interior design inspired by crowd well-being. In P. Vink (Ed.), *Advances in Social and Organizational factors*, pp. 11-18. Published by the 5th International Conference on Applied Human Factors and Ergonomics AHFE 2014, Kraków, Poland, 19-23 July, 2014.

Watt, C. D. (1998). *Event management in leisure and tourism.* Harlow, Essex, England: Addison Wesley Longman.

Waterman, A. S. (1993). Two conceptions of happiness: Contrasts of personal expressiveness (eudaimonia) and hedonic enjoyment. *Journal of Personality and Social Psychology, 64*(4), 678.

Weisbuch, M., & Ambady, N. (2008). Affective divergence: automatic responses to others' emotions depend on group membership. *Journal of Personality and Social Psychology, 95*(5), 1063-1079.

Weppner, J., & Lukowicz, P. (2013). Bluetooth based collaborative crowd density estimation with mobile phones. In *2013 IEEE international conference on Pervasive computing and communications (PerCom),* pp. 193-200. IEEE.

Wijermans, N. (2011). *Understanding crowd behavior: Simulating situated individuals.* PhD Thesis. Published by University of Groningen, Groningen, The Netherlands. ISBN: 978-90-367-4839-1

Wijermans, N., Jorna, R., Jager, W., van Vliet, T., & Adang, O. (2013). CROSS: Modelling crowd behaviour with social-cognitive agents. *Journal of Artificial Societies and Social Simulation, 16* (4), 1-23.

Wijermans, N., Conrado, C., Van Steen, M., Martella, C. & Li, J. (2016). A landscape of crowd-management support: an integrative approach. *Safety Science, 86*, 142-164.

Williams P., & Aaker, J. L. (2002). Can mixed emotions peacefully coexist?. *Journal of Consumer Research 28*, 636–649.

Wilson, T. D., Lisle, D. J., Kraft, D., & Wetzel, C. G. (1989). Preferences as expectation-driven inferences: Effects of affective expectations on affective experiences. *Journal of Personality and Social Psychology, 56,* 519–530.

Wirz, M., Mitleton-Kelly, E., Franke, T., Camilleri, V., Montebello, M., Roggen, D., ... & Troster, G. (2013). Using mobile technology and a participatory sensing approach for crowd monitoring and management during large-scale mass gatherings. In *Co-evolution of Intelligent Socio-technical Systems* (pp. 61-77). Springer, Berlin, Heidelberg.

Xi, H., Lee, S., & Son, Y. J. (2011). An integrated pedestrian behavior model based on extended decision field theory and social force model. In *Human-in-the-Loop Simulations (pp. 69-95)*. Springer, London.

Yuan, Y., Daamen, W., Duives, D., & Hoogendoorn, S. (2016). Comparison of three algorithms for real-time pedestrian state estimation-supporting a monitoring dashboard for large-scale events. In *2016 IEEE 19th International Conference on Intelligent Transportation Systems (ITSC), pp. 2601-2606*. IEEE.

Yaseen, S., Al-Habaibeh, A., Su, D., & Otham, F. (2013). Real-time crowd density mapping using a novel sensory fusion model of infrared and visual systems. *Safety science, 57*, 313-325.

Zacherle, C. (2010). *Crowd Management-Möglichkeiten der Prävention und Intervention bei Massenpaniken am Beispiel von Fußballspielen, Public Viewing und Open-Air-Veranstaltungen*. GRIN Verlag.

Zeitz, K.M., Tan, H.M., & Zeitz, C.J. (2009). Crowd behavior at mass gathering: A literature review. *Prehospital Disaster Medicine, 24*(1), 32-38.

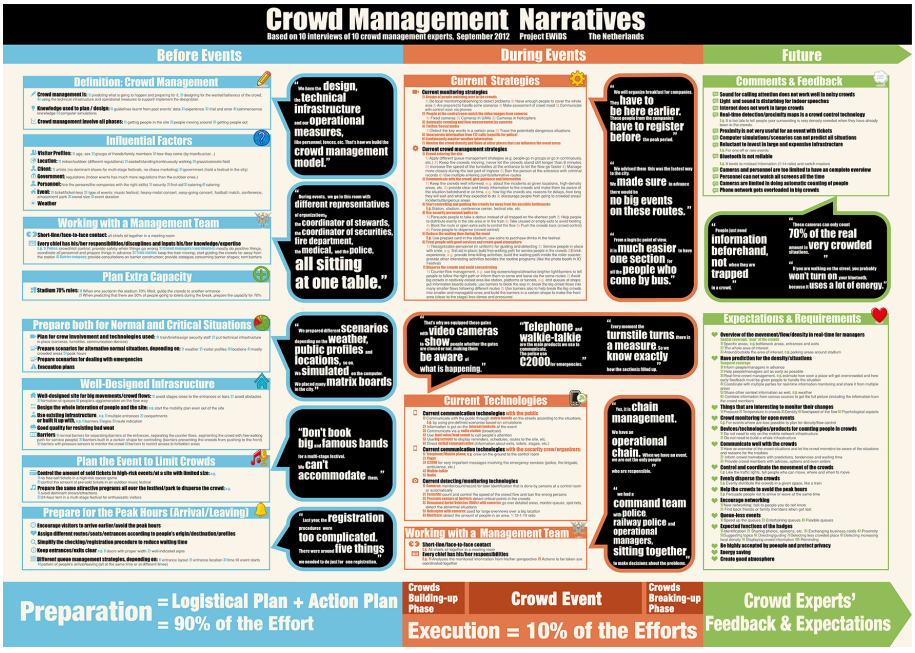
Zhan, B., Monekosso, D. N., Remagnino, P., Velastin, S. A., & Xu, L. Q. (2008). Crowd analysis: a survey. *Machine Vision and Applications, 19*(5-6), 345-357.

Zimbardo, P. (1969). The human choice. Individuation, reason and order versus deindividuation, impulse and chaos. *Nebraska Symposium on Motivation*, *17*, 237–307.

