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Effect of the presence or absence of upper limb support on posture when a smartphone user is in a seated position under ambient light conditions.

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Abstract

Background: Home, public transport, work, the number of environmental positions constraining the use of smartphones is significant.

Research question: How can the presence of an upper limb support influence the sitting posture of smartphone users under fixed illumination and brightness?

Methods: Twelve subjects ($21,6 \pm 5,5$ years old) performed web browsing under two environmental positions (POSITION): sitting with and without support (table). The users' postures were evaluated through relative kinematics joint angles analysis. A repeated measure analysis of variance and Tukey post-hoc tests were performed to test the effect of POSITION on posture.

Results: In sitting position in front of a table, neck is less stressed (flexion $< 10^\circ$) and trunk and shoulder are supported which suggests less constrains for the joints.

Relevance to industry: To prevent injury or pain, the use of an upper limb support (to lean on) should be considered for people/workers who use the smartphone frequently.

Keywords: *Ergonomic recommendation, Musculoskeletal disorders, Smartphone interaction, support effect.*

1. INTRODUCTION

Whether at work or at home, the mobile phone is more and more present in people's lives (Khalaf, 2014; Tecmark, 2014). Many studies have examined the risks related to the use of these new technologies (Salvia, 2018; Eitivipart, 2019). The studies are unanimous regardless of the method used: there are risks of pain or MSDs in the cervical spine. Neck flexions inflicted on smartphone users appear to be harmful as proved by studies based on joint variables or muscle analysis (Kim, 2015; Kim and Koo, 2016; Han and Shin, 2019; Namwongsa *et al.*, 2019). The neck is not the only joint region affected. Others joint areas such as the trunk, the lumbar spine and the upper limbs are exposed to constraints that can lead to pain, discomfort and even MSDs (Gustafsson *et al.*, 2017).

Furthermore, the environmental conditions for interaction with a smartphone are very varied (sitting, standing, one-handed, two-handed, walking). Thus, depending on the location, time of day or weather, light conditions may fluctuate. As a result, the postures adopted by subjects and the MSD risks associated with each joints region are likely to be different (Merbah *et al.*, 2020a). The use of external help such as supports (armrests, table) were also conditions that were studied and appear to be a good way to reduce the stress of the neck while using a tablet (Young, 2012). Depending on these environmental conditions, strategies for use appear and are more or less likely to be considered ergonomically at risk (Merbah *et al.*, 2020b). Global tools such as the Rapid Upper Limb Assessment (RULA) (McAtamney and Corlett, 1993) score provide an ergonomic evaluation of the subject's complete posture but it requires a quantification, ideally from a 3D capture of the subject's movements which is rarely found in the field of human-machine interaction.

The objective of our study was twofold: 1) to evaluate the effects of the presence or absence of a support on the biomechanical parameters characteristic of the posture adopted by the subjects, and 2) to qualify the incidence of these postures on the risk of developing MSDs in each of the two conditions tested during web browsing with a smartphone in a seated position.

Ambient light and the brightness of the smartphone screen were monitored to recreate a situation encountered in everyday life. The evaluation of the subjects' 3D posture was carried out by quantifying the joint angles of the axial skeleton and the upper limbs in order to get an overview of the user-smartphone relationship. The Rapid Upper Limb Assessment (RULA) was then used to evaluate the exposure of users to ergonomic risk factors associated with axial skeleton and upper extremity MSDs.

2. Method

2.1. Participants

Axial skeleton and upper limb movements during an interaction task were analyzed for twelve smartphone users aged $21,6 \pm 5,5$ years old (five females: $19,6 \pm 3,0$ years old; seven males: $23,0 \pm 6,6$ years old). Three were left-handed and nine were right-handed. They all assumed having no pathology of the upper limb. They also assured having normal or corrected-to-normal vision and none of them reported discomfort and impairments. They had experience with smartphone for more than five years and were using the one they had for more than one year. Each subject was informed of the complete contents of the protocol and gave its written consent before taking part. All of them were naïve as to the aims and the expected outcome of this study. The

experiment was performed in keeping with the declaration of Helsinki (World Medical, 2013).

