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Understanding physical distancing compliance behaviour using proximity and survey data: A case study in the Netherlands during the COVID-19 pandemic

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Abstract

Physical distancing has been an important asset in limiting the SARS-CoV-2 virus spread during the COVID-19 pandemic. This study aims to assess compliance with physical distancing and to evaluate the combination of observed and self-reported data used. This research shows that it is difficult to operationalize new rules, that context affects compliance, that there needs to be a need for compliance, and that rules require upkeep. From a methodological point of view, this study found that the combined methods provide a comprehensive picture of compliance behaviour, that it is challenging but essential to mitigate response fatigue in long-term monitoring studies, and that it would be interesting in future research to learn how actual behaviour is influenced by personal narratives.

Peer-review under responsibility of the International Steering Committee for Transport Survey Conferences (ISCTSC)

Keywords: SARS-CoV-2; COVID-19 pandemic; physical distancing; compliance behaviour; proximity sensing; longitudinal survey

1. Introduction

From December 2019 onwards, the SARS-CoV-2 virus rapidly spread across the world. By January 2022, 5.63 million people lost their lives world-wide because of the COVID-19 disease (Dong et al., 2020). To limit the spread of the virus, governments took drastic measures to limit the number of contacts between their citizens. The Netherlands, as many other countries, went into lockdown multiple times due to consecutive rapid outbreaks of SARS-CoV-2 infections, during which the physical presence of people in educational institutions was restricted and most other venues were closed for a prolonged period (Rijksinstituut voor Volksgezondheid en Milieu, 2022a).

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Viruses, such as SARS and MERS, are less likely to be transferred when people keep their distance from each other (Chu et al., 2020). The probability of acquiring a SARS-CoV-2 infection increases with smaller interaction distances, higher levels of respiratory activity, longer contact times and lower air exchange rates (Azimi et al., 2021). Consequently, one important Non-Pharmaceutical Intervention (NPI) to curb the SARS-CoV-2 virus spread is physical distancing. Physical distancing requires people to maintain between 1- and 1.82-meters physical distance between any two individuals that do not belong to the same household (Centers for Disease Control and Prevention, 2021; World Health Organization, 2021).

Yet, there are doubts regarding the extent to which people comply with physical distancing regulations. Human movement dynamics, such as walking and interacting with objects and people while walking, are primarily an unconscious process. So, it might be difficult for people to take conscious decisions regarding their interaction behaviour. Moreover, increasingly frequent conscious detours are required, as spaces meet their capacity sooner.

To understand the effectiveness of physical distancing in practice, understanding physical distancing compliance is essential. To the authors' knowledge, limited empirical observations (i.e., Blanken et al., 2021; Hoogendoorn et al., 2021; Leoni et al., 2022) have been reported on the practice of physical distancing behaviour, which have predominantly focused on observed behaviour. Research pertaining to the intentions and motivations of pedestrians is essential to fully understand physical distance behaviour. An understanding of the relations between beliefs, intentions, and actions featuring physical distancing is much needed to support policy making and crowd management.

The goal of this study is two-sided: (a) to assess compliance with physical distancing in an educational institution, and (b) to evaluate to what extent a combination of observed and self-reported subjective data featuring physical distancing behaviour allows for a better understanding of physical distancing compliance.

This study presents a case study on physical distancing behaviour featuring students and staff in the Dutch Academy of Performing Arts in The Hague. We adopted a longitudinal survey and proximity sensing system to study the students' and staff's attempts to comply with physical distancing regulations. Based on these analyses, we provide conclusions regarding their ability to comply as well as the extent to which these techniques allow for a thorough comprehension of physical distancing behaviour.

This paper continues as follows. First, chapter 2 presents the research methodology. The results of the case study are presented in chapter 3. Chapter 4 highlights the implications of our findings for practice. Lessons regarding the complementary nature of the measurement methodologies are discussed in chapter 5. The last chapter (6) highlights the main conclusions and presents avenues for future research.

2. Research methodology to study physical distancing compliance behaviour

The aim of this study is to assess compliance with physical distancing in educational institutions. At the start of this research, policy makers had three questions regarding the compliance behaviour of students and staff in educational institutions:

1. To what extent do students and staff comply to physical distancing?
2. To what extent does the physical context support compliance behaviour?
3. What are the reasons for non-compliance?

These are the leading research questions and will be addressed empirically in a case study in the Netherlands. To answer these questions, we need to collect insights into the objective physical distancing compliance behaviour and into the experience and sentiment regarding physical distancing and other aspects of the COVID-19 pandemic. For this, we will use a combination of proximity data and longitudinal survey data.

This chapter will further elaborate on the research methodology. First, the case is presented in section 2.1. Sections 2.2 and 2.3 introduce the proximity and survey data respectively. Section 2.4 discusses the scope of the study and section 2.5 presents the characterization of the data.

2.1. Introducing the Dutch Academy of Performing Arts

The case study concerns the Dutch Academy of Performing Arts (DAPA), which is a comprehensive theatre and musical program located in the Koorenhuis building in the Hague. At DAPA, students train for a career as a professional artist. At the start of this research (April 2021), most educational institutions in the Netherlands have been closed due to the high SARS-CoV-2 infection rate. The Dutch government initiated several pilots to investigate under which circumstances schools could safely open in times of a pandemic. By taking part in this pilot, DAPA was allowed to resume on-site educational activities. Students and staff of DAPA could participate in this pilot on the condition that a SARS-CoV-2 self-test was taken twice a week. The pilot took place between April and June 2021.

The Koorenhuis building, hereafter referred to as the building, features three levels with a similar layout (see Fig. 1). The tight corridors bear the shape of a horseshoe. On the left and right sides, the corridor width is 1.5 meters. On both the left and right side, several studios are located. Here, most singing, acting, and dancing lessons take place. Changing takes place in one of the two changing rooms, located on the ground floor and first floor, which are both approximately 25 m^2 and are often shared by two classes simultaneously. During the day, students change their clothes regularly in one of the changing rooms.