Zimmerman, J., Forlizzi, J., & Evenson, S. (2007). Research through design as a method for interaction design research in HCI. In *Proceedings of the SIGCHI conference on Human factors in computing systems* (pp. 493-502). ACM.

Appendix 1

The complete version of the “crowd management narratives”



You can download the high resolution version via this QR Code:

Appendix 2

A full list of collected 107 positive emotional feelings

107 positive emotional feelings			
Positive emotional feelings	Number of times being mentioned	Positive emotional feelings	Number of times being mentioned
Accompanied	1	Important	1
Active	1	In harmony	1
Affected	2	Inspired	3
Anonymous	1	Interactive	1
Anticipated	1	Interested	1
Belongingness	2	Intoxicated	1
Blessed	2	Involved	3
Bustling	9	Joyful	4
Calm	3	Legitimate	1
Carefree	1	Light-hearted	2
Caring	2	Live in the moment	1
Casual	1	Lively	1
Cheerful	4	Looking forward	2
Close	1	Lulled	1
Collaborative	1	Marvelous	1
Comfortable	3	Motivated	2
Community	1	Multi-tasking	1
Contacting	1	Mutual support	1
Content	1	Not lonely	1
Cooperative	1	Observant	1
Cozy	8	On the flow	1
Crazy (in a positive way)	2	Open	1
Crowd wisdom	1	Part of a big group	2
Curious	3	Party	2
Delighted	1	Passionate	1
Dizzying	1	Peaceful	1
Drunk (positively)	3	Pleasant	1
Easy going	1	Pleased	1
Ecstasy	1	Powerful	3
Elated	1	Prosperous	1
Energetic	1	Proud	2
Enjoyable	1	Quiet	1
Enthusiastic	7	Relaxed	6
Euphoria	1	Same mindset	1
Eventful	1	Satisfied	2
Excited	23	Secure	5
Exploring	1	Sense of achievement	1
Expressive	1	Sense of support	1
Familiar	1	Sense of variety	1
Family	1	Sharing	4
Feeling accepted	1	Smiling	4
Feeling connected	3	Sociable	2
Festival feel	2	Solidary	1
Free	2	Spontaneous	2
Friendly	1	Structured	1
Fulfilling	1	Surprised (positively)	1
Glad	1	Tight	1
Gratified	1	Togetherness	5
Happy	22	Touched	1
Heated	1	United	2
High	1	Vibrant	1
Hopeful	1	Warm (psychologically)	13
Hyper-funny	2	Warm-hearted	1
		Well-being	2

A full list of collected 127 negative emotional feelings

127 negative emotional feelings			
Negative emotional feelings	Number of times being mentioned	Negative emotional feelings	Number of times being mentioned
Afraid	3	Jealousy	1
Aggressive	3	Lack of freedom	1
Agitated	2	Lack of privacy	1
Aimless	1	Locked	1
Alert	2	Lonely	5
Always standing	1	Losing track of friends	1
Angry	11	Lost	1
Annoyed	9	Loud	1
Anxious	16	Meaningless	1
Ashamed of others	1	Meddling	1
Awkward	4	Mind others	1
Being criticized	1	Muggy	1
Being ignored	5	Nauseated	2
Being pissed off	1	Nervous	5
Being pushed	1	Noisy	2
Being repressed	1	Numb	1
Blue	1	Oppressed	2
Boiling	1	Outsider	2
Bored	5	Overcrowded	1
Breathless	5	Overwhelmed	2
Cautious	1	Panic	2
Chaotic	1	Physical contact	1
Cheated	1	Powerless	1
Claustrophobia	1	Rage	1
Clueless	1	Restless	1
Confined	1	Restricted	1
Confused	4	Sad	3
Dangerous	1	Scared (of being trapped)	2
Depressed	3	Scrambled	1
Desperate	2	Shame	1
Disappointed	4	Shy	1
Disgusted	6	Smelly	5
Dislike	1	Stressful	8
Disorganized	1	Stuffy	3
Disoriented	3	Stupid	1
Dissatisfied	1	Suffocated	1
Distracted	1	Sweat (from strangers)	1
Distraught	1	Tense	2
Disturbed	1	Tired	7
Drunk	2	Trapped	1
Empty	1	Troublesome	1
Exhausted	1	Uncomfortable	4
Fake politeness	1	Unconfident	2
Fake smiling	1	Uncontrolled	1
Fearful	4	Uneasy	3
Feeling inferior	1	Unexpected	1
Feeling pressure	2	Unfair	1
Feeling small	3	Unhappy	3
Frustrated	8	Unimportant	1
Fury	1	Unintelligent	1
Getting over-attention	1	Uninterested	1
Hasty	1	Unkind	1
Helpless	4	Unsafe	2
Hot	5	Unsettled	2
Hunted	1	Urged	1
Hurtful	1	Want to go home	1
Immobile	1	Waste of time	2
Indifferent	1	Weak	3
Indisposed	1	Wishing to escape	2
Injured	1	Wordless	1
Insecure	1	Worried to miss accompanies	4
Intolerable	1		
Invasion of personal space	1		
Invisible	1		
Irritated	11		
Isolated	1		

Appendix 3

Sorted emotional categories

The numbers highlighted in blue represent the number of emotional terms in that category.

