The interaction effect of working postures on muscle activity and subjective discomfort during static working postures and its correlation with OWAS

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ABSTRACT

Methods assessing exposure to workload calculate risk scores of individual body segments which are added up to calculate an overall risk score for the whole body. However, these methods ignore interaction effects of body segments. This may lead to inaccurate assessment of risk scores of workload. The aim of the study was to examine interaction effects of shoulder flexion angle and back angle on rating of perceived exertion (RPE) and muscle activity, and to investigate the correlation between corresponding Ovako Working Posture Analysing System (OWAS) risk scores on the one hand and RPE and muscle activity on the other. The study revealed that there is a significant interaction effect of back angle and shoulder angle on muscle activity and RPE. Furthermore, OWAS seems to correlate only with back muscle activity. Thus, integration of interaction effects to ergonomic assessment methods seems to provide a higher accuracy of risk scores.

Relevance to industry: This article introduces the relevance of interaction effects of body segments to the assessment of workload. The study revealed that isolated assessment of working postures ignores interaction effects. A consideration of interaction effects leads to a higher accuracy of risk scores quantifying exposure to workload.

1. Introduction

Research has shown high workload as a major risk factor in the development of MSD (Roman-Liu, 2014). Therefore an appropriate way for risk reduction is the development of corrective measures to reduce workload (Brandl et al., 2017b), van Niuenhuyse et al. (2006) defined workload as a function of working posture, exerted force and time sequences. Amongst these factors, working posture and exerted force are the main factors influencing workload (Brandl et al., 2017b; Roman-Liu, 2014). In order to develop corrective measures, it is necessary to assess workload by analysing the risk of developing MSDs such as in the case of working postures. Today, a large number of methods for analysing working postures and assessing workload are available - see for example the overview of Takala et al. (2010). Established methods, such as the Ovako Working Posture Analysing System (OWAS), developed by the Finish steel industry (Karhu et al., 1977, 1981) and evidently applied most often in several fields of ergonomics (Brandl et al., 2017a), the Rapid Upper Limb Assessment (RULA) (McAtamney and Corlett, 1993), the Rapid Entire Body Assessment (REBA) (Hignett and McAtamney, 2000) and the Postural Loading on the Upper Body Assessment (LUBA) (Kee and Karwowski, 2001a) estimate a risk score for individual body segments based on observed working postures. Postural scores increase when workers adopt awkward working postures. Finally, the risk scores of individual body segments are added up to calculate an overall risk score for the whole body. This risk score can be compared to tables indicating different risk levels and action categories (AC) and stating the necessity of measurements for risk reduction (Takala et al., 2010).

However, there is a current lack of knowledge relating to the assessment of interaction between body segments, i.e. according to the risk assessment of German and European standard DIN EN 1005-4, 2009 and international standard ISO 11226, 2000, a trunk inclination angle of 10° in the sagittal plane is a working posture that carries no health hazards, just like twisting trunk 5°. Nevertheless, assessment of a working posture combining these body segment postures is not yet possible (DIN EN 1005-4, 2009). Until now, ergonomic assessment methods like OWAS fail to consider the interaction effects of body segments. Disregarding the interaction effects of body segments in this way may lead to inaccurate assessment of entire risk scores for workload calculated using such ergonomic methods (Lim et al., 2011).

Few researchers have addressed the interaction effects of body segments, such as the effect of increasing discomfort ratings caused by changes in body segment postures. Lin et al. (2010) investigated correlations between shoulder flexion angles and discomfort ratings and
identified shoulder flexion as the most important factor influencing whole body discomfort ratings. Kong (2014) examined effects of shoulder flexion angles and elbow flexion angles on muscle activity and grip strength. Kee and Karwowski (2001b) observed increasing discomfort levels for increasing joint angles in various body segments in sitting and standing positions. Coury et al. (1998) analysed combinations of different body segment postures with five different elbow flexion angles and five different shoulder flexion angles. Farooq and Khan (2014) studied the effects of shoulder rotation combined with elbow flexion. Lim et al. (2011) examined interaction effects between back angle and shoulder flexion angles on perceived discomfort rating, heart rate and muscle activity for seven muscle groups. In general, they could proof significant interaction effects of shoulder flexion angles and elbow flexion angles and influence on perceived discomfort and muscle activity. Hence, reducing the risk of MSD findings of interaction effects have to be considered for the design of work systems.

