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Research Article

Effect of Texting/Web Browsing with A Mobile Phone while Sitting/Standing on Upper Body: Risk Factors for Musculoskeletal Disorders

Philippe Gorce, Johan Merbah, Julien Jacquier-Bret*

Laboratoire HandiBio-EA 4322-Université de Toulon, CS60584-83041 Toulon Cedex 9, France

ABSTRACT

Background: The increasing use of smartphones in everyday life has been identified as an important risk factor for developing musculoskeletal disorders (MSDs) in the neck and upper extremities.

Methods: Objective and quantitative posture evaluation adopted by smartphone users has been conducted. 3D upper body kinematics of 12 participants were recorded when performing two common smartphone tasks (texting and web browsing) while sitting and standing. The risk of developing musculoskeletal disorders was assessed using the Rapid upper Limb assessment (RULA) and the postural Loading on Upper Body Assessment (LUBA).

Results: Results shown that neck flexion and shoulder elevation were higher in the standing position (about 8° and 2° respectively) and that trunk and shoulder flexion were higher in the sitting position (about 5° and 7° respectively). Ulnar deviation was measured regardless of the experimental conditions. However, no task effect was observed. The ergonomic scores obtained with the RULA were 2-3 and 9-10 with the LUBA, i.e. long-term MSDs risk.

Conclusion: The kinematic results, coupled with the MSDs risk assessment tools, showed that all the upper body joints are involved to a greater or lesser extent in occurrence of MSDs, depending on the interaction condition.

Keywords: Texting; Web browsing; Mobile phone; 3D kinematics; Musculoskeletal disorders; Risk assessment

INTRODUCTION

The smartphone is an unavoidable device in the daily life of young adults around the world. For example, in the United States or in France, more than 95% of 18-35 years old own one [1]. Moreover, the amount of time spent using them on a daily basis is constantly increasing [2]. Among the multiple functionalities available on these devices, sending a message, browsing the Internet or watching videos are the most used. Faced with this growing penetration of the smartphone within the population, many studies have investigated these different interactions.

The analysis of texting has been studied extensively as it is the most frequently used means of communication among young scholars [3]. Experimental and observational studies have shown that there are different typing techniques [4], different postures, and different muscle activities for writing a message [5,6]. The various works have reported marked neck flexion and significant demands on the extremities, especially the thumbs [4]. Texting has often been studied in association with web browsing or watching a video [7]. Experimental protocols have also been proposed to study multiple interaction positions, including sitting and standing with a cohort of 800 students [4]. Lee et al. [8] studied the effect of position and when performing these different tasks on head flexion. They found greater flexion while sitting and texting. Similar results were observed with higher head flexion when texting compared to web browsing [9]. Merbah et al. [10] also highlighted the existence of different postural strategies between the head and trunk during sitting and standing for these two tasks. Other work has reported similar results in other situations such as during walking [7]. For the upper limb, an effect of the support was reported on the shoulder flexion, elbow and wrist [11]. Another study highlighted an ulnar deviation during one-handed interaction with a smartphone [12].

A major issue in all of these studies is the risk of developing musculoskeletal disorders in the medium/long term to which users are exposed, particularly in the neck, shoulders, and extremities [13]. A 5-year longitudinal study of over 7,000 young adults found that messaging is associated with short-term and, to a lesser extent, long-term effects on musculoskeletal disorders of the neck and upper extremities [14]. One of the direct ways to study the risk of MSDs onset is through the use of ergonomic tools such as the

Correspondence to: Jacquier-Bret Julien, Laboratoire HandiBio-EA 4322-Université de Toulon, CS60584-83041 Toulon Cedex 9, France, Tel: +33494142755; E-mail: jacquier@univ-tln.fr

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RULA, Rapid Upper Limb Assessment [15], or the LUBA, Postural Loading on the Upper Body Assessment [16]. However, these tools are rarely used in the study of smartphone postures because they require measurements of axial skeletal and upper limb joint angles that are very rarely studied simultaneously. Researchers proposed a RULA analysis of texting based on video analysis [17]. With the same evaluation method, a study was performed in a seated position to test the effect of a support on the risk of MSDs occurrence in a seated position during a web browsing task [18].