A1-A7. Positive emotional categories in Session 1

A1	A2	A3	A4	A5	A6	A7	Unsorted
Accompanied	Bustling	Cheerful	Content	Blessed	Active	Affected	Structured
Anonymous	Carefree	Delighted	Enthusiastic	Calm	Curious	Caring	
Anticipated	Crazy	Enjoyable	Expressive	Casual	Exploring	Contacting	
Belongingness	Dizzying	Fulfilling	Heated	Comfortable	Inspired	Cozy	
Close	Drunk (positively)	Glad	Important	Easy going	Interested	Hopeful	
Collaborative	Ecstasy	Gratified	Legitimate	Free	Looking forward	Open	
Community	Elated	Happy	Motivated	Light-hearted	Observant	Tight	
Cooperative	Energetic	Joyful	Multi-tasking	Lulled	Sense of variety	Touched	
Crowd wisdom	Euphoria	Passionate	Powerful	Peaceful	Solidary	Warm-hearted	
Familiar	Eventful	Pleasant	Prosperous	Quiet	Surprised (positively)		
Family	Excited	Pleased	Proud	Relaxed			
Feeling accepted	Festival	Satisfied	Sense of achievement	Secure			
Feeling connected	High	Smiling					
Friendly	Hyper-funny	Well-being					
In harmony	Intoxicated						
Interactive	Live in the moment						
Involved	Lively						
Mutual support	Marvelous						
Not lonely	On the flow						
Part of a big group	Party						
Same mind-set	Spontaneous						
Sense of support	Vibrant						
Sharing							
Sociable							
Togetherness							
United							
Warm							
27	**22**	**14**	**12**	**12**	**10**	**9**	**1**

B1-B5. Positive emotional categories in Session 2

B1	B2	B3	B4	B5	Unsorted
Accompanied	Active	Blessed	Affected	Bustling	Multi-tasking
Anonymous	Cheerful	Calm	Anticipated	Carefree	Sense of variety
Belongingness	Crazy	Comfortable	Collaborative	Casual	
Caring	Delighted	Content	Crowd wisdom	Free	
Close	Dizzying	Cozy	Curious	Light-hearted	
Community	Drunk (positively)	Fulfilling	Exploring	Live in the moment	
Contacting	Ecstasy	Gratified	Hopeful	Spontaneous	
Cooperative	Elated	Lulled	Inspired	Well-being	
Easy going	Energetic	Peaceful	Legitimate		
Familiar	Enjoyable	Pleasant	Looking forward		
Family	Enthusiastic	Pleased	Motivated		
Feeling accepted	Euphoria	Quiet	Observant		
Feeling connected	Eventful	Relaxed	Open		
Friendly	Excited	Satisfied	Sense of achievement		
Important	Expressive	Secure	Surprised (positively)		
In Harmony	Festival	Smiling			
Interactive	Glad				
Involved	Happy				
Mutual support	Heated				
Not lonely	High				
On the flow	Hyper-funny				
Part of a big group	Interested				
Party	Intoxicated				
Same mind-set	Joyful				
Sense of support	Lively				
Sharing	Marvelous				
Sociable	Passionate				
Solidary	Powerful				
Structured	Prosperous				
Tight	Proud				
Togetherness	Vibrant				
Touched					
United					
Warm					
Warm-hearted					
35	**31**	**16**	**15**	**8**	**2**

C1-C11. Negative emotional categories in Session 1

C1	C2	C3	C4	C5	C6	C7
Being ignored	Agitated	Aggressive	Anxious	Always standing	Afraid	Bored
Being repressed	Alert	Angry	Awkward	Being pushed	Aimless	Fake politeness
Claustrophobic	Annoyed	Being pissed off	Being criticized	Disorganized	Clueless	Fake smiling
Feeling inferior	Dangerous	Cheated	Blue	Invasion of personal space	Confused	Indifferent
Feeling small	Disturbed	Distraught	Depressed	Losing track of friends	Desperate	Meaningless
Immobile	Frustrated	Feeling pressure	Invisible	Lost	Disoriented	Numb
Lack of freedom	Hunted	Fury	Lonely	Loud	Fearful	Stupid
Lack of privacy	Insecure	Hasty	Outsider	Meddling	Helpless	Unimportant
Locked	Nervous	Irritated	Shame	Noisy	Isolated	Uninterested
Muggy	Panic	Jealousy	Shy	Overcrowded		
Oppressed	Stressful	Rage	Troublesome	Scrambled		
Overwhelmed	Tense	Unfair	Unconfident	Worried to miss		
Powerless	Uncontrolled	Unkind	Unhappy			
Scared (of being	Unsafe	Urged	Wordless			
Stuffy	Want to go home	Waste of time				
Unintelligent						
Wishing to escape						
17	**15**	**15**	**14**	**12**	**9**	**9**

C8	C9	C10	C11	Unsorted 1	Unsorted 2	Unsorted 3	Unsorted 4
Boiling	Chaotic	Hurtful	Dislike	Cautious	Distracted	Ashamed of others	Empty
Breathless	Disgusted	Injured	Intolerable	Getting over-attention		Disappointed	Exhausted
Confined	Drunk	Mind others	Sad	Unexpected		Dissatisfied	Tired
Hot	Indisposed	Physical contact	Uncomfortable				Weak
Restless	Nauseated	Sweat (from strangers)	Uneasy				
Restricted	Smelly						
Suffocated							
Trapped							
Unsettled							
9	**6**	**5**	**5**	**3**	**1**	**3**	**4**

D1-D9. Negative emotional categories in Session 2

D1	D2	D3	D4	D5	D6
Agitated	Always standing	Ashamed of others	Afraid	Awkward	Aggressive
Annoyed	Being pushed	Being criticized	Alert	Bored	Angry
Anxious	Boiling	Being repressed	Cautious	Disorganized	Being pissed off
Blue	Hot	Empty	Claustrophobia	Exhausted	Desperate
Breathless	Immobile	Feeling inferior	Dangerous	Indifferent	Disappointed
Depressed	Lack of privacy	Feeling small	Fearful	Indisposed	Disgusted
Dislike	Locked	Meddling	Hunted	Meaningless	Distraught
Dissatisfied	Loud	Outsider	Hurtful	Overcrowded	Fury
Fake politeness	Muggy	Powerless	Injured	Stupid	Jealousy
Fake smiling	Physical contact	Shame	Insecure	Tired	Nauseated
Frustrated	Restless	Shy	Irritated	Uncomfortable	Noisy
Hasty	Scrambled	Unconfident	Panic	Uninterested	Rage
Intolerable	Smelly	Uncontrolled	Scared (of being trapped)	Unkind	Tense
Lack of freedom	Stuffy	Unimportant	Trapped	Want to go home	
Nervous	Sweat (from strangers)	Unintelligent	Troublesome	Waste of time	
Sad	Wishing to escape	Weak	Uneasy		
Stressful					
Suffocated					
Unhappy					
Unsafe					
Urged					
Wordless					
Worried to miss accompanies					
23	**16**	**16**	**16**	**15**	**13**

