

Improving car passengers' comfort and experience by supporting the use of handheld devices

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Abstract.

BACKGROUND: There is a demand for interiors to support other activities in a car than controlling the vehicle. Currently, this is the case for the car passengers and – in the future – autonomous driving cars will also facilitate drivers to perform other activities. One of these activities is working with handheld devices.

OBJECTIVE: Previous research shows that people experience problems when using handheld devices in a moving vehicle and the use of handheld devices generally causes unwanted neck flexion [Young et al. 2012; Sin and Zu 2011; Gold et al. 2011]. In this study, armrests are designed to support the arms when using handheld devices in a driving car in order to decrease neck flexion.

METHODS: Neck flexion was measured by attaching markers on the C7 and tragus. Discomfort was indicated on a body map on a scale 1–10. User experience was evaluated in a semi-structured interview.

RESULTS: Neck flexion is significantly decreased by the support of the armrests and approaches a neutral position. Furthermore, overall comfort and comfort in the neck region specifically are significantly increased. Subjects appreciate the body posture facilitated by the armrests and 9 out of 10 prefer using handheld devices with the armrests compared to using handheld devices without the armrests.

CONCLUSION: More efforts are needed to develop the mock-up into an established product, but the angles and dimensions presented in this study could serve as guidelines.

Keywords: Discomfort, neck flexion, user experience, armrests, car seat

1. Introduction

1.1. Seat development for car passenger's needs

Current car seat development has been primarily focussing on drivers instead of car passengers and as a result their postures and activities are not optimally

facilitated [1]. However, a competitive advantage can be achieved if a car manufacturer also considers car passengers' needs and desires regarding two scenarios. The first scenario consists of the current situation of a person being chauffeured, for instance to business appointments. The second is the future scenario of an autonomous driving car. Several car manufacturers, such as VW (TAP [2]) and BMW (Connected drive Connect [3]) as well as Google in collaboration with Stanford University [4] are developing systems that enable self-driving cars. A future where motor vehicles will

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Fig. 1. Design of the innovative armrests.

drive on their own is not far away. Currently, cars like the BMW 7 series [5] are already equipped with features such as active speed control (the vehicle maintains a safe distance with the car ahead, reducing speed until standstill). Both scenarios allow people to use their travel time for other activities rather than driving the car.

1.2. Literature indicates that travel time is used for working

Possible passenger activities found are reading, the use of mobile devices, relaxing, sleeping, the use of the entertainment system and having conversations [6]. People could also deal efficiently with travel time by using it for work. Previous studies [7] have shown that people state that they would also use travel time to finish work. Kamp et al. [6] observed passenger activities during train journeys and report working/using larger electronic devices as one of the eight most observed activities. This agrees with the first scenario where people are on business travel. Regarding the second scenario, it also seems likely that people will use (a part of) their travel time to finish work when commuting.

1.3. The use of handheld devices will continue to increase in future working

An increasing amount of personal computing is done away from the desktop PC, using among others the capabilities of small, mobile devices [8,9]. The term mobile devices is assigned to the product group of laptops, PDAs, smart phones, e-readers and tablet-PCs. At the 2011 Human Factors and Ergonomics Society congress [10], the fast developments in the field of mo-

bile devices became evident. For the first time, desktop computer sales dropped in 2008 in favor of laptops. Then – a month after the introduction of the Apple iPad was announced – laptop sales slowed down in February 2010. It is expected that the growth of the tablet-PC's market share will continue in the coming years. Thus, personal computing will become even more mobile in the years to come, influencing the way people work and subsequently their posture. It is now easier to work while travelling and commuting, for instance by car.

1.4. Support is needed for the use of handheld devices in a car

Young et al. [11] showed that using a tablet resulted in more neck flexion than for desktop computing. The neck flexion was far from neutral, which might result in discomfort. Although this research was conducted in a living room-setting, it pin-points the general problem related to the use of handheld devices. Other studies show that working with touch screen devices results in more muscle activity in the neck and shoulders [12], caused by lifting the arm in higher positions. In the study of Gold et al. [13] a bent neck for the use of mobile devices was also observed and it was concluded that the posture of the wrists in this activity also creates a risk for musculoskeletal disorders in wrists, arms and hands.

