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Linking head and neck posture with muscular activity and perceived discomfort during prolonged smartphone texting

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Keywords: text neck; upper trapezius; posture

Highlights

Upper body kinematics and EMG from upper trapezius were recorded while standing and sitting

Absence of muscle resting phases during texting was found

Decreased angular excursions and increased muscular activity during standing suggest higher discomfort

Abstract

Prolonged use of the smartphone for texting was studied on a sample of 17 healthy young adult participants (11 females), who were asked to type interactively on a handheld device while standing and sitting. Upper body kinematics ad upper trapezius surface EMG were recorded to capture parameters of joint kinematics and muscular activity, which were then compared with self-reported indicators of discomfort through the Borg's CR 10 scale questionnaire. The results indicated that, while showing a similar postural strategy in both conditions that is assumed to be controlled by the visual system to maintain a constant viewing distance from the device, the participants adopted a "stiffer" posture of the head and neck during standing than when sitting, with a direct correlation between upper trapezius muscle activity, neck angle and perceived discomfort. The evidence obtained in this study highlights the importance of monitoring muscle activity and head and neck kinematics, to assess the biomechanical risk factors of neuromuscular disorders associated with smartphone overuse.

1. Introduction

In the last two decades, the use of mobile touch screen devices (MTSD) in daily life has been constantly growing: affordable prices, simplicity of usage and portability have encouraged widespread and intensive use among teenagers and adults for communication and information exchange, and the introduction in education (Couse & Chen 2010), healthcare (Luxton et al., 2011) and various working environments (Honan, 2015).

Studying the effects of intensive and daily use of MTSD on health is a matter of particular interest. While there has been an established association between electromagnetic field exposure and certain non-specific symptoms such as fatigue, sleep disturbance, headache and earache; the quantification of potential adverse effects of MTSD overuse on the musculoskeletal system is currently an object of debate (Valentini et al., 2007; Roosli et al., 2010; Zirek et al., 2020). The term "text-neck" (Neupane et al., 2017) was recently introduced to indicate a set of musculoskeletal symptoms, such as neck and shoulder pain, related to a prolonged and incorrect flexion of the cervical spine during smartphone and tablet use for texting (it is the most frequent activity carried out during the day (Gold et al., 2012)). It has been hypothesized that maintaining an inclined head-down posture could stress muscular activity, causing an alteration in the functional characteristics of the cervical spine (Vasavada et al., 2015). It has also been suggested that increased head flexion could be associated with higher muscular loads and increased stress in the cervical region (D'Anna et al., 2018). These hypotheses have been recently supported by researches based on questionnaires administered to report perceived discomfort, neck pain and upper limb fatigue during smartphone use. Berolo et al. (2011) observed a relationship between the use of mobile device and some muscular symptoms at the upper limb and neck level; Han et al. (2019) investigated the link between the amount of time spent on smartphones and these symptoms, and found that the use of mobile devices for more than five hours a day was associated with neck-shoulders pain (Hakala et al., 2006); the cross-sectional study conducted by Gustafsson et al. (Gustafsson e al., 2017) revealed an association between text messaging and pain at the neck, upper extremity and finger level, suggesting a long-term effect on musculoskeletal disorders; in terms of short-term effects, neck discomfort was shown to increase when using the device for more than ten minutes (Xie et al., 2017).

To quantify the relationship between the use of MTSD and posture alterations, the amount of stress to the cervical spine caused by prolonged anterior displacement has been assessed in a variety of ways, including simulations through finite element model analysis (Hansraj, 2004), and kinematics analysis from in-vivo testing (D'Anna et al., 2018). Regarding in-vivo tests, text messaging has been shown to cause a significant effect on the flexion of the head and neck complex (Lee et al., 2015), and this cervical flexion has been linked to two-handed texting in particular, while one-handed texting has been observed to lead to asymmetrical neck postures (Xie et al., 2018). An important aspect is that associated with typing, which leads to changes in the kinematics of cervical spine, thus resulting in an increased risk of developing cervical pain (Ning et al., 2015). This effect has been shown to also appear if typing is performed while walking (Han et al., 2019).

The involvement of muscle activity has been, on the other hand, rather underrepresented in research analysing MTSD use: the possible increase or decrease of myoelectric activity in non-focal muscles while typing is still matter of debate, with studies on children demonstrating greater neck muscle involvement during tablet use than during desktop computer use (Straker et al., 2008), while lower activations have been found on upper trapezius (UT) muscle of young adults when typing on the smartphone than during computer typing (Xie et al., 2016). MTSD screen size has also been shown to play a relevant role in UT muscle involvement in this regard (Kietrys et al., 2015), while it is agreed that there is an increased perception of muscle fatigue after smartphone use (Kim, 2015; Choi et al., 2016). The UT has been identified as the muscle playing a major role during both active (texting, gaming) and passive (reading) tasks (Chiu et al., 2015), and, despite being a non-focal complex when typing on a MTSD, it is agreed as the key muscle to study when investigating the relationship between typing-driven postural modifications and neck discomfort.

Following this perspective, in the present study we aim to investigate the kinematics of the upper complex when a prolonged texting activity on an MTSD is performed in both stance and sitting posture, and to quantify its relationship with surface EMG parameters of UT muscle activity, and with self-reported measures of perceived discomfort. The hypothesis we want to test is whether the possible modifications of joint kinematics at the head and neck level caused by the two different investigated whole-body postures are related with modifications of the UT muscle activity, and with the level of perceived discomfort.

2. Materials and Method

2.1. Participants

Seventeen young adults without musculoskeletal symptoms and diseases were recruited for the study. All participants have been using smartphones for at least six years and reported a daily use of more than three hours, principally for texting. All of them were right-handed, used both hands to hold the smartphone and to text, none of the them wore glasses. Anthropometric data and information about smartphone usage are given in Table 1.

All subjects provided informed written consent before taking part in the study, which complied with the Helsinki Declaration and had local approval from the Ethics Committee of the Applied Electronics Section of the Department of Engineering, Roma Tre University, and the experiments were conducted at BioLab³ in the same University.

2.2. Experimental Protocol

The experiments were conducted considering two different conditions reflecting different postures: *Sit* and *Stand*. In both conditions, we asked the participants to maintain a comfortable posture and to use a smartphone (Huawei P8 Lite 2017-5.2 inch) to text. For the Sit condition, participants sat on a stool without armrests and backrests to simulate similar upper trunk support as the Stand condition (Jin et al., 2019). The participants were allowed to adjust the seat height for comfortability. The sequence between the two posture conditions was chosen randomly for each participant.

In each condition, a reference (30 s long) was recorded before the texting task (10 mins long); in the reference condition the participants were asked to remain in a natural position, with their arms along their sides, and looking at a point in front of them; in the texting task the participants were invited to type on the smartphone to communicate with the experimenter using a common messaging application. Before starting the experiment, participants were allowed to familiarise themselves with the smartphone for two minutes. Between one condition and the next, there was a five-minute pause. The font size set to 1.1 *em* (screen resolution 720 x 1280 pixels) was visually comfortable for all participants (Bababekova et al., 2011).

Table 1. Anthropometric data, years of use and time of use for texting during the day (group mean ± standard deviation).

	Males (n=6)	**Females (n=11)**
Age (yrs)	22.16 ±1.47	22.70±1.82
Height (cm)	182.66±1.96	170.52±10.13
Weight (kg)	79.16±9.86	60.18±9.95
Smartphone usage (yrs)	8.83±2.63	8.54±2.29
Time spent using the smartphone (hrs/day)	3.33±1.03	3.36±0.67

2.2.1. Kinematics measurements

The kinematics was acquired through an optoelectronic motion analysis system (SMART-DX 6000, BTS, Milan, Italy) consisting of eight infrared cameras (sampling frequency 250 Hz). Reflective markers (diameter 15 mm), with double-sided adhesive tape, were applied to the skin projections of the C7, sacrum, cyclops, tragus, acromion, epicondyle, wrist, and one on the smartphone (see Fig.1). The calibration procedure was performed before the first data capture. Spatial accuracy in the reconstruction of the markers 3-D position was approximately 0.2 mm.

2.2.2. Surface EMG measurements

The muscular activity of the right and left upper trapezius (UT) was acquired at a sampling rate of 1000 Hz using a wireless surface electromyograph (FreeEMG300, BTS, Milan, Italy). After skin preparation (shaving the area if covered with hair, and cleaning the skin with alcohol) bipolar Ag/AgCl surface electrodes (diameter 2 cm) were placed on UT (distance 2 cm between electrode centers) according to (Freriks and Hermens, 2000). Before the experimental session, for sEMG normalization, the maximal voluntary contraction (MVC) was acquired three times, following the European Recommendations for Surface Electromyography (Freriks and Hermens, 2000).

Figure 1: experimental protocol for both *Sit* and *Stand* posture

The two systems for kinematic data and electromyography recording were automatically synchronized by the SMART-DX 6000 system.

2.2.3. Borg's CR 10 scale

To collect information on the level of muscle fatigue and/or pain perceived during the texting task, participants were invited to fill in a questionnaire based on Borg's CR 10 scale (Borg, 1982). The questions asked in the questionnaire were as follows:

1) Did you feel pain and/or fatigue in cranio-cervical zone?
2) If yes, select the level that you feel from 1 to 10 (Borg's CR 10 Scale, Table 2).

Questions 1) and 2) were repeated after each posture condition.

Table 2. Borg's CR 10 Scale

0	Nothing at all
0.5	Extremely weak
1	Very weak
2	Weak
3	Moderate
4	Somewhat strong
5	Strong (heavy)
6	
7	Very strong
8	
9	
10	Extremely strong

2.3. Data Processing

2.3.1. Kinematics data processing

After each acquisition, the 3-D trajectories of the markers were reconstructed using a frame-by-frame tracking system and a label to each marker was assigned. The data were processed using SMART Analyzer software and Matlab2019a (MathWorks Inc. USA) software. Trajectories were then low-pass filtered (10 Hz), and from them, the following angles were extracted:

1. Neck flexion-extension angle (*NA*): angle between the line passing through the marker placed on the seventh cervical vertebra and the one on the tragus, and the vertical (Y) axis of the laboratory reference system.
2. Trunk flexion-extension angle (*TA*): angle between the line passing through the marker placed on the seventh cervical vertebra and that on the sacrum, and the vertical (Y) axis of the laboratory reference system.
3. Gaze angle (*GA*): angle between the line passing through the marker placed on the cyclops and that on the smartphone, and the horizontal (X) axis of the laboratory reference system.
4. Elbow flexion-extension angle (*EA*): angle between the line connecting the marker placed on the acromion and that on the epicondyle, and the line connecting the marker on the epicondyle and that on the wrist.

For all the angles and for each posture condition, the values over time were purged of the mean value taken in the reference condition; from the resulting distribution, the median value ($P50_{NA}$, $P50_{TA}$, $P50_{GA}$, $P50_{EA}$ for the four described angles) and the posture range (PR_{NA}, PR_{TA}, PR_{GA}, PR_{EA}) taken as the difference between the 10th and the 90th percentile, were calculated (Straker et al., 2009). To capture information on the viewing distance for each participant, the distance *d* between the cyclops and the smartphone was also extracted.

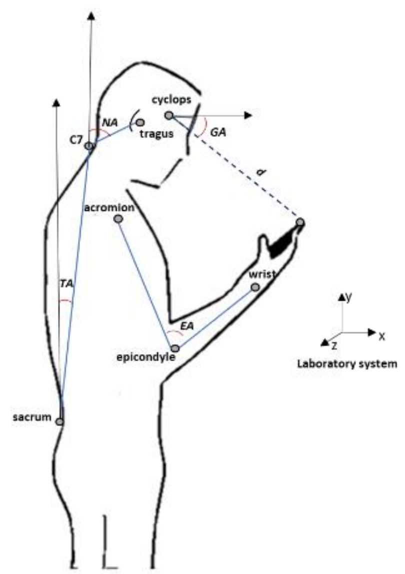

Figure 2: marker positions and extracted angles

2.3.2. Surface EMG processing

Surface EMG signal processing was performed in Matlab2019a (MathWorks Inc. USA) following these steps:

i) raw surface EMG data, for both MVC and experimental conditions, were band-pass filtered (4th order, Butterworth filter bandpass = 20-400 Hz) and powerline interference was removed by applying a notch filter (4th order, Butterworth f_t = 49.8-50.2 Hz). The filtered signals were then full-wave rectified and low-pass filtered with a 4th order Butterworth filter (cut-off frequency 10 Hz) to obtain the linear envelopes of each muscle;

ii) the obtained envelopes were normalized to the average peak value coming from the three MVC repetitions (% MVC). The root mean square (RMS) values from 100 ms non-overlapping windows were then calculated;

iii) the median value ($P50_{RMS}$) and the 10th percentile of the RMS distribution ($P10_{RMS}$), and the difference between the 90th and 10th percentile (RMS_{range}) were calculated. In particular, $P10_{RMS}$ is considered an indicator of static muscular activity (Straker et al., 2009), while RMS_{range} is linked to the size of the change in muscle activity (Szeto et al., 2009);

iv) the relative rest time (*RRT*), defined as the sum – relative to the entire duration – of the time durations when RMS is below 1% MVC for more than 100 ms, was calculated according to (Thorn et al., 2007). The chosen threshold (1% MVC) was considered in the literature as a good indicator of individual differences in terms of gap frequency analysis (Thorn et al, 2007).

As the task resulted almost symmetrical (all participants typed on the smartphone with both hands), the data for both kinematics and muscular activity were processed only for the dominant side.

2.3.3. Correlation analysis between kinematics, muscular activity and Borg's scale

To investigate the relationship among UT muscular activity, neck angle, and perceived discomfort, coefficients of linear correlation between $P10_{RMS}$, $P50_{NA}$ and Borg's 10 CR scale were calculated.

2.4. Statistics

Descriptive statistics included measures of central tendency and dispersion, and it was calculated for both kinematics and electromyography parameters. To check for differences caused by the condition, inferential statistics was performed by considering posture as main factor and including gender as an additional factor. Interaction between these two factors was also calculated. The normality of data distribution was verified using Lilliefors test. If normality was rejected at the chosen significance level ($p < 0.05$), the Kruskal-Wallis test was used, otherwise a two-way ANOVA was performed.

The presence of possible linear correlation between the kinematics angles, between $P10_{RMS}$ and $P50_{NA}$ and between $P10_{RMS}$ and *Borg 10 CR scale* was checked through Pearson's coefficient, while possible inverse proportionality between *RRT* and $P10_{RMS}$ was checked according to Spearman's rho coefficient. The level of significance was set at $p < 0.05$.