D7	D8	D9	Unsorted
Aimless	Being ignored	Cheated	Drunk
Chaotic	Confined	Distracted	Numb
Clueless	Invasion of personal	Feeling pressure	
Confused	Invisible	Getting over-	
Disoriented	Isolated	Mind others	
Disturbed	Lonely	Unexpected	
Helpless	Oppressed	Unfair	
Losing track of friends	Overwhelmed		
Lost	Restricted		
Unsettled			
10	**9**	**7**	**2**

Appendix 4

One version of the questionnaire

Questionnaire Version 1:
Positive Emotional Feelings in Event Crowds

Dear participants,

Thank you for spending 10 minutes on this questionnaire.

Please answer the questions according to your experience in event crowds. There is a definition and a collage of event crowds on next page.

All your personal information will be treated confidentially.

Greetings,

Jie Li

J.Li-2@tudelft.nl

Your Personal Information

Nationality: _____

Gender: ☐ **Male** ☐ **Female**

Age: _____

Height: _____ **cm**

What is an Event Crowd?

An event crowd is always event-based, where people enjoy performances or activities, and want to interact with others, e.g., concerts, exhibitions, conferences and parties etc.

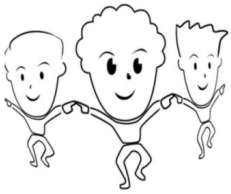
A Collage of Event Crowds

Please recall your experience in event crowds, write them down in the box.

For example, IO Festival, ...

Feel Connected

Feeling connected in crowds is an experience of belongingness or togetherness.



Feel Connected

1) Have you ever felt connected in event crowds?

☐ **Yes** ☐ **No**

If yes, go to Question 2. If no, go to next page.

2) Please indicate how intense you felt it.

☐ **Very slightly** ☐ **Somewhat** ☐ **Moderately** ☐ **Very much** ☐ **Extremely**

3) When you Feel Connected in event crowds, please indicate on a 5-point scale, to what extent the following statements match your experience.

1=Not at all, 2=Slightly, 3=Moderately, 4=Very much, 5=Extremely

Statement	Score 1→5
Be with. I wanted to be or stay close with others.	
Protection. I wanted to protect myself from someone or something.	
Avoidance. I wanted to have nothing to do with something or someone, to be bothered by it as little as possible, to stay away.	
Attending. I wanted to see things well, to try to understand them, or I paid attention.	
Distance. I wanted to keep something or someone out of my way, to keep it at a distance.	
Don't want. I wanted something or someone not to be so, not to exist.	
Helping. I wanted to help someone, to take care of someone.	
Excited. I was excited, restless, could not sit still.	
Exuberant. I wanted to move, be exuberant, sing, jump, undertake things.	
Laughter. I laughed, had to laugh, or wanted to laugh.	
Rest. I felt at rest, thought everything was ok, felt no need to do anything.	

Feel Warm

Feeling warm in crowds is an experience of feeling touched and being cared by people.

Feel Warm

1) Have you ever felt warm in event crowds?

☐ Yes ☐ No

If yes, go to Question 2. If no, go to next page.

2) Please indicate how intense you felt it.

☐ Very slightly ☐ Somewhat ☐ Moderately ☐ Very much ☐ Extremely

3) When you Feel Warm in event crowds, please indicate on a 5-point scale, to what extent the following statements match your experience.

1=Not at all, 2=Slightly, 3=Moderately, 4=Very much, 5=Extremely

Statement	Score 1→5
Be with. I wanted to be or stay close with others.	
Protection. I wanted to protect myself from someone or something.	
Avoidance. I wanted to have nothing to do with something or someone, to be bothered by it as little as possible, to stay away.	
Attending. I wanted to see things well, to try to understand them, or I paid attention.	
Distance. I wanted to keep something or someone out of my way, to keep it at a distance.	
Don't want. I wanted something or someone not to be so, not to exist.	
Helping. I wanted to help someone, to take care of someone.	
Excited. I was excited, restless, could not sit still.	
Exuberant. I wanted to move, be exuberant, sing, jump, undertake things.	
Laughter. I laughed, had to laugh, or wanted to laugh.	
Rest. I felt at rest, thought everything was ok, felt no need to do anything.	

Excited

Being excited in crowds is an experience of feeling elated, eager or enthusiastic.

Excited

1) Have you ever felt excited in event crowds?

☐ **Yes** ☐ **No**

If yes, go to Question 2. If no, go to next page.

2) Please indicate how intense you felt it.

☐ **Very slightly** ☐ **Somewhat** ☐ **Moderately** ☐ **Very much** ☐ **Extremely**

3) When you are Excited in event crowds, please indicate on a 5-point scale, to what extent the following statements match your experience.

1=Not at all, 2=Slightly, 3=Moderately, 4=Very much, 5=Extremely

Statement	Score 1→5
Be with. I wanted to be or stay close with others.	
Protection. I wanted to protect myself from someone or something.	
Avoidance. I wanted to have nothing to do with something or someone, to be bothered by it as little as possible, to stay away.	
Attending. I wanted to see things well, to try to understand them, or I paid attention.	
Distance. I wanted to keep something or someone out of my way, to keep it at a distance.	
Don't want. I wanted something or someone not to be so, not to exist.	
Helping. I wanted to help someone, to take care of someone.	
Excited. I was excited, restless, could not sit still.	
Exuberant. I wanted to move, be exuberant, sing, jump, undertake things.	
Laughter. I laughed, had to laugh, or wanted to laugh.	
Rest. I felt at rest, thought everything was ok, felt no need to do anything.	