2.2. Experimental procedure

A web browsing task was selected because it is one of the most practiced activities, around 10% to 15% of the time spent on the smartphone (Kia *et al.*, 2019), and it includes two characteristic actions: typing text and scrolling. Thus, subjects were asked to carry out an internet search to find the timetable of a train connecting the cities of Toulon and Marseille in two environmental positions (POSITION): seated with support (ST) and seated without support (SWT). This search took place on the official website of the SNCF (the only train company in France), by typing in google or safari the keyword “snCF” and clicking on the first link (www.sncf.com). Participants had to write “Toulon” in the current city and “Marseille” in the destination. The travelling time and other parameters were not modified. Then the button “Rechercher” (search) was pressed. After the loading of the web page, the task was to scroll down to the last schedule available and saying out loud the schedule to the operator (Figure 1). A training session was conducted prior to the protocol in order to familiarize the subject with the task and to verify that no settings would interfere with the research.

For each environmental condition, the manipulation was repeated 3 times identically with rest times of 90 seconds in a random order. The subject’s starting and ending positions have been standardized for each POSITION. In ST condition, the subject was seated on a rigid school chair (the seat was 45 cm off the ground) with her/his forearms rested on a wooden rectangular table (with a height of 77cm) and the phone was placed in front her/him on the table. In SWT condition, the subject was seated on the same chair as in the ST condition and had to put her/his hands on

her/his thighs. The phone was placed on a support on her/his right side. From this position, subjects were informed that they could perform the task (web browsing) as they wished in terms of posture after the start signal. Once the task was completed, the subject was to return the phone to its original location and return to her/his first position. Before each trial, subjects were asked to clear their browsing history and close all applications so that the phone would be in exactly the same configuration throughout the experiment.

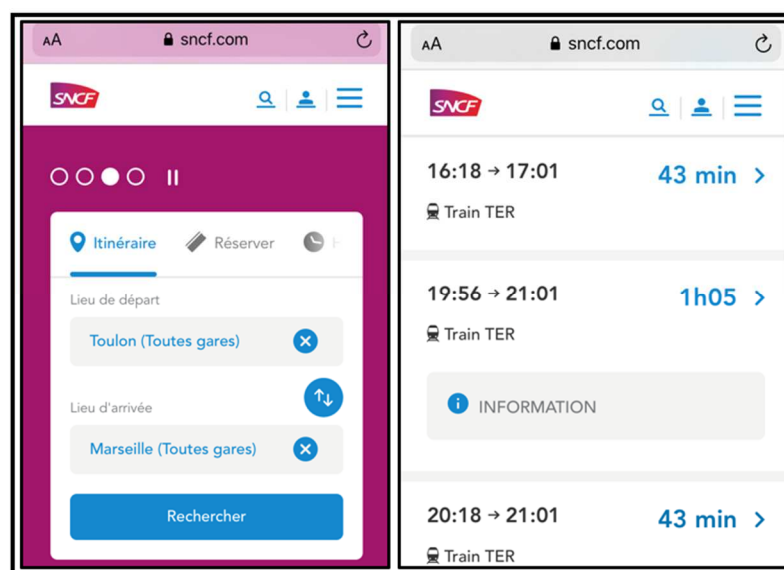


Figure 1: Illustrations of the SNCF (French railway company) website navigation interfaces on smartphones. On the left: interface for entering city names; on the right: interface for displaying the available timetables. The subject was asked to say out loud the latest available train schedule after scrolling down the page.

2.3. Stimuli

This study wanted to take into consideration the environmental variables that can have effects when using smartphones. For this reason, room light and screen brightness were controlled. First, thirty rooms throughout the University (conference rooms, classroom, library, cafeteria...) were measured to determine the amount of light available during a normal use with a lux meter (Luxmeter BF06 from Trotec company). Results were 350 ± 40 lux. This illumination represents a so-called ambient

light in the working environment (offices, classrooms, meeting rooms). Then, the illumination of the room in which the experiments were to take place was adjusted to be equivalent to this ambient light. With shutters closed and all the fluorescent (neon) lights in the room on, the illumination of the laboratory was set at 345 lux. The value was measured using the same lux meter as that used in the previous measurements. About brightness of the screen, a survey was conducted among nearly 60 smartphone users. Results showed that more than 85% of the users had their brightness setting above 90% with more than half of them having their brightness at maximum. So, in order to recreate a real-life situation, subjects were asked to adjust the light on their phones to maximum.