(a) (b) (c)

Fig. 1. (a) Layout of the Koorenhuis building, and an impression of (b) the corridor and of (c) the changing rooms.

The population of DAPA comprises of 97 students and 18 staff members. DAPA has two educational programs: (a) a regular three-year program that takes place during the week, totalling 74 students and 12 staff members, and (b) a weekend program of one year, totalling 23 students and 6 staff members. Thus, a total of 86 people are expected in the building per day during the week and 29 people at the weekend (i.e., mainly on Saturdays). The students are divided into eight classes: six week groups (i.e., two groups per year of entry) and two weekend groups. The student group size varies between 7 and 16 students. For this study, we consider both the individual groups and their aggregation into three categories: (a) all week students, (b) all weekend students, and (c) all staff. The ages of the categories range from 15-27 for week students, from 9-18 for weekend students, and from 34-54 for staff.

The aim of the pilot at DAPA was to identify the impact of measures that educational institutions can take when opening again during the COVID-19 pandemic. The aim of these measures is to increase awareness and compliance with physical distancing. The total study period of twelve weeks was divided into four periods, from now on called scenarios.

The national measures to minimize SARS-CoV-2 infections, such as physical distancing[1] and wearing face masks, have been taken as the benchmark scenario (scenario 1). From these measures, the following nine rules have been derived that were implemented in the building before the start of this pilot:

1. I have to avoid contact with students outside my own group (i.e., social bubble)
2. I can only use the stairs in one direction
3. A maximum of two people can use the elevator at the same time
4. I have to keep right in the corridor
5. I have to keep 1.5 meters distance from others in the corridor
6. I have to wear a face mask in the corridor
7. I have to stay in the classroom during breaks
8. I have to wear a face mask in the changing room
9. I have to keep 1.5 meters distance from others in my own group, except in scenes and choreographies.

During each subsequent experimental scenario, new measures were added to the mix based on insights from previous scenarios. All rules and measures were kept active until the end of the study period. The sets of new measures include addressing important bottlenecks in the building and introducing a daily exercise to raise awareness of 1.5 meters (scenario 2), reminding students about physical distancing through posters and through communication by staff (scenario 3), and reminding students about wearing their tag (for explanation see section 2.2) and their face mask through communication by staff (scenario 4).

To place the experiment in context of the COVID-19 pandemic, Fig. 2 illustrates the planning of the experimental scenarios in relation to the national trend regarding SARS-CoV-2 infections, vaccinations, and policy changes.

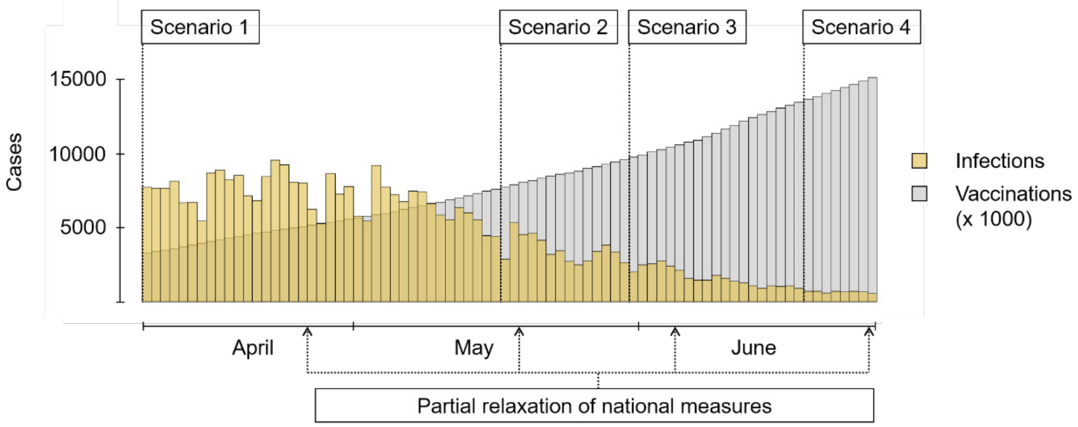

Fig. 2. The relation between the experimental scenarios and the evolution of the COVID-19 pandemic (i.e., infection rate, vaccination rate, and the national policy changes[2]) in the Netherlands (April – June 2021).

2.2. Measuring proximity

The proximity monitor of Forkbeard (2022) is used to measure the objective compliance behaviour of staff and students. This system consists of two main elements: (a) static beacons located at strategic points throughout the building, and (b) student wristbands that are to be worn in the building throughout the entire experimental period (April – June 2021). Most staff members used a smartphone application with similar functionality. Hereafter, both the

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[1] The threshold for physical distancing in the Netherlands is 1.5 meters, and a violation of this for a total duration of over 15 minutes per day is considered a high-risk exposure (Rijksinstituut voor Volksgezondheid en Milieu, 2022b).
[2] The data is collected from (Mathieu et al., 2021; Rijksoverheid, 2021; Rijksinstituut voor Volksgezondheid en Milieu, 2022a).

wristbands and smartphone applications are called tags. The tags determine their position in relation to the beacons and other tags in the building at a resolution of 1 time per second. The distance bins in the data have a bin size of 0.25 meter (for phones) and 0.5 meter (for wristbands). According to Forkbeard (2022), a precision of 0.1 meter can be reached.

The data from the proximity monitor is aggregated by the researchers into two categories: <1.5 meters and ≥ 1.5 meters. The data of the <1.5 meters bin have been used to analyze the compliance behaviour of the DAPA population, by means of analyzing contact events.

A *contact event* is an interaction between two tags within 1.5 meters (at a given point in time with a certain duration). This can be an aggregation of multiple records in one distance bin (i.e., <1.5 meters). We distinguish between intra-group and inter-group contact events, which are respectively contact events within the same group or between groups (groups are defined in section 2.1).

2.3. Measuring experience and sentiment

A series of questionnaires was conducted among the staff and the students of DAPA to determine their perception of, and the intentions and motivations behind their compliance behaviour.

