Leg and back muscle activity, heart rate, performance and comfort during sitting, standing, and using a sit-stand-support with different seat angles

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Abstract

Long-lasting sitting and standing is related to several health risks and alternatives to these positions are needed. This study compared muscle activity, heart rate, performance, and comfort between sitting, standing, and using a stable sit-stand-support with four different seat angles. Twenty-one subjects fulfilled three tasks (typing, a tweezing task and a task simulating ironing) in every position for five minutes. The heart rate was higher using a sit-stand-support and standing compared to sitting. The activity of the m. erector spinae was similar or lower using a sit-stand-support compared to sitting or standing. The activity of the m. gastrocnemius was in between the levels of sitting or standing. No significant differences were observed for the performance. The sit-stand-support most often was preferred to sitting. A stable sit-stand-support may be a solution for short interruptions of sitting or standing.

Relevance to industry: A stable sit-stand-support may be an option for short interruptions of sitting and standing and may reduce the consequences of these static positions.

Keywords muscle activity, sit-stand-support, sitting

1. Introduction

At many work places during the whole day, the employees are required to remain in a standing or a sitting position. Graf et al. (2015) showed that in 2010 in Europe 46 % of all employees stand for more than three quarter of their working time. A study from Canada reported that 61% of men and 48% of women usually stand at work and 39% of men and 52% of women usually sit at work (Tissot et al., 2009). Prolonged standing as well as prolonged sitting work is known to lead to health problems. Well-known health problems of long-lasting sitting are musculoskeletal problems like back, neck and shoulder problems (Grandjean and Hunting, 1977). Furthermore cardiovascular disorders (Gardiner et al., 2011; Saidj et al., 2013), obesity (Owen et al., 2010; Zeng et al., 2014), and cancer (Matthews et al., 2012) were found to be related to prolonged sitting. Recent studies additionally reported a direct augmentation of the mortality due to prolonged sitting (Chau et al., 2013; Dunstan et al., 2011; Katzmarzyk et al., 2009; Owen et al., 2010). Katzmarzyk et al. (2009) showed a dose-response relation between sitting and mortality. Furthermore, several authors show no or only a weak positive influence of physical activity that is done beside the sitting time (Chau et al., 2013; Katzmarzyk et al., 2009; Matthews et al., 2012). On the other side, prolonged standing is associated with health risks, too. Reported health risks of prolonged standing are low back pain (Andersen et al., 2007), pain in the lower limbs (Graf et al., 2015), chronic venous disorders (Sudol-Szopinska et al., 2011) and plantar fasciitis (Werner et al., 2010). These results show that prolonged sitting as well as prolonged standing should be reduced.

Different options are discussed to reduce sitting time. An often discussed possibility to reduce sitting time is a sit-stand table (Chau et al., 2014; Gao et al., 2016). Studies showed that sit-stand-tables were well accepted but the reduction of sitting time was only moderate. Further options are active breaks (Bailey and Locke, 2014), treadmill desks (Koepp et al., 2013), or cycling workstations (Elmer and Martin, 2014). Finally, a sit-stand-support could be a possibility to reduce sitting time as well as standing time. A big variety of sit-stand-supports are on the market, but only little research analyzing their effect on the working subject exist. Furthermore, all studies analyzed the effect of one sit-stand-support against sitting and/or standing. To our knowledge, no study exist comparing different stable sit-stand-support systems and analyzing their influence on the user. Especially no study comparing different seat angles or guidelines that give literature-based recommendation of the best seat angle of a stable sit-stand-support could be found. Only five studies were located that analyzed sit-stand-support systems that are at least partly comparable to the system analyzed in this study. One of these studies analyzed a saddle chair with a backrest (Bendix et al., 1985) and found better subjective ratings and lower peak levels of trapezius muscle activity for the saddle chair, compared to standing and sitting without legroom. Irving (1992) compared a sit-stand-support, distributing the pressure between the buttocks, the shins and the feed, to standing and found positive subjective ratings in surgeons. Three studies (Antle et al., 2015; Chester et al., 2002; Seo et al., 1996) analyzed a stable, forward-bended sit-stand-support and found mixed results for the comfort, muscle activity and leg swelling compared to sitting and standing. Thus, considering literature, further research about the possible use of stable sit-stand-support is needed.

Therefore, the aim of this study was to measure muscle activity, heart rate, performance, and comfort in subjects using a sit-stand-support with different seat angles and to compare these parameters with those while sitting or standing. This study should help to understand if a sit-stand-support is a reasonable alternative to sitting and standing and to determine which seat angle is the best for which kind of a work task.

2. Material and methods

2.1 Subjects

Twenty-one subjects (eleven females, age 24.2 ± 3.3; ten males, age 26.8 ± 8.2) participated in this study. Subjects fulfilling one of the following criteria were excluded: skin disease, chronic pain (more than 30 days in the last 12 months), leg or lower back injuries, or a BMI >30. The study was approved by the ethical committee of ETH Zurich (Switzerland) and all subjects gave their written informed consent. Subjects were instructed according to the Helsinki declaration, participated voluntarily and were free to discontinue their participation at any time without explanation.

2.2 Procedure

After the subjects were introduced to the study and gave their informed consent, the electrodes for the electromyography (EMG) were attached bilaterally to the m. gastrocnemius, m. vastus lateralis and m. erector spinae according to the recommendations of SENIAM (2015). For the electrocardiogram (ECG) a two electrodes lead was used. One electrode was placed on the left side of the chest wall below the breast, the other one below the clavicle. To reduce movement artifacts, the cables were taped to the skin. The measurements were done in six positions (sitting, standing, using a sit-stand-support prototype (s. Figure 1) with a seat angle of 0°/25°/50°/65° against the horizontal axis) and with three different tasks in every position (Figure 2). The order of the positions and of the tasks was randomized. Before the start of the experiment, the subjects had time to find the best height of the chair and the sit-stand-support in every angle as well as the according height of the table. For the sit-stand-support with a horizontal seat, the subjects were instructed, that the height has to be clearly higher than the height of the chair. The height the subject chose was accepted if the knee angle was at least 115°. A fine adjustment of the height of the table to every task was done directly before the start of the task. Subjects were allowed to work with their arms supported on the table. The experiment consisted of computer work (typing; Figure 2a), a tweezing task (arranging electrical resistors, SMD (surface-mounted device) components, in an array using a tweezer; Figure 2b), and a task using gross motor skills (following a line using an unplugged iron; Figure 2c). Every task was done in every position for five minutes with a five minutes break in between. The subjects spent the break sitting on an office chair. The measured muscle activity was normalized to a reference voluntary contraction (RVE). All the normalizations were done three times for 20 s with a break of 40 s. To normalize the m. gastrocnemius the subject had to stand on tiptoe with one leg. The distance between the floor and the heel was given. To normalize the activity of the m. vastus lateralis, the subject had to lie on the back and lift one leg with a 90° angle in the hip and the knee. A weight of 500 g was added to the foot. To normalize the activity of the m. erector spinae, the subject had to lie prone and lift the upper body.