3. Results

3.1. Kinematics

Two-way ANOVA performed on kinematics revealed an effect of the condition on several parameters, and of the gender on a subset of them, while the interaction between the main factors was not significant for any parameter.

Regarding the median values of the joint angles, only $P50_{NA}$ showed a higher neck flexion when the participants were seated than when they were standing. Instead, the results on postural ranges were significantly different across conditions for all angles, with lower values (decreased variability) when the participants typed while standing.

Mean and standard deviation for *P50* are reported on Table 3; results related to PR values are shown in Figure 3.

Table 3: group mean ± standard deviation for P50 angles in both postures (*p < 0.05, n.s. p ≥ 0.05).

	$P50_{NA}$ (°)		$P50_{TA}$ (°)		$P50_{EA}$ (°)		$P50_{GA}$ (°)	
Sit	17.77 ± 7.43	*	2.45 ± 1.47	n.s	101.40 ± 25.65	n.s	57.97 ± 4.99	n.s
Stand	12.71 ± 5.32		1.92 ± 1.02		104.00 ± 36.76		56.03 ± 4.63	

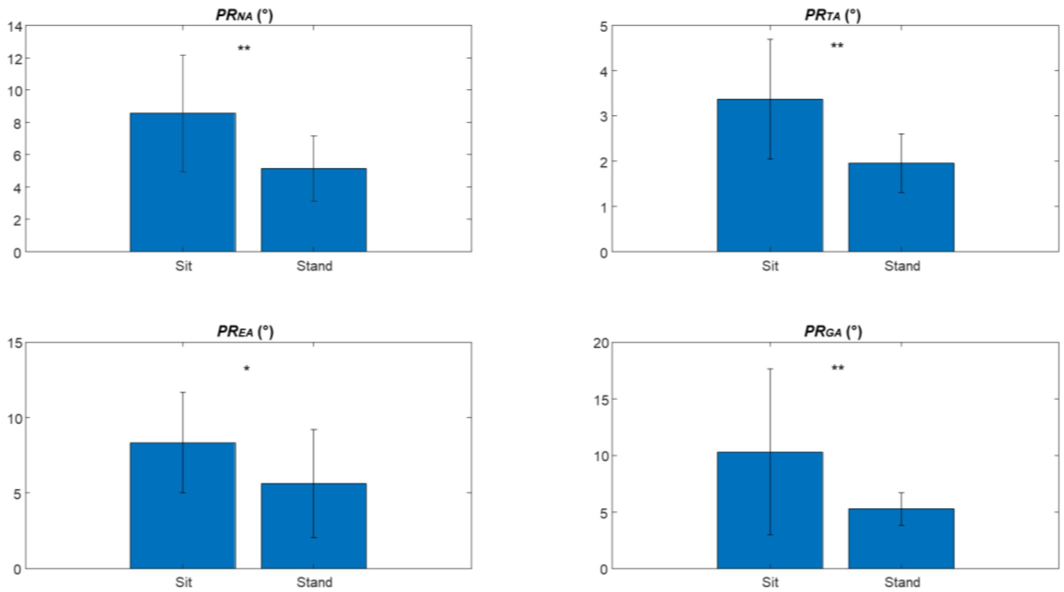

Figure 3: mean ± standard deviation (error bar) for postural ranges of all angles in both postures (*p < 0.05, **p < 0.001)

The viewing distance from the smartphone was not different between the two postures. The participants kept the smartphone distance almost constant during each test, with an average value and a standard deviation of 0.363 m ± 0.077 m, and 0.368 m ± 0.038 m, for the *Seat* and *Stand* condition, respectively. Regarding the shoulder flexion, this angle did not vary relevantly with respect to the reference condition (less than 3° on average), and no differences appeared between the two conditions.

The statistical analysis showed no significant difference between males and females for all *PR* parameters in both postures; instead, significant differences were found between the gender groups for the median values of all joint angles across conditions, with the exclusion of $P50_{TA}$ when standing and $P50_{GA}$ when sitting. In both postures, males showed higher flexion-extension of both neck and elbow angles than females. Moreover, the analysis of the viewing distance from the smartphone was not different between males (*Seat*

0.41 m ± 0.11 m, *Stand* 0.38 m ± 0.04 m) and females (*Seat* 0.33 m ± 0.02 m, *Stand* 0.35 m ± 0.03 m). Mean and standard deviation for each parameter are reported on Tables 4-5

Table 4: mean ± standard deviation for P50 angles in *Stand* posture divided by gender group (*p < 0.05, n.s. p ≥ 0.05)

Stand	$P50_{NA}$ (°)		$P50_{TA}$ (°)		$P50_{EA}$ (°)		$P50_{GA}$ (°)	
Males	18.04 ± 5.34	*	1.92 ± 1.03	n.s.	124.57±56.85	*	59.64±3.64	*
Females	10.46 ± 4.57		1.93 ± 1.07		92.78±12.37		54.06±3.80	

Table 5: mean ± standard deviation for P50 angles in *Sit* posture divided by gender group (*p < 0.05, n.s. p ≥ 0.05)

Sit	$P50_{NA}$ (°)		$P50_{TA}$ (°)		$P50_{EA}$ (°)		$P50_{GA}$ (°)	
Males	22.95 ± 7.24	*	3.55 ± 1.74	*	123.52 ± 32.48	*	60.10 ± 3.64	n.s.
Females	13.59 ± 4.17		1.79 ± 0.79		89.57 ± 8.93		57.32 ± 5.37	

The analysis of the linear correlation between the kinematics angle pairs was performed to better characterize the postural strategies adopted by the participants when texting. The results showed: i) positive correlation between $P50_{EA}$ and $P50_{NA}$, for both postures (in the *Sit* condition, r = 0.54, *p* = 0.02; in the *Stand* condition r = 0.48, *p* = 0.04); ii) positive correlation between $P50_{GA}$ and $P50_{NA}$, for both postures (in the *Sit* condition, r = 0.59, p = 0.01; in the *Stand* condition, r = 0.60, p = 0.009). Correlation graphs are shown in Figure 4.

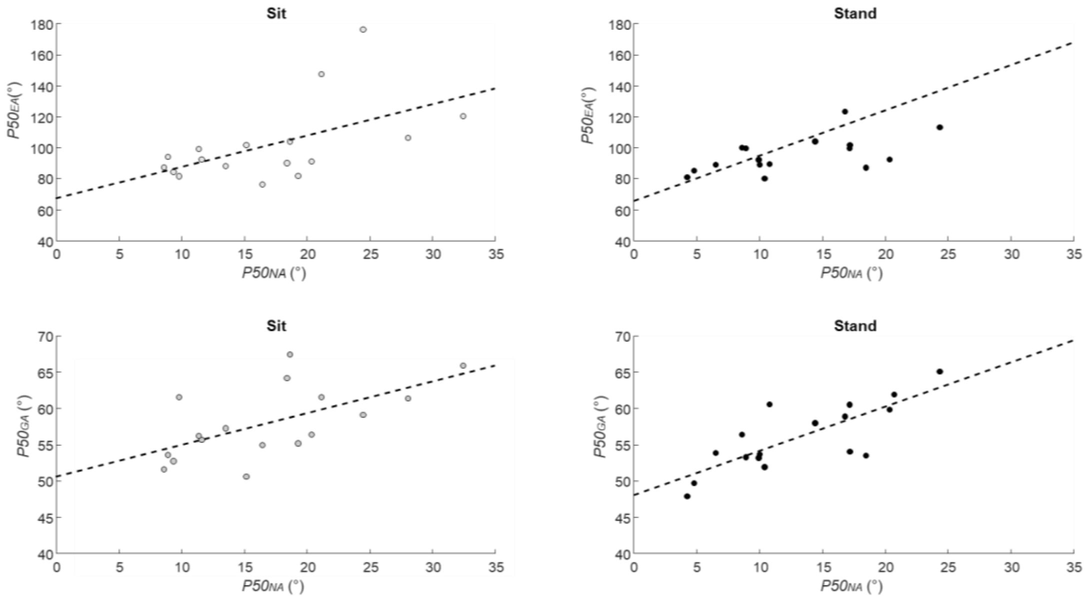

Figure 4: Scatter plot between P50 elbow angle and P50 neck angle, and between P50 gaze angle and P50 neck angle for both postures. Regression lines for each pair of parameters are shown in dashed black.

3.2. Surface EMG

Regarding surface EMG, two-way ANOVA did not reveal any effect on parameters resulting from posture condition or gender group, and the interaction between these factors was also not significant. The numerical values (median and quartile limits) are shown in Table 6.

Table 6. Median values (lower-upper quartile) of $P50_{RMS}$, $P10_{RMS}$, RMS_{range} and RRT for the upper trapezius.

	$P50_{RMS}$ (%MVC) median (Q3-Q1)	***$P10_{RMS}$ (%MVC)*** median (Q3-Q1)	***RMS_{range} (%MVC)*** median (Q3-Q1)	***RRT (%time)*** median (Q3-Q1)
Sit	2.60 (1.01-8.73)	2.14 (0.85-6.83)	1.99 (1.05-4.80)	0.05 (0-45.25)
Stand	2.54 (1.37-8.55)	2.23 (0.95-4.18)	2.26 (0.76-4.94)	0 (0-12.12)

Regarding correlation between surface EMG parameters, $P10_{RMS}$ was found to be linked with *RRT*, for both postures: an inverse proportionality was found, with Spearman coefficients of -0.79 ($p < 0.001$) and -0.85 ($p < 0.001$) for *Sit* and *Stand* respectively. The correlation graphs are shown in Figure 5.

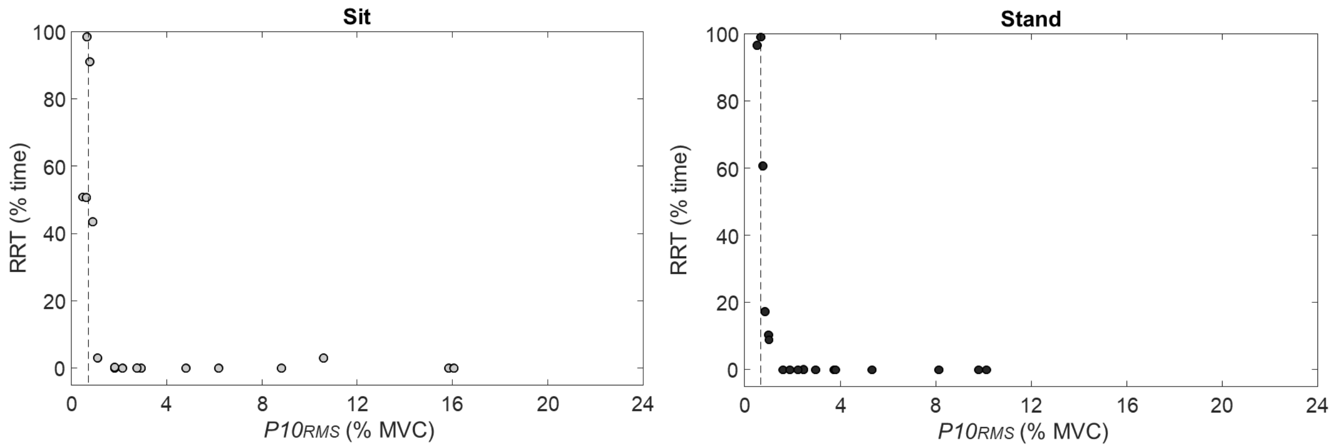

Figure 5. Scatter plot for *P10RMS* and RRT in both conditions. The dashed vertical line marks the RRT threshold level set to 1%MVC.

3.3. Borg's CR 10 scale

Regarding the level of perceived discomfort, all participants declared that they felt fatigue in the cranio-cervical area after each posture condition. The declared scale values of perceived fatigue ranged from 0.5 to 4 in both postures, apart from one participant who told he felt a strong sense of fatigue in the sitting posture condition (scale level of 5). Histograms of obtained Borg values after both conditions are shown in Figure 6.

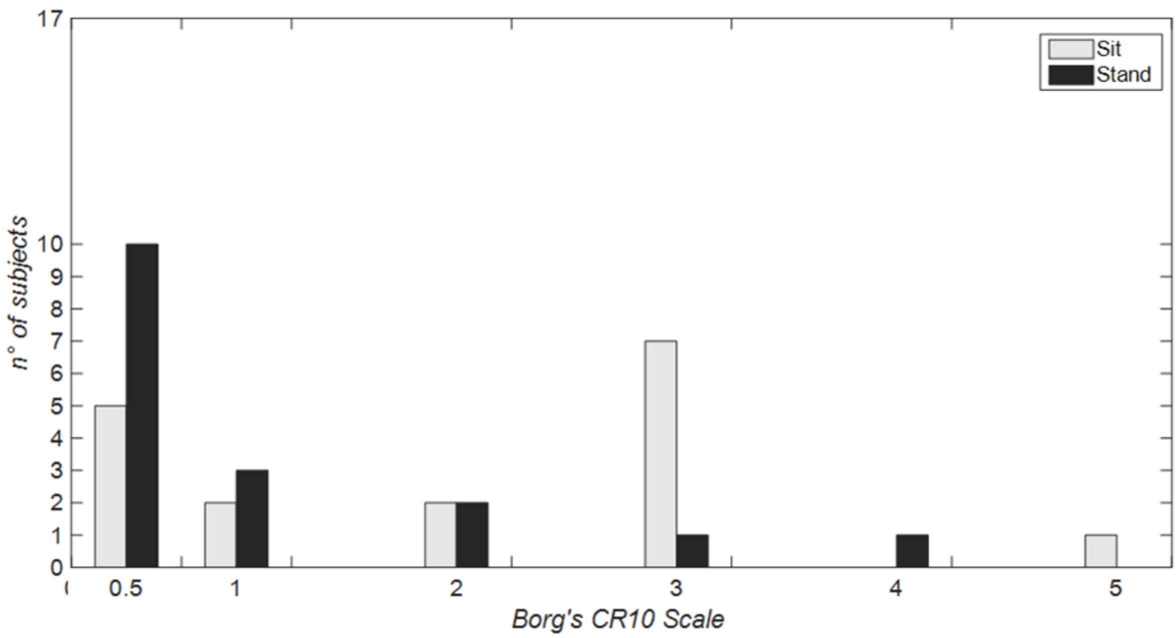

Figure 6. Frequency distribution of Borg's CR10 Scale in *Sit* (gray bars) and *Stand* (black bars) posture. The median value of the individual differences between Sit condition and Stand condition is 1.