The series comprised of four waves, one during each scenario, and each wave comprised of two parts. A static selection of questions that was presented to the participants in all waves and a dynamic selection of questions that varied depending on the students' behaviour and the set of measures that was just introduced. In all cases, the questionnaire was sent out to the staff and students via email. As the non-response increased with each wave, a small incentive was provided in the last two waves (i.e., a lottery for three fifty-euro gift vouchers).

2.4. Scope

In section 2.1 we have aggregated the individual groups into three categories: week students, weekend students and staff. In this study, we will primarily focus on the week students and involve the weekend students and staff to a lesser extent. The reasoning behind this choice is that we expect that the three categories naturally have different interaction dynamics and therefore should not be combined for analysis. We chose to study the largest category, the week students, because they are the most representative (student) group for educational environments in the Netherlands. Where relevant in this paper, we also highlight the other categories.

In addition, we will mainly focus on the interactions between the six week students groups (i.e., the inter-group interactions). The reasoning behind this choice is that we expect interactions within the groups to take place more regularly as a group spend several hours a day together and they are exempt from the physical distancing rule during theatre and dance training (see rule 9 in section 2.1). If a member of a group is unknowingly infected and present despite testing, the social bubble structure limits the risk of the virus spreading to the other groups. For this reason, preventing inter-group contact events is considered most important, and will therefore be the main focus in the contact event analyses.

To curb privacy concerns, no connection is made at the level of distinct individuals between the survey and proximity data. Consequently, we cannot establish relations between actual behaviour and personal narratives.

2.5. Characterization of the proximity and survey data

The proximity data was collected over twelve weeks. Fig. 3 illustrates the number of student tags (i.e., wristbands) that were present in the building per day. Any student tag for which a record exists on a given day is identified as a participating tag. The graph shows three gaps: the exam period and the May holidays (scenario 1), the bank holidays around Ascension Day (scenario 1), and around Pentecost (scenario 2).

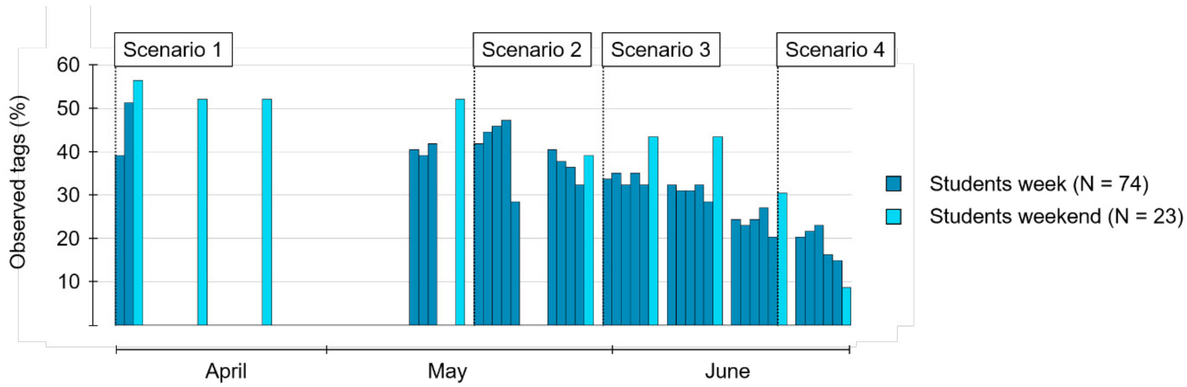

Fig. 3. The number of observed student tags relative to the theoretical demand (N) in the building per day (April – June 2021).

For the majority of the study, less than 50% of the students participate daily (i.e., by wearing a functioning tag). On average, the participation of weekend students (42%) is higher than of week students (33%). For both groups the participation decreases over time.

The survey results partly mirror and explain the trends in the proximity data. In the first scenario, over half of the students agree that it's fine to wear a wristband (Fig. 4a). This is especially true for the weekend students, for which most also agree to wear their wristband all the time (Fig. 4b). This is in line with the trend in the proximity data (i.e., higher participation rate). Fig. 4b also shows that a substantial part of the week students admits not to wear their wristband all the time. In the second and fourth scenario, week students were asked to indicate which statement about wearing the wristband applied to them (Table 1). The students were most affirmative about not wearing their wristbands at the beginning of the day and during the dance classes. This (partly) explains why students admit to not wear their wristband all the time. Moreover, in the fourth wave, a higher percentage of students indicates the wristband is not worn at all (i.e., it is either broken or left at home). This (partly) explains the decreasing participation in the proximity data over time.

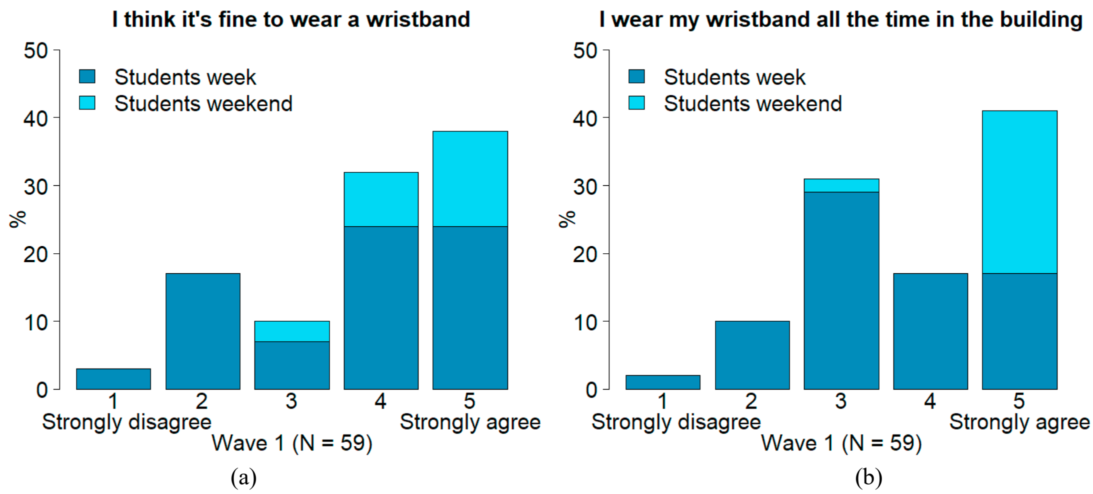

Fig. 4. Sentiment about (a) the acceptance and (b) the wearing of wristbands among students in wave 1.