During the work tasks the performance and the comfort were assessed. The performance was assessed by counting the tipped signs (typing task), the arranged SMD components (tweezing task) and the number of times following the line with the iron (ironing task). The comfort was assessed with questions, asking “how comfortable is your position in general/for your neck/back/arms/buttocks and upper legs/lower legs and feet” on a scale from 0 “highly comfortable” until 10 “highly uncomfortable” (adapted from Nordic questionnaire; (Kuorinka et al., 1987)). At the end of the experiment we asked the subjects about the most comfortable position for every of the three tasks.

2.3 Apparatus

The muscle activities were measured with bipolar surface EMG (PS11-UD, THUMEDI GmbH & Co. KG, Thum-Jahnsbach, Germany) at a sampling rate of 4096 Hz. Pre-gelled Ag/AgCl electrodes (35 x 26 mm, Kendall Arbo, Covidien, England) were used and the subjects’ skin was prepared with abrasive paste (Nuprep, Weaver and Company, Aurora, CO, USA). Data was filtered with an analogue 3rd order high pass filter with a cut off frequency of 4 Hz (-3 dB) and a 10th order anti-aliasing filter adjusted to 650 Hz (-3 dB). Subsequently, a digital high pass filter at 12 Hz, a digital band replacement filter at 50 Hz, 100 Hz, 150 Hz, 200 Hz, 250 Hz, 300 Hz and 350 Hz, and two algorithms which used low and very low frequencies (7-13 Hz and 0.5-1.7 Hz) were applied. The flatness (ripple) of the transfer function from 20 Hz-500 Hz of the device is ± 0.1 dB and the intrinsic effective noise of the entire system was about 250 nV (12-650 Hz). Using the PS11-UD, a two-electrode electrocardiogram (ECG) was acquired and used to calculate the heart rate.

2.4 Analysis

All data were processed with Matlab R2014a. The root mean square (RMS) signal (window length 500 ms, 50% overlap) of the EMG was normalized with the reference voluntary electrical activation (RVE) of the submaximal reference contractions. The RVE value was calculated as the mean of the most constant 10 s of every of the three reference contractions. As a result, the EMG was expressed in % RVE.

Based on the normalized EMG signal and the heart rate, the 10th and the 50th percentile were calculated for every task in every position. These percentiles were considered as important, as they can represent the static muscle load (10th percentile) and the median muscle load (50th percentile) (Jonsson, 1982). From the data of the performance and the comfort, means and standard errors over all subjects were calculated and from the height of the sit-stand-support and the chair, means and standard deviations were calculated.

2.5 Statistics

To test for significant differences between the positions and the tasks, a mixed model analysis was used in SAS 9.3. The model included the position (sitting, sit-stand-support with an angle of 0°, 25°, 50° and 65° to the horizontal axis and standing), the task (typing, tweezing task and ironing task,) the body side (left, right) and their interactions. The dependent variables were the percentiles of the EMG signal of the three muscles (right and left side), the heart rate and the comfort of the different body parts. The EMG data were not normally distributed and therefore, the logarithm of the basis 10 was used. A significance level of $p<0.05$ was chosen. To evaluate the significance between the differences of the single positions, adjusted p values according to the method by Tukey-Kramer (McDonald, 2008) were separately calculated for the three different tasks. The figures show the mean values together with their standard errors to illustrate the results for the six positions of the three tasks (typing, tweezing and ironing).

3. Results

Twenty-one subjects (25 ± 6 years; height 177 ±10 cm) participated in the study. Because of an error of the measurement device, data of the right m. gastrocnemius of one female subject had to be excluded.

3.1 Height of the chair and sit-stand-support

The chosen height (average ± standard deviation) was as follows: for the chair, 21.0% ± 1.4% body height; for the sit-stand-support with an angle of 0°, 40.0% ± 1.4% body height; for the sit-stand-support with an angle of 25°, 43.0% ± 1.6% body height; for the sit-stand-support with an angle of 50°, 46.2% ± 1.4% body height; and for the sit-stand-support with an angle of 65°, 50.1% ± 1.5% body height.

3.2 Heart rate

The heart rate values (mean ± standard error) for the tasks writing, tweezing and ironing are presented in Figure 3. It can be seen that sitting resulted in lower heart rate values than the other positions and heart rate was lower for the tweezing task compared to the other two tasks. The F values for the position (F=14.3) and the task (F=8.3) were significant. The interaction of task and position was not significant (F=0.5).