When using a tablet-PC in a car, people reported that they were missing support for this activity [7]. During this study, it was observed that people search support (for instance on the middle console). However, the support of the middle console is insufficient. Furthermore, Kamp [1], in her study on activities when travelling, concludes that “there is a demand for more flexible and comfortable seating possibilities supporting the use of mobile devices in general and the automotive industry specifically”.

1.5. What is the effect of the developed armrests on comfort and user experience?

The aforementioned context inspired the design of innovative armrests (see Fig. 1), providing the desired arm support and decreasing neck flexion by enabling a higher position of the handheld device. The armrests were developed using anthropometric data and a 3D-human model aimed at creating a more comfortable body posture. The design was evaluated in a user research involving a mock-up of the armrests. The goal

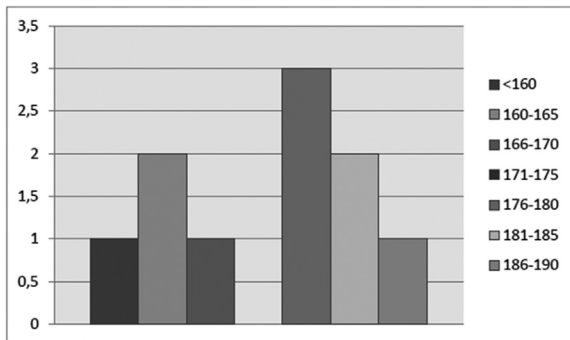


Fig. 2. The number of participants per range of height.



Fig. 3. The model of the seat with the armrests.

of the research was to evaluate the design's effects on neck flexion, subjective (dis-)comfort and user experience.

This research was set out to learn:

1. If neck flexion is decreased by the armrests and approaches a neutral posture.
2. If experienced comfort and discomfort is positively influenced by the armrests.
3. How participants experience the use of the armrests in terms of dimensions, usability and such.

2. Method

2.1. Subjects and seat design

Ten participants (6 male, 4 female), aged 18–67 years (average = 36.8, sd = 18.1), participated in the mock-up test. The standing height ranged from 1.57 to 1.90 m (average = 1.74, sd = 0.10), see Fig. 2. Figure 3 shows two pictures of the mock-up model of the seat with armrests. The seat pan and backrest angle were modeled according to Harrison [14], see

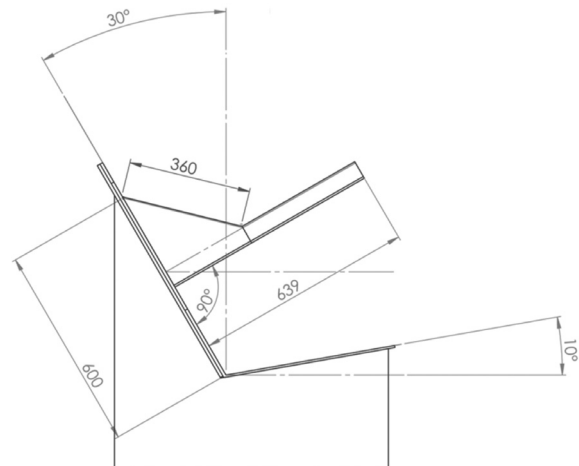


Fig. 4. Dimensions (mm) of the model with armrests positioned in the second slot from above.