Table 1. Statements that apply to wearing a wristband among week students in wave 2 and 4.

The following applies to wearing a wristband	Wave 2 N = 30	Wave 4 N = 19
"I often forget to put on my wristband immediately when I get to school, and don't put it on until later in the day"	63%	42%
"I don't wear my wristband during dance classes because it's dangerous"	33%	16%
"I forget my wristband at home"	20%	26%
"As soon as I get to school I go to my locker to put on the wristband"	17%	11%
"My wristband is broken"	7%	21%

Also in the survey data the participation decreases (Fig. 5). For most groups, the response rate was highest during the first wave. Overall, the experience of almost all individual groups are represented. Only one group of week students was not successfully captured in all waves.

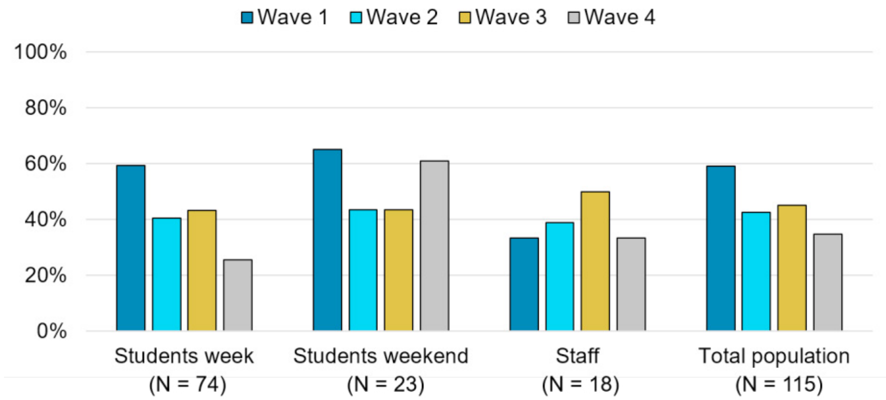

Fig. 5. Response rate per wave per aggregated group (i.e., category), and of the total population.

In conclusion, both the proximity and survey data show response fatigue. The survey data provides a few insights as to why this is the case, which can serve as a starting point for mitigating response fatigue.

3. Results regarding physical distancing compliance behaviour at DAPA

At the start of this research, policy makers had three questions regarding the physical distancing compliance behaviour of students and staff in educational institutions (presented in chapter 2). In this chapter, these questions are addressed one-by-one using a combination of insights from the proximity and survey data. As explained in section 2.4, we will primarily focus on week students.

3.1. To what extent do students and staff comply to physical distancing?

To objectively study compliance behaviour, we measure the number of contact events participants had. Fig. 6 visualizes the temporal trend (i.e., the number of contact events within and between week student groups per period of day, aggregated per 5 minutes) of the first weekday in each scenario. In the data, fewer intra-group and inter-group contact events are observed over time, suggesting that students are increasingly able to keep their distance from students from their own and other groups. However, we can only draw conclusions on this metric on the condition that all attending students wear their tags and that the tags function properly. Given that Fig. 3 has shown that the number of observed student tags is decreasing over time, we find it more plausible that the observed decline in contact events is mainly due to decreasing participation, rather than students improving their physical distancing behaviour.

Hence, based on this metric in combination with this data we cannot draw conclusions about students' compliance behaviour.

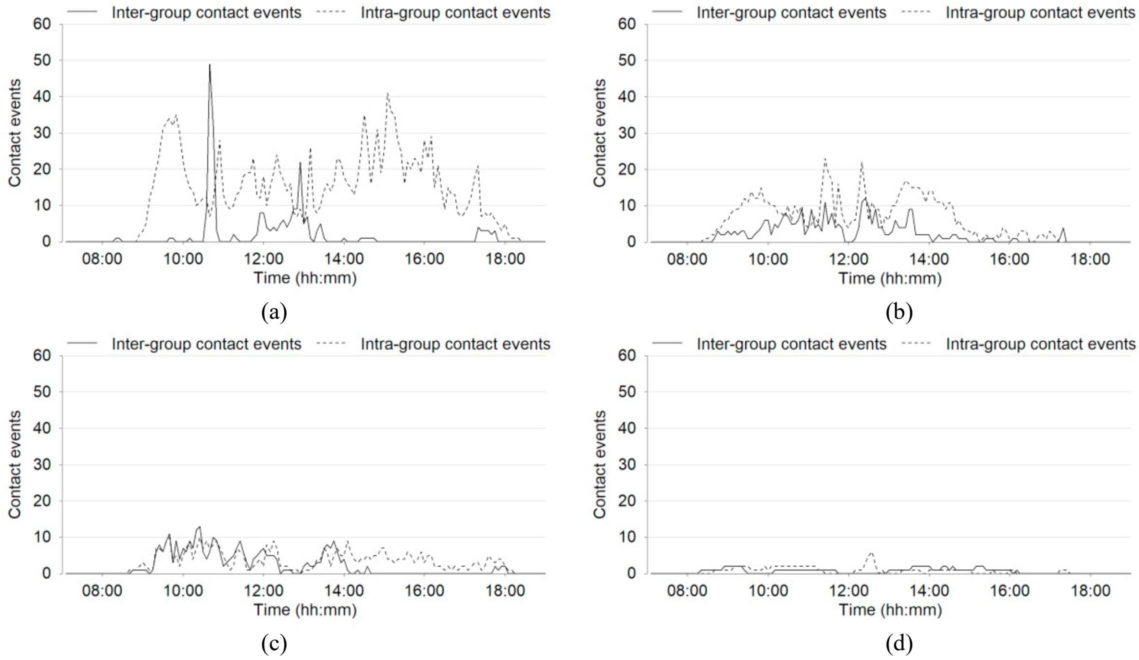

Fig. 6. Number of contact events between week students on a day, aggregated per 5 minutes, for (a) April 8th, 2021 (scenario 1), (b) May 17th, 2021 (scenario 2), (c) May 31st, 2021 (scenario 3), and (d) June 21st, 2021 (scenario 4).