Much research in recent years has focused on the interaction between shoulder flexion angle and elbow flexion angle and its effect on grip strength. However, very little consideration has been given to the interaction effects of shoulder flexion angle and back angle. Nevertheless, studies have shown the back and shoulder as the most specific body region for MSD among industrial workers (Lager et al., 2015; Widadarno et al., 2011). Thus, the purpose of this study is to examine interaction effects of shoulder flexion angle and back angle on perceived discomfort and muscle activities.

Furthermore, no attention has yet been devoted to the interaction effects of body segments on the assessment of workload in practice. OWAS appears to be the most relevant ergonomic assessment method because it is used most often in practice. This is advantageous because OWAS assesses all body parts relevant to MSD (Brandl et al., 2017a). Consequently, the second aim of this study is to investigate the correlation between corresponding postural load reflected by OWAS on the one hand and perceived discomfort ratings and muscle activity on the other.

2. Method

2.1. Participants

For the current investigation of interaction effects of working postures on perceived discomfort, muscle activity and muscle fatigue, 17 participants (9 woman and 8 man) aged between 19 and 29 (M = 22.4 ± SD = 2.8) were recruited. Their stature and weight ranged from 155 to 184 cm (M = 172 cm; SD = 0.08), and 50 to 87 kg (M = 68.9 kg; SD = 8.3), respectively. Participants were not included in this study if they reported symptoms of musculoskeletal injuries (12 months). Informed written consent was obtained prior to participating in the experiment, in accordance with study procedure.

2.2. Experimental design

During the experimental procedure, participants were guided to assume and hold 25 different working postures illustrated in Fig. 1. Each working posture is defined by a combination of one back angle and one shoulder angle in a standing position. Back angles in the sagittal plane of 0°, 20°, 40°, 60° and 80° were directed forward. Shoulder flexion angles of 0°, 30°, 60°, 90° and 120° had to be assumed. Back angles and shoulder angles were selected to investigate the complete range of back inclination angle and shoulder flexion angle. Additionally, the study should not exceed a feasible duration time.

Muscle activity of each one minute isometric contraction period was measured using surface electromyography. For the investigation of interaction effects, muscle activity from the following muscles was sampled: right trapezius pars descendens (UT), right anterior deltoideus (AD), right erector spinae longissimus (ES) and right rectus femoris (RF). Selection of the UT was based on its activity as a shoulder stabiliser and arm activator (Kadefers et al., 1999) and the AD was selected for its supporting activity for upper limb posture (Roman-Liu and Tokarski, 2005). The ES and RF were chosen as representative muscles of the back and the legs and therefore responsible for an upright working posture. To eliminate influence of muscle fatigue after each working posture, a one-minute rest period was granted to the participants, and a five-minute rest period after five working postures. A comparison of median power frequency (MPF) of the measurements revealed an almost constant level of MPF, hence fatigue effects can be ruled out.

Each participant was asked to assess ratings of perceived exertion (RPE) for their whole body in each working posture, since working postures are one of the most significant factors affecting RPE (Kee and Karwowski, 2001b). RPE was measured using Borg’s RPE scale (Borg, 1970). The RPE allows participants to describe the increasing perceived intensity of physical load they experience with increasing physical intensity. Since the scale was designed to record increasing physical work load with an increasing heart rate, it ranges from 6 to 20 (Borg, 1990).