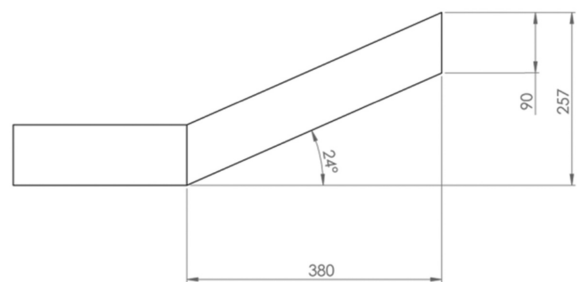
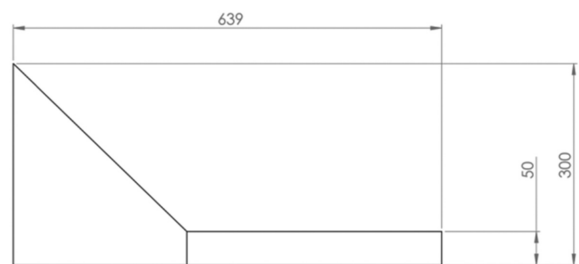


Fig. 5. Dimensions (mm) of the mock-up armrests.

Fig. 4 (manufactured of MDF, cushioned with 30 mm polyether foam). Harrison's angles (seat pan angle of 10° , backrest angle of 120°) were adapted since they were specifically developed for car passengers. The dimensions and angles (Fig. 5) of the armrests were estimated using data on anthropometry: DINED [15]. The armrests were made out of polystyrene. Their height was adjustable over the angle of the backrest in five steps of 50 mm using slots shown in Fig. 2, with the highest position at 650 mm above the seatpan. This point is located under the user's armpit. The length of the upper arm support was 360 mm. The support for

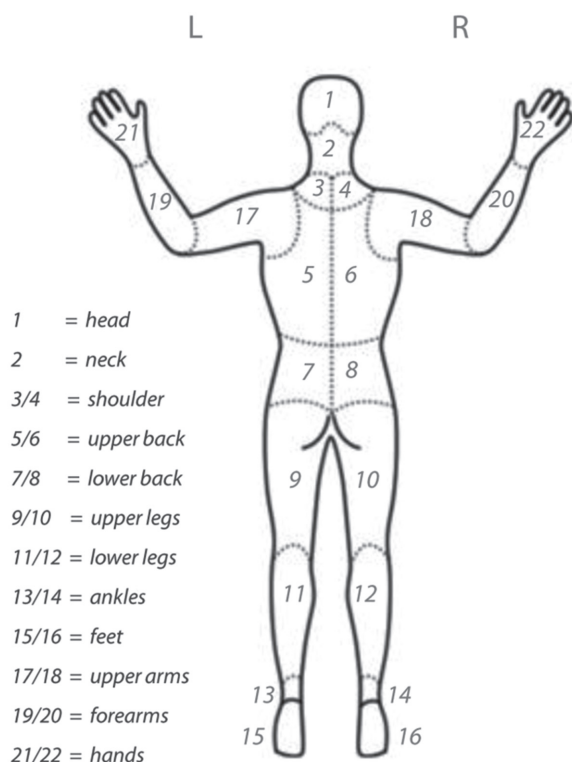


Fig. 6. The body map.

the fore arms angled inwards (24°). The width of the armrests was 90 mm in order to create enough support for the handheld device.

2.2. Protocol

The subjects were asked to perform three tasks on a tablet (Yarvik TAB 420, 10 inch) for six minutes: typing, playing a game and reading. It was estimated that this would be long enough to find differences and evaluate if the concept is promising to pursue. The different tasks were chosen to be able to determine potential difficulties the participants could have with the different types of interaction. The participants were asked to perform the tasks in two positions: without armrests (position 0) and with armrests (in the same chair) on a height determined by the researcher approaching the ideal position as designed (position 1). Finally the subjects were asked to choose their own preferred height for the armrests. The order in which the conditions were presented to the participants varied, i.e. five participants first performed the tasks without armrests and five participants started with armrests.

For each position, the experiment started with the subject performing the three tasks, during which the

(Dis-)comfort scale	
0	No (dis-)comfort at all
0.5	Extremely little (dis-)comfort: almost not noticeable
1	Very little (dis-)comfort
2	Little (dis-)comfort
3	Average (dis-)comfort
4	Raised (dis-)comfort
5-6	High (dis-)comfort
7-9	Very high (dis-)comfort
10	Extremely high (dis-)comfort

Fig. 7. (Dis-)comfort scale presented to the participants.

neck flexion was recorded for each task. Next, the participant filled out the body map (explained in Section 2.4) and was interviewed.