We also analysed the duration of interactions between week students. Fig. 7 shows the distribution of the total duration of both inter-group and intra-group contact events per pair per day, for all days in each scenario. The data shows that high-risk interactions (>15 minutes) occur within and between social bubbles in each scenario. This implies that students have difficulties to comply to physical distancing throughout the entire study period, despite the implemented measures (see section 2.1). As expected (see section 2.4), this happens far more often within the social bubbles than between them (i.e., the median total duration throughout the period is 26.4 minutes for intra-group contact events and 2.0 minutes for inter-group contact events). Yet, based on the revealed long inter-group interactions (i.e., >15 minutes), we also conclude that students belonging to different social bubbles meet for prolonged durations of time (i.e., at lunch, before and after classes). This seems to be more so the case for later scenarios, as the frequency of high-risk interactions between groups increases over time. This apparent behavioural trend may have been influenced by multiple factors, including students' awareness of a decrease in the prevalence of COVID-19 infections and an increase in vaccination coverage within the population (see Fig. 2).

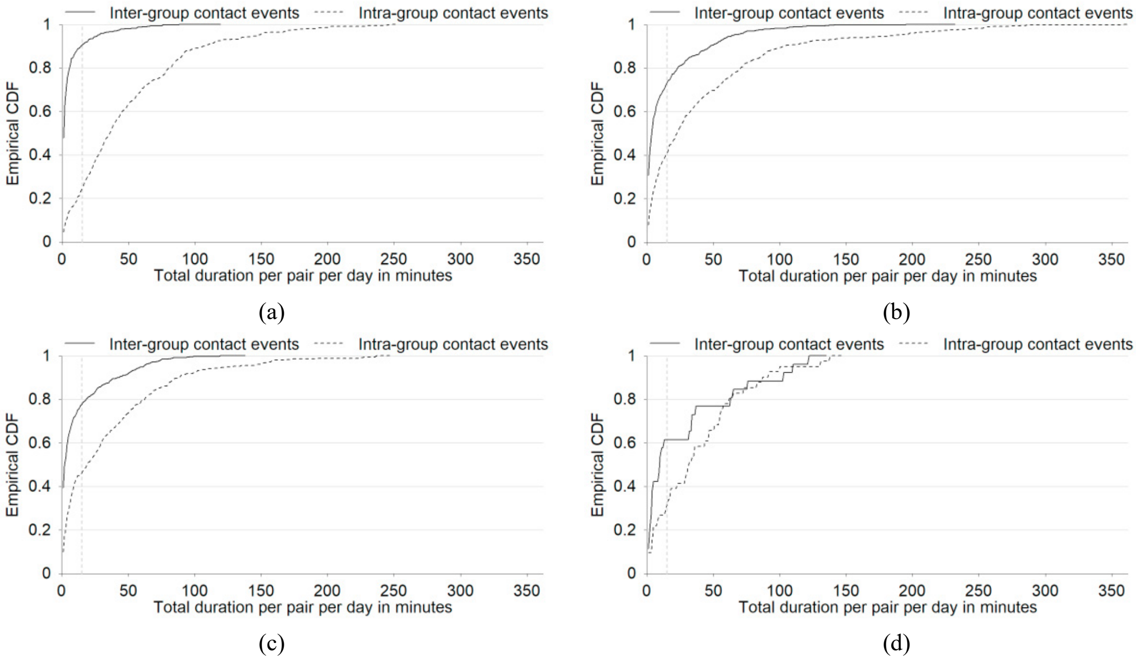

Fig. 7. Total duration of all contact events per pair per day in the building, only considering week student interactions, for all days in (a) scenario 1, (b) scenario 2, (c) scenario 3, and (d) scenario 4. The threshold for a higher SARS-CoV-2 transmission risk is indicated at 15 minutes by a dashed grey line.

Using the surveys, we collected participants' own perceptions on compliance with physical distancing. Fig. 8 shows that none of the week students think they can always (score = 5) keep their distance. During the first wave, 34% of the week students (N = 44) report that they can often (score = 4) keep their distance. This percentage gradually drops during consecutive waves to 5% of the week students (N = 19) in the last wave. This trend points in the same direction as the trend observed in inter-group contact events in the proximity data (Fig. 7). However, the participants were not asked in the survey (Fig. 8) to differentiate between intra-group and inter-group interactions, so they either kept all interactions in mind or one type specific when answering. The results of the survey therefore cannot be directly linked to the results of the proximity data (which clearly distinguish between intra-group and inter-group contact events). We cannot say without a doubt that the two data types validate each other.