The work presented here proposes a complete kinematic analysis of the upper body for the two positions most commonly used by young adults (sitting and standing) and for two of the most frequently performed tasks: sending a message and surfing the Internet. The objective was to evaluate the effects of these interaction conditions on the posture and to identify the joints MSDs risk.

MATERIALS AND METHODS

Twelve healthy subjects (mean: 21.6 ± 5.5 years old; youngest: 17-year-old; oldest: 33-year-old), five females (19.6 ± 3.0 years old; youngest: 17-year-old; oldest: 25-year-old) and seven males (23.0 ± 6.6 years old; youngest: 18-year-old; oldest: 33-year-old), voluntarily took part to the experience. Three were left-handed and nine right-handed. All subjects included in the experiment had to satisfy the following criteria: have no upper limbs or spine pathology, have at least 6 months of smartphone use experience and have owned a smartphone for at least 3 months. Each subject was informed about the protocol and gave her/his written consent before participation. The experimental procedure was in agreement with the Helsinki declaration [19] and was approved by the local ethics committee of the HandiBio laboratory (project number: 2018-003).

Participants had to perform two different tasks. The first one was a texting task. Each subject was asked to send the following message to an experimenter with their own smartphone (TEXT): “on se retrouve devant la gare à 20:00.” (“let’s meet in front of the train station at 8.00 pm”). The second was a web browsing task. From the navigation application, subjects were asked to search for the last available train schedule on the official website of the only train company in France and say it out loud. Only the city of departure, Toulon, and the destination, Marseille, had to be filled in before launching the search. Once the results were displayed, it was necessary to scroll down the page to reach the last schedule. The browsing history was erased after each attempt so as to be in the same conditions at the beginning of each trial. A training session was conducted prior to the protocol in order to familiarize the subject with the tasks and to verify that no settings would interfere with the research.

The tasks were repeated three times in two different experimental positions (POS, Figure1): Seated Without any Support (SWT) and Standing (STA). The sequence of the position has been randomized for each subject. Two consecutive trials were separated by a 90-second rest period and two conditions were separated by a 2-minute rest period. A standard schoolboy's chair (Width 47 × Height 81 × Depth 49 cm, Seat depth: 36 cm, Seat height: 46.4 cm) with a backrest and without armrests was used for the seated condition (SWT). A stool (with a height of 78 cm, Figure 1, pictures A and B) covered with a black cloth was placed 30 cm to the right of the subjects and used in both conditions to place the phone at the beginning and end of each trial (screen towards ceiling in normal direction of use).

Each test was carried out as follows. First of all, depending on the experimental position tested, the subject was asked to adopt a well-defined initial posture. For the SWT condition, the subject was seated with the forearms-on the thighs. For the STA condition, the subject simply had to stand upright with the upper limbs relaxed along the body. From this posture, the subject was then asked to grasp the phone, enter the application corresponding to the current task (texting or web browsing), enter the text and send it to the experimenter or perform the schedule research and state aloud the result, put the phone down on the stool, and repositions him/herself in the initial posture. Except for the fact that the subject was required to remain seated for the SWT conditions and standing still for the STA condition, no instructions were given as to how to achieve the task. Subjects were completely free to move their neck, trunk and upper limbs and all postures were allowed.