Happy

Feeling happy in crowds is an experience of being cheerful, and having great pleasure.

Happy

1) Have you ever felt happy in event crowds?

☐ Yes ☐ No

If yes, go to Question 2. If no, go to next page.

2) Please indicate how intense you felt it.

☐ Very slightly ☐ Somewhat ☐ Moderately ☐ Very much ☐ Extremely

3) When you are Happy in event crowds, please indicate on a 5-point scale, to what extent the following statements match your experience.

1=Not at all, 2=Slightly, 3=Moderately, 4=Very much, 5=Extremely

Statement	Score 1→5
Be with. I wanted to be or stay close with others.	
Protection. I wanted to protect myself from someone or something.	
Avoidance. I wanted to have nothing to do with something or someone, to be bothered by it as little as possible, to stay away.	
Attending. I wanted to see things well, to try to understand them, or I paid attention.	
Distance. I wanted to keep something or someone out of my way, to keep it at a distance.	
Don't want. I wanted something or someone not to be so, not to exist.	
Helping. I wanted to help someone, to take care of someone.	
Excited. I was excited, restless, could not sit still.	
Exuberant. I wanted to move, be exuberant, sing, jump, undertake things.	
Laughter. I laughed, had to laugh, or wanted to laugh.	
Rest. I felt at rest, thought everything was ok, felt no need to do anything.	

Relaxed

Feeling relaxed in crowds is an experience of being calm, comfortable, secure and mentally free.

Relaxed

1) Have you ever felt relaxed in event crowds?

☐ Yes ☐ No

If yes, go to Question 2. If no, go to next page.

2) Please indicate how intense you felt it.

☐ Very slightly ☐ Somewhat ☐ Moderately ☐ Very much ☐ Extremely

3) When you are Relaxed in event crowds, please indicate on a 5-point scale, to what extent the following statements match your experience.

1=Not at all, 2=Slightly, 3=Moderately, 4=Very much, 5=Extremely

Statement	Score 1→5
Be with. I wanted to be or stay close with others.	
Protection. I wanted to protect myself from someone or something.	
Avoidance. I wanted to have nothing to do with something or someone, to be bothered by it as little as possible, to stay away.	
Attending. I wanted to see things well, to try to understand them, or I paid attention.	
Distance. I wanted to keep something or someone out of my way, to keep it at a distance.	
Don't want. I wanted something or someone not to be so, not to exist.	
Helping. I wanted to help someone, to take care of someone.	
Excited. I was excited, restless, could not sit still.	
Exuberant. I wanted to move, be exuberant, sing, jump, undertake things.	
Laughter. I laughed, had to laugh, or wanted to laugh.	
Rest. I felt at rest, thought everything was ok, felt no need to do anything.	

Curious

Feeling curious in crowds is an experience of being interested in something and a desire to explore.

Curious

1) Have you ever felt curious in event crowds?

☐ Yes ☐ No

If yes, go to Question 2. If no, go to next page.

2) Please indicate how intense you felt it.

☐ Very slightly ☐ Somewhat ☐ Moderately ☐ Very much ☐ Extremely

3) When you are Curious in event crowds, please indicate on a 5-point scale, to what extent the following statements match your experience.

1=Not at all, 2=Slightly, 3=Moderately, 4=Very much, 5=Extremely

Statement	Score 1→5
Be with. I wanted to be or stay close with others.	
Protection. I wanted to protect myself from someone or something.	
Avoidance. I wanted to have nothing to do with something or someone, to be bothered by it as little as possible, to stay away.	
Attending. I wanted to see things well, to try to understand them, or I paid attention.	
Distance. I wanted to keep something or someone out of my way, to keep it at a distance.	
Don't want. I wanted something or someone not to be so, not to exist.	
Helping. I wanted to help someone, to take care of someone.	
Excited. I was excited, restless, could not sit still.	
Exuberant. I wanted to move, be exuberant, sing, jump, undertake things.	
Laughter. I laughed, had to laugh, or wanted to laugh.	
Rest. I felt at rest, thought everything was ok, felt no need to do anything.	

Appendix 5

The questionnaire (event crowd version) for self-reporting emotional feelings and action tendencies after the experiments

Thank you for participating the experiment. ☺

Please write down your emotional feelings and behavioral tendencies on Page 4.

The descriptions of 13 emotional feelings and 11 behavioral tendencies are on Page 1-2.

The instructions and examples are on Page 3.

Your name:

Gender:

Age:

Sensor ID:

13 Emotional Feelings
(6 Positive)

Feel Connected The experience of belongingness or togetherness

Excited The experience of feeling very happy, eager or enthusiastic

Feel Warm The experience of being accepted, cared and supported by people

Curious The experience of being interested in something and a desire to explore

Relaxed The experience of being calm, comfortable, secure and mentally free

Happy The experience of being cheerful, and having great pleasure

13 Emotional Feelings
(7 Negative)

The experience of being over-exposed, receiving too much attention or being cautious about threats

The experience of feeling tired, indifferent or impatient because you lose interest in something or have nothing to do

The experience of feeling strong dislike or impatience, or being irritated about something or somebody

The experience of being helpless, disoriented, and not knowing exactly what is happening or what to do

The experience of being nervous or worried about something, or even being panic about unexpected incidents

The experience of being trapped in an unpleasantly warm and limited space, where is not enough fresh air

The experience of being overwhelmed by the scene, feeling unconfident to interact with others, or feeling ignored or oppressed

11 Behavioral Tendencies

Behavioral Tendencies	Description
Be with	I wanted to be or stay close with others.
Protection	I wanted to protect myself from someone or something.
Avoidance	I wanted to have nothing to do with something or someone, to be bothered by it as little as possible, to stay away.
Attending	I wanted to see things well, to try to understand them, or I paid attention.
Distance	I wanted to keep something or someone out of my way, to keep it at a distance.
Don't want	I wanted something or someone not to be so, not to exist.
Helping	I wanted to help someone, to take care of someone.
Excited	I was excited, restless, could not sit still.
Exuberant	I wanted to move, be exuberant, sing, jump, undertake things.
Laughter	I laughed, had to laugh, or wanted to laugh.
Rest	I felt at rest, thought everything was ok, felt no need to do anything.