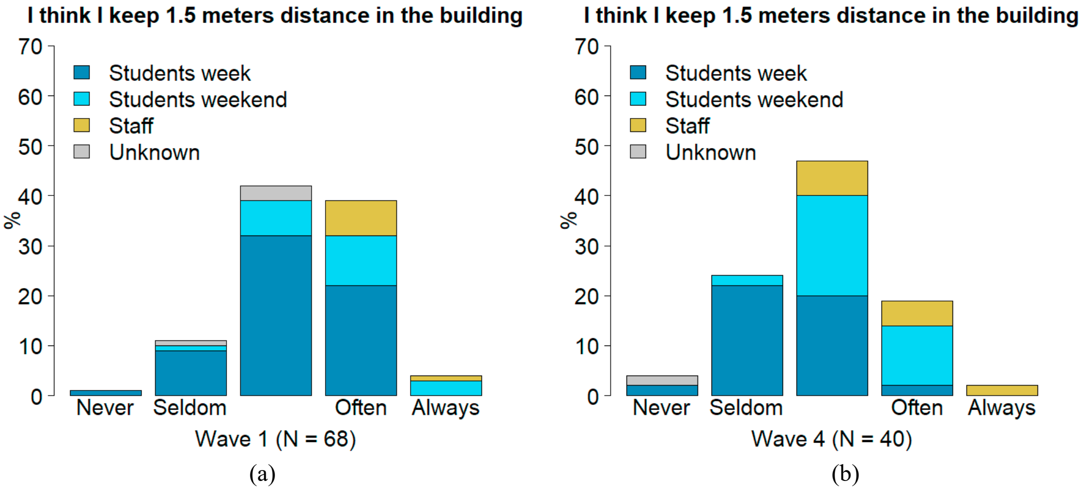

Fig. 8. Perception of compliance behaviour among participants during (a) wave 1 and (b) wave 4 (Likert scale: (1) Never, (2) Seldom, (3) Sometimes, (4) Often, (5) Always).

Based on the findings of the proximity and survey data, we conclude that all week students struggle to comply to physical distancing to some extent, and that this struggle increases over time. The proximity data suggests that at least a part of the week students meets one or more students from other social bubbles for an extended period of time throughout the entire study period. Whether it is intentional non-compliance or a lacking ability to keep one's distance is difficult to say based on the observations above. In section 3.2 and 3.3 we further study the reasons for non-compliance.

3.2. To what extent does the physical context support compliance behaviour?

We attempted to identify the location of contact events in the proximity data. Yet, our data analysis shows that there is too much noise in communication between the tags and the beacons to identify in which exact room or corridor the participants were standing. Therefore, we have decided not to analyze this further. To our understanding, the tag-to-tag communication is more accurate and thus less affected by noise.

In all waves of the survey, the students and staff members were asked to identify at what areas in the building it was difficult to comply to physical distancing. Fig. 9 shows the responses of the week students of all waves. At the beginning of the pilot, the four most identified areas are the changing rooms on the first and second floor, the classrooms and the corridors. In later waves, the classroom is mentioned less and the stairs are mentioned more often. These areas are typically small or narrow, and feature a low capacity. In addition, these areas also feature high demand, during which multiple groups cross each other during lecture breaks or while changing. The toilets are identified much more often after wave 1 because it was included as a fixed answer in the survey from wave 2 onwards. Interestingly, none of the students mentioned that nowhere it was difficult to comply to physical distancing.

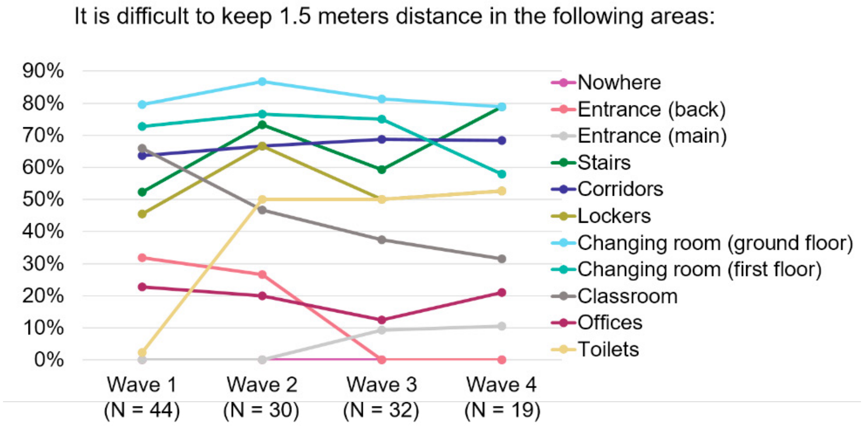

Fig. 9. The perceived difficulty among week students in keeping a distance of 1.5 meters in certain areas of the building.

Based on the survey data, several low capacity, high demand areas have been identified, where most week students (>64%) find it difficult to comply to physical distancing. This implies that the students' sense of behavioural control is limited in these areas, which can lead to less compliant behaviour. That is, the physical context (in certain areas) does not support compliance behaviour.

We could not validate the results of the survey data with the proximity data, because the localization capabilities of the proximity detection system are not adequate. In future research, it would be interesting to investigate how perceptions of capacity problems relate to the actual observed dynamics at high demand areas.

3.3. What are the reasons for non-compliance?

The results to the previous two questions illustrate that it is to some extent difficult to comply to physical distancing in the building (section 3.1), and that it can be assumed that part of the non-compliance is caused by lack of space or high demand (section 3.2).

In all waves of the survey, the participants were asked directly about their reasons for non-compliance. Table 2 shows the responses of the week students of all waves. Across all waves, the most frequently cited reason for non-compliance is that students forget to keep their distance. This might suggest that incorporating physical distancing into a person's movement behaviour is a demanding intervention and difficult for students to implement. After the first wave, fewer students report that there is not enough space. This may be the result of the measures (see section 2.1) that have been implemented since the second wave, in which we focused on mitigating capacity problems in the building. Towards the end of the study period, students indicate significantly more often that their non-compliance is related to (the behaviour of) others (i.e., "others do not keep their distance either", "keeping distance is not social"). It seems that their individual attitude is influenced by a changing collective attitude towards physical distancing. It could be that students question the social sacrifices for obeying the rules, and their argumentation can be strengthened by the reduction in severity of the COVID-19 pandemic in the Netherlands (Fig. 2). This trend could explain the increasing long inter-group interactions (Fig. 7).

Table 2. Reasons for non-compliance among week students in wave 1, 2, 3 and 4.

If I do not keep 1.5 meters distance at school, it is because	Wave 1 N = 44	Wave 2 N = 30	Wave 3 N = 32	Wave 4 N = 19
"I forget to keep distance"	75%	60%	66%	74%
"There is not sufficient space to keep distance"	68%	47%	50%	47%
"Others do not keep their distance either"	43%	33%	38%	63%
"Keeping distance is not social"	23%	33%	22%	47%
"I think other people do not have COVID-19"	23%	47%	25%	42%
"I think it is not necessary to keep 1.5 meters distance"	2%	27%	6%	16%

In addition, we identified three other potential reasons for non-compliance:

1. They do not exactly know the rules they need to comply to
2. They question the usefulness of the rules, which curbs their overall compliance
3. They try to comply, but their perception of distance is off.