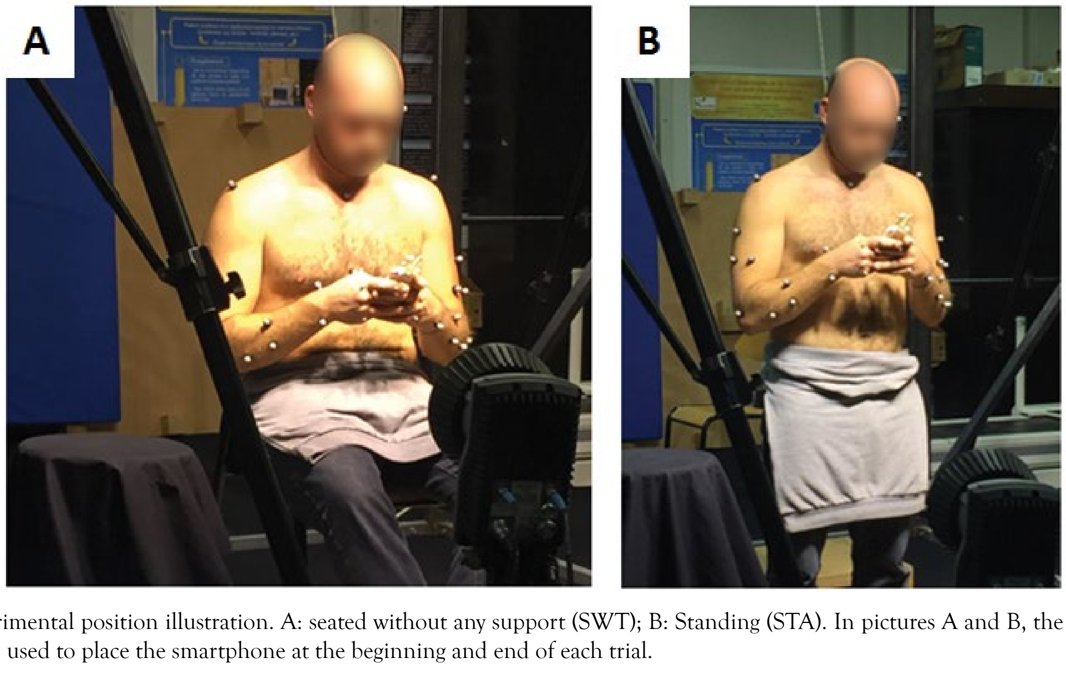

Figure1: Two experimental position illustration. A: seated without any support (SWT); B: Standing (STA). In pictures A and B, the stool hidden under the black drape was used to place the smartphone at the beginning and end of each trial.

After a detailed presentation of the protocol, thirty-six reflective markers were placed on the head, trunk, and right and left upper limbs of the subject (Figure 1). Twenty-four of them were positioned on bony anatomical landmarks identified by palpation, in agreements with the International Society of Biomechanics recommendations [20]. The remaining twelve were assembled in sets of three and were positioned on the arms and forearms as technical markers to compensate for the possible loss of anatomical markers. Five other markers were added on the smartphone to study its position during the task. To not disturb the subjects while texting or web browsing, these markers were positioned on a custom-made lightweight resin device glued to the back of the smartphone. The relative position of these markers to the screen was established before the start of the protocol. This allowed the smartphone position to be reconstructed at any time from the resin device.

To perform the motion analysis, the forty-one reflexive markers trajectories were recorded using an optoelectronic system with 8 Oqus 400 cameras (Qualisys AB, Gothenburg, Sweden) at a sampling rate of 200 Hz. From the 3D coordinates of the reflective markers, a local coordinate system has been defined at each step of the movement for each studied segments: the head, the trunk as well as the arms, forearms and hands of the two upper limbs. Then, the rotation matrices between two consecutive segments were computed. Thus, the relative angles of the neck, trunk, sterno-costo-clavicular joints, shoulders, elbows and wrists were extracted using the rotation sequences of the International Society of Biomechanics [20]. For the shoulder, the sequence proposed by Senk et al. [21] was applied (total of 24 degrees of freedom).

All these parameters represent the dependent variables. To complete the biomechanical analysis, the Rapid Upper Limb Assessment (RULA) and the postural Loading on the Upper Body Assessment (LUBA) were performed on the mean posture of each experimental position. To study the upper limb joint coupling during the achievement of the tasks, the pick-up and drop-off phase of the telephone have not been considered. Then, only the interaction phase corresponding to texting or web browsing were analyzed. Light conditions were fixed. Ambient illumination (800 lux) of the laboratory was measured with a lux meter (Luxmeter BF06 from Trotec company). Subjects were asked to adjust the light on their phones to maximum. Repeated analysis of variance (ANOVA) was performed to test the SIDE (left versus right upper limb) and POS (STW, STA) effect on all dependent variables. Tukey post-hoc test was conducted to identify the significant differences. The level of significance was set at $p<0.05$ (Statistica 7.1, Statsoft, Tulsa, OK, USA).