3.3 Muscle activity

Table 1, Table 2, Figure 4 and 5 show the values, the statistical parameters and the progression of the muscle activity over the different tasks and positions. The 10th percentile of muscle activity was generally low but in a few subjects, especially during ironing and standing, it reached rather high levels (e.g. 39 % RVE for the m. gastrocnemius and 596 % RVE for the m. vastus lateralis in a single case). Such high levels indicate a continuously high muscle activity during the four minutes analyzed of a single condition. The 50th percentile of muscle activity was below 5 % RVE for the m. gastrocnemius and m. vastus lateralis, and slightly higher for the m. erector spinae. In the case of the 50th percentile of muscle activity, higher levels are most often caused by more dynamic activities. The position showed a highly significant relationship with the level of muscle activity in the three muscles studied. For the 50th percentile of EMG activity, the following significant differences were found: Standing was always the position with the highest activity level and sitting was most often the position with the lowest activity level. The sit-stand-support showed most often activity levels in between sitting and standing. Considering the m. erector spinae and the tasks writing and ironing, the activity levels happened to be slightly but not statistically significantly lower using a sit-stand-support compared with sitting. For the m. gastrocnemius, the position had the most significant effect (see Figure 5). During sitting, the activity level in the m. vastus lateralis was significantly ($p<0.01$) lower than in each of the other positions with the exception that the sit-stand-support of 25° had similar low activity levels as sitting in writing and ironing. For the m. erector spinae the most significant influence was found for the factor task. Ironing was accompanied by a significantly higher muscle activity especially of the right body side (see Figure 4). Compared with standing the muscle activity was significantly lower, especially with the sit-stand-support of 25°. Compared with sitting it also was significantly lower for the task ironing, and slightly, but not significantly, lower in the writing task and higher in the tweezing task.

Table 1: Statistical parameters of muscle activity

F values and significances of the statistical model for the position, the task, the side (right or left) and their interaction for the 10th (P10) and the 50th (P50) percentile of muscle activity of the m. gastrocnemius (GA), m. vastus lateralis (VL) and m. erector spinae (ES).

Muscle	Parameter	Position	Task	Side	Task x Position	Side x Position	Side x Task
GA	EMG P10 [%RVE]	9.5 ***	1.7	1.4	1.1	1.0	2.3
	EMG P50 [%RVE]	20.8 ***	10.7 ***	3.8	1.9*	0.2	1.9
VL	EMG P10 [%RVE]	11.6 ***	11.7 ***	0.4	0.3	0.3	2.2
	EMG P50 [%RVE]	18.8 ***	14.4 ***	0.2	0.9	0.6	4.5 *
ES	EMG P10 [%RVE]	28.9 ***	97.2 ***	0.3	6.0 ***	0.4	15.9 ***
	EMG P50 [%RVE]	26.6 ***	164.1 ***	0.6	4.5 ***	0.6	29.3 ***

* <0.05; ** <0.01; *** <0.001

Table 2: Level of muscle activity

Median value and range from the 25th to the 75th percentile for the tasks (writing, tweezing, ironing) and the positions sitting, using a sit-stand-support with an angle of 0° (sh 0°), using a sit-stand-support with an angle of 25° (sh 25°), sit-stand-support with an angle of 50° (sh 50°), sit-stand-support with an angle of 65° (sh 65°) and standing for the 50th percentile of muscle activity of the m. gastrocnemius (GA), m. vastus lateralis (VL) and m. erector spinae (ES).

muscle	task	sitting [% RVE]	sh 0° [% RVE]	sh 25° [% RVE]	sh 50° [% RVE]	sh 65° [% RVE]	standing [% RVE]
GA	writing	**0.9**	3.4	3.0	**1.5**	2.8	4.2
		(0.6 - 2.7)	(1.0 - 6.2)	(1.0 - 5.2)	(0.4 - 5.9)	(0.6 - 6.6)	(1.7 - 7.9)
	tweezing	**1.9**	**3.7**	**2.7**	**4.2**	4.1	5.0
		(0.8 - 5.5)	(0.5 - 5.7)	(0.5 - 6.4)	(0.4 - 6.9)	(0.9 - 7.3)	(2.1 - 10.4)
	ironing	**1.1**	**4.4**	**3.4**[§]	**3.7**	5.9[§]	7.8
		(0.5 - 2.5)	(1.2 - 7.9)	(0.6 - 6.7)	(0.5 - 7.7)	(3.1 - 9.8)	(3.7 - 13.1)
VL	writing	**1.1**	2.5	1.7	2.5	2.2	3.5
		(0.0 - 2.2)	(0.6 – 13.4)	(0.0 - 7.8)	(0.0 - 6.9)	(0.0 - 7.1)	(0.4 – 10.3)
	tweezing	**1.3**	8.5	5.8	5.5	5.9	8.0
		(0.0 – 3.4)	2.5 – 18.4)	(2.3 – 16.8)	(2.3 – 12.6)	(3.0 – 11.0)	(3.4 – 14.4)
	ironing	**1.3**	5.3	2.6	4.4	4.8	8.0
		(0.0 – 2.8)	1.3 – 15.7)	0.8 – 7.0)	1.6 – 10.2)	1.7 – 16.4)	3.9 – 16.9)
ES	writing	**1.9**	**1.4**[#]	**1.6**[#]	2.7[#]	3.2[#]	4.3
		(0.7 – 6.2)	(0.9 – 2.1)	(1.0 – 2.8)	(1.4 – 5.8)	(1.6 – 6.7)	(2.2 – 11.0)
	tweezing	**2.1**	**3.6**[$§]	**3.6**[$]	**8.0**[§]	9.0[$]	14.7
		(1.2 – 7.0)	(1.7 – 8.7)	(1.9 – 10.2)	(2.9 – 14.4)	(4.9 – 14.6)	(9.3 – 21.2)
	ironing	12.3	**7.5**	**7.7**	9.2	10.2	13.9
		(6.8 – 19.3)	(4.0 – 16.4)	(3.4 – 15.0)	(4.9 – 17.0)	(4.4 – 17.0)	(8.6 – 20.9)

Bold: significantly different compared with standing ($p < 0.05$, adjusted according to Tukey-Kramer (TK))
Underlined: significantly different compared with sitting ($p < 0.05$, TK)
[§] significantly different from each other ($p < 0.05$, TK)
[#] sit-stand-support 0° and 25° are significantly different from sit-stand-support 50° and 65° ($p < 0.05$, TK)
[$] sit-stand-support 0° and 25° are significantly different from standing 65° ($p < 0.05$, TK)

3.4 Comfort

Regional discomfort was correlated with the position and the type of the task. The most significant effects ($F > 4$, $p< 0.01$) can be described as follows: i) Neck and low back discomfort was lowest in the typing task; ii) discomfort in the arm showed a highly significant interaction effect that could be explained by especially high discomfort ratings while sitting in the chair and doing the ironing work; iii) discomfort in buttocks and thighs was lowest while sitting and especially high while ironing with the sit-stand-support with an angle of 0°; iv) discomfort in the lower legs and feet was lower in sitting than standing or with the sit-stand-support, with the exception of ironing that was combined with less discomfort in the lower legs and feet compared to the other two tasks in the conditions with standing or with the sit-stand-support with an angle of 65°.