2.4. Apparatus

To perform the motion analysis of the web browsing task, the trajectories of the forty-one reflective markers were recorded using an optoelectronic system with 8 Oqus 400 cameras (Qualisys AB, Gothenburg, Sweden) at a sampling rate of 200 Hz. The markers were placed as follow:

- Thirty-six reflective markers were placed on the head, trunk, and right and left upper limbs of the subject (Figure 2). Twenty four markers were positioned on bony anatomical landmarks identified by palpation, in agreements with the International Society of Biomechanics recommendations (Wu *et al.*, 2005). Twelve technical markers assembled in sets of three were positioned on the arms and forearms.
- Five markers were added on the smartphone to study its position during the task. To not disturb the subjects while performing the task, these markers

were positioned on a custom-made lightweight resin device glued to the back of the smartphone (Figure 2).

Before the experiment, a static capture was made with the device glued (and its five markers) and with nine additional markers: two in each corner on the front side and one on the back side to determine the shape of the smartphone. Then a rigid model was used to rebuild the smartphone.

2.5. Dependent variables

To study the upper limb joint coupling during the achievement of the task, the pick-up and drop-off phase of the smartphone have not been considered. Then, only the interaction phase corresponding to the web browsing was analyzed.

First, the biomechanical parameters were considered. From the 3D coordinates of the reflective markers and following ISB instructions (Wu *et al.*, 2005), neck, trunk and upper limb joint angles (24 degrees of freedom) as well as the distance and 3D orientation (pitch, roll and yaw) between the face and the smartphone were first calculated for each instant of the interaction and then the data were averaged over the entire phase (Matlab, The Mathworks, Inc., Natick, MA). About the orientation, the position of the smartphone was considered neutral when the screen was parallel to the face. Pitch, roll and yaw were respectively defined as the rotation about the medio-lateral, antero-posterior, and vertical axis. The duration of the interaction has been also calculated for each trial.

To complete this biomechanical analysis, the Rapid Upper Limb Assessment (RULA) was performed for trial of each experimental position from the mean angles computed for the interaction phase to evaluate the ergonomic risk factors associated

with axial skeleton and upper extremity MSDs. All these parameters represent the dependent variables.

2.6. Data analysis

Repeated measures analyses of variance (ANOVA) were performed to test the effects of SIDE (left versus right upper limb) and POSITION (ST versus STW) on all dependent variables. Tukey post-hoc tests were conducted to identify the significant differences. A non-parametric Mann-Whitney test was also conducted to test the effect of the gender. The level of significance was set at $p < 0,05$ (Statistica 7.1, Statsoft, Tulsa, OK, USA).