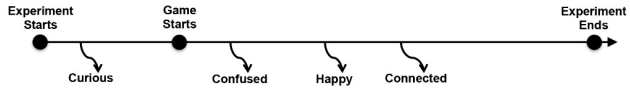
Page 2

Instructions and Examples

Step 1: Write down your emotional feelings on your timeline.

How did you feel? Please indicate on your timeline on Page 4, using the 13 emotional feelings.

For example:



Step 2: Indicate the intensity of your emotional feelings.

Please also indicate (from 1 to 5) how intense did you feel each emotion?

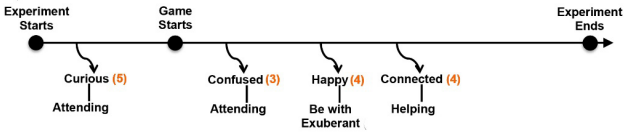
1=Very slightly; 2=Somewhat; 3=Moderately; 4=Very much; 5=Extremely

For example:

Step 3: Write down your behavioral tendencies on your timeline, linked to the emotional feelings.

Please reflect: when you were feeling this emotion, what did you tend to do (using the 11 behavioral tendencies)?
Please write down your behavioral tendencies, linked to that emotion.

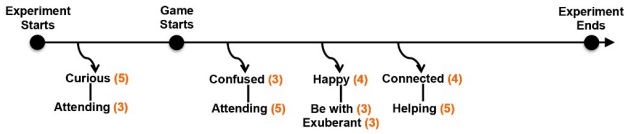
For example:



Step 4: Indicate the intensity of your behavioral tendencies.

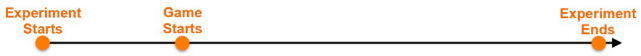
Please also indicate the intensity (from 1 to 5) of each behavioral tendency.
1=Very slightly; 2=Somewhat; 3=Moderately; 4=Very much; 5=Extremely

For example:



Your timeline

Please indicate your emotional feelings, related behavioral tendencies and their intensity on this timeline.



Appendix 6

The possible grouping and theoretical connectivity rate of a 10-person crowd.

Number of subgroups in the 10-person crowd (Each subgroup has at least two persons.)	**Number of persons within subgroups**	**Ratio ***	**Crowd composing** (subgroups and individuals)	**Theoretical connection count** (Assuming that connections only exist within subgroups, not between subgroups)	**Theoretical connectivity rate** (The 100% connectivity of 10 persons is (10×9) /2= **45** connections.)
5	10	1.00	2+2+2+2+2	5	11.11%
4	10	2.00	4+2+2+2	9	20.00%
		1.50	3+3+2+2	8	17.78%
	9	1.50	3+2+2+2+1	6	13.33%
	8	1.00	2+2+2+2+1+1	4	8.89%
3	10	3.00	6+2+2	17	37.78%
		2.50	5+3+2	14	31.11%
		2.00	4+4+2	13	28.89%
	9	2.50	5+2+2+1	12	26.67%
		2.00	4+3+2+1	10	22.22%
		1.00	3+3+3+1	9	20.00%
	8	2.00	4+2+2+1+1	8	17.78%
		1.50	3+3+2+1+1	7	15.56%
	7	1.50	3+2+2+1+1+1	5	11.11%
	6	1.00	2+2+2+1+1+1+1	3	6.67%
2	10	4.00	8+2	29	64.44%
		2.33	7+3	24	53.33%
		1.50	6+4	21	46.67%
		1.00	5+5	20	44.44%
	9	3.50	7+2+1	22	48.89%
		2.00	6+3+1	18	40.00%
		1.25	5+4+1	16	35.56%
	8	3.00	6+2+1+1	16	35.56%
		1.67	5+3+1+1	13	28.89%
		1.00	4+4+1+1	12	26.67%
	7	2.50	5+2+1+1+1	11	24.44%
		2.00	4+3+1+1+1	9	20.00%
	6	2.00	4+2+1+1+1+1	7	15.56%
		1.00	3+3+1+1+1+1	6	13.33%
	5	1.50	3+2+1+1+1+1+1	4	8.89%
	4	1.00	2+2+1+1+1+1+1+1	2	4.44%
1	10	5.00	10	45	100.00%
	9	4.50	9+1	36	80.00%
	8	4.00	8+1+1	28	62.22%
	7	3.50	7+1+1+1	21	46.67%
	6	3.00	6+1+1+1+1	15	33.33%
	5	2.50	5+1+1+1+1+1	10	22.22%
	4	2.00	4+1+1+1+1+1+1	6	13.33%
	3	1.50	3+1+1+1+1+1+1+1	3	6.67%
	2	1.00	2+1+1+1+1+1+1+1+1	1	2.22%

$$\text{* Ratio} = \frac{\textit{The number of persons in the largest subgroup}}{\textit{The number of persons in the smallest subgroup (at least two persons)}}$$

ACKNOWLEDGEMENT

Almost 10 years ago, I landed in the Netherlands in an early morning of August. A kind stranger at the Schiphol airport gave me a prepaid mobile phone sim card, and said, "I am leaving. This might be helpful for you. It has a few euros on it." Since then, my adventure in the Netherlands officially started. I am still using the same mobile phone number from that stranger. Looking back, I am awed by the 10 years I have spent in the Netherlands, by all the changes in my life, and all the helps and blesses I have received.