For the writing task, nine subjects rated the sitting position as the most comfortable one (s. Table 2) and twelve subjects preferred one of the positions using a sit-stand-support. For the tweezing task, nine subjects preferred to use a sit-stand-support with an angle of 25°, eight subjects preferred one of the other angles of the sit-stand-support, three subjects preferred to sit and one subject to stand. For the ironing task, eight subjects preferred to stand and 13 to use a sit-stand-support. The two steeper angles of the sit-stand-support were preferred by most of the subjects. In sum the sitting position was preferred twelve times, the sit-stand-support with angle of 0° seven times, the sit-stand-support with an angle of 25° 14 times, the sit-stand-support with the angle 50° ten times, the sit-stand-support with the angle 65° eleven times and standing nine times.

Table 3: Most preferred position

Every subject indicated for every task the most comfortable position. The table shows the number of subjects that rated a position "most comfortable one". The subjects were asked to rate the most comfortable position for every task. Furthermore, the sum of the three tasks was built.

Most comfortable position	writing [n of subjects]	Tweezing [n of subjects]	Ironing [n of subjects]	Sum [n of selections]
sitting	9	3	0	12
sh 0°	3	3	1	7
sh 25°	3	9	2	14
sh 50°	4	2	4	10
sh 65°	2	3	6	11
standing	0	1	8	9
Total [n of ratings]	21	21	21	63

3.5 Performance

In the performance high inter-individual differences were found, but no differences between the positions. The number of characters written was 1035 ± 283 in the sitting position, 1008 ± 277 using a sit-stand-support with an angle of 0°, 1012 ± 271 with the angle 25°, 1006 ± 270 with the angle 50°, 1024 ± 284 with the angle 65° and 1046 ± 297 while standing. The number of electrical resistors put into the grid with the tweezer was 59 ± 19 in the sitting position, 62 ± 17 using a sit-stand-support with an angle of 0°, 60 ± 17 with the angle 25°, 60 ± 11 with the angle 50°, 59 ± 16 with the angle 65° and 59 ± 17 while standing. In the ironing task finally, the number of rounds was 10 ± 4 in the sitting position, 11 ± 4 using a sit-stand-support with an angle of 0°, 11 ± 4 with the angle 25°, 11 ± 5 with the angle 50°, 12 ± 5 with the angle 65° and 11 ± 3 while standing.

4. Discussion

Heart rate was significantly higher using a sit-stand-support and standing compared to sitting during all three tasks. The muscle activity of the m. erector spinae was slightly but not significantly lower using a sit-stand-support with flat angles than sitting and was getting higher towards standing, with the exception of the ironing task. The activity of the left and right m. gastrocnemius tended to be higher using a sit-stand-support than during sitting and was lower or similar compared to the standing position. The most preferred position was the sit-stand-support with a seat angle of 25°.

4.1 Height of the chair and sit-stand-support

The differences between the subjects in the chosen height of the chair and the sit-stand-support were minimal. Beside the sit-stand-support with a horizontal seat, where the subjects were instructed to choose a height clearly higher than the height of the chair (the knee angle had to be at least 115°), the subjects were free to choose the height. Without any guidelines given, the subjects chose similar heights in relation to their body height (standard deviation below 2% body height in all positions). Why body height so precisely predicts the chosen height of the sit-stand-support might lay in the fact that using a stable sit-stand-support, as the ones used in this study, leads to a system that is supported in three points (the two feet and the sit-stand-support). The different angels of the seat led to different amounts of the body weight on the feet. These differences in the distribution of body weight may lead to different knee angles that are comfortable and therefore to different heights of the sit-stand-support. If the results of this study can be confirmed, guidelines for the construction (in which height range the sit-stand-support has to be adaptable) may be deduced, and guidelines for the height the users should choose can be suggested.

4.2 Heart rate

The heart rate for the tweezing task was lower than for the other two tasks. The activities of the upper extremities and of the head were not registered so that the reason for this difference cannot be deduced. In sitting, the heart rate is significantly lower than in the other positions. No significant differences between the positions using the sit-stand-support and standing were observed. Therefore, using a sit-stand-support can lead to similar heart rate levels as free standing and significantly higher ones compared with sitting. This augmentation in heart rate can partly be due to orthostatic reactions. However, Barone Gibbs et al. (2016) found a significant rise of the metabolic rate and the heart rate from sitting to standing. This study provides indications that the differences between sitting and the other positions might not only be due to orthostatic reactions. In the single periods, a steady state was reached for the sitting condition and a slight increase was visible for the conditions with the sit-stand-supports as well as for standing. It can be concluded that with longer duration of the single experiments the differences in HR between the standing postures compared to sitting would become slightly larger but would stay unchanged between the conditions of standing with or without using sit-stand-supports. As no significant differences in the heart rate between standing and the positions using a sit-stand-support were found in our study, it can be assumed that using a sit-stand-support may also increase the metabolic rate, and may lead to positive effects for employees sitting the whole day. Yet, we have not found published evidence for such an interpretation. The interpretation is promising but at the time, it must be considered as highly speculative.