RESULTS

The average time for web browsing was 58.6 ± 15.9 s and for texting was 22.6 ± 5.5 s. Table 1 summarizes all the 3D kinematic parameters of the upper body for the two tasks and the two interaction positions studied. A position effect was found regardless of the task on neck flexion ($p<0.05$). The neck flexion was significantly greater when standing (-35.2 ± 6.4° vs. -27.0 ± 6.8° for texting and -33.1 ± 5.9° vs. -25.9 ± 4.2° for web browsing). The position also influenced trunk flexion whatever the task considered. However, unlike the neck, the values were higher for the sitting (SWT) condition (-7.8 ± 9.0° vs. -2.3 ± 4.7° for texting and -5.2 ± 6.5° vs. -2.2.1 ± 4.0° for web browsing).

Regarding the upper limb, ANOVA results revealed differences in sterno-costo-clavicular elevation and shoulder flexion between the two positions for the two tasks. The shoulders were more elevated and less flexed (Left side: -0.6 ± 4.9° vs. 7.4 ± 5.3° and 0.0 ± 5.0° vs. 6.1 ± 5.2° for texting and web browsing respectively; Right side: -0.2 ± 5.8° vs. 9.0 ± 6.1° and -0.3 ± 5.4° vs. 6.9 ± 4.7° for texting and web browsing respectively) in the standing position.

Furthermore, more specific effects have been observed. A slightly greater elbow flexion on the right side in comparison to the left for web browsing in both positions was evidenced (SWT: 108.1 ± 6.8° vs. 109 ± 8.9°; STA: 105.4 ± 6.4° vs. 107.6 ± 7.8° for left and right respectively). A difference in flexion for the left wrist was also observed for web browsing between the two positions: in the sitting position the wrist was flexed while it was in extension in the standing position (-4.0 ± 11.6° vs. 2.0 ± 8.1°). Finally, a significantly greater ulnar deviation was measured for the right wrist, in comparison to the left one, in both positions (SWT: 6.9 ± 6.0° vs. 3.3 ± 8.6°; STA: 6.9 ± 5.5° vs. 3.3 ± 6.3°). No task effect (texting vs. web browsing) was found for all of the 3D kinematic variables of the upper body.

Table 2 presents the MSDs risk with scores for each joint obtained from the RULA and LUBA. Regarding RULA scores, the local neck score was 3 and the trunk score was 2 regardless of task and position. Elbow flexion was rated at 2 while shoulder flexion was rated at 1, as was wrist flexion. However, a shoulder elevation and an ulnar deviation were recorded, which increased the shoulder and wrist scores by 1 point under all conditions. Due to the difference in duration time, the RULA provided an overall score of 3 for texting and 4 for the web browsing task. All of the upper limb joints (Group A) led to a score equivalent to that of Group B. Both groups participated in the establishment of a level 2 score according to the RULA interpretation grid.

Regarding the scores obtained with the LUBA, we obtained postural loading indexes of 9 for the sitting position and 10 for the standing position for both tasks. The degrees of freedom involved in the computation of these scores are neck, shoulder and elbow flexion and forearm pronation. The sitting web browsing condition presented different results when analyzed on the right side. Indeed, the ulnar deviation measured being higher than 10°, the rating was increased to 3, which increased the postural loading index to 13.

The RULA scores 3 and 4 as well as the LUBA scores 9 and 10 obtained respectively for the sitting and standing positions classify the texting and web browsing tasks with a smartphone in category 2, i.e., these are situations to be monitored to avoid risks of MSDs appearance in the long term.