3.4. Correlation analysis

To investigate the relationship between upper trapezius muscle activation and neck posture, coefficients of linear correlation were also calculated. Direct proportion between $P10_{RMS}$ and $P50_{NA}$ was observed when the participants typed standing (ρ = 0.47, p = 0.04), while no significant correlation was found in sitting position (ρ = 0.11, p = 0.66). The regression line is shown in Figure 7.

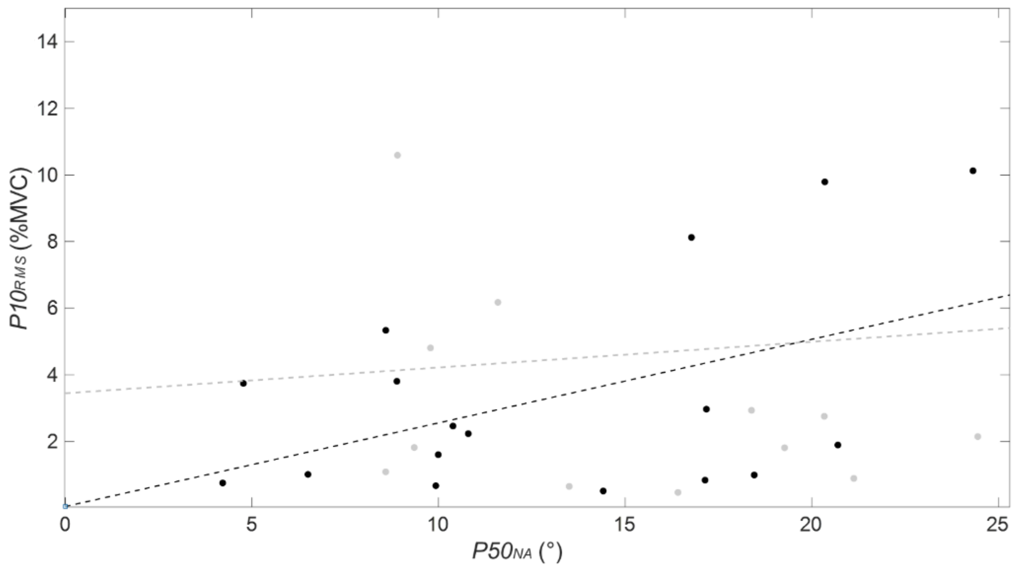

Figure 7. Correlation between P50 neck values and $P10_{RMS}$ in *Sit* (gray dots and regression line) and *Stand* (black dots and regression line) posture.

Then, to check possible relationships between muscle activity and perceived discomfort during texting, the coefficients of linear correlation between Borg's CR 10 scale and $P10_{RMS}$ were calculated: a direct relationship was found for both postures, and this was significant only when standing (In *Stand* condition, ρ = 0.80, p = 0.01; in *Sit* condition, ρ = 0.36, p = 0.1). The scatter plot and the regression lines are shown in Figure 8 for both postures.

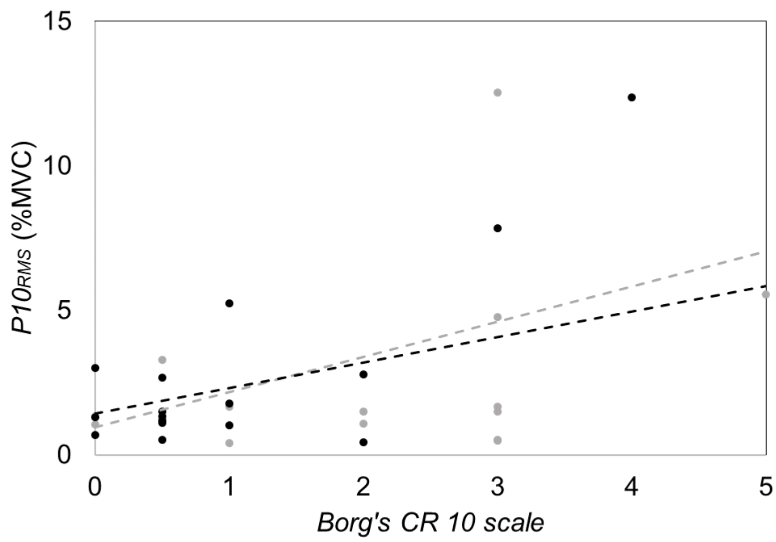

Figure 8. Correlation between Borg's CR 10 scale values and $P10_{RMS}$ for both postures (dots and dashed regression line in gray for *Sit*, dots and dashed regression line in black for *Stand*).

4. Discussion

We therefore observed that the postures of the trunk, neck and head complex, and its variability are partly influenced by prolonged typing activity on MTSD, and that this effect varies depending on the posture condition of the whole body (i.e. while sitting or standing). This is related to some variations in terms of upper trapezius muscle involvement, and both variables are linked with perceived discomfort. In the next sections we will briefly discuss the results obtained for each group of variables, and then an interpretation of the correlation between variables will be drawn.

4.1. Kinematics

When the participants used the smartphone to text, they tended to adopt a similar neutral posture of the upper body regardless of whether they were sitting or standing: we found no difference on the values of the median angle between the two conditions, with the exclusion of the neck flexion-extension angle that, in agreement with values obtained by Lee et al. (2015), was higher (i.e. more flexed) when sitting than when standing (approximately 18° when sitting, compared to around 13° when standing). The comparison between the sexes instead highlighted that the neck tilt and the elbow extension are greater in males than in females, suggesting a different posture strategy adopted.

In terms of temporal variability of posture, all angles showed a decreased postural range while standing than when sitting (about 5° for almost all angles when standing, compared to around 10° when sitting): this decrease in posture variability may be the result of an increase of trunk stiffness in upright stance, which may be caused by the fact that the whole body has tighter limits of stability when standing; postural range variability has also been linked in the literature to the risk of developing musculoskeletal symptoms (i.e. neck pain (Cheng et al., 2015)), and maintaining a more rigid posture over a prolonged period of time has been shown to generate states of fatigue and discomfort and potential risk of developing chronic musculoskeletal disorders (Rudolfsson et al., 2012).

The study also showed that in both conditions the participants maintained a constant viewing distance from the smartphone, at about 36 cm, and this is in agreement with other observations (Bababekova, 2011; Boccardo, 2020). This result suggests that the visual system drives the postural strategy: the direct correlation between the elbow flexion-extension angle and the neck flexion-extension angle showed that, to maintain this fixed distance, people who show higher neck flexion tend to extend the elbow more and vice versa: with anthropometric data at hand, for a median neck angle greater than 10° the median elbow angle is greater than around 100°. Moreover, the results have also showed a positive correlation between the angle of gaze and neck flexion, suggesting that, in order for the body to maintain a neck angle of a few degrees (< 10°), the upper trunk posture must be adjusted to ensure an angle of gaze of around 45°–50°. The strategy adopted by females to ensure maintaining the viewing distance at the shown values is instead different from the males: females tend to rely on elbow flexion, while males tend to increase neck flexion.

4.2. Upper Trapezius muscular activity

With an observed median value around 2.5% of MVC, the results on upper trapezius muscle activity confirmed those reported by Thorn et al. (2007) for precision typing. Similarly, the value around 2% of MVC for variability of muscular activity indicated an approximately low-level constant muscular activity during the experiment. In addition, evidence that $P10_{RMS}$ resulted around 2% of MVC indicated that the degree of muscle tonic activity during texting is not entirely negligible, even for a muscle that is not focal in the task: it reflects the continuous muscle load during sustained activity, and could be associated with a potential development of musculoskeletal disorders (Xie et al., 2016). This aspect was better investigated through the analysis of relative rest time and its strong inverse proportionality with $P10_{RMS}$: lower *RRT* values and a higher level of $P10_{RMS}$ during smartphone texting, for all conditions, showed that this low-level sustained tonic muscle activity is associated with a virtual absence of rest phases. As presented by a previous research (Jonsson, 1982), this absence is a plausible risk factor for the development of trapezius myalgia, neck pain and cervical discomfort.

4.3. Correlation between muscular activity, perceived discomfort and posture kinematics

Correlation analysis confirmed an association between low level muscle tonic activity ($P10_{RMS}$) and perceived discomfort. The people who showed a higher level of muscle tonic activity at the upper trapezius were on average those that reported higher discomfort according to the Borg's3 scale.

In addition, in standing condition, $P10_{RMS}$ was positively correlated with neck flexion: we highlight here that the upper trapezius is not directly involved in neck flexion, therefore, this correlation is not the simple result of the neuromechanical action of the muscle, rather a side effect associated with a possible increase in tension associated with angle flexion. The results obtained on this correlation suggest that, as confirmed by the analysis of the postural range, when subjects are texting in upright stance for a long period of time, they may not only adopt a more rigid posture, but may also experience an increase in tension at the neck-shoulder level if neck shows excessive flexion.

4.4. Strengths and limitations of study

With the combined collection of data coming from kinematics, muscular activity, and self-reported indicators of discomfort perception, we were able to investigate more pointedly the relationships between prolonged use of smartphone devices and possible effects on the musculoskeletal system. In particular, we identified the fixed distance-from-smartphone strategy as a common behaviour among participants, with differences, however, in the choice through which this strategy is pursued, with corresponding differences in the amount of muscular involvement, and consequently in discomfort perception. We believe this may be considered a useful addition to the current state of the art in the analysis of risks associated with prolonged use of MTSD.

Some limitations need to be highlighted. Although not negligible in general terms, the sample size prevented us from investigating the possible covariates of the results obtained: with a larger sample size, the correlation with anthropometric factors and their interaction with gender would have helped to distinguish purely biomechanical predictors from the postural strategies adopted. Moreover, we opted for a reduced set of markers to minimize the discomfort for individuals: it is possible that, using a complete set of markers, other elements related to kinematics could have been better captured (for example, the kinematics of different spinal regions). For the same reason, we opted on focusing on one muscle only, and it might have been useful to include the recording of other involved muscles (both focal and non-focal) to get a more complete picture of the neuro-mechanics associated with the chosen postural strategies. Furthermore, the study was conducted only on young population (20-24 year), this relatively narrow age range limits the generalizability of these results to younger and older populations. Old users could adopt a different strategy during texting (Wright et al., 2000) and could be more susceptible to the development of musculoskeletal symptoms (Ghasemkhani et al., 2008).

5. Conclusion

We believe that the results obtained from the present study on the use of smartphone for texting suggest possible developments: to ensure an adequate viewing distance from the device, the control system adopts a postural strategy such that, as the elbow tends to extend, the neck flexes more. In this regard, the data analysis suggests that, in order to keep maintaining a limited flexion of the neck, the flexion-extension of the elbow should be maintained at around 100°, and the gaze angle at around 45°-50°. This information might could have useful practical effects: if a smartphone is able to detect its distance from the viewer's head and its orientation with respect to the vertical (both pieces of information can be captured by using the on-board camera and the built-in accelerometer), it could be possible to design an application that monitors neck flexion, and advises the smartphone user on any excessive neck flexion (e.g. by suggesting a rest break or even shut the screen off if users ignore the break prompts for a given time frame). Similarly, with regard to the muscles involved, by monitoring the relative rest time, it could be assumed that the same application could give advice in case of excessive muscle involvement or tension, and suggest strategies to prevent discomfort or pain, such as the neck stabilization exercises (Dusunceli et al., 2009).

Moreover, prolonged use of smartphone devices while standing seems to result in a more rigid posture than while sitting, and this hypothesis is supported by the link between upper trapezius activity, increased neck flexion and perceived discomfort. These findings suggest that sustained texting activities with MTSD could be a plausible factor for the development of cervical discomfort and potential risk of neck pain; thus, in contrast to the findings of the use of desktop typing while standing as less physically demanding than while sitting, we observed a possible increased discomfort when typing while standing, rather than sitting. This aspect will need to be studied more carefully, factoring in the remaining muscles involved, including the focal ones.

Finally, the observed correlation between the amplitude-based surface EMG parameter $P10_{RMS}$ and the indicator of discomfort perception further highlights the usefulness of recording EMG also for such kind of applications, where sustained low-level tonic muscular activity may play a relevant role in the onset of work-related musculoskeletal disorders, and biomechanical risk assessment. The findings of the present research could be used to define intervention strategies to prevent the biomechanical risk both in daily life and in educational and work environments. Future studies, based on different age groups, and recording these data for long-term smartphone use, could highlight further effects on the musculoskeletal system and on the onset of neck discomfort.

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We would like to thank both reviewers for their comments, which helped use produce a revised version of the manuscript. While we will respond individually inline (red font) to each Reviewer 2 specific comment.

Reviewer #1: The authors have addressed the queries raised by the reviewers very well. Congratulations for the efforts and all thebest for future research.

Thank you.

Reviewer #2: The submission is greatly improved and I appreciate the hard work that has been put into this revision. There are still a few recommendations that I would make:

Lines 31-33 - When citing, citations should be included at the end of the sentence and in numerical order, starting with the earliest.

We modified the numerical order and we included the references at the end of the sentence.

Line 27 - Should the citation be Couse & Chen, 2010 instead of Leslie, Chen, 2010?

We corrected the reference.

There is an unusually large us of the colon throughout the document to separate thoughts. You should summarize and then list the citing documentation to support your statement. I would suggest the following rewrite as an example (Lines 29 - 33.)

The effects of intensive and daily use of MTSD on health is of particular interest. While there has been an established association between electromagnetic field exposure and certain non-specific symptoms such as fatigue, sleep disturbance, headache and earache; the quantification of potential adverse effects of MTSD overuse on the musculoskeletal system is currently an object of debate (Valentini et al., 2007; Roosli et al., 2010; Zirek et al., 2020).

Introduction - again, most of the introduction is strung together citations. You should summarize your interpretation of the citing documents and how they tell the story (provide history and how your research answers the gaps)

Thank you. We have modified the sentence with the text you kindly provided us with, and we have rewritten paragraphs at Lines 50-70 to follow your suggestions.

Line 42 should be a period after smartphone use. A new sentence should begin with "Berolo et al..."
Line 42 - Double citation. Either reword as "Berolo et al (2011)" or move citation to the end of the sentence.

We modified the sentence and the reference following your suggestion

Line 60 - "researches" should be research

Done

Line 91-92: You should reword. Ex. "For the Sit condition, participants sat on a stool without armrests and backrests to simulate similar upper trunk support as the Stand condition (Jin et al., 2019). The participants were allowed to adjust the seat height for comfortability."

We modified the sentence following your suggestion.

Line - 306 Period after calculated not colon. "A direct proportion between P10 RMS and P50 NA was observed" (not appeared)

We modified the sentence.