4.3 Muscle activity

For the 50th and the 10th percentile of the activity of the m. erector spinae, especially the two sit-stand-support variations with a seat angle of 0° and 25° were favorable. They allowed for a muscle activity at the level of sitting or even lower. The steeper angles of the sit-stand-support as well as standing were associated with a higher activity of the m. erector spinae. An exception was found in the ironing task. There, the activity in the m. erector spinae was stable over all positions. Only two of the existing studies about sit-stand-supports analyzed the muscle activity of the lower back. One found no differences between a sit-stand-support and a standing position (Oude Vrielink et al., 1994). The other found in the position using a sit-stand-support in the first 8.5 minutes a higher activity compared to standing, but for the rest of the 34 minutes period, no differences were found (Antle et al., 2015). This is comparable to our results. However, comparisons are difficult as different sit-stand-supports were used in the available studies. Especially the pendulum type system used by Oude Vrielink et al. (1994) could lead to a different muscular strain. Sitting work is clearly not a risk factor for low back pain (Roffey et al., 2010). However, long hours sitting are reported to be associated with low back pain (Gupta et al., 2015). Experience tells that people with low back pain can reduce their discomfort when they have the possibility to switch between a standing and a sitting position (Ognibene et al., 2016). Considering an employee working in a sitting position for the whole day, a change of posture surely is beneficial and interrupts the static load (Davis and Kotowski, 2014). The 10th percentile of muscle activity can be seen as a measure of the static activity of a muscle. It is known that an increased static activity of a muscle is related to discomfort and pain (Jonsson, 1982). Therefore, a sit-stand-support with flat angles seems to have positive effects on the muscles of the lower back. This is seen as an important result, as discomfort in the lower back is regularly found in employees working in a sitting position (Grandjean, 1991). Considering employees working in a standing position, a sit-stand-support offers the possibility to reduce the strain on the lower back and therefore may be an option to reduce discomfort, especially in tasks requiring precision such as package or control of little pieces.

Comparing with sitting the median activity of the m. gastrocnemius was slightly higher using a sit-stand-support and clearly higher while standing. It is known that standing for a longer period of time can lead to disorders in the lower legs (Andersen et al., 2007; Graf et al., 2015). Therefore, the higher activity in the lower legs while standing can be problematic, if the position is hold for several hours (Garcia et al., 2017; Garcia et al., 2016). Only one publication was found analyzing the muscle activity in the lower legs while using a sit-stand-support. Oude Vrielink et al. (1994) found no differences in the activity of the m. soleus using a sit-stand-support (pendulum type) or standing. However, this study analyzed a different muscle in the lower leg than ours and the type of the sit-stand-support was different. It seems that during using a sit-stand-support lower leg muscles are not much more active than during sitting on an office chair so that negative effects in the lower legs are not to be expected if a sit-stand-support is used to interrupt periods of sitting. On the other hand, the lower muscle activity in the lower legs using a sit-stand-support compared to standing is a strong argument to interrupt standing work with a sit-stand-support. No significant differences were found in the 10th percentile of the muscle activity, therefore none of the analyzed positions seems to offer advantages in regard to static muscle activity. The activity of the m. vastus lateralis was significantly lower in sitting than in the other positions. Higher activity of the m. vastus lateralis was found using a sit-stand-support and in some tasks also while standing. This should not lead to any troubles because at work upper leg pain is rare. Therefore, considering the muscle activity of the upper legs no preference is given to any of the investigated positions. No other study was found analyzing the activity of the upper legs while working with a sit-stand-support.

Taking all the muscle activity measurements together, a sit-stand-support can be highly recommended to interrupt long-lasting sitting and standing work. All the effects found were either positive, minimal or neutral compared to sitting and standing. Further studies should clarify if a sit-stand-support allows a higher level of leg movements during work than sitting and therefore a more dynamic working posture. This may be another positive effect of a sit-stand-support.

4.4 Comfort

The most comfortable position was dependent on the task. Nearly half of the subjects preferred a sitting position for the writing task. Nevertheless, eleven of 21 subjects preferred a sit-stand-support instead of an office chair. In the tweezing task, 17 of the subjects preferred a sit-stand-support and for the ironing task 13 subjects preferred a sit-stand-support. These results showed that the sit-stand-support was widely accepted by the subjects. The sum of the preferences in the three tasks showed that a wide variety of positions was well accepted. The sit-stand-support with an angle of 25°

showed the highest preference value. The sit-stand-support with an angle of 0° lead to some pressure points as explained by some subjects. The other angles could already be too steep to be comfortable. No subject preferred sitting during the ironing task. This may be due to the higher discomfort ratings of the arm that were reported. The discomfort ratings in the three studies evaluating a sit-stand-support system (Antle et al., 2015; Chester et al., 2002; Seo et al., 1996) similar to the one that was evaluated in this study, were inconsistent, but showed widely higher discomfort using the evaluated sit-stand-supports compared to sitting or standing. The study of Le and Marras (2016) found discomfort ratings of a sit-stand-support system between the discomfort of sitting and standing. This could not be confirmed in this study, where many subjects preferred the sit-stand-support instead of sitting or standing. However, the measurements lasted only for 5 minutes. It has to be further investigated for what time period a sit-stand-support is preferred by the subjects and if the subjects would prefer other positions for longer working durations. Nevertheless, in our understanding, a sit-stand-support should be an alternative to interrupt sitting or standing work of long duration and may not be used for an eight hours day.

4.5 Performance

The performance showed big variations between the subjects, but no difference between the positions. The variation between the subjects is expected to be mainly due to training effects from the subjects' everyday life. Thus, the decision which working position to prefer can be made without taking performance into consideration.

4.6 Limitations

The main limitation of the study is the measurement duration of only five minutes. This study was meant to compare several positions in three different tasks. Therefore, the duration had to be short. However, our concept is not to find a sit-stand-support that should be used for a full workday. The sit-stand-support is meant to be an alternative to sitting and standing and should allow for a change of position. Therefore, an examination for short time use is relevant, too.

Furthermore, we did not evaluate the postural adaptations of the individual subjects, as we did not take three-dimensional measurements. As reported by Zemp et al. (2013) the inter-subject variability of the spinal posture during sitting is large. Therefore, it would be necessary to describe the distribution of the individual postural adaptations for the six tested sit-stand-supports with different seat angles. The study concentrates on muscle activity of selected muscles, performance and subjective evaluations of discomfort, but the individual postural adaptations were not measured.

4.7 Conclusions

Compared to sitting and standing, mostly positive or neutral effects of a sit-stand-support were found and the sit-stand-support was well accepted by all the participating subjects during the five minutes measurement period. A stable sit-stand-support with an angle of 25° to the horizontal axis can be recommended for short interruptions of sitting or standing of long duration and may help to reduce the well-known health disorders that may happen if these positions are hold too long.