2.3. Neck flexion

Markers were placed on the C7 and tragus according to Young et al. [11] in order to evaluate the neck flexion with and without the armrests. Neck flexion was determined by taking pictures during each task in order to record the body angles while seated.

2.4. (Dis-)comfort

After using the tablet for 6 minutes, the participants were asked to rate the (dis-)comfort on a body map (Fig. 6) in order to determine where they perceived comfort and where they perceived discomfort. They were first handed a red pen and asked to determine body parts that suffered inconvenience/required comfort improvement. Those body parts had to be scored on discomfort on a scale Borg [16] 1–10 according to a procedure described by Grinten and Schmitt [17] (see Fig. 7). Next, they were asked to determine the body parts where they experienced comfort and mark them with scores using a green pen on a scale 1–10 (with 1 = no comfort at all, 10 = extreme comfort).

2.5. User experience

The purpose of the interview was to gather background information on the motivation of the scores on the body map, to gain understanding of the difficulties when using a tablet in the given configuration, to

Table 1

Minimum, maximum and average neck flexion angles for both positions

	Position 0	Position 1
Min.	36	29
Max.	68	58
Avg.	52.2	41.2

Table 2

Average (dis-)comfort results per body part for position 0 and 1

	Body part	0_Avg Discomfort	1_Avg Discomfort	0_Avg Comfort	1_Avg Comfort
Neck region	1	0	0	0	0
	2	2.7	0.4	0	3
	3	2.6	0.2	0	3
	4	2.6	0.2	0	3.1
	5	1.2	0	2.2	4
	6	1.2	0	2.2	4
	7	1.7	1	2.4	3.8
	8	1.7	0.7	3.2	3.8
	9	0.9	0.6	1.1	2.3
	10	0.9	0.6	1.1	2.3
	11	0	0	0	0
	12	0	0	0	0
	13	0.7	0.4	0.7	0.8
	14	0.7	0.4	0.7	0.8
	15	0	0	0	0
	16	0	0	0	0
Arms	17	1.1	0.3	0	3.3
	18	1.1	0.4	0	3.2
	19	0.7	0.5	1.1	3.5
	20	0.5	0.5	0.9	3.3
Hands	21	1	0.9	0.2	2.5
	22	0.3	0.4	0.2	2.5

evaluate the dimensions and to receive an overall comfort experience in the participants' own words. During the semi-structured interview, questions like the following were asked: what do you think of the volume of the armrests, do you experience problems, what do you think of the dimensioning of the armrests, how do you feel about the armrests when performing the task, would they use such armrests in a car?

2.6. Data analysis

A paired samples t-test ($p < 0.05$ analyzed with SPSS, 19.0) was conducted to compare the neck flexion for using the tablet without armrests (position 0) and while being supported by armrests (position 1).

The discomfort data were evaluated to determine if there is a significant difference (t-test for paired samples, $p < 0.05$) in comfort and/or discomfort overall and for several particular body areas between the two positions. For the overall (dis-)comfort evaluation, the scores of all participants are added up for each of the

22 body areas. These data are compared statistically between position 0 and position 1 using a Wilcoxon Signed Ranks test. The (dis-)comfort scores are also compared statistically (Wilcoxon Signed Ranks test, $p < 0.05$) for the most important body areas for this design: the neck region (the sum area 2, 3 and 4 in Fig. 6), the arms (the sum of area 17, 18, 19 and 20 in Fig. 6) and the hands (the sum of area 21 and 22 in Fig. 6).

Descriptive analysis was used for the results on user experience: the frequencies of similar responses were counted.