There are several tense errors (using "is" instead of "are") please review the manuscript and change accordingly

Done

Line 380 Limitations. You should address age as a limitation. It is possible that older use groups could be more susceptible to the development of MSDs with a shorter time exposure. Are there any research studies on older/elderly populations and "text neck"?

Thank you for the suggestions. We have renamed the section "Strengths and limitations of the study", added a paragraph summarizing the main strengths (lines 380-38), and added the aspect regarding age groups in the paragraph summarizing the limitations.

Line 391 Relabel as Conclusion not Conclusions

Done

Line 400-403 Since you have already suggested an app that can warn the users for excessive neck flexion could it not also prompt for rest breaks or even shut the screen off if users ignore the break prompts for a given "X" time frame?

Thank you for your suggestion. We added this on lines 410-411

Highlights

- Upper body kinematics and EMG from upper trapezius were recorded while standing and sitting
- Absence of muscle resting phases during texting was found
- Decreased angular excursions and increased muscular activity during standing suggest higher discomfort

Linking head and neck posture with muscular activity and perceived discomfort during prolonged smartphone texting

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Keywords: text neck; upper trapezius; posture

Highlights

Upper body kinematics and EMG from upper trapezius were recorded while standing and sitting

Absence of muscle resting phases during texting was found

Decreased angular excursions and increased muscular activity during standing suggest higher discomfort

Abstract

Prolonged use of the smartphone for texting was studied on a sample of 17 healthy young adult participants (11 females), who were asked to type interactively on a handheld device while standing and sitting. Upper body kinematics ad upper trapezius surface EMG were recorded to capture parameters of joint kinematics and muscular activity, which were then compared with self-reported indicators of discomfort through the Borg's CR 10 scale questionnaire. The results indicated that, while showing a similar postural strategy in both conditions that is assumed to be controlled by the visual system to maintain a constant viewing distance from the device, the participants adopted a "stiffer" posture of the head and neck during standing than when sitting, with a direct correlation between upper trapezius muscle activity, neck angle and perceived discomfort. The evidence obtained in this study highlights the importance of monitoring muscle activity and head and neck kinematics, to assess the biomechanical risk factors of neuromuscular disorders associated with smartphone overuse.

1. Introduction

In the last two decades, the use of mobile touch screen devices (MTSD) in daily life has been constantly growing: affordable prices, simplicity of usage and portability have encouraged widespread and intensive use among teenagers and adults for communication and information exchange, and the introduction in education (Couse & Chen 2010), healthcare (Luxton et al., 2011) and various working environments (Honan, 2015).

Studying the effects of intensive and daily use of MTSD on health is a matter of particular interest. While there has been an established association between electromagnetic field exposure and certain non-specific symptoms such as fatigue, sleep disturbance, headache and earache; the quantification of potential adverse effects of MTSD overuse on the musculoskeletal system is currently an object of debate (Valentini et al., 2007; Roosli et al., 2010; Zirek et al., 2020). The term "text-neck" (Neupane et al., 2017) was recently introduced to indicate a set of musculoskeletal symptoms, such as neck and shoulder pain, related to a prolonged and incorrect flexion of the cervical spine during smartphone and tablet use for texting (it is the most frequent activity carried out during the day (Gold et al., 2012)). It has been hypothesized that maintaining an inclined head-down posture could stress muscular activity, causing an alteration in the functional characteristics of the cervical spine (Vasavada et al., 2015). It has also been suggested that increased head flexion could be associated with higher muscular loads and increased stress in the cervical region (D'Anna et al., 2018). These hypotheses have been recently supported by researches based on questionnaires administered to report perceived discomfort, neck pain and upper limb fatigue during smartphone use. Berolo et al. (2011) observed a relationship between the use of mobile device and some muscular symptoms at the upper limb and neck level; Han et al. (2019) investigated the link between the amount of time spent on smartphones and these symptoms, and found that the use of mobile devices for more than five hours a day was associated with neck-shoulders pain (Hakala et al., 2006); the cross-sectional study conducted by Gustafsson et al. (Gustafsson e al., 2017) revealed an association between text messaging and pain at the neck, upper extremity and finger level, suggesting a long-term effect on musculoskeletal disorders; in terms of short-term effects, neck discomfort was shown to increase when using the device for more than ten minutes (Xie et al., 2017).

To quantify the relationship between the use of MTSD and posture alterations, the amount of stress to the cervical spine caused by prolonged anterior displacement has been assessed in a variety of ways, including simulations through finite element model analysis (Hansraj, 2004), and kinematics analysis from in-vivo testing (D'Anna et al., 2018). Regarding in-vivo tests, text messaging has been shown to cause a significant effect on the flexion of the head and neck complex (Lee et al., 2015), and this cervical flexion has been linked to two-handed texting in particular, while one-handed texting has been observed to lead to asymmetrical neck postures (Xie et al., 2018). An important aspect is that associated with typing, which leads to changes in the kinematics of cervical spine, thus resulting in an increased risk of developing cervical pain (Ning et al., 2015). This effect has been shown to also appear if typing is performed while walking (Han et al., 2019).

The involvement of muscle activity has been, on the other hand, rather underrepresented in research analysing MTSD use: the possible increase or decrease of myoelectric activity in non-focal muscles while typing is still matter of debate, with studies on children demonstrating greater neck muscle involvement during tablet use than during desktop computer use (Straker et al., 2008), while lower activations have been found on upper trapezius (UT) muscle of young adults when typing on the smartphone than during computer typing (Xie et al., 2016). MTSD screen size has also been shown to play a relevant role in UT muscle involvement in this regard (Kietrys et al., 2015), while it is agreed that there is an increased perception of muscle fatigue after smartphone use (Kim, 2015; Choi et al., 2016). The UT has been identified as the muscle playing a major role during both active (texting, gaming) and passive (reading) tasks (Chiu et al., 2015), and, despite being a non-focal complex when typing on a MTSD, it is agreed as the key muscle to study when investigating the relationship between typing-driven postural modifications and neck discomfort.

Following this perspective, in the present study we aim to investigate the kinematics of the upper complex when a prolonged texting activity on an MTSD is performed in both stance and sitting posture, and to quantify its relationship with surface EMG parameters of UT muscle activity, and with self-reported measures of perceived discomfort. The hypothesis we want to test is whether the possible modifications of joint kinematics at the head and neck level caused by the two different investigated whole-body postures are related with modifications of the UT muscle activity, and with the level of perceived discomfort.

2. Materials and Method

2.1. Participants

Seventeen young adults without musculoskeletal symptoms and diseases were recruited for the study. All participants have been using smartphones for at least six years and reported a daily use of more than three hours, principally for texting. All of them were right-handed, used both hands to hold the smartphone and to text, none of the them wore glasses. Anthropometric data and information about smartphone usage are given in Table 1.

All subjects provided informed written consent before taking part in the study, which complied with the Helsinki Declaration and had local approval from the Ethics Committee of the Applied Electronics Section of the Department of Engineering, Roma Tre University, and the experiments were conducted at BioLab³ in the same University.

2.2. Experimental Protocol

The experiments were conducted considering two different conditions reflecting different postures: *Sit* and *Stand*. In both conditions, we asked the participants to maintain a comfortable posture and to use a smartphone (Huawei P8 Lite 2017-5.2 inch) to text. For the Sit condition, participants sat on a stool without armrests and backrests to simulate similar upper trunk support as the Stand condition (Jin et al., 2019). The participants were allowed to adjust the seat height for comfortability. The sequence between the two posture conditions was chosen randomly for each participant.

In each condition, a reference (30 s long) was recorded before the texting task (10 mins long); in the reference condition the participants were asked to remain in a natural position, with their arms along their sides, and looking at a point in front of them; in the texting task the participants were invited to type on the smartphone to communicate with the experimenter using a common messaging application. Before starting the experiment, participants were allowed to familiarise themselves with the smartphone for two minutes. Between one condition and the next, there was a five-minute pause. The font size set to 1.1 *em* (screen resolution 720 x 1280 pixels) was visually comfortable for all participants (Bababekova et al., 2011).

Table 1. Anthropometric data, years of use and time of use for texting during the day (group mean ± standard deviation).

	Males (n=6)	**Females (n=11)**
Age (yrs)	22.16 ±1.47	22.70±1.82
Height (cm)	182.66±1.96	170.52±10.13
Weight (kg)	79.16±9.86	60.18±9.95
Smartphone usage (yrs)	8.83±2.63	8.54±2.29
Time spent using the smartphone (hrs/day)	3.33±1.03	3.36±0.67

2.2.1. Kinematics measurements

The kinematics was acquired through an optoelectronic motion analysis system (SMART-DX 6000, BTS, Milan, Italy) consisting of eight infrared cameras (sampling frequency 250 Hz). Reflective markers (diameter 15 mm), with double-sided adhesive tape, were applied to the skin projections of the C7, sacrum, cyclops, tragus, acromion, epicondyle, wrist, and one on the smartphone (see Fig.1). The calibration procedure was performed before the first data capture. Spatial accuracy in the reconstruction of the markers 3-D position was approximately 0.2 mm.

2.2.2. Surface EMG measurements

The muscular activity of the right and left upper trapezius (UT) was acquired at a sampling rate of 1000 Hz using a wireless surface electromyograph (FreeEMG300, BTS, Milan, Italy). After skin preparation (shaving the area if covered with hair, and cleaning the skin with alcohol) bipolar Ag/AgCl surface electrodes (diameter 2 cm) were placed on UT (distance 2 cm between electrode centers) according to (Freriks and Hermens, 2000). Before the experimental session, for sEMG normalization, the maximal voluntary contraction (MVC) was acquired three times, following the European Recommendations for Surface Electromyography (Freriks and Hermens, 2000).

Figure 1: experimental protocol for both *Sit* and *Stand* posture

The two systems for kinematic data and electromyography recording were automatically synchronized by the SMART-DX 6000 system.

2.2.3. Borg's CR 10 scale

To collect information on the level of muscle fatigue and/or pain perceived during the texting task, participants were invited to fill in a questionnaire based on Borg's CR 10 scale (Borg, 1982). The questions asked in the questionnaire were as follows:

1) Did you feel pain and/or fatigue in cranio-cervical zone?
2) If yes, select the level that you feel from 1 to 10 (Borg's CR 10 Scale, Table 2).

Questions 1) and 2) were repeated after each posture condition.

Table 2. Borg's CR 10 Scale

0	Nothing at all
0.5	Extremely weak
1	Very weak
2	Weak
3	Moderate
4	Somewhat strong
5	Strong (heavy)
6	
7	Very strong
8	
9	
10	Extremely strong

2.3. Data Processing

2.3.1. Kinematics data processing

After each acquisition, the 3-D trajectories of the markers were reconstructed using a frame-by-frame tracking system and a label to each marker was assigned. The data were processed using SMART Analyzer software and Matlab2019a (MathWorks Inc. USA) software. Trajectories were then low-pass filtered (10 Hz), and from them, the following angles were extracted:

1. Neck flexion-extension angle (*NA*): angle between the line passing through the marker placed on the seventh cervical vertebra and the one on the tragus, and the vertical (Y) axis of the laboratory reference system.
2. Trunk flexion-extension angle (*TA*): angle between the line passing through the marker placed on the seventh cervical vertebra and that on the sacrum, and the vertical (Y) axis of the laboratory reference system.
3. Gaze angle (*GA*): angle between the line passing through the marker placed on the cyclops and that on the smartphone, and the horizontal (X) axis of the laboratory reference system.
4. Elbow flexion-extension angle (*EA*): angle between the line connecting the marker placed on the acromion and that on the epicondyle, and the line connecting the marker on the epicondyle and that on the wrist.

For all the angles and for each posture condition, the values over time were purged of the mean value taken in the reference condition; from the resulting distribution, the median value ($P50_{NA}$, $P50_{TA}$, $P50_{GA}$, $P50_{EA}$ for the four described angles) and the posture range (PR_{NA}, PR_{TA}, PR_{GA}, PR_{EA}) taken as the difference between the 10^{th} and the 90^{th} percentile, were calculated (Straker et al., 2009). To capture information on the viewing distance for each participant, the distance *d* between the cyclops and the smartphone was also extracted.

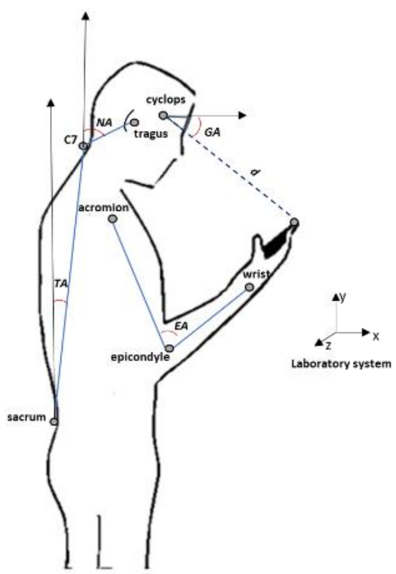

Figure 2: marker positions and extracted angles

2.3.2. Surface EMG processing

Surface EMG signal processing was performed in Matlab2019a (MathWorks Inc. USA) following these steps:

i) raw surface EMG data, for both MVC and experimental conditions, were band-pass filtered (4^{th} order, Butterworth filter bandpass = 20-400 Hz) and powerline interference was removed by applying a notch filter (4^{th} order, Butterworth f_t = 49.8-50.2 Hz). The filtered signals were then full-wave rectified and low-pass filtered with a 4^{th} order Butterworth filter (cut-off frequency 10 Hz) to obtain the linear envelopes of each muscle;

ii) the obtained envelopes were normalized to the average peak value coming from the three MVC repetitions (% MVC). The root mean square (RMS) values from 100 ms non-overlapping windows were then calculated;

iii) the median value ($P50_{RMS}$) and the 10^{th} percentile of the RMS distribution ($P10_{RMS}$), and the difference between the 90^{th} and 10^{th} percentile (RMS_{range}) were calculated. In particular, $P10_{RMS}$ is considered an indicator of static muscular activity (Straker et al., 2009), while RMS_{range} is linked to the size of the change in muscle activity (Szeto et al., 2009);

iv) the relative rest time (*RRT*), defined as the sum – relative to the entire duration – of the time durations when RMS is below 1% MVC for more than 100 ms, was calculated according to (Thorn et al., 2007). The chosen threshold (1% MVC) was considered in the literature as a good indicator of individual differences in terms of gap frequency analysis (Thorn et al, 2007).

As the task resulted almost symmetrical (all participants typed on the smartphone with both hands), the data for both kinematics and muscular activity were processed only for the dominant side.