Finally, working postures were assigned to the OWAS ACs to investigate correlation between OWAS ACs and muscle activity and RPE.

2.3. Procedure

The experimental procedure involved two phases: (1) preparation and (2) the assumption of 25 different working postures as test contractions.

During the first phase, preparations were made for obtaining EMG signals from the four muscles by means of the sensor and electrode placement procedure in accordance with the European Recommendations for Surface Electromyography (SENIAM) (Hermens, 1999). To guarantee good signal quality, participants’ skin was prepared by shaving any hair off it and cleaning it using an abrasive paste. After application of electrodes to the muscle belly, a five-minute waiting period was maintained to allow the interface between the electrodes and the skin to stabilise. Visual verification of signal quality was then conducted (Iriadiastadi et al., 2008).

During the second phase of the experiment, participants were guided to assume 25 different working postures, each for one minute. An accurate and correct execution of each working posture was monitored and, if necessary, corrected by the investigator, therefore body templates were used. Measurement of muscle activity (60 s) was started at the moment participants had assumed the corresponding working posture.

2.4. Data recording and processing

2.4.1. Surface electromyography

In this study, a surface electromyography (EMG) device (Desktop DTS Receiver, Noraxon, Scottsdale, AZ, USA) was used to measure bilateral muscle activity of four muscles. Ag/AgCl self-adhesive 8-shaped dual electrodes (dimensions of adhesive: 4 × 2.2 cm; diameter of the two circular adhesives: 1 cm; inter-electrode distance: 1.75 cm) were placed on the muscles in accordance with SENIAM standards (Hermens, 1999). Signals were amplified with a gain of 1000 V/V, input impedance of 100MΩ and a common mode rejection ratio of 100 dB. Signals were sampled during muscle contractions with a sampling frequency of 1500 Hz and digitally band-pass filtered (10–500 Hz) with a first-order high-pass filter. Signals were recorded using the biomechanical analysis software MyoResearch 3.8 (Noraxon, Scottsdale, AZ, USA). EMG data were recorded during the 60-second contraction periods. Root mean square (RMS) amplitude was calculated with an overlapping moving window of 100 ms. In order to compare EMG data for different conditions of working postures, RMS values were normalised by calculating standardised electromyographic activity (sEA) based on equation (1) in accordance with Kluth et al. (1994):
According to Burden (2010) and in agreement with Yang and Winter (1984), a normalisation according to equation (1) minimises variability between participants. Hence, the power of statistical comparisons is also increased. Since muscle activity is not compared between different muscles, normalisation according to the maximum RMS from the task is more advantageous than other normalisation methods.

\[ sEA = \frac{RMS - RMS_{\text{min}}}{RMS_{\text{max}} - RMS_{\text{min}}} \times 100\% \]  

(1)

According to Burden (2010) and in agreement with Yang and Winter (1984), a normalisation according to equation (1) minimises variability between participants. Hence, the power of statistical comparisons is also increased. Since muscle activity is not compared between different muscles, normalisation according to the maximum RMS from the task is more advantageous than other normalisation methods.

2.4.2. Correlation of OWAS action categories with RPE and muscle activity

In order to consider interaction effects of shoulder flexion angle and back angle in an assessment of working postures, we investigated the correlation of postural load reflected by OWAS AC with RPE and muscle activity. Consequently, working postures assumed by the participants during the study were described using the four-digit code of OWAS and assigned to the four ACs of OWAS. ACs quantify the risk of musculoskeletal injury. OWAS recognises four ACs:

- AC 1: acceptable postures without any risk of injury
- AC 2: corrective measures are appropriate during the next regular check
- AC 3: risk of injury is present and corrective measures must be taken into consideration in the near future
- AC 4: high risk of injury, measures are necessary immediately

2.5. Data analysis

Since a within-subject design was used in this study a repeated-measures multivariate analysis of variance (MANOVA) was used to identify the effects of back angle and shoulder angle (independent variables) on the set of dependent variables (muscle activity of four muscles, RPE). As suggested by Field (2013) we used Pillai’s trace, which is considered to have the least error, to be most powerful and most robust. To investigate effects of each dependent variable (muscle activity and RPE) separate univariate ANOVAs have been applied. To consider the effects of violations of sphericity assumption, p-values were based on degrees of freedom, corrected with Greenhouse-Geisser’s epsilon. Significance was accepted at \( p < .05 \).