DISCUSSION

The main results of this study were, the joint quantification of the upper body of young adults during texting and web browsing while sitting and standing, and, the associated risk of developing MSDs. In particular, the analysis showed that trunk flexion, elbow flexion and ulnar deviation of the wrist should be monitored in addition to neck flexion. More generally, the results suggest that all the upper body joints are involved to a greater or lesser extent in the

Table 1: Upper limb angle values in degrees (mean ± SD) measured for each experimental condition and both sides.

			Texting			Web browsing		
			SWT	STA	ANOVA	SWT	STA	ANOVA
Axial skeleton	Neck	Flexion (-)/Extension (+)	-27.0 ± 6.8	-35.2 ± 6.4*	pp<0.001	-25.9 ± 4.2	-33.1 ± 5.9*	pp<0.001
		Left (-)/Right (+) inclination	-1.3 ± 4.2	-0.8 ± 6.9	pp=0.76; NS	0.1 ± 4.9	-0.2 ± 5.1	pp=0.80 ; NS
		Left (+)/Right (-) rotation	-0.1 ± 3.2	-1.3 ± 3.1	pp=0.32; NS	-0.2 ± 1.9	-0.8 ± 2.3	pp=0.19 ; NS
	Trunk	Flexion (-)/Extension (+)	-7.8 ± 9.0	-2.3 ± 4.7*	pp<0.05	-5.2 ± 6.5	-2.2 ± 4.0*	pp<0.05
		Left (-)/Right (+) inclination	0.6±2.1	-0.4 ± 2.5	pp=0.11; NS	0.3 ± 2.4	-0.4 ± 2.6	pp=0.24 ; NS
		Left (+)/Right (-) rotation	-5.3 ± 4.9	-2.6 ± 8.7	pp=0.24; NS	-3.7 ± 6.0	-2.6 ± 8.9	pp=0.49 ; NS

			SWT		STA			SWT		STA		
			Left	Right	Left	Right	ANOVA	Left	Right	Left	Right	ANOVA
Upper limb	Sterno-costo-clavicular	Protraction (+)/Retraction (-)	-15.2 ± 4.7	-15.7 ± 4.3	-14.5 ± 4.9	-16.0 ± 5.4	pp=0.82; NS ps=0.61; NS	-14.9 ± 5.1	-16.4 ± 4.9	-14.7 ± 5.6	-16.9 ± 5.2	pp=0.74 ; NS ps=0.31 ; NS
		Elevation (-)/Depression (+)	-8.1 ± 5.6	-8.0 ± 5.5	-6.2 ± 4.6*	-5.8 ± 4.6*	pp<0.01 ps=0.80; NS	-7.7 ± 5.4	-7.4 ± 5.2	-7.0 ± 4.7*	-6.1 ± 5.0*	pp<0.01 ps=0.65 ; NS
	Shoulder	Flexion (+)/Extension (-)	7.4 ± 5.3	9.0 ± 6.1	-0.6 ± 4.9*	-0.2 ± 5.8*	pp<0.001 ps=0.35; NS	6.1 ± 5.2	6.9 ± 4.7	0.0 ± 5.0*	-0.3 ± 5.4*	pp<0.001 ps=0.73 ; NS
		Abduction (-)/Adduction (+)	-4.1 ± 3.3	-7.9 ± 7.2	-3.9 ± 3.2	-6.9 ± 7.0	pp=0.33; NS ps=0.10; NS	-4.5 ± 4.5	-8.3 ± 7.6	-4.4 ± 3.8	-7.3 ± 7.1	pp=0.50 ; NS ps=0.08 ; NS
		Medial (+)/lateral (-) rotation	36.2 ± 7.8	30.8 ± 10.6	35.2 ± 9.3	31.8 ± 8.3	pp=0.99; NS ps=0.25; NS	38.5 ± 8.6	30.1 ± 9.5	38.4 ± 9.9	31.7 ± 7.5	pp=0.82 ; NS ps=0.06 ; NS
	Elbow	Flexion (+)/Extension (-)	106.9 ± 8.4	107.0 ±10.2	106.1 ± 5.6	107.2 ± 7.2	pp=0.90; NS ps=0.58; NS	108.1 ± 6.8	109.7 ± 8.9£	105.4 ± 7.4	107.6 ± 7.8£	pp=0.12 ; NS ps<0.05
		Pronation (+)/Supination (-)	93.6 ± 19.5	91.8 ± 15.8	92.0 ± 16.0	93.2 ± 12.1	pp=0.93; NS ps=0.96; NS	93.4 ± 18.7	90.6 ± 17.5	89.4 ± 14.4	96.2 ± 16.8	pp=0.43 ; NS ps=0.75 ; NS
	Wrist	Flexion (+)/Extension (-)	-0.6 ± 11.0	3.5 ± 6.8	2.1 ± 8.6	4.6 ± 7.0	pp=0.26; NS ps=0.24; NS	-4.0 ± 11.6	3.2 ± 6.4	2.0 ± 8.1*	3.1 ± 8.0	pp<0.05 ps=0.18 ; NS
		Radial (-)/Ulnar (+) deviation	3.3 ± 8.6	6.9 ± 6.0£	3.3 ± 6.3	6.9 ± 5.5£	pp=0.98; NS ps<0.05	6.1 ± 6.9	10.7 ± 7.4	6.0 ± 6.8	8.9 ± 6.8	pp=0.27 ; NS ps=0.10 ; NS