2.3.3. Correlation analysis between kinematics, muscular activity and Borg's scale

To investigate the relationship among UT muscular activity, neck angle, and perceived discomfort, coefficients of linear correlation between $P10_{RMS}$, $P50_{NA}$ and Borg's 10 CR scale were calculated.

2.4. Statistics

Descriptive statistics included measures of central tendency and dispersion, and it was calculated for both kinematics and electromyography parameters. To check for differences caused by the condition, inferential statistics was performed by considering posture as main factor and including gender as an additional factor. Interaction between these two factors was also calculated. The normality of data distribution was verified using Lilliefors test. If normality was rejected at the chosen significance level ($p < 0.05$), the Kruskal-Wallis test was used, otherwise a two-way ANOVA was performed.

The presence of possible linear correlation between the kinematics angles, between $P10_{RMS}$ and $P50_{NA}$ and between $P10_{RMS}$ and *Borg 10 CR scale* was checked through Pearson's coefficient, while possible inverse proportionality between *RRT* and $P10_{RMS}$ was checked according to Spearman's rho coefficient. The level of significance was set at $p < 0.05$.

3. Results

3.1. Kinematics

Two-way ANOVA performed on kinematics revealed an effect of the condition on several parameters, and of the gender on a subset of them, while the interaction between the main factors was not significant for any parameter.

Regarding the median values of the joint angles, only $P50_{NA}$ showed a higher neck flexion when the participants were seated than when they were standing. Instead, the results on postural ranges were significantly different across conditions for all angles, with lower values (decreased variability) when the participants typed while standing.
Mean and standard deviation for *P50* are reported on Table 3; results related to PR values are shown in Figure 3.

Table 3: group mean ± standard deviation for P50 angles in both postures (*p < 0.05, n.s. p ≥ 0.05).

	$P50_{NA}$ (°)		$P50_{TA}$ (°)		$P50_{EA}$ (°)		$P50_{GA}$ (°)	
Sit	17.77 ± 7.43	*	2.45 ± 1.47	n.s	101.40 ± 25.65	n.s	57.97 ± 4.99	n.s
Stand	12.71 ± 5.32		1.92 ± 1.02		104.00 ± 36.76		56.03 ± 4.63	

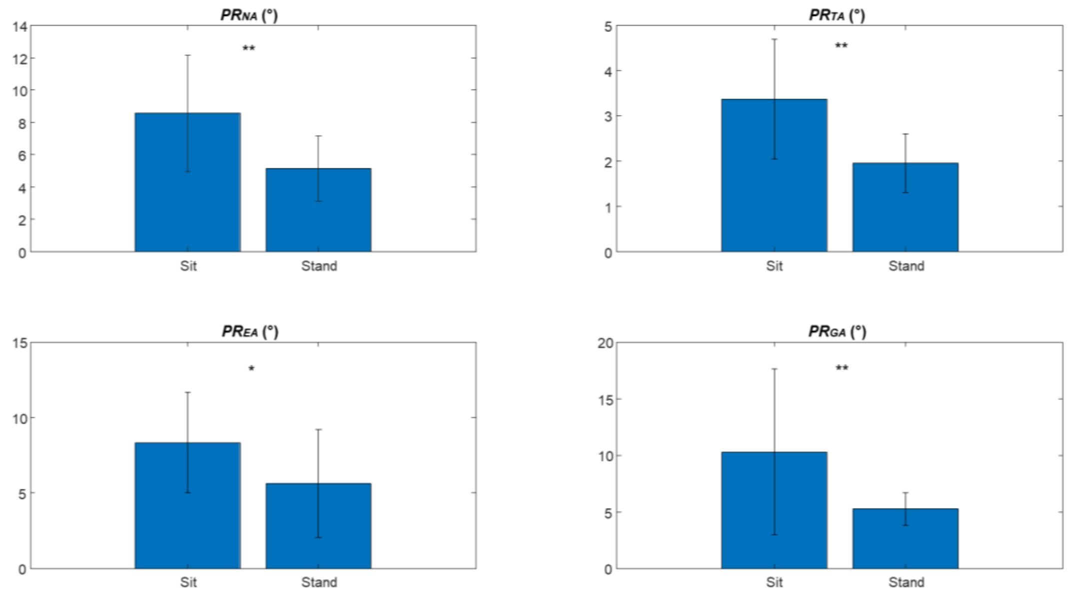

Figure 3: mean ± standard deviation (error bar) for postural ranges of all angles in both postures (*p < 0.05, **p < 0.001)

The viewing distance from the smartphone was not different between the two postures. The participants kept the smartphone distance almost constant during each test, with an average value and a standard deviation of 0.363 m ± 0.077 m, and 0.368 m ± 0.038 m, for the *Seat* and *Stand* condition, respectively. Regarding the shoulder flexion, this angle did not vary relevantly with respect to the reference condition (less than 3° on average), and no differences appeared between the two conditions.

The statistical analysis showed no significant difference between males and females for all *PR* parameters in both postures; instead, significant differences were found between the gender groups for the median values of all joint angles across conditions, with the exclusion of $P50_{TA}$ when standing and $P50_{GA}$ when sitting. In both postures, males showed higher flexion-extension of both neck and elbow angles than females. Moreover, the analysis of the viewing distance from the smartphone was not different between males (*Seat*

0.41 m ± 0.11 m, *Stand* 0.38 m ± 0.04 m) and females (*Seat* 0.33 m ± 0.02 m, *Stand* 0.35 m ± 0.03 m). Mean and standard deviation for each parameter are reported on Tables 4-5

Table 4: mean ± standard deviation for P50 angles in *Stand* posture divided by gender group (*p < 0.05, n.s. p ≥ 0.05)

Stand	***$P50_{NA}$ (°)***		***$P50_{TA}$ (°)***		***$P50_{EA}$ (°)***		***$P50_{GA}$ (°)***	
Males	18.04 ± 5.34	*	1.92 ± 1.03	n.s.	124.57±56.85	*	59.64±3.64	*
Females	10.46 ± 4.57		1.93 ± 1.07		92.78±12.37		54.06±3.80	

Table 5: mean ± standard deviation for P50 angles in *Sit* posture divided by gender group (*p < 0.05, n.s. p ≥ 0.05)

Sit	***$P50_{NA}$ (°)***		***$P50_{TA}$ (°)***		***$P50_{EA}$ (°)***		***$P50_{GA}$ (°)***	
Males	22.95 ± 7.24	*	3.55 ± 1.74	*	123.52 ± 32.48	*	60.10 ± 3.64	n.s.
Females	13.59 ± 4.17		1.79 ± 0.79		89.57 ± 8.93		57.32 ± 5.37	

The analysis of the linear correlation between the kinematics angle pairs was performed to better characterize the postural strategies adopted by the participants when texting. The results showed: i) positive correlation between $P50_{EA}$ and $P50_{NA}$, for both postures (in the *Sit* condition, r = 0.54, *p* = 0.02; in the *Stand* condition r = 0.48, *p* = 0.04); ii) positive correlation between $P50_{GA}$ and $P50_{NA}$, for both postures (in the *Sit* condition, r = 0.59, p = 0.01; in the *Stand* condition, r = 0.60, p = 0.009). Correlation graphs are shown in Figure 4.

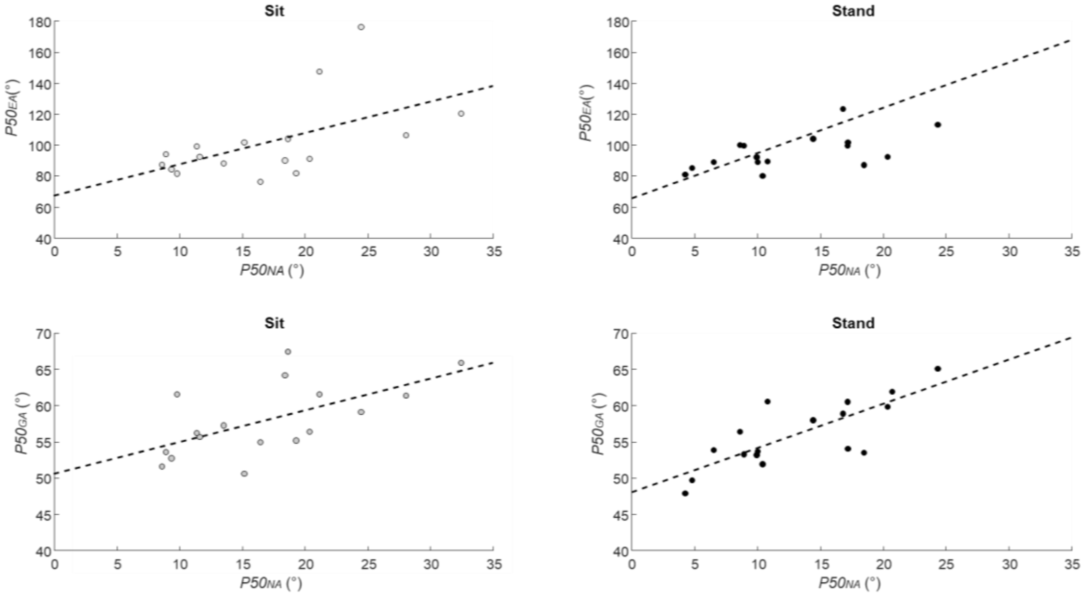

Figure 4: Scatter plot between P50 elbow angle and P50 neck angle, and between P50 gaze angle and P50 neck angle for both postures. Regression lines for each pair of parameters are shown in dashed black.

3.2. Surface EMG

Regarding surface EMG, two-way ANOVA did not reveal any effect on parameters resulting from posture condition or gender group, and the interaction between these factors was also not significant. The numerical values (median and quartile limits) are shown in Table 6.

Table 6. Median values (lower-upper quartile) of $P50_{RMS}$, $P10_{RMS}$, RMS_{range} and RRT for the upper trapezius.

	***$P50_{RMS}$* (%MVC)** median (Q3-Q1)	***$P10_{RMS}$* (%MVC)** median (Q3-Q1)	***RMS_{range}* (%MVC)** median (Q3-Q1)	***RRT* (%time)** median (Q3-Q1)
Sit	2.60 (1.01-8.73)	2.14 (0.85-6.83)	1.99 (1.05-4.80)	0.05 (0-45.25)
Stand	2.54 (1.37-8.55)	2.23 (0.95-4.18)	2.26 (0.76-4.94)	0 (0-12.12)

Regarding correlation between surface EMG parameters, *$P10_{RMS}$* was found to be linked with *RRT*, for both postures: an inverse proportionality was found, with Spearman coefficients of -0.79 ($p < 0.001$) and -0.85 ($p < 0.001$) for *Sit* and *Stand* respectively. The correlation graphs are shown in Figure 5.

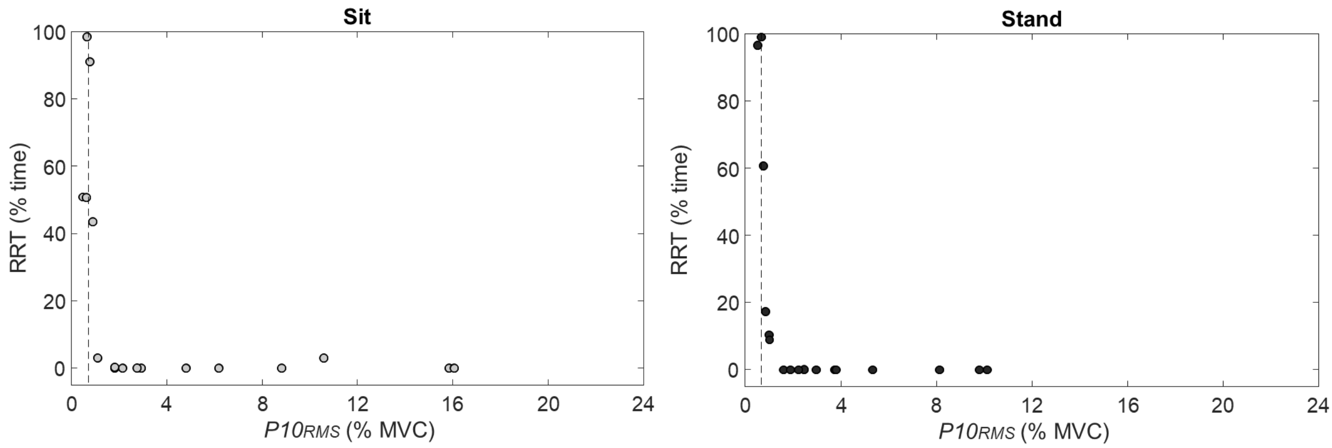

Figure 5. Scatter plot for *P10RMS* and RRT in both conditions. The dashed vertical line marks the RRT threshold level set to 1%MVC.

3.3. Borg's CR 10 scale

Regarding the level of perceived discomfort, all participants declared that they felt fatigue in the cranio-cervical area after each posture condition. The declared scale values of perceived fatigue ranged from 0.5 to 4 in both postures, apart from one participant who told he felt a strong sense of fatigue in the sitting posture condition (scale level of 5). Histograms of obtained Borg values after both conditions are shown in Figure 6.

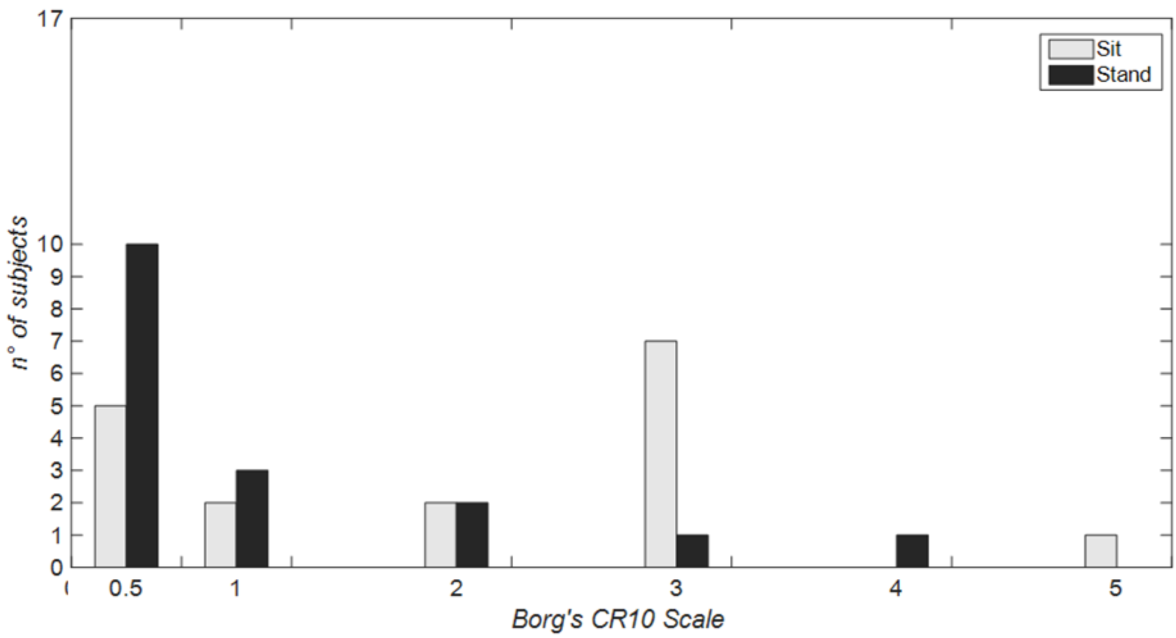

Figure 6. Frequency distribution of Borg's CR10 Scale in *Sit* (gray bars) and *Stand* (black bars) posture. The median value of the individual differences between Sit condition and Stand condition is 1.