3. Results and discussion

3.1. Neck flexion

There is a significant difference in the scores in neck flexion angle between both positions for all tasks ($p = 0.000$). The recorded neck flexion is significantly less with armrests compared to using a tablet without armrests for all tasks. Thus, the objective of the armrests – decreasing neck flexion – is accomplished.

Several studies have been conducted in order to determine neutral angles for neck flexion: Raine and Twomey [18] found an angle of 41.1 degrees for an erect posture and Johnson [19] found 40.6 degrees for an erect posture. Ankrum [20] found 43.7 degrees as perceived most comfortable. In Table 1 the minimum, maximum and average neck flexion for tablet usage with and without armrests is shown. The average neck flexion for tablet usage while supported by the armrests is 41.2 degrees, which corresponds with the neutral angle for neck flexion found in the literature. This indicates that the armrests contribute to a better posture of head and neck.

3.2. Subjective discomfort and comfort

Table 2 shows the average scores of the body map for using the tablet with (position 1) and without armrests (position 0). For the configuration without armrests, discomfort in the neck region is highest (average discomfort on the Borg-scale and no comfort at all). This discomfort is probably caused by bending the neck to look at the display (as reported by the subjects in the interview and corresponding to literature as described in 1.4). This could also be the reason for discomfort in the upper back and shoulders according to the participants. Discomfort (extremely little to very

Table 3

The ranks table of the Wilcoxon Signed Ranks Test comparing overall (dis-)comfort between position 0 and position 1

		N	Mean rank	Sum of ranks
1_Overall-DisSUM – 0_Overall-DisSUM	Negative ranks	15 ^a	9.00	135.00
	Positive ranks	1 ^b	1.00	1.00
	Ties	6 ^c		
	Total	22		
1_Overall-ComSUM – 0_Overall-ComSUM	Negative ranks	0 ^d	0.00	0.00
	Positive ranks	17 ^e	9.00	153.00
	Ties	5 ^f		
	Total	22		

^a.1_Overall-DisSUM < 0_Overall-DisSUM.

^b.1_Overall-DisSUM > 0_Overall-DisSUM.

^c.1_Overall-DisSUM = 0_Overall-DisSUM.

^d.1_Overall-ComSUM < 0_Overall-ComSUM.

^e.1_Overall-ComSUM > 0_Overall-ComSUM.

^f.1_Overall-ComSUM = 0_Overall-ComSUM.

Table 4

The test statistics table of the Wilcoxon Signed Ranks test comparing overall (dis-)comfort between position 0 and position 1

	1_Overall-DisSUM - 0_Overall-DisSUM	1_Overall-ComSUM - 0_Overall-ComSUM
Z	−3.467 ^a	−3.624 ^b
Asymp. Sig. (2-tailed)	0.001	0.000

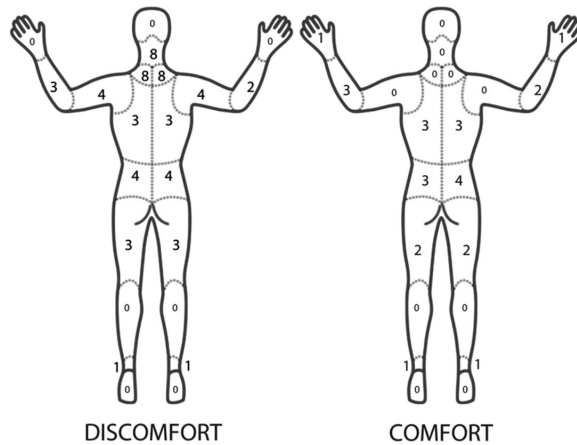
^a.Based on positive ranks. ^b.Based on negative ranks. ^c.Wilcoxon Signed Ranks Test.

little discomfort on the Borg-scale) in the arms and hands is reportedly caused by holding the device, tilting the screen and/or holding it up. Comfort in the back and (dis-)comfort in the legs is reported to be due to the seat angles.