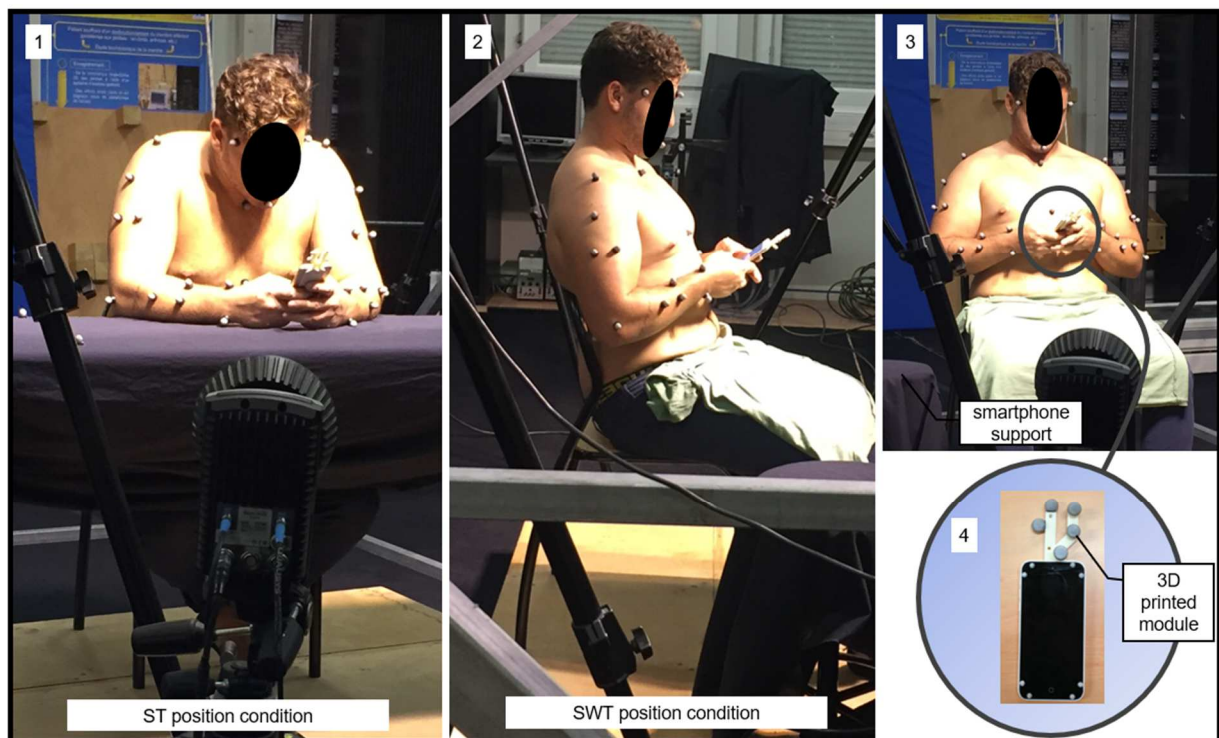


Figure 2: Experimental position set-up and subject equipped with anatomical and technical markers. Picture 1: task achieved in the ST position. Picture 2 and 3: task achieved in the SWT position. Picture 4: smartphone equipped with all the markers used for static capture. Only the printed module was kept during web browsing. A construction from the static trial and based on a rigid model was made to obtain the 3D orientation of the smartphone during the interaction phase.

3. Results

As far as the interaction parameters with the smartphone are concerned, no effect was observed on the interaction time and the distance between the head and the screen (Table1). Only the pitch was higher in SWT condition ($p < 0,05$).

Table 1: distance head/smartphone, task duration, and smartphone orientation (mean \pm SD) measured for each experimental condition.

	ST	SWT
Head-Smartphone Distance (mm)	385,9 \pm 84,8	353,6 \pm 41,2
Task duration (s)	61,1 \pm 21,3	57,5 \pm 18,0
Smartphone Pitch (°)	-21,3 \pm 6,6	-24,5 \pm 7,0*
Smartphone Yaw (°)	-2,7 \pm 3,5	-2,8 \pm 3,5
Smartphone Roll (°)	1,8 \pm 5,2	1,7 \pm 3,4

* indicates significant differences from ST condition.

Pitch corresponds to a rotation around the medio-lateral axis, yaw to a rotation around the vertical axis, and roll to a rotation around the antero-posterior axis.

Concerning the angular parameters, significant differences were found in all joint regions but not necessarily in all planes between the two experimental conditions (Figure 3). Neck and elbow flexions and forearm pronation appeared higher in SWT condition, while trunk flexion and shoulder joint angles were lower. No effect of POSITION was evidenced for the axial rotation of the head and the trunk.

The Mann-Whitney test revealed gender differences for four of the parameters. Statistically, contrary to the males, females held the phone closer to their face (320,2 \pm 36,7 mm vs 405,2 \pm 61,8 mm, $p < 0,05$), had higher elbow flexion (106,7 \pm 12,2° vs 95,3 \pm 12,8°, $p < 0,05$) and clavicle elevation (-18,0 \pm 8,9° vs -9,4 \pm 7,0°, $p < 0,05$), and presented higher trunk flexion (-19,3 \pm 6,2° vs -11,9 \pm 4,3°, $p < 0,05$) only in the ST condition.

All the participants used the phone with two hands during the interaction phase. A SIDE effect was observed for two joint angles: the shoulder abduction (-11,4 \pm 9,6° vs

-14,9±11,3°) and the ulnar deviation (2,8±7,1° vs 8,2±6,7°) were slightly lower for the left side.

The RULA score in environmental position ST was 3 while in SWT the score was 4. Both of these scores are at Level 2 and classify the risk of MSDs as low, but some changes may need to be made to reduce this risk.