'*' indicates significant differences from ST condition (effect of position). The values were compared independently for each side.
'£' indicates significant differences from Left side (effect of side).

Table 2: RULA and LUBA score for the mean postures measured for each experimental condition.

			Texting				Web browsing			
			SWT		STA		SWT		STA	
			RULA	LUBA	RULA	LUBA	RULA	LUBA	RULA	LUBA
Axial skeleton	Neck	Flexion (-)/Extension (+)	3	3	3	3	3	3	3	3
		Left (-)/Right (+) inclination	0	1	0	1	0	1	0	1
		Left (+)/Right (-) rotation	0	1	0	1	0	1	0	1
	Trunk	Flexion (-)/Extension (+)	2	1	2	1	2	1	2	1
		Left (-)/Right (+) inclination	0	1	0	1	0	1	0	1
		Left (+)/Right (-) rotation	0	1	0	1	0	1	0	1
		Total score Group B (RULA)	3	-	3	-	4	-	4	-

			SWT				STA				SWT				STA			
			Left		Right		Left		Right		Left		Right		Left		Right	
			RULA	LUBA	RULA	LUBA	RULA	LUBA	RULA	LUBA	RULA	LUBA	RULA	LUBA	RULA	LUBA	RULA	LUBA
Upper limb	Sterno-costo-clavicular	Protraction (+)/Retraction (-)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
		Elevation (-)/Depression (+)	+1	-	+1	-	+1	-	+1	-	+1	-	+1	-	+1	-	+1	-
	Shoulder	Flexion (+)/Extension (-)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
		Abduction (-)/Adduction (+)	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1
		Medial (+)/lateral (-) rotation	0	2	0	2	0	2	0	2	0	2	0	2	0	2	0	2
	Elbow	Flexion (+)/Extension (-)	2	2	2	2	2	2	2	2	2	3	2	3	2	3	2	3
		Pronation (+)/Supination (-)	0	2	0	2	0	2	0	2	0	2	0	2	0	2	0	2
	Wrist	Flexion (+)/Extension (-)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
		Radial (-)/Ulnar (+) deviation	+1	1	+1	1	+1	1	+1	1	+1	1	+1	3	+1	1	+1	1
	Total score Group A (RULA)		3	-	3	-	3	-	3	-	4	-	4	-	4	-	4	-
TOTAL			3	9	3	9	3	9	3	9	4	10	4	13	4	10	4	10

occurrence of MSDs during smartphone interaction, depending on the interaction condition.