3.4. Correlation analysis

To investigate the relationship between upper trapezius muscle activation and neck posture, coefficients of linear correlation were also calculated. Direct proportion between $P10_{RMS}$ and $P50_{NA}$ was observed when the participants typed standing (ρ = 0.47, p = 0.04), while no significant correlation was found in sitting position (ρ = 0.11, p = 0.66). The regression line is shown in Figure 7.

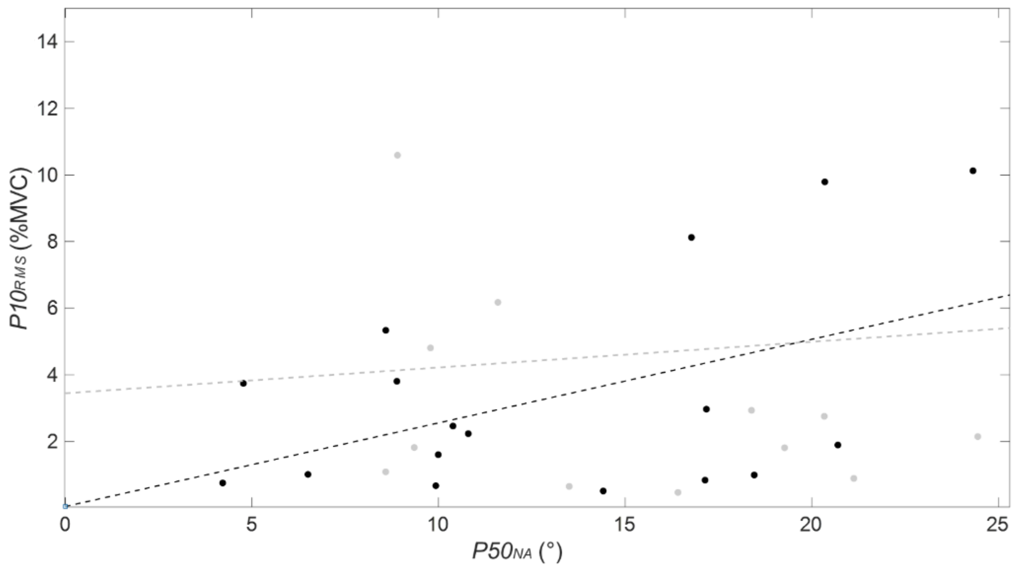

Figure 7. Correlation between P50 neck values and $P10_{RMS}$ in *Sit* (gray dots and regression line) and *Stand* (black dots and regression line) posture.

Then, to check possible relationships between muscle activity and perceived discomfort during texting, the coefficients of linear correlation between Borg's CR 10 scale and $P10_{RMS}$ were calculated: a direct relationship was found for both postures, and this was significant only when standing (In *Stand* condition, ρ = 0.80, p = 0.01; in *Sit* condition, ρ = 0.36, p = 0.1). The scatter plot and the regression lines are shown in Figure 8 for both postures.

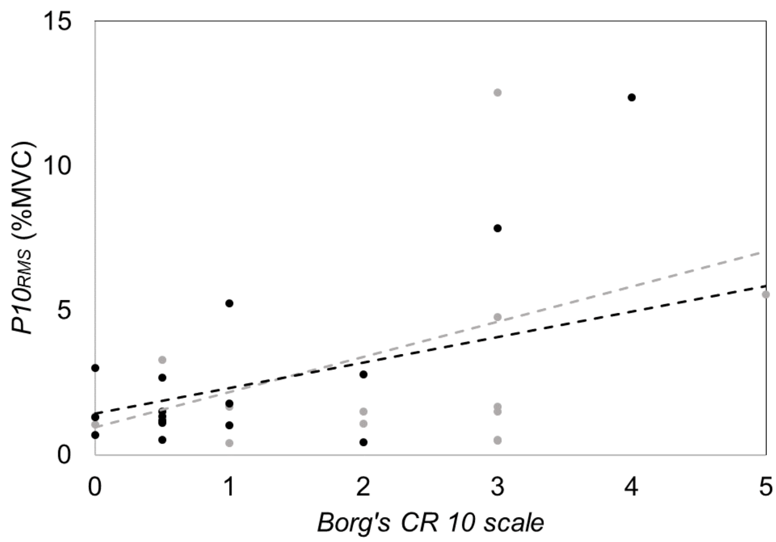

Figure 8. Correlation between Borg's CR 10 scale values and $P10_{RMS}$ for both postures (dots and dashed regression line in gray for *Sit*, dots and dashed regression line in black for *Stand*).

4. Discussion

We therefore observed that the postures of the trunk, neck and head complex, and its variability are partly influenced by prolonged typing activity on MTSD, and that this effect varies depending on the posture condition of the whole body (i.e. while sitting or standing). This is related to some variations in terms of upper trapezius muscle involvement, and both variables are linked with perceived discomfort. In the next sections we will briefly discuss the results obtained for each group of variables, and then an interpretation of the correlation between variables will be drawn.

4.1. Kinematics

When the participants used the smartphone to text, they tended to adopt a similar neutral posture of the upper body regardless of whether they were sitting or standing: we found no difference on the values of the median angle between the two conditions, with the exclusion of the neck flexion-extension angle that, in agreement with values obtained by Lee et al. (2015), was higher (i.e. more flexed) when sitting than when standing (approximately 18° when sitting, compared to around 13° when standing). The comparison between the sexes instead highlighted that the neck tilt and the elbow extension are greater in males than in females, suggesting a different posture strategy adopted.

In terms of temporal variability of posture, all angles showed a decreased postural range while standing than when sitting (about 5° for almost all angles when standing, compared to around 10° when sitting): this decrease in posture variability may be the result of an increase of trunk stiffness in upright stance, which may be caused by the fact that the whole body has tighter limits of stability when standing; postural range variability has also been linked in the literature to the risk of developing musculoskeletal symptoms (i.e. neck pain (Cheng et al., 2015)), and maintaining a more rigid posture over a prolonged period of time has been shown to generate states of fatigue and discomfort and potential risk of developing chronic musculoskeletal disorders (Rudolfsson et al., 2012).

The study also showed that in both conditions the participants maintained a constant viewing distance from the smartphone, at about 36 cm, and this is in agreement with other observations (Bababekova, 2011; Boccardo, 2020). This result suggests that the visual system drives the postural strategy: the direct correlation between the elbow flexion-extension angle and the neck flexion-extension angle showed that, to maintain this fixed distance, people who show higher neck flexion tend to extend the elbow more and vice versa: with anthropometric data at hand, for a median neck angle greater than 10° the median elbow angle is greater than around 100°. Moreover, the results have also showed a positive correlation between the angle of gaze and neck flexion, suggesting that, in order for the body to maintain a neck angle of a few degrees (< 10°), the upper trunk posture must be adjusted to ensure an angle of gaze of around 45°–50°. The strategy adopted by females to ensure maintaining the viewing distance at the shown values is instead different from the males: females tend to rely on elbow flexion, while males tend to increase neck flexion.

4.2. Upper Trapezius muscular activity

With an observed median value around 2.5% of MVC, the results on upper trapezius muscle activity confirmed those reported by Thorn et al. (2007) for precision typing. Similarly, the value around 2% of MVC for variability of muscular activity indicated an approximately low-level constant muscular activity during the experiment. In addition, evidence that $P10_{RMS}$ resulted around 2% of MVC indicated that the degree of muscle tonic activity during texting is not entirely negligible, even for a muscle that is not focal in the task: it reflects the continuous muscle load during sustained activity, and could be associated with a potential development of musculoskeletal disorders (Xie et al., 2016). This aspect was better investigated through the analysis of relative rest time and its strong inverse proportionality with $P10_{RMS}$: lower *RRT* values and a higher level of $P10_{RMS}$ during smartphone texting, for all conditions, showed that this low-level sustained tonic muscle activity is associated with a virtual absence of rest phases. As presented by a previous research (Jonsson, 1982), this absence is a plausible risk factor for the development of trapezius myalgia, neck pain and cervical discomfort.

4.3. Correlation between muscular activity, perceived discomfort and posture kinematics

Correlation analysis confirmed an association between low level muscle tonic activity ($P10_{RMS}$) and perceived discomfort. The people who showed a higher level of muscle tonic activity at the upper trapezius were on average those that reported higher discomfort according to the Borg's3 scale.

In addition, in standing condition, $P10_{RMS}$ was positively correlated with neck flexion: we highlight here that the upper trapezius is not directly involved in neck flexion, therefore, this correlation is not the simple result of the neuromechanical action of the muscle, rather a side effect associated with a possible increase in tension associated with angle flexion. The results obtained on this correlation suggest that, as confirmed by the analysis of the postural range, when subjects are texting in upright stance for a long period of time, they may not only adopt a more rigid posture, but may also experience an increase in tension at the neck-shoulder level if neck shows excessive flexion.

4.4. Strengths and limitations of study

With the combined collection of data coming from kinematics, muscular activity, and self-reported indicators of discomfort perception, we were able to investigate more pointedly the relationships between prolonged use of smartphone devices and possible effects on the musculoskeletal system. In particular, we identified the fixed distance-from-smartphone strategy as a common behaviour among participants, with differences, however, in the choice through which this strategy is pursued, with corresponding differences in the amount of muscular involvement, and consequently in discomfort perception. We believe this may be considered a useful addition to the current state of the art in the analysis of risks associated with prolonged use of MTSD.

Some limitations need to be highlighted. Although not negligible in general terms, the sample size prevented us from investigating the possible covariates of the results obtained: with a larger sample size, the correlation with anthropometric factors and their interaction with gender would have helped to distinguish purely biomechanical predictors from the postural strategies adopted. Moreover, we opted for a reduced set of markers to minimize the discomfort for individuals: it is possible that, using a complete set of markers, other elements related to kinematics could have been better captured (for example, the kinematics of different spinal regions). For the same reason, we opted on focusing on one muscle only, and it might have been useful to include the recording of other involved muscles (both focal and non-focal) to get a more complete picture of the neuro-mechanics associated with the chosen postural strategies. Furthermore, the study was conducted only on young population (20-24 year), this relatively narrow age range limits the generalizability of these results to younger and older populations. Old users could adopt a different strategy during texting (Wright et al., 2000) and could be more susceptible to the development of musculoskeletal symptoms (Ghasemkhani et al., 2008).

5. Conclusion

We believe that the results obtained from the present study on the use of smartphone for texting suggest possible developments: to ensure an adequate viewing distance from the device, the control system adopts a postural strategy such that, as the elbow tends to extend, the neck flexes more. In this regard, the data analysis suggests that, in order to keep maintaining a limited flexion of the neck, the flexion-extension of the elbow should be maintained at around 100°, and the gaze angle at around 45°-50°. This information might could have useful practical effects: if a smartphone is able to detect its distance from the viewer's head and its orientation with respect to the vertical (both pieces of information can be captured by using the on-board camera and the built-in accelerometer), it could be possible to design an application that monitors neck flexion, and advises the smartphone user on any excessive neck flexion (e.g. by suggesting a rest break or even shut the screen off if users ignore the break prompts for a given time frame). Similarly, with regard to the muscles involved, by monitoring the relative rest time, it could be assumed that the same application could give advice in case of excessive muscle involvement or tension, and suggest strategies to prevent discomfort or pain, such as the neck stabilization exercises (Dusunceli et al., 2009).

Moreover, prolonged use of smartphone devices while standing seems to result in a more rigid posture than while sitting, and this hypothesis is supported by the link between upper trapezius activity, increased neck flexion and perceived discomfort. These findings suggest that sustained texting activities with MTSD could be a plausible factor for the development of cervical discomfort and potential risk of neck pain; thus, in contrast to the findings of the use of desktop typing while standing as less physically demanding than while sitting, we observed a possible increased discomfort when typing while standing, rather than sitting. This aspect will need to be studied more carefully, factoring in the remaining muscles involved, including the focal ones.

Finally, the observed correlation between the amplitude-based surface EMG parameter $P10_{RMS}$ and the indicator of discomfort perception further highlights the usefulness of recording EMG also for such kind of applications, where sustained low-level tonic muscular activity may play a relevant role in the onset of work-related musculoskeletal disorders, and biomechanical risk assessment. The findings of the present research could be used to define intervention strategies to prevent the biomechanical risk both in daily life and in educational and work environments. Future studies, based on different age groups, and recording these data for long-term smartphone use, could highlight further effects on the musculoskeletal system and on the onset of neck discomfort.