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Figure captures

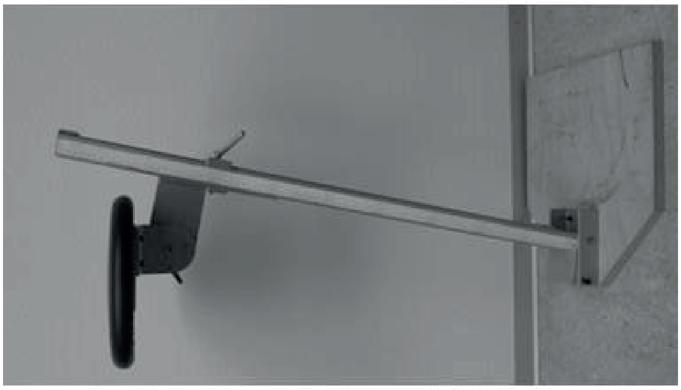
Figure 1: The office chair and the prototype of the sit-stand-support with the angles 0° to the horizontal axis, 25°, 50° and 65°. The height of the devices that was chosen by the subjects was 21.0% ± 1.4% body height, 40.0% ± 1.4% body height, 43.0% ± 1.6% body height, 46.2% ± 1.4% body height and 50.1% ± 1.5% body height from the left to the right.

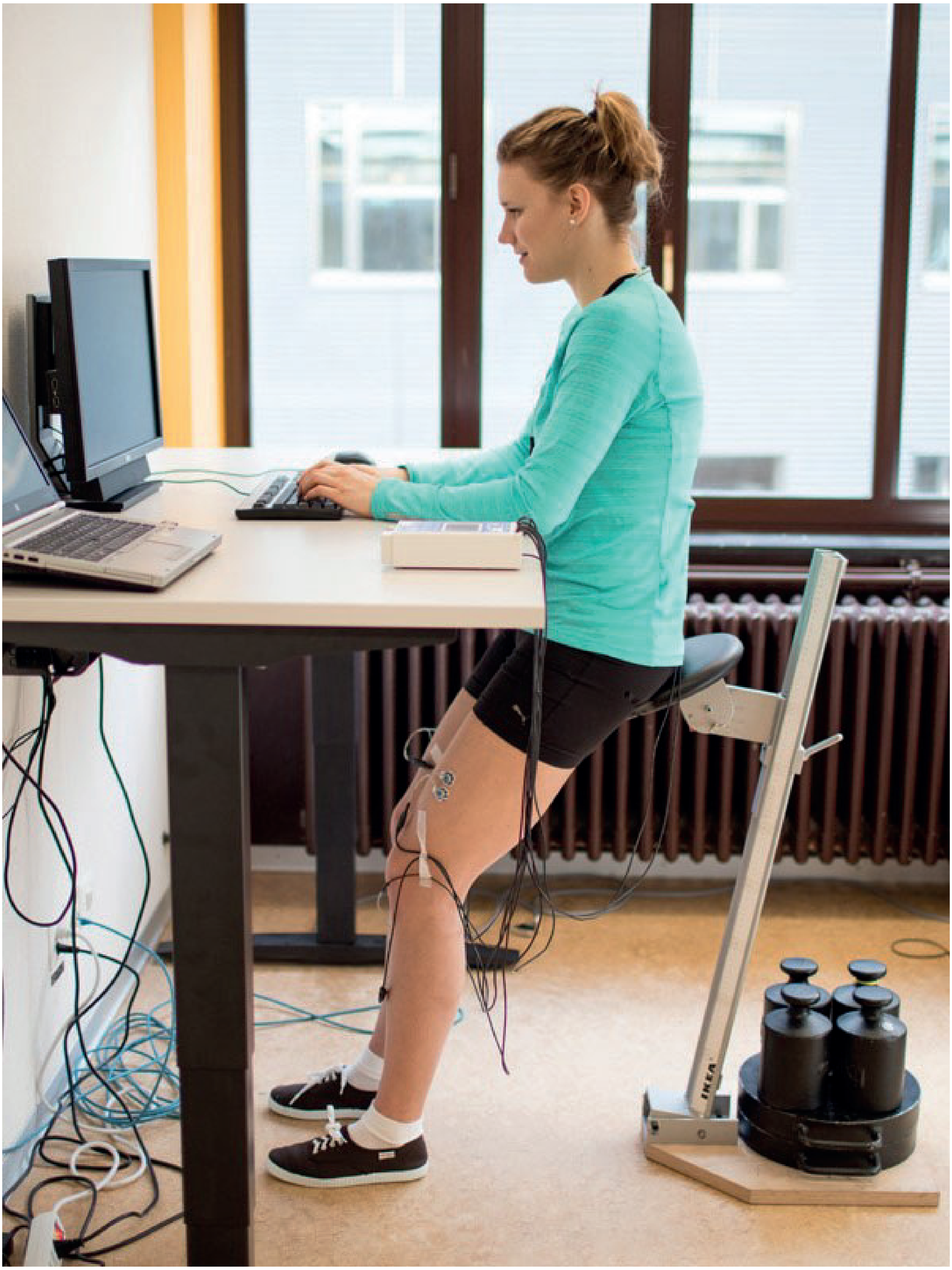
Figure 2: A subject fulfilling the three tasks: computer work (typing; Figure 2a), a tweezing task (arranging electrical resistors, SMD (surface-mounted device) components, in an array using a tweezer; Figure 2b), and a task using gross motor skills (following a line using an unplugged iron; Figure 2c).