Huib and Arnold, my English is really limited to express how grateful I am to be your student and to work with you. Thank you so much for years of guidance and patience. I enjoyed the countless meetings with you, full of positive energies, profound discussions, hilarious moments, and of course my cakes. Thank you for accompanying me through this journey and always sharing your positiveness and knowledge with me. I appreciate the trust, encouragement and freedom you give to me, allowing me to explore the research topics and to try out new possibilities in my life as a "*Cake Researcher*". Through all these years, I can easily see that I gradually grow into a more independent researcher, a more critical thinker and a more fulfilled person.

Sylvia, it was an honor and pleasure to be your first master graduation student at TU Delft (with a Cum Laude title that I am proud of :D). I admire your "lighten up" spirits and your enthusiasm towards research. Thank you for introducing me to Huib and Arnold, and encouraging me to do a PhD. I still keep your "little grandma advises" in my mail box: "*Carefully look over all possibilities and whether the position really fits your ultimate wishes and goals. A PhD project takes a long time so the topic really should inspire you*." Now, when I look back, I feel deeply grateful.

Dragan, it was inspiring to have you supervising me at Philips Research. Thank you for bringing me to the world of academic research and fascinating me with the magic of data analysis. The time I spent at Philips boosted my confidence and convinced me to be a researcher.

Pablo, I feel so lucky to join our DIS group at CWI. It is unusual for a person like me with an industrial design background to find a position at a research organization specialized in computer science and mathematics. That's what we call cross-disciplinary research, right? Thank you for giving me the opportunity to collaborate with the world-class scientific researchers. It is a privilege to do a post-doc without a PhD title. Finally, I make it through! Thank you for allowing me to be flexible, giving me time to finalize my thesis, to take care of my daughter, to learn driving, and to run my *Cake Researcher* business. I really appreciate all your support in my work and my life. I am looking forward to building the future of DIS group together with our team.

I really appreciate the time that I spent in the faculty of Industrial Design Engineering of TU Delft with all my awesome colleague friends. Koos and Elmer, you are my role models. Koos, when I first bought your book *Sketching* in 2007, I could not imagine that you were going to be my teacher and friend later on. I enjoyed the trip with you and Elmer to Beijing and learned a lot from you.

Thank you, Koos and Elmer, for showing me that life has many possibilities and encouraging me to explore mine. Elif, thank you for being so nice to me all the time, supporting my cake business and sharing with me your motherhood experiences. Peter, it was an honor to work with you and Christina (Yuting) Wang on the Airbus project. Thank you for giving me an opportunity to give a talk on your inaugural day. It is an important affirmation for an inexperienced researcher. Aadjan, you feel like the "father" of the Studiolabs, thank you for the years of support. Abhigyan, Boedewijn, Chen, Gert, Hester, Holly, Lavender, Lye, Marco, Marian, Patrizia, Reinier, Stella, it was a pleasure to share Studio Mingle with you. Thank you for the nice coffee break talks and your inspiring spirits. Reinier, thank you for being a good example of what a rigorous researcher should be and sharing with me your experience of being a lecturer and guiding students. Qian, we have so many common interests which we can talk ceaselessly for days: handcrafts, research, cakes, dolls, babies...Thank you for the years we spent together in Delft. Ling, brave girl, thank you for letting me know "When life hits you hard. Persevere, never give up and do your best to move on.". Paula, you have been there for me in some tough times and I am so happy to show you how strong and mature I am now. I would particularly like to thank our secretary team: Joost, Daphne, Denise, Amanda and Charleyne, for arranging all kinds of administrative things.

My CWI colleagues, thank you for making me feel valued at work. Zhiyuan, thank you for bringing me to CWI. Abdo, you are the walking Wikipedia at work. Thank you for inspiring me with your free and fearless spirit, your efficiency, and the last-minute supports in experiments, statistics and writing. Tom, I enjoyed the work trips with you. Thank you for all the sleepless hard working and being a listener to my complaints. Ayman, Fons, Francesca, Jack, Kees, Sergio and Steven, thank you for being good examples of world-class researchers. Enestatia, Nacho, Shishir, Tianyi, thank you for sharing the office, the work and the mind-relaxing coffee breaks. Jan Willem and Wouter, thank you for translating my propositions and thesis summary. Yiping, my CWI sister, our minds think alike. You always remain cool and calm no matter rain or shine. Working with you made the dull experiments enjoyable.

I always feel that I am such a lucky person to have so many good friends with me. Di (Cao), I could not imagine how I was going to deal with the sensor data if you did not help me. Thank you for sacrificing your personal time in the late nights and weekends. I really appreciate your help besides your full-time job. Di (Zhang), thank you for being my 18-year friend, enlightening me, and being a good listener to my worries and dreams. We all know the reality, but this does not stop us pursuing our dreams, right? Min and Qingqing, 20 years have passed since we became close friends. You are always there in my hearts. Thank you for encouraging me and always being with me when I need you. My dearest "girl" friends, Chang Liu, Fang Lan, Han Zou, Tiantian Zhang, Qianru Liu, Qinqing Zheng, Wenying Pan, Wenyuan Xia, Yan Fang, Yuanyuan Zhang, from you, I have learned that "being excellent is a habit". Farzaneh, I am so grateful to have you in my life. I will always remember the days when we held each other's hands and told ourselves "We will finally make it!" Yoyo, Prang and Heidi, thank you so much for accompanying me at the beginning of my Netherlands' adventure and

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Finally, I would like to dedicate this thesis to my family. Mama, thank you for being there for me all the time and reminding me that kindness is the most precious thing. Papa, thank you for being "strict" to me, encouraging me to be creative and critical. I still remember the time when we painted together and travelled around in Tibet. My parents-in-law, thank you for loving me and being supportive for all my crazy ideas. Haozheng, no words can express my gratitude to you. The whole world see the strong and cheerful side of me. You are the one comforts the occasionally irritable and vulnerable me. At our age, being together for 13 years is rare. Thank you for the 13-year love and accompany. Leyan, my little funny angel, thank you for coming to mama's life and bringing us so much happiness and laughter. Thank you, Haozheng and Leyan, for understanding me and making my life meaningful.