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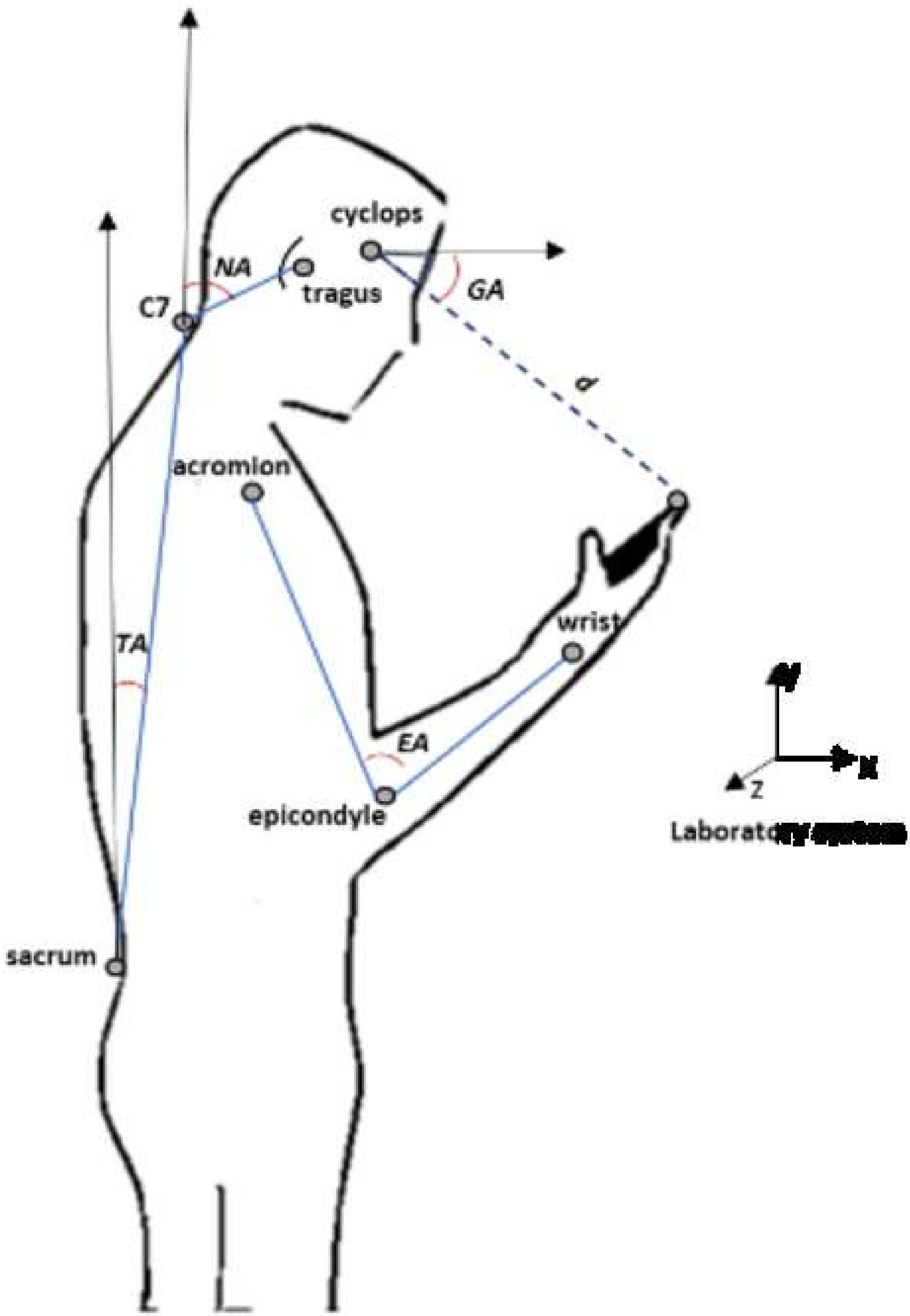
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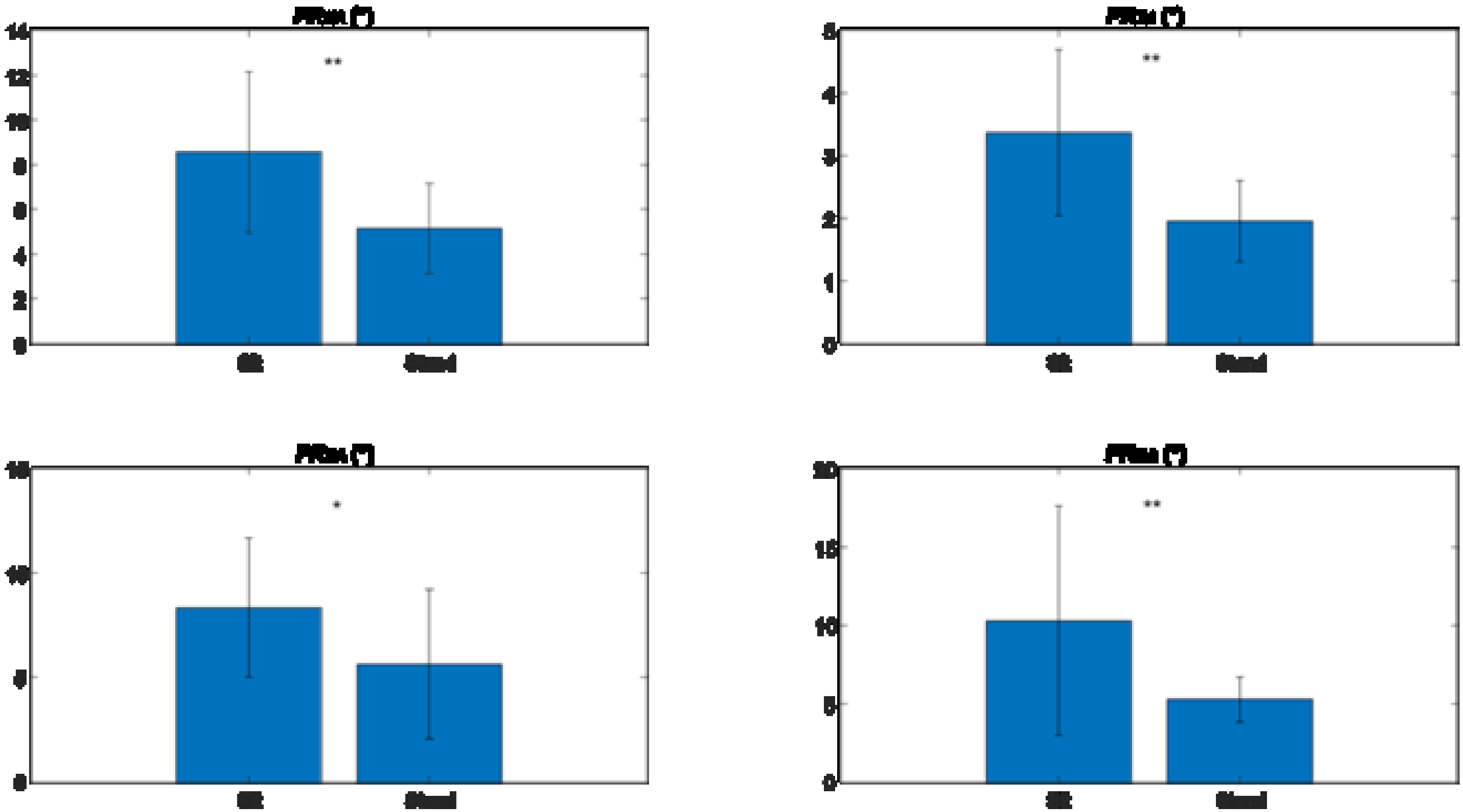

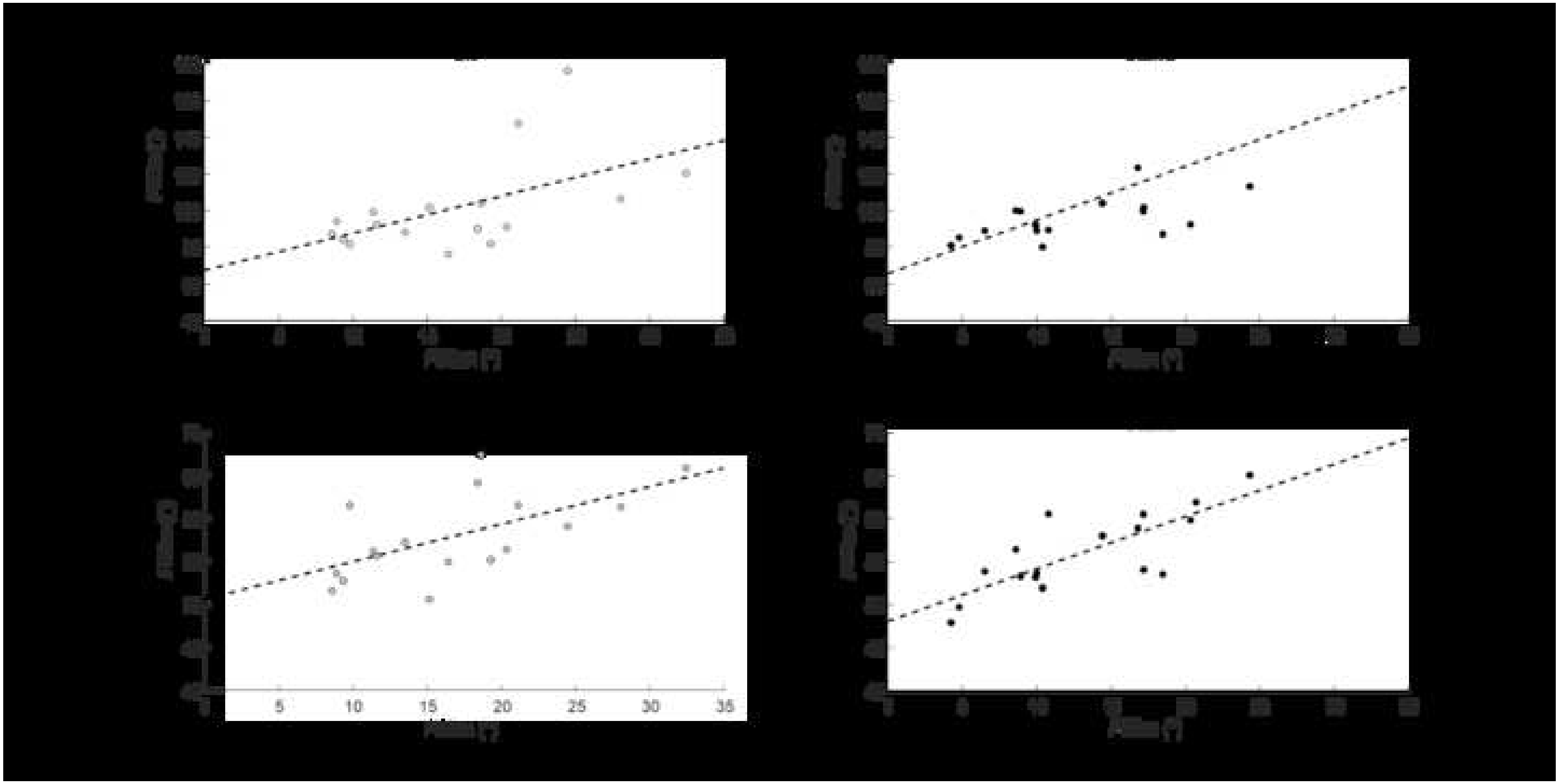
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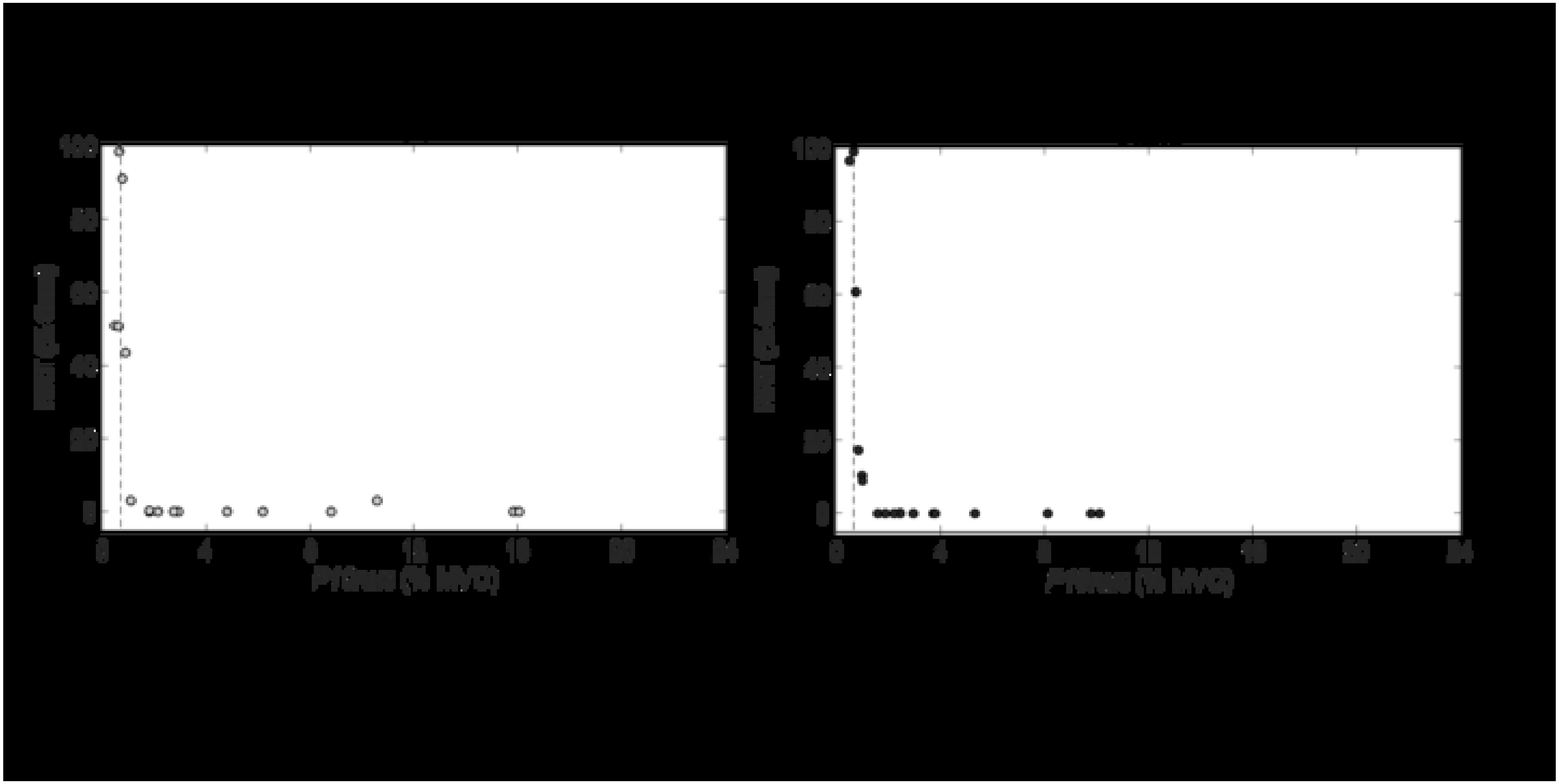