Underneath, we use the survey data to investigate to what extent these reasons are plausible.

3.3.1. Knowledge of the rules applied in the building

In the first wave, the participants were asked what rules applied in the building. The responses of the week students show that of the nine rules (as presented in section 2.1), some rules were better known than others. To wear a face mask in the corridor (rule 6) was known by 98% of the week students and ranked highest. To keep 1.5 meters distance from others in the corridor (rule 5) was known by 80% and ranked third. The rules that aim to prevent contact between groups, namely to avoid contact with students outside my own group (rule 1) and to stay in the classroom during breaks (rule 7), were known by 52% and 39% respectively. Interestingly, the latter two rules are considered the most effective against the spread of a virus, as it prevents people from different groups from interacting at close distance. Yet, many students did not seem to know that these rules applied in the building.

The week students were also asked about the physical distancing rule that applied within their own group (rule 9). A substantial part (45%) indicated that they should either always or never keep their distance in class, while the rule states that they have to keep distance in class, except during a choreography or scene. We assume that this rule has caused confusion among the students to some extent.

These findings indicate that at the start of this study a substantial portion of the week students (at least 61%) did not have sufficient knowledge regarding all the rules in the building. This might partially explain why contact events were seen frequently. After the first wave, the students were reminded of the nine rules by email.

3.3.2. What is their opinion on the usefulness of rules

In the first wave, participants were also asked about their views and attitudes towards the rules. A small portion of the week students indicates that wearing a face mask in the corridor (rule 6) is an important rule (32%), as well as physical distancing in the corridor (rule 5) (14%). A larger part is willing to follow these rules, namely 55% and 48% of the week students indicate that they follow rule 6 and rule 5 as well as possible. Yet, the small number of affirmative answers regarding the usefulness of these two rules surprised us, as these two rules are the cornerstone of the world-wide regulations to limit the SARS-CoV-2 virus spread. The students' answers highlight a limited support for these rules in the building, and imply a somewhat negative attitude towards physical distancing. However, we cannot rule out that their attitude towards physical distancing is different in other areas of the building or in general.

3.3.3. Ability to perceive 1.5 meters

Fig. 10 depicts the answers of both staff and students regarding their self-reported ability to correctly identify 1.5 meters. During the second wave, a substantial proportion (63%) of the students and staff are confident that they can identify 1.5 meters correctly (score ≥ 4). During the fourth wave, both the number of highly confident individuals (score $= 5$) as well as the number of less confident (score ≤ 3) individuals increase, respectively to 31% and 52% of the population. Based on only their perception, it is difficult to say whether a person correctly evaluates the distance to another person (or not) and acts accordingly (or not). More research is needed to evaluate whether or not it is plausible that self-reported inaccurate perception of 1.5 meters results in actual non-compliance.

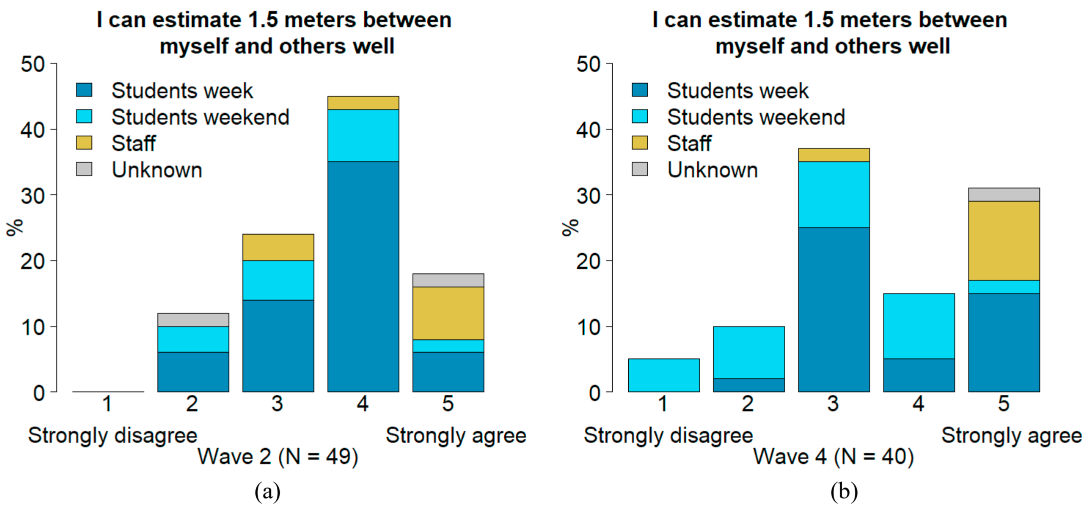

Fig. 10. Perception of ability to estimate 1.5 meters correctly among participants during (a) wave 2 and (b) wave 4.

4. Conclusions regarding physical distancing compliance behaviour at DAPA

The results presented in chapter 3 provide insights into the physical distancing compliance behaviour at DAPA. The proximity and survey data provided important insights into the behaviour and the underlying (mental) processes of, primarily, the students. The main conclusions are presented underneath.

Difficult to operationalize new (counter-intuitive) rules – The survey data shows that at the start of the study a substantial portion of the students does not know about all the rules in the building related to COVID-19. However, still a sizeable part of the students is familiar with the physical distancing rules, deem themselves capable to identify 1.5 meters distance, and are willing to comply with the rules. Even under these supporting conditions, the proximity data of the students shows that 'willing' is not the same as 'able to'. As a result, the social bubble structure was breached throughout the entire study period, implying that students find it difficult to operationalize the physical distancing rules.