For the configuration with armrests (position 1 in Table 2), comfort is reported for the neck region probably due to the upright posture (average comfort on the Borg-scale). Subjects like the high position and relaxed posture (angles) of the arms, resulting in comfort scores for the upper and fore arm. The support of hand and wrist is also valued positively as the comfort scores in the hand show. Using the armrests also results in reported comfort in the upper back (raised comfort on the Borg-scale). Discomfort (extremely little discomfort on the Borg-scale) in the arms is found and during the interviews the material is mentioned as the cause: subjects feel that the foam was too hard resulting in discomfort especially in the elbow region. Discomfort in the hands is caused by difficulties in holding and/or tilting the device, especially when typing.

Discomfort in the neck is reported by two participants: one mentions that multifocal glasses cause the subject to bend the head backwards and the other mentions overstretching due to being shorter.

Position 0



Position 1

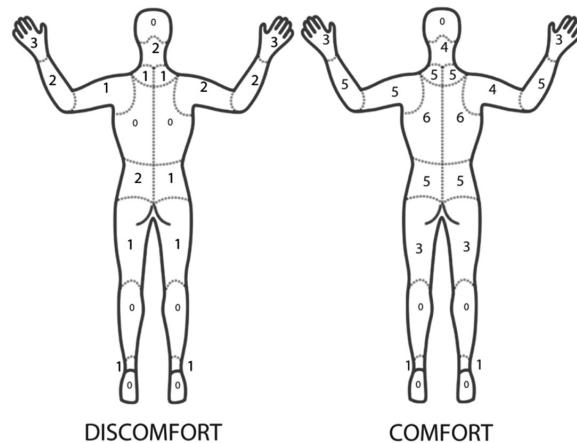


Fig. 8. Frequencies of reported (dis-)comfort voor position 0 (top) and position 1 (bottom).

3.2.1. Overall (dis-)comfort compared between position 0 and 1

The ranks table (Table 3) shows that discomfort decreases for 15 body parts, increases for one body part and that there is no change for 6 body parts. Comfort decreases for none of the body parts, increases for 17 body parts and 5 body parts experience no change in comfort. A Wilcoxon Signed Ranks Tests (Table 4) shows that the armrests elicit a significant change in overall discomfort for using a tablet device while seated ($Z = -3.467$, $P = 0.001$). Furthermore, the Wilcoxon Signed Ranks Test (Table 4) shows that there is a significant difference in comfort between position 0 and 1 ($Z = -3.624$, $P = 0.000$). Therefore, it can be concluded that overall comfort is increased while overall discomfort is decreased when using the

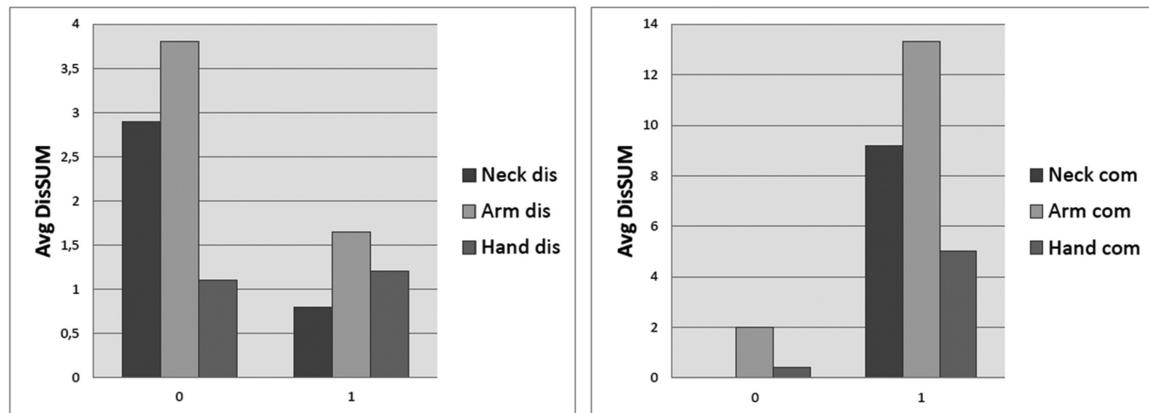


Fig. 9. Average of the total (dis-)comfort per body area at position 0 and position 1.