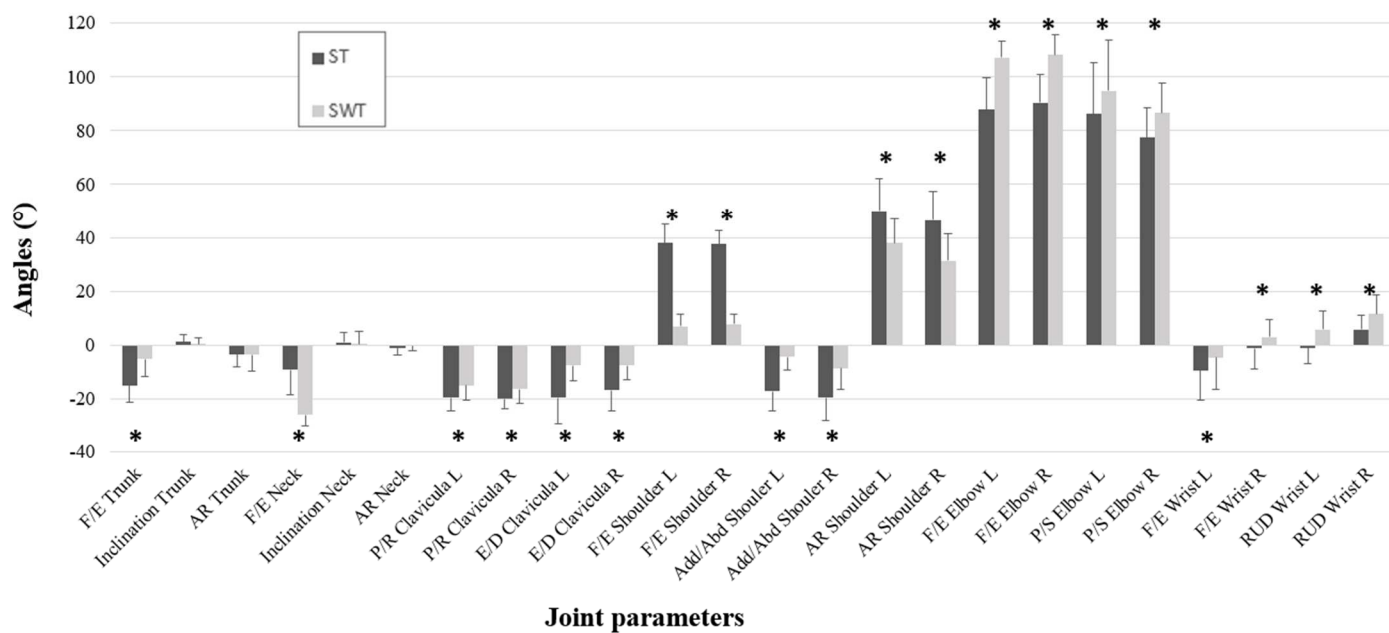


Figure 3. Mean angular parameters of the axial skeleton and upper limbs across the two experimental conditions. Error bars indicate 1- standard deviation. ‘*’ indicates significant differences between the two experimental positions (p<0.05). L: Left, R: Right, F/E: Flexion/Extension, AR: Axial Rotation, P/R: Protraction/Retraction, E/D: Elevation/Depression, Add/Abd: Adduction/Abduction, P/S: Prono-Supination, RUD: Radio-Ulnar Deviation.

4. Discussion

This study presents the effect of a support, like a table, on posture adopted by smartphone users in a sitting position while doing a research on the web. First, it was observed that all participants used the device with two hands as reported in a recent study on smartphone work (Bodin *et al.*, 2019). As a previous field study has shown,

the majority of college students interact with their smartphone with both hands (Gold *et al.*, 2012). However, contrary to the results of our study, this represented only 51% of the observations (compared to 100% in our study) while they were all free to do as they pleased. Several elements may explain this difference. Firstly, in laboratory studies, subjects are focused on the task that asked them to do, which could encourage them to use their smartphone more with two hands. Moreover, this “two-handed grip” allows a better thumb performance and decrease the variability which could explain why subjects choose this mode of interaction (Trudeau, 2016). This way to interact with a smartphone could be described as symmetric and could explained why only two parameters, shoulder abduction and the ulnar deviation, are different concerning the side effect. In Gold's study, the observations were made in an environmental setting. No information was provided on what secondary activities college students were likely to do while using their smartphone that required the use of one hand (eating, carrying a bag, smoking ...). This makes it possible to do several activities simultaneously, which is a real advantage. Another explanation could come from the age of the subjects. Indeed it is possible that the interaction techniques differ according to the generation. One could think that young people tend to interact with two hands, unless circumstances do not allow it. Further work is needed to identify what would be the interaction modality preferred by users, whether this depends on factors such as age or experience, and what are the parameters that induce an interaction modality with one or two hands.

From a biomechanical point of view, it can be trivial that any support improves postures when using smartphones. Indeed, the support adds a support point to the posture, which provides better stability. The point is whether its presence may or may not reduce the risk of MSDs. Ergonomic analysis of the observed postures led to

RULA scores of 3 and 4 respectively for the supported (ST) and unsupported sitting (SWT) condition. These scores both belong to level 2, suggesting on the one hand that the postures adopted are not ideal and on the other hand that at first glance support would not reduce the overall risk of developing MSDs. However, biomechanical analysis of joint angles revealed significant differences for some joints, which may explain the difference in RULA scores, and may also indicate the presence of more localized effects of the presence or absence of support on MSD risk.