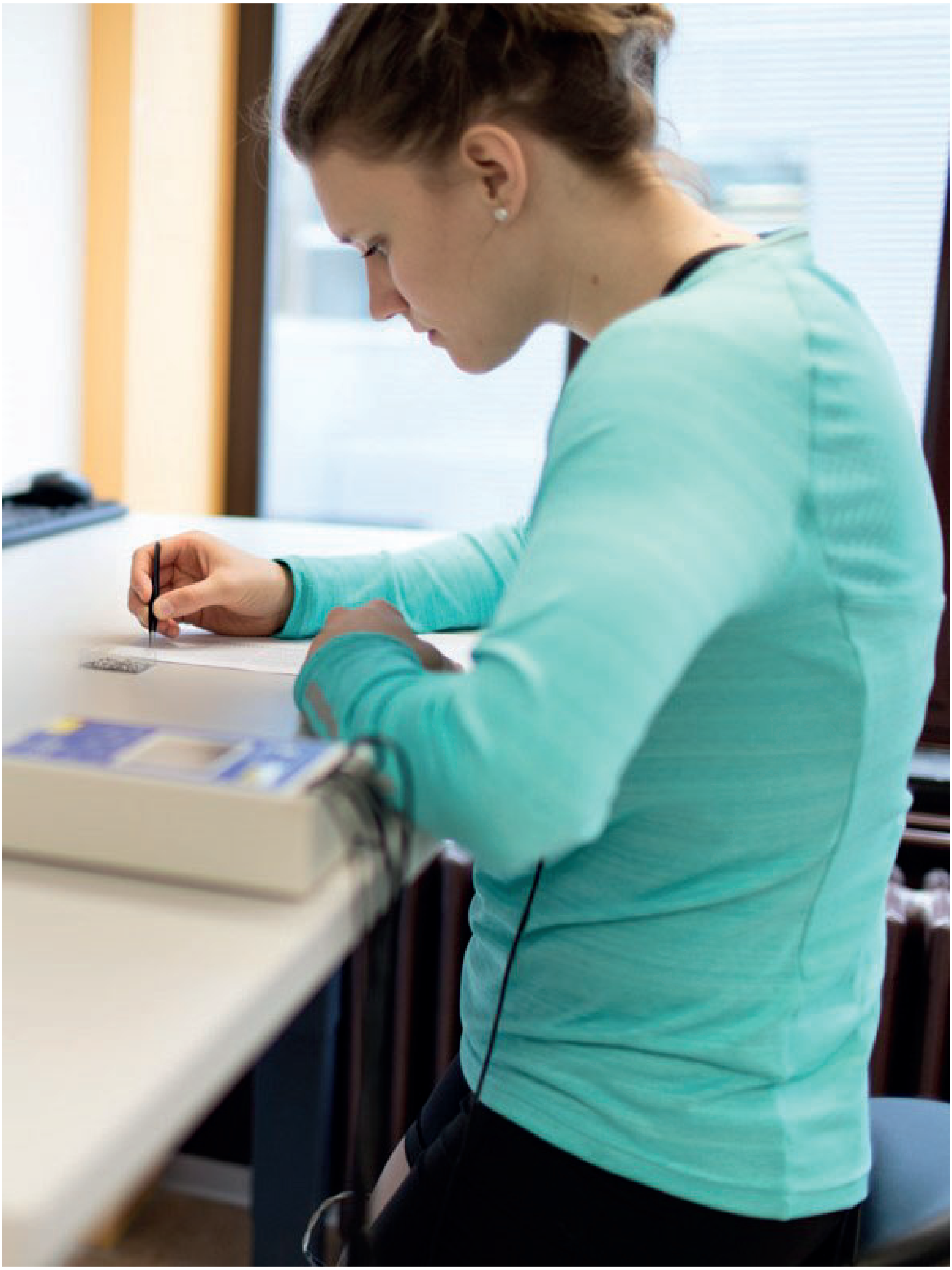
Figure 3: Heart rate values for the different tasks and positions. Heart rate values for the tasks writing (filled circle), tweezing (unfilled triangle) and ironing (cross) in the positions sitting, using a sit-stand-support with an angle of 0° to the horizontal axis (sh 0°), 25° to the horizontal axis (sh 25°), 50° (sh 50°), 65° (sh 65°), and standing.

Figure 4: The activity of the m. erector spinae for the different positions and tasks. The 50th percentile of the muscle activity of the m. erector spinae for the task a) writing, b) tweezing, and c) ironing in the positions sitting, using a sit-stand-support with an angle of 0° to the horizontal axis (sh 0°), 25° to the horizontal axis (sh 25°), 50° (sh 50°), 65° (sh 65°), and standing. The filled circle represents the muscle on the right side of the body, the unfilled triangle the left side.

Figure 5: The activity of the m. gastrocnemius for the different positions and tasks. The 50th percentile of the muscle activity of the m. gastrocnemius for the task a) writing, b) tweezing, and c) ironing in the positions sitting, using a sit-stand-support with an angle of 0° to the horizontal axis (sh 0°), 25° to the horizontal axis (sh 25°), 50° (sh 50°), 65° (sh 65°), and standing. The filled circle represents the muscle on the right side of the body, the unfilled triangle the left side.