Table 5

The test statistics table of the Wilcoxon Signed Ranks test comparing (dis-)comfort between position 0 and position 1 per body area

Body area	(Dis-)comfort	Z	Asymp. Sig. (2-tailed)
Neck	DisSUM	-2.550 ^a	0.011
	ComSUM	-2.023 ^b	0.043
Arms	DisSUM	-1.156 ^a	0.248
	ComSUM	-1.612 ^b	0.107
Hands	isSUM	-0.368 ^b	0.713
	ComSUM	-1.461 ^b	0.144

^a.Based on positive ranks. ^b.Based on negative ranks. ^c.Wilcoxon Signed Ranks Test.

designed armrests for operating a tablet device while seated.

Figure 8 visualizes the frequencies of (dis-)comfort reports for both positions. It can be seen that there are less discomfort reports and more comfort reports when using the armrests for support. Again, it is remarkable how often discomfort is reported in the neck without armrests within this short amount of time and how comfort reports increase for the neck, back and arms when using the armrests. Participants affirm this result when asked about their overall comfort experience when using the tablet with armrests, stating it was “relaxed”, “created a good body posture”, “pleasant, also without using the tablet”, “very attractive” and “comfortable”.

3.2.2. Neck, arms and hands (dis-)comfort compared between position 0 and 1

Figure 9 shows the sum of discomfort and comfort of the selected body areas (neck, arms and hands) mediated over the number of participants for both positions. It suggests that discomfort decreases for the neck and the arms and that comfort increases for all three body areas.

Table 5 shows the results of the Wilcoxon Signed Ranks test, conducted to compare the sum of both comfort and discomfort per body area for using the tablet without armrests (position 0) and while being supported by armrests (position 1). For the neck region, a significant difference is found between both positions for comfort ($Z = -2.023$, $P = 0.043$) and discomfort ($Z = -2.550$, $P = 0.011$). There is no significant difference for comfort ($Z = -1.612$, $P = 0.107$) and discomfort ($Z = -1.156$, $P = 0.248$) of the arms. Also for the hands, there is no significant difference found for comfort ($Z = -1.461$, $P = 0.144$) and discomfort ($Z = -0.368$, $P = 0.713$).

Thus, the results suggests that for neck region comfort increases significantly when the car passenger is supported with the armrests when using a tablet. This is not the case for the two other body areas. Discomfort decreases significantly for the neck region when using armrests, but not for the arms and hands. Input from the participants in the interviews suggests that for the arms this is due to the material of the armrests: the styropor proved to be too hard. The response of the interviews suggests that for the hands this is due to difficulties holding the device (especially when typing) when the subject is supported by the armrests. The slope of the armrests prevents the subject from resting the weight of the tablet on the armrest, since it would slide down. A design improvement is necessary to solve this problem.

3.3. User experience

Overall, the dimensioning of the armrests is evaluated as good. Most subjects (80%) think that the steepness of the forearm is good: 20% think it could be a

little less steep. The angle of the forearms in the transverse plane is also appreciated by the majority (80%) and subjects describe the posture as “good” and “natural”: the other subjects mention that the angle could be tweaked a little. The same results can be observed for the distance between the armrests.

The width of the armrests – the surface – is evaluated as “good”, “good enough” or “perfect” by all participants. Although only three out of ten subjects state that they would prefer it if the elbow support was positioned less forward, the design needs to be altered in this aspect because two shorter subjects (157 and 165 cm) experienced serious difficulties in terms of overstretching the shoulders in order to reach the elbow support. More support for the hands/the device is required by 90% of the subjects: especially typing was a problem as also mentioned in Section 3.2.