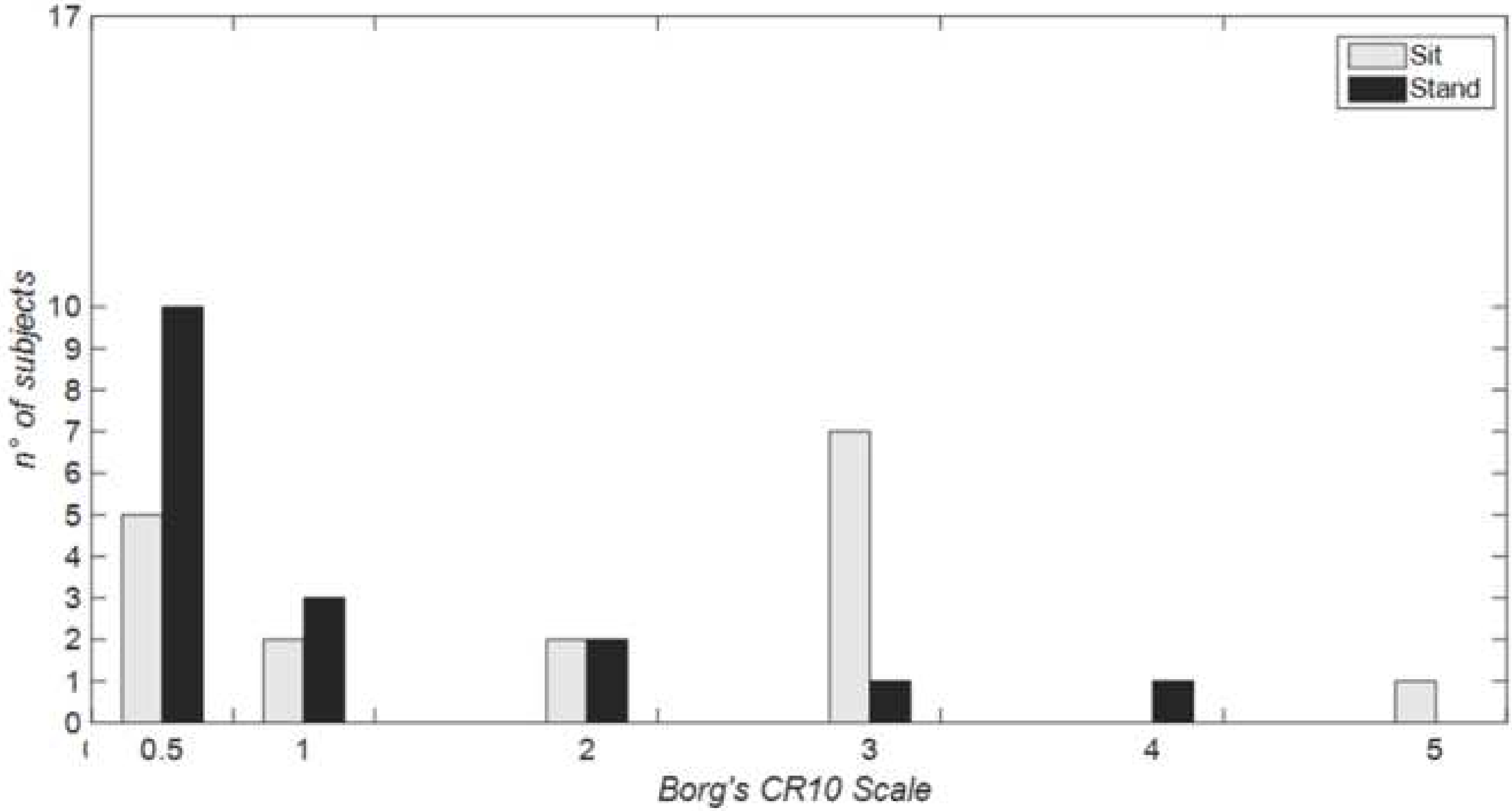

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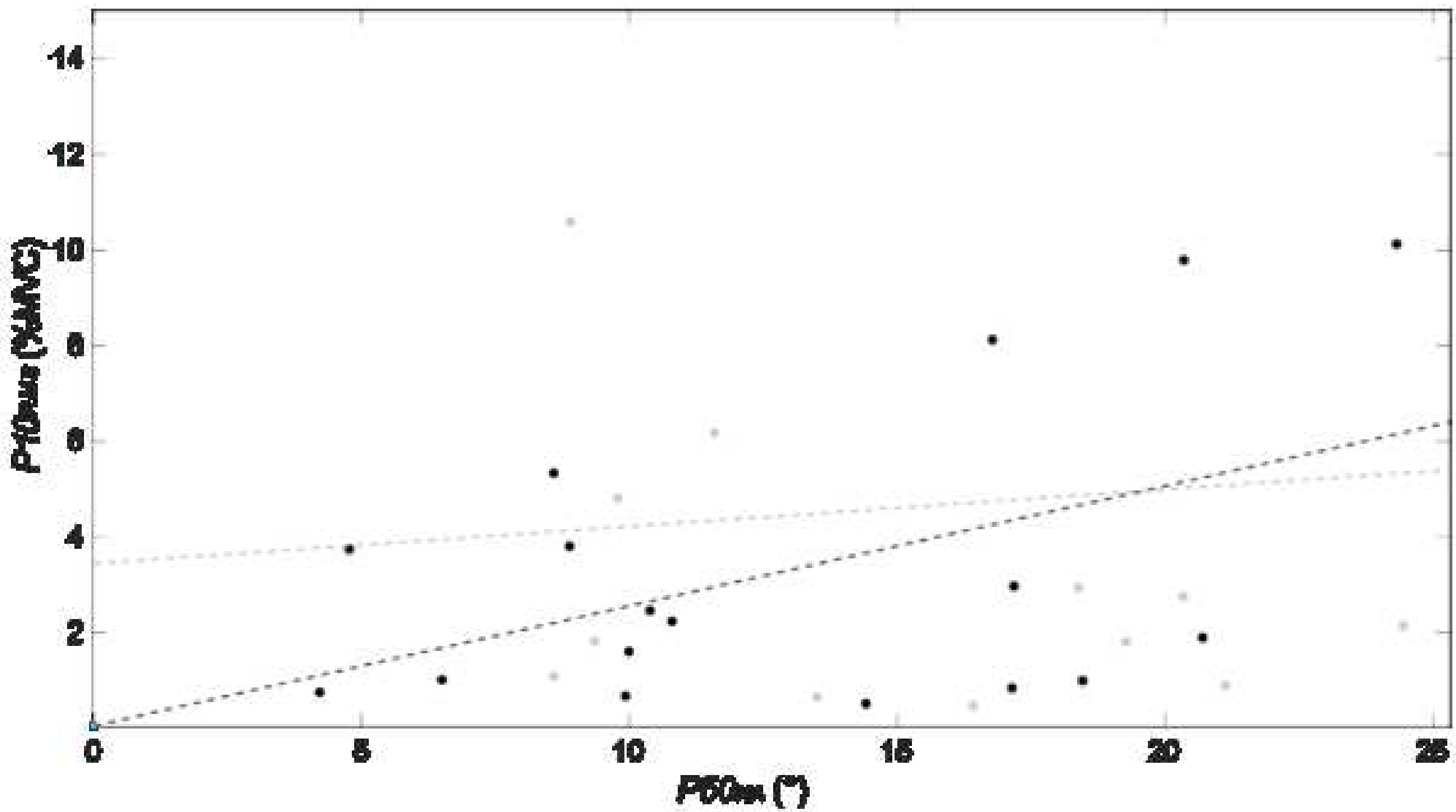
Sit
Stand


14
12
10
8
6
4
2
0
5
10
15
20
25

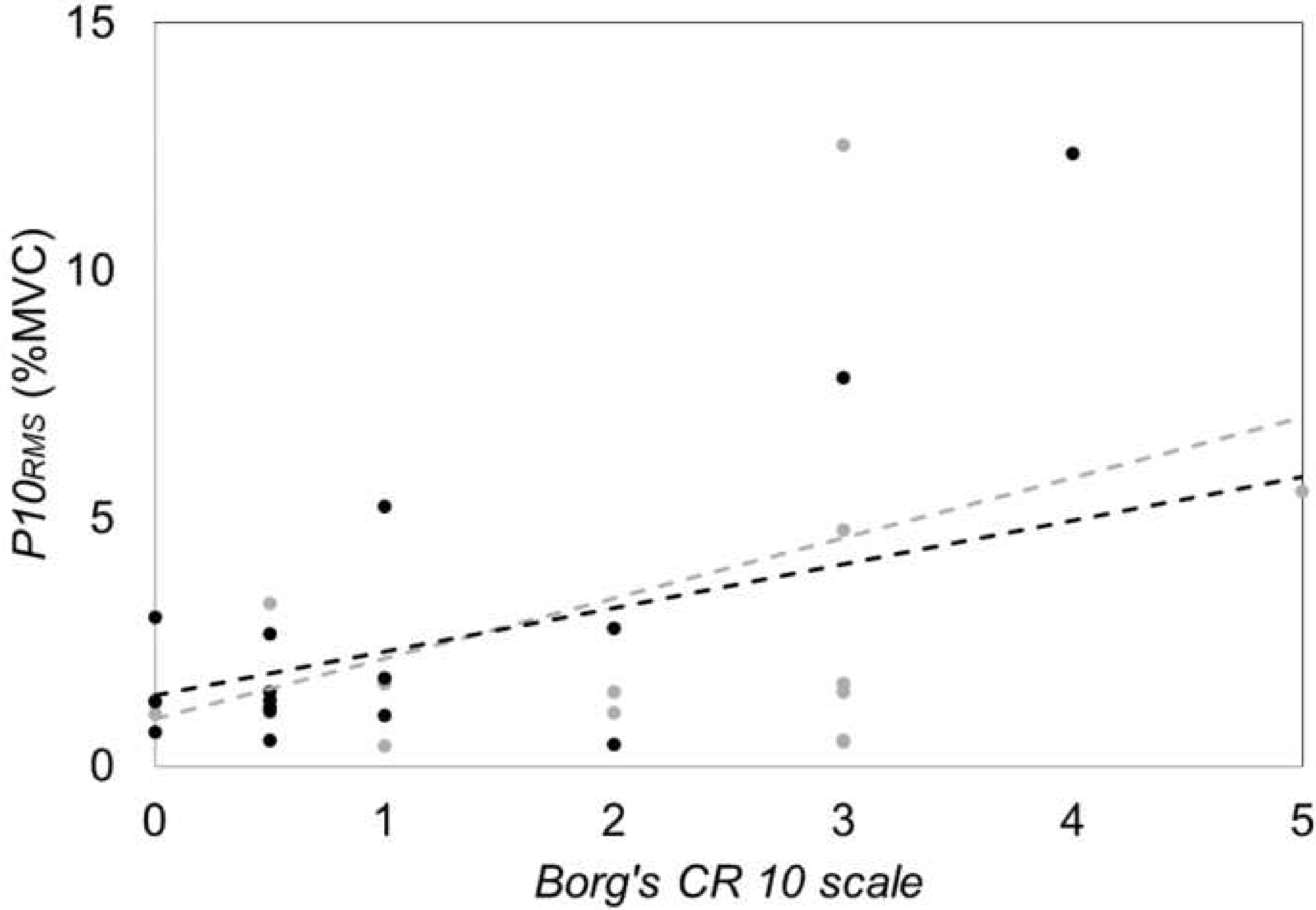

15
10
5
0
P10RMS (%MVC)
0
1
2
3
4
5
Borg's CR 10 scale

Table 1. Anthropometric data, years of use and time of use for texting during the day (group mean ± standard deviation).

	Males (n=6)	Females (n=11)
Age (yrs)	22.16 ±1.47	22.70±1.82
Height (cm)	182.66±1.96	170.52±10.13
Weight (kg)	79.16±9.86	60.18±9.95
Smartphone usage (yrs)	8.83±2.63	8.54±2.29
Time spent using the smartphone (hrs/day)	3.33±1.03	3.36±0.67

Table 2. Borg's CR 10 Scale

0	Nothing at all
0.5	Extremely weak
1	Very weak
2	Weak
3	Moderate
4	Somewhat strong
5	Strong (heavy)
6	
7	Very strong
8	
9	
10	Extremely strong

Table 3: group mean ± standard deviation for P50 angles in both postures (*p < 0.05, n.s. p ≥ 0.05).

	P50NA (°)		***P50TA (°)***		***P50EA (°)***		***P50GA (°)***	
Sit	17.77 ± 7.43	*	2.45 ± 1.47	n.s	101.40 ± 25.65	n.s	57.97 ± 4.99	n.s
Stand	12.71 ± 5.32		1.92 ± 1.02		104.00 ± 36.76		56.03 ± 4.63	

Table 4: mean ± standard deviation for P50 angles in *Stand* posture divided by gender group (*p < 0.05, n.s. p ≥ 0.05)

Stand	***P50$_{NA}$* (°)**		***P50$_{TA}$* (°)**		***P50$_{EA}$* (°)**		***P50$_{GA}$* (°)**	
Males	18.04 ± 5.34	*	1.92 ± 1.03	n.s.	124.57±56.85	*	59.64±3.64	*
Females	10.46 ± 4.57		1.93 ± 1.07		92.78±12.37		54.06±3.80	

Table 5: mean ± standard deviation for P50 angles in *Sit* posture divided by gender group (*p < 0.05, n.s. p ≥ 0.05)

Sit	***P50$_{NA}$* (°)**		***P50$_{TA}$* (°)**		***P50$_{EA}$* (°)**		***P50$_{GA}$* (°)**	
Males	22.95 ± 7.24	*	3.55 ± 1.74	*	123.52 ± 32.48	*	60.10 ± 3.64	n.s.
Females	13.59 ± 4.17		1.79 ± 0.79		89.57 ± 8.93		57.32 ± 5.37	

Table 6. Median values (lower-upper quartile) of $P50_{RMS}$, $P10_{RMS}$, RMS_{range} and RRT for the upper trapezius.

	***P50$_{RMS}$* (%MVC)** median (Q3-Q1)	***P10$_{RMS}$* (%MVC)** median (Q3-Q1)	***RMS$_{range}$* (%MVC)** median (Q3-Q1)	***RRT (%time)*** median (Q3-Q1)
Sit	2.60 (1.01-8.73)	2.14 (0.85-6.83)	1.99 (1.05-4.80)	0.05 (0-45.25)
Stand	2.54 (1.37-8.55)	2.23 (0.95-4.18)	2.26 (0.76-4.94)	0 (0-12.12)

Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☐The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

CD: Conceptualization; Investigation; Data curation; Formal analysis; Methodology; Roles/Writing – original draft;

MS: Methodology; Supervision; Resources; Writing – review & editing

SC: Project administration; Funding acquisition; Formal analysis; Supervision; Writing – review & editing