Physical, educational and social context affect compliance – Students indicate that physical distancing compliance is difficult in certain areas of the building due to the lack of space or high demand. In addition, based on the students' knowledge of the rules, we assume that the exception to physical distancing in theatre and dance training has caused some confusion among students about the physical distancing rules in general. Furthermore, students indicate in the survey that they tend not to abide by the rules if they see that others do not do the same, and that "keeping distance is not social". Therefore, in this study, the physical, educational and social context do not seem to support physical distancing compliance.

There needs to be a need for compliance – In line with the reduction in severity of the COVID-19 pandemic in the Netherlands towards the summer, the compliance of students to the physical distancing rule dwindles. Also, the rationales "other people do not have COVID-19" (students had to self-test twice a week) and "it is not necessary to keep 1.5 meters distance" are frequent answers to explain the potential lack of need for students (and potentially staff) to comply.

Constant upkeep of rules required – The most interesting answer in the survey identifies that students (and potentially staff) forget which rules are active and forget to comply. This suggests that constant reminders of the rules are required to keep the compliance from dwindling over time.

Overall, these conclusions regarding the physical distancing behaviour are in line with the theory of planned behaviour (Ajzen, 1991). This theory postulates that the intention to perform a certain behaviour follows from three independent predictors: (1) the attitude toward the behaviour, (2) the subjective norm, and (3) the perceived behavioural control. If these predictors are more favourable towards the behaviour, the intention grows to perform the behaviour. Using this theory in our research, we can expect compliance to the physical distancing rules to improve, when

1. Physical distancing rules are accepted as an effective tool to curb virus transmission (normative beliefs translated into a compliant attitude)
2. The social environment of students and staff enables compliance (subjective norms)
3. The circumstances exist in the building to comply to the rules easily (perceived behavioural control).

In case of DAPA, and most likely many other educational institutions, the correct normative beliefs are widespread among the population. Yet, positive attitudes toward the physical distancing rule, compliance-supporting subjective norms and perceived behavioural control are far more difficult to achieve.

5. Lessons learnt during the joint application of proximity and survey data

This study used a new combination of personalized tags and a longitudinal survey to study physical distancing compliance. Based on our experiences, some lessons can be drawn regarding the innovative data collection endeavor.

First, both data sources rely heavily on the participants. Participants must put on the wristband every morning and complete a survey every few weeks. In both cases, a conscious decision is required every day and every wave on whether to participate or not. We see that this requires effort as the participation decreases over time. For the quality of this data collection combination, it is essential to find ways to limit response fatigue. This research showed that insights provided by a survey can serve as starting points for limiting response fatigue.

Nevertheless, the combination of quantitative (objective) measurements of the population's behaviour and subjective measurements regarding their attitudes and experiences provides a comprehensive picture of students' (and potentially staff's) dealing with the COVID-19 rules. This allowed us to not only record what was happening, but also better understand why compliance with the rules changed over time. The inclusion of questions regarding participants' perceptions and experiences allowed us to better explain the recorded behaviour.

Furthermore, to curb privacy concerns, no connection was made at the level of distinct individuals between the survey and proximity data. Consequently, we cannot establish beyond doubt that the participants that make comments regarding non-compliance are also the participants that do not comply with the physical distancing rules.

Lastly, an important lesson regarding the proximity data is that its location independence can make it difficult to interpret the results. The version of the proximity monitor used in this study could not accurately measure the location of interactions. More information on the exact location of each tag would allow a more specific analysis of the high-risk interaction regions in the building. At the same time, very precise triangulation is also not advised, as this would also represent a large ingression of participants' privacy.

6. Conclusions and future work

This study evaluated to what extent the combination of observed and self-reported subjective data featuring physical distancing behaviour allows for a better understanding of physical distancing compliance. A case study was presented on physical distancing behaviour of students (and partly staff) in the Dutch Academy of Performing Arts in The Hague. A combination of a longitudinal survey and a proximity sensing system was used to study the students' (and partly the staff's) compliance behaviour.

The results show that a combination of proximity data and longitudinal survey data can be used to study the physical distancing compliance behaviour, as well as the underlying (mental) processes. This study finds that it is difficult for students to operationalize these new (counter-intuitive) rules. Moreover, we established that the physical, educational and social context affect their compliance. In addition, with the progressive decline of the COVID-19 pandemic severity, their self-reported 'need' for physical distancing further dwindled. Lastly, any new rule requires upkeep, as a significant portion of the students report to 'forget' the rules regularly. The specific context of this study (i.e., educational institution and adolescent population), makes it difficult to generalize these findings. More research is needed to gain (generic) insights into physical distancing compliance behaviour of different types and compositions of populations and in different environments.

From a methodological point of view, this study found that the combination of quantitative (objective) measurements of the population's behaviour and subjective measurements regarding their attitudes and self-reported experiences provides a comprehensive picture of students' (and potentially staff's) dealing with the physical distancing regulations. The combination allowed us to not only record what was happening, but also better understand why compliance with the rules changed over time. At the same time, the proximity monitor could potentially falsify some of the self-reported behaviours. The combination of these methods can also be very powerful in other areas of transportation research for two reasons. First, having two methods (i.e., for objective and subjective measures) can validate whether the observed behaviour is consistent with the person's perception of the behaviour and vice versa. And secondly, it is not only valuable to measure certain (perception of) behaviour or certain choices, but also to understand why subjects make certain decisions about, for example, route or mode choice (or operational movement choice as in this study). These insights can provide valuable support for policy development and contribute to understanding behaviour and the underlying (mental) processes.

In this study, we also established that both data sources rely heavily on the participants. For the quality of this data collection combination, it is essential to find ways to limit response fatigue, which is a challenge for prolonged studies like ours. Thus, response fatigue needs to be pro-actively monitored and dealt with during the entire runtime of the study. In addition, it would be interesting to forge a connection between the survey results and proximity data in future studies, to see how actual behaviour is impacted by personal narratives regarding the normative beliefs, attitudes, subjective beliefs and the physical context. Moreover, for future studies, it is advised to improve the locating abilities of the proximity sensing system to the extend where one can identify in which room each tag is residing (i.e., no penetration of signals through walls and doors) to allow for a more specific analysis of certain areas.

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