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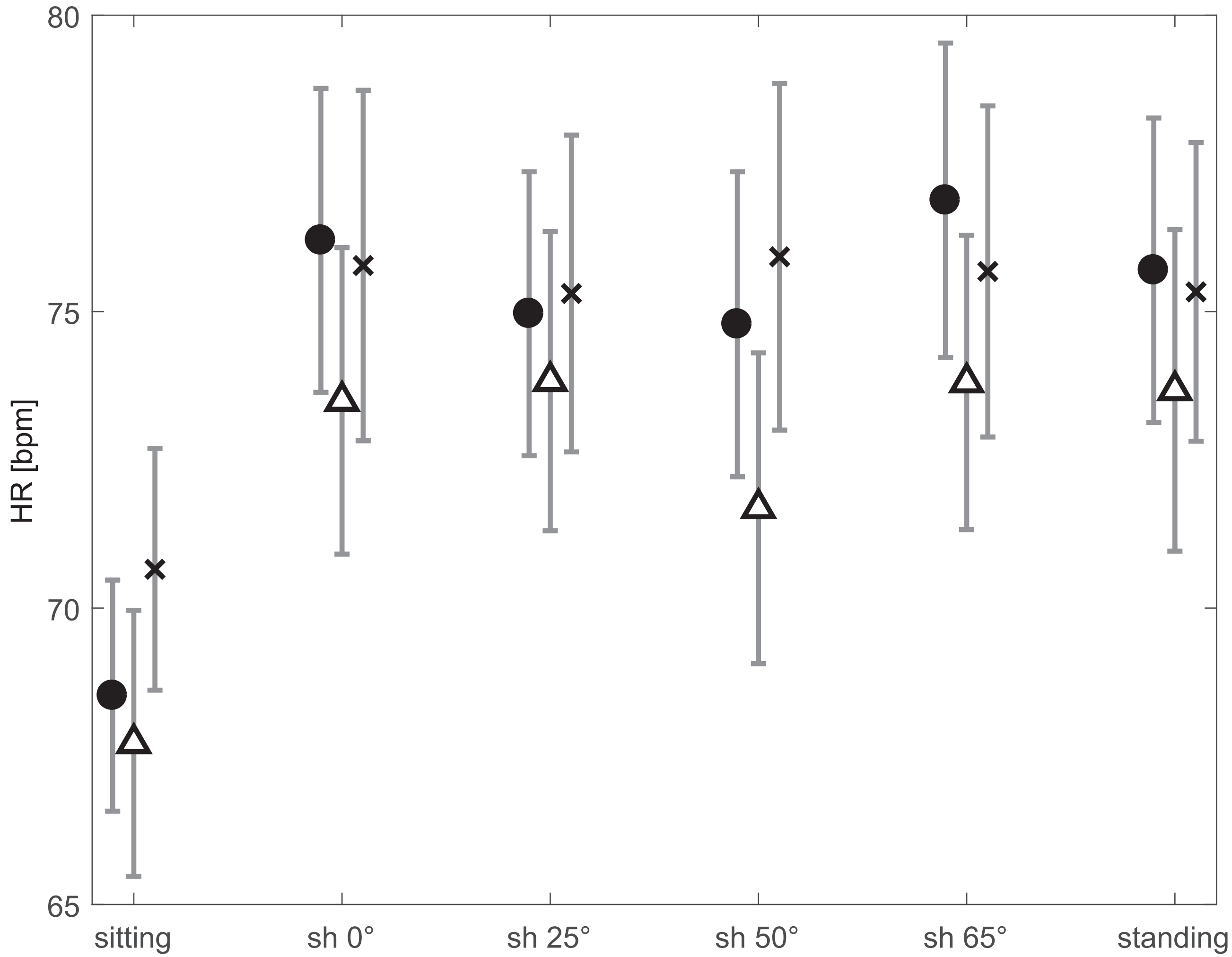
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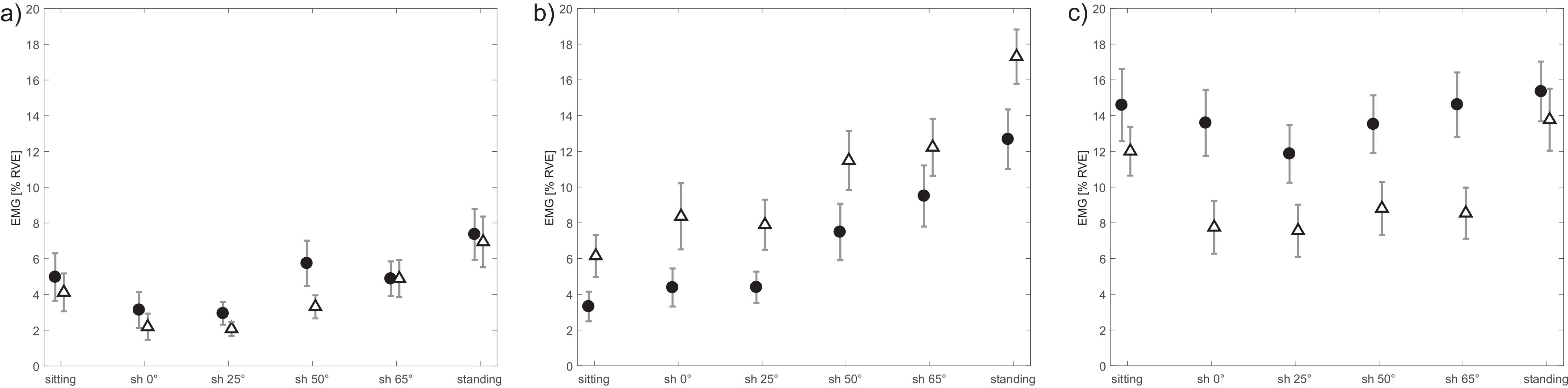
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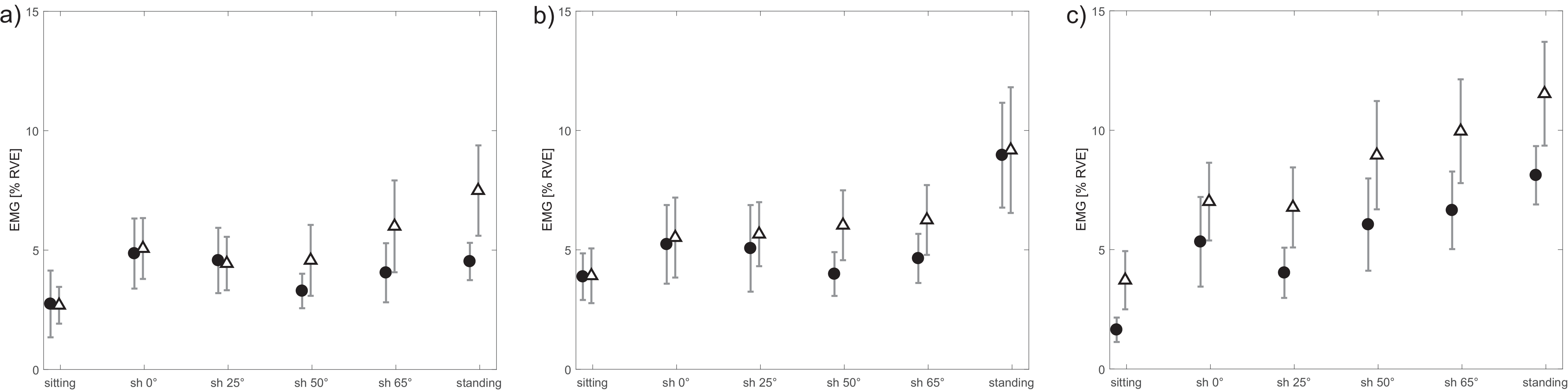
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