Jie

Delft

December 31, 2018

CURRICULUM VITAE

Jie Li was born in Chengdu (China) on December 5, 1986. After receiving her bachelor diploma in the Sun Yat-Sen University in Guangzhou (China), she moved to Delft in 2009 to study Strategic Product Design in the faculty of Industrial Design Engineering, TU Delft. She did her master thesis with Philips Research, received her master of science degree in 2011 with Cum Laude, and started her PhD in 2012. Since March 2017, she has worked as a post-doc researcher in the Distributed Interactive Systems group of Centrum Wiskunde & Informatica (CWI) in Amsterdam.

Her PhD research was funded by the Dutch national COMMIT program, as part of the project EWiDS. The goal of the EWiDS project is to develop and test large-scale wireless sensor networks to be used in crowd management practices. During the project, Jie aimed at understanding and sustaining human well-being in crowd situations through measuring the physical and psychological states of a crowd. The core value of her research is to bridge the gap between the technology and human factors.

As a human factor researcher at CWI, Jie is currently working on two European projects: 2-Immerse (https://2immerse.eu) and VRTogether (http://vrtogether.eu). For the 2-Immerse project, her research aims at understanding broadcasting workflows and developing new object-based TV production tools for multiscreen TV viewing experiences. For the VRTogether project, her work focuses on developing appropriate Quality of Experience (QoE) metrics and evaluation methods for social virtual reality experiences.

Besides her academic career, Jie is (almost) a professional cake designer/maker, who runs a café called *Cake Researcher* in the city center of Delft on Saturdays (https://cake-researcher.com).

List of publications

Li, J., Kong, Y., Röggla, T., De Simone, F., Ananthanarayan, S., de Ridder, H., El Ali, A. & Cesar, P. (2019). Measuring and Understanding Photo Sharing Experiences in Social Virtual Reality. **Accepted** as a long paper in *proceedings of 2019 CHI Conference on Human Factors in Computing Systems*.

Li, J., Röggla, T., Glancy, M., Jansen, J., & Cesar, P. (2018). A New Production Platform for Authoring Object-based Multiscreen TV Viewing Experiences. In *Proceedings of the 2018 ACM International Conference on Interactive Experiences for TV and Online Video (TVX 2018)*, pp. 115-126. (**ACM Best Paper Award**).

Li, J., Zheng, Z., Meixner, B., Röggla, T., Glancy, M., & Cesar, P. (2018). De-signing an Object-based Preproduction Tool for Multiscreen TV Viewing. In *Extended Abstracts of the 2018 CHI Conference on Human Factors in Computing Systems (p. LBW600)*. ACM.

Li, J., Vermeeren, A.P.O.S. & De Ridder, H. (2014). Designerly ways of exploring crowds. *International Journal of Cultural and Creative Industries, 2*(1), p. 4-17.

Li, J., Cai, R., De Ridder, H., Vermeeren, A, & Van Egmond, R. (2014). A study on relation between crowd emotional feelings and action tendencies. In *Proceedings of the 8th Nordic Conference on Human-Computer Interaction: Fun, Fast, Foundational (NordiCHI 2014)*, p. 775-784.

Li, J. Erkin, Z., De Ridder, H. & Vermeeren, A.P.O.S. (2013). A field study on real-time self-reported emotions in crowds. In *Proceedings of ICT OPEN 2013*, p. 80-84.

Li, J., De Ridder, H., Vermeeren, A.P.O.S., Conrado, C. & Martella, C. (2013). Designing for crowd well-being: Current designs, strategies and future design suggestions. In *Proceedings of IASDR 2013*, p. 2279-2289.

Li, J., De Ridder, H., Vermeeren, A.P.O.S., Conrado, C. & Martella, C. (2013). Desinging for crowd well-being: Needs and design suggestions. In *Proceedings of the 7th International Conference on Planning and Design*, p. 373-382.

Röggla, T., Li, J., Fjellsten, S., Jansen, J., Kegel, I., Pilgrim, L., Trimby, M., Williams, D., Cesar, P. (2019). From the Lab to the OB Truck: Object-Based Broadcasting at the FA Cup in Wembley Stadium. **Accepted** as a case study paper by *2019 CHI Conference on Human Factors in Computing Systems*.

Röggla, T., Li, J., Jansen, J., Gower, A., Trimby, M., & Cesar, P. (2018). 2IMMERSE Production Suite: A Platform for Creating Interactive MultiScreen Experiences. In *Adjunct Proceedings of the ACM International Conference on Interactive Experiences for Television and Online Video (TVX 2018)*.

Martella, C., Li, J., Conrado, C., & Vermeeren, A. (2017). On current crowd management practices and the need for increased situation awareness, prediction, and intervention. *Safety science, 91*, 381-393.

Wang, Y. T., Li, J., & Vink, P. (2014). The future aircraft interior design in-spired by crowd well-being. In *Advances in Social and Organizational Factors (edited By Peter Vink)*. Published by *the 5th International conference on Ap-plied Human Factors and Ergonomics (AHFE2014)*, p. 11-20.

Wang, Y. T., Li, J., & Vink, P. (2014). Urban legend: A BWB interior that en-hances passenger well-being. *Aircraft Interior International (March Issue)*, p.37.

Erkin, Z., Li, J., Vermeeren, A. P., & de Ridder, H. (2014). Privacy-preserving emotion detection for crowd management. In *International Conference on Active Media Technology*, pp. 359-370. Springer, Cham.

Wijermans, N., Conrado, C., van Steen, M., Martella, C., & Li, J. (2016). A landscape of crowd-management support: An integrative approach. *Safety science, 86*, 142-164.

Martella, C., Van Halteren, A., Van Steen, M., Conrado, C. & Li, J. (2014). Crowd texture as proximity graphs. *IEEE Communications Magazine, 52*(1), p. 115-121.