It is remarkable to notice that only two subjects use the possibility to determine the height themselves in a third position, next to the height determined by the researcher according to the design in position 1. The height for one subject was estimated too high by the researcher (this was only the second participant). The other subject desired a higher position in order to determine if this would solve the overstretching problem, but after testing the subject still prefers the armrest height as determined by the researcher. The majority of the participants prefer the designed configuration and feel no need to change. Thus, it can be concluded that the designed configuration is promising. Another striking observation is the little variation in height of the armrests for the large variation in height of the participants. All participants preferred the armrests positioned at 550 mm (distance of the top point of the foam to the seat pan) except for one subject (preferred positioned at 600 mm, with a body height of 190 cm).

The majority of the subjects (70%) perceive their freedom of movement as good. They explain this as follows: “I did not feel clamped”, “nothing touches me, I can even reach my pockets”, “I feel space, I feel not trapped” and “I can actually move quite a lot”. One subject expects a disadvantage in the armrest restricting the variation of posture and another subject does not like the armrests at all and felt trapped.

Finally, the subjects were asked which configuration they prefer (with or without armrests) and if they would use the armrests when seated in the back of a car. Almost all subjects (90%) prefer the armrests when using a tablet and would use them when available (90%). Comparable results (80%) were observed for the question “would you use such armrests when

available in a car for using a handheld device?”, although one participant did not like the armrests at all and did not see their value. Another participant could not indicate whether or not to use the armrests in a car.

3.4. Recommendations

This study shows that the effects of the armrests were already noticeable when using them for a short amount of time. However, further research is necessary to determine the effects of the armrests on experienced comfort and discomfort over a longer period (for instance 30 to 60 minutes).

Further research is also needed to determine comfort and usability when using the armrests in a moving vehicle. Performing activities in a dynamic situation differs from doing these activities in a static situation. Several studies have shown the influence of dynamics on the executed activities [21,22]. Therefore, it is also important that further research is conducted to evaluate the armrests in a dynamic situation, i.e. a driving car.

The designed armrests could also influence the car passenger's perception of safety and space when in a car. Hence, this should be evaluated. In such a research, comfort improvements of the armrests could be compared to using the middle console or door for support. It could be also of interest to learn the effects of such armrests on comfort when using other types of handheld devices, such as e-readers.

This research suggests the importance of combining subjective comfort data like comfort scores on a body map with interviews, in order to be able evaluate the results as also suggested in other studies [23]. This does not only give insight in the motivations of the comfort data, but also enables the researcher to put them into perspective. In this case, there are no significant comfort improvements for the arms found but participants state that they appreciate them: subjects prefer working on a tablet supported by the armrests and think that they enable a good and natural posture.

The research also results in three design recommendations. The first is a change in dimensions, to avoid overstretching when shorter subjects use the armrests. However, the design should still enable one armrest shape to be sufficient for a large range of population. The second is the need of an additional feature, that enables users to rest the weight of the device on the armrests while still holding it, i.e. preventing the device from sliding down the armrest. Finally, cushioning of the armrests should be added to prevent discomfort in the elbows.

4. Conclusion

This study on the effects of the designed armrests when using a handheld device shows positive effects on the posture of the neck. The neck flexion was found to be significantly less when operating the tablet-device with the developed armrests compared to the configuration without armrests. Thus, the body posture is partly improved. Furthermore, the average neck flexion corresponds with the neutral values found in literature and this is an objective indication that discomfort in the neck region could be prevented for operating a tablet-device with the use of these armrests. This could also be true for using other handheld devices such as e-readers, books, smart phones and such with these armrests.

Both the (dis-)comfort ratings on the body map and the responses of the interview show that the support of the armrests while using a tablet improves the user's comfort. The overall comfort significantly increases, while the overall discomfort significantly decreases when using the armrests compared to not being supported by any armrests. Furthermore, the subjects prefer the configuration with armrests and evaluate the resulting body posture as relaxed and natural. When looking at the neck region, specifically, comfort is also significantly increased while discomfort is significantly decreased as a result of the improved body posture. Discomfort is not significantly decreased for the arms and hands. This is due to hard materials and problems with holding the device, especially when typing. Design improvements should be able to solve these problems.

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