The most alarming parameter seems to be the flexion of the cervical spine. This result is in line with many studies that characterize through different approaches (questionnaires, EMG) the harmful consequences of a pronounced bending of the neck when interacting with a smartphone (Lee, 2015; Namwongsa *et al.*, 2018a; Namwongsa *et al.*, 2018b; Chan *et al.*, 2020). It is pointed out here that even if neck bending is always considered harmful when interacting with the smartphone, it seems less constrained when elbow or forearm support (a table in this study) is used (average of $-9,3^\circ$ versus $-25,9^\circ$) corresponding to a local RULA score of 1 and 3 respectively, which would contribute to a reduction in neck pain (Angelini *et al.*, 2020). This confirms previous work focused on the effect of armrests and back support which are reducing “biomechanical loading in the neck and upper extremities during mobile phone use” (Syamala, 2018).

At the same time, the presence of the support causes a flexion of the trunk and a greater mobilization of the shoulder. This could be explained by the fact that the subject adopts a posture that allows him or her to lean on the table. Although at first sight this behavior may seem harmful because the joints move away from joint neutral (Namwongsa *et al.*, 2018b), it is not, as the use of additional support would

considerably reduce the muscular effort required to maintain such postures. This aspect is also considered in the RULA, and explains that despite higher angular values, the risk is lower when a support is used. Finally, the lack of support also results in greater elbow flexion and ulnar deviation of the wrist far from the neutral position, reflecting a potentially significant risk of MSDs in the long term (Figure 3).

Thus, although the global RULA scores are in the same alert level (level 2), they differ and suggest that sitting without support is more harmful, especially considering the fact that subjects interact for an average of 2,5 hours per day , which represents long durations that recur with high frequency.

Despite the small sample size, some differences seemed to appear between females and males. These tendencies are consistent with the results presented by Gold and colleagues (Gold *et al.*, 2012). The authors showed that females tended to bend the elbow region more, which had the effect of bringing the smartphone closer to their trunk. This is confirmed by the measurement of the distance that appears to be smaller between the face and the smartphone in females. Further research is needed to address in more detail the effect of gender on biomechanical parameters when using smartphones.

These results need to be considered within the context of the limitations of the study. First, the web browsing task was rather short compared to gaming or scrolling social medias. In this study, during the interaction phase postures adopted were maintained and no main adjustments were made by users, certainly due to the fact that a 60-second task is not enough to generate a discomfort. An interaction with a longer task may lead to different results. Indeed, it can be hypothesized that for a longer task, individuals would be likely to adjust their posture, reflecting the development of posture-related discomfort, especially if that posture exposes certain areas to MSD

hazards and is repeated or maintained over time. Second, the number of participants is a main limitation of this work and with more subject differences observed could differ. Third, each participant performed the task with her/his own smartphone to avoid learning effects from the use of a non-familiar user interface. Screen sizes, shape, interface are then different and could influence heavily the results. And finally, for each environmental condition, the subjects were considered as a whole. No postural strategy cross-sections were conducted in this study. The fact that the subjects were free to make postural adjustments during the manipulation resulted in a relative variability of the angular variables. A larger number of subjects would minimize doubts about the results.

5. Conclusion

In conclusion, the general posture adopted by subjects when interacting with their smartphone requires special attention, especially as the duration and frequency of use during the day is important. The use of a support seems to be a favorable solution as it would reduce the muscular implications of the trunk and shoulders while allowing subjects to reduce neck flexion. Future work could include more subjects, different interaction tasks in different situations that are representative of daily life, in order to evaluate their effects on the posture of subjects when interacting with their smartphone.

Credit authorship contribution statement

MERBAH Johan: Methodology, Software, Validation, Formal analysis, Investigation, Resources, Data Curation, Writing - Original Draft, Writing - Review & Editing, Visualization;

JACQUIER-BRET Julien: Methodology, Software, Validation, Formal analysis, Investigation, Resources, Data Curation, Writing - Original Draft, Writing - Review & Editing, Visualization;

GORCE Philippe: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Resources, Data Curation, Writing - Original Draft, Writing - Review & Editing, Visualization, Supervision, Project administration, Funding acquisition.

Declaration of Competing Interest

None.

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