First of all, the involvement of the neck, with flexion values greater than 25° in the sitting position and greater than 30° in the standing position during the two interaction tasks, was similar to that commonly found in the literature. Indeed, in the same tasks, Han and Shin [7] measured a neck flexion of 38.5° (median angle) and reported neck flexions between 37.2° (standing) and 46.8° (sitting) for texting and between 33.4° (standing) and 42.5° (sitting) for web browsing [8]. However, unlike other studies, the measured values are lower and no effect of the task was observed. The difference could be explained by the joint angle measurement technique. For both authors cited, the measurement of neck flexion was performed from a recording of an initial head position, whereas in our study, neck flexion was computed from anatomical norms, i.e., directly between the axis of the head and the axis of the trunk obtained from the 3D kinematics analysis. Although lower, these flexion values are still significant and are consistent with the existence of MSDs risk during interaction with a smartphone.

The trunk analysis showed that the thoraco-lumbar region was more flexed in the seated position than in the standing position, independently of the task. To our knowledge, very few studies have focused on this joint. A previous work by Merbah et al. [11] reported a similar result but only for the texting task with different light conditions as did Xie et al. [6] who showed trunk involvement when sending a message with one or two hands. This was also reflected in the results by a trunk score of 2 for the RULA (which appears more sensitive than the LUBA for trunk flexion). This joint seems important because it presents a risk, admittedly moderate, which could characterize in the long term a risk of appearance of MSDs of the lumbar area in the use of smartphones despite the low load carried.

An effect of the position has been demonstrated on shoulder flexion and sternocostoclavicular elevation. Flexion was greater when standing and elevation was higher when sitting. Berolo et al. [13] showed through a questionnaire that the shoulder is involved in MSD when using a smartphone for different tasks including texting and web browsing. This result was confirmed by a longitudinal study reporting pain in the shoulder [14]. Regarding shoulder flexion, the measured values are less than 20° and do not seem to present any particular risks, whatever the task. On the other hand, the shoulder elevation could present a moderate risk, which is taken into account the ergonomic score computation in the RULA and must be monitored. Indeed, the discomfort and pain would result both from the fact that the shoulder elevator muscles (such as the trapezius) would be more solicited and from the fact that some of them would also be involved in holding the head in flexion.

Concerning the elbow, there is an effect between the left and the right when standing during the navigation. The duration of this task could have generated slight changes of posture at the elbow during the interaction and would explain this difference. However, it does not allow us to draw any conclusion. But it could suggest a slight dissymmetry during standing web browsing. A dissymmetry, even slight, can lead to a risk posture. On the other hand, for all conditions, the measured flexions generate intermediate RULA and LUBA scores. This result suggests that this joint should be monitored.

For the wrist, ulnar deviation away from joint neutral was measured as done during one-handed interaction with a smartphone [12]. The authors reported ulnar deviations between 13° and 22°. In our study, the angles appear to be smaller, probably because all the subjects interacted with their smartphone with both hands. However, our results suggest that attention should be paid to this joint even in a two-handed grip because, as shown in the standing web browsing condition for right upper limb (Table 2), a deviation greater than 10° leads to a significant increase in the risk of MSDs in the LUBA as demonstrated in the occupational activities [22,23].

In summary, our results suggested that the shoulder elevation, elbow flexion, ulnar deviation of the wrist and the thoraco-lumbar spine should to be monitored as well as the neck flexion even in two-handed smartphone interaction tasks. Indeed, despite the low load handled, these joints would present potential MSDs risks in the more or less long-term depending on the experimental condition.

In our study, a major limitation is the sample. The experimental design was created in such a way that the subjects could perform the task in a completely free way. Only the sitting or standing position was constrained. Thus, this allowed us to measure the spontaneous behavior of the subjects. On the other hand, this generated a greater variability in the joint angles. However, the observed results showed significant differences despite this large variability.

Moreover, only the average postures were evaluated during this study. Future work on similar tasks but for longer durations could make it possible to study changes in postures over time, markers of discomfort or fatigue, and thus further characterize the risks over the duration of smartphone use.

CONCLUSION

This study showed an absence of task effect but a position effect (sitting vs. standing) on the upper body joints during interaction with a smartphone. The 3D kinematic results and ergonomic analysis suggest a long-term effect on the risk of developing MSDs in the neck, thoracolumbar spine, shoulders, elbows and wrists.

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