In order to investigate the correlation between OWAS ACs and muscle activity and between OWAS and RPE Spearman’s correlation coefficient was calculated. Furthermore a correlation analysis according to Pearson was conducted to obtain the relationship between RPE and muscle activity.

All statistical analyses were conducted using IBM SPSS Statistics 22.

3. Results

3.1. Repeated-measures MANOVA

Repeated-measures MANOVA was used to detect effects of back angle and shoulder angle on RPE and muscle activity in all four muscles. Using Pillai’s trace, back angle was found to have a significant effect on RPE and muscle activity of all four muscles (AD, UT, ES, RF), \( V = 1.37, F(20, 252) = 6.55, p < .001 \). Again, using Pillai’s trace, shoulder angle was found to have a significant effect on RPE and muscle activity of all four muscles, \( V = 1.36, F(20, 252) = 6.52, p < .001 \), and back angle and shoulder angle were found to have a significant interaction effect on RPE and muscle activity of all four muscles, \( V = 1.22, F(80, 1280) = 5.18, p < .001 \).

Separate univariate ANOVAs on the outcome variables revealed significant treatment effects on RPE and muscle activity which are presented in Table 1. Where Mauchly’s test indicated that the assumption of sphericity had been violated, Greenhouse-Geisser corrected tests are reported in Table 1.
3.2. Rating of perceived exertion (RPE)

Interaction effects of back angle and shoulder angle on RPE revealed significance (p < .001). Results are given in Fig. 2a and b. Fig. 2a reveals that RPE for all back angles increases with an increasing shoulder angle. Fig. 2b shows that, for shoulder angles of 0° and 30°, an increasing back angle increases RPE. For greater shoulder angles, RPE shows a nearly constant course.

In order to investigate the relationship between RPE and muscle activity Pearson's correlation coefficient was calculated. RPE was significantly related to muscle activity in AD, r_{AD} = .485, p < .001, and muscle activity in UT, r_{UT} = .472, p < .001, and muscle activity in ES, r_{ES} = .432, p < .001. There was no significant relationship between RPE and muscle activity of RF, r_{RF} = .009, p < .853.

### Table 1

Results of univariate ANOVAs for effects of back angle, shoulder angle and back angle x shoulder angle on sEA and RPE as post hoc test of MANOVA.

<table>
<thead>
<tr>
<th>Independent variable</th>
<th>Dependent variable</th>
<th>Type III sum of squares</th>
<th>df</th>
<th>Mean square</th>
<th>F-value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Back angle</td>
<td>UT</td>
<td>17591.5</td>
<td>2.2</td>
<td>7926.5</td>
<td>16.4</td>
<td>&lt; .001</td>
</tr>
<tr>
<td></td>
<td>AD</td>
<td>33852.4</td>
<td>1.8</td>
<td>18981.3</td>
<td>32.2</td>
<td>&lt; .001</td>
</tr>
<tr>
<td></td>
<td>ES</td>
<td>81744.4</td>
<td>1.9</td>
<td>43269.6</td>
<td>12.6</td>
<td>&lt; .001</td>
</tr>
<tr>
<td></td>
<td>RF</td>
<td>7155.9</td>
<td>2.6</td>
<td>2769.7</td>
<td>9.9</td>
<td>.428</td>
</tr>
<tr>
<td></td>
<td>RPE</td>
<td>461.3</td>
<td>4.000</td>
<td>115.3</td>
<td>16.0</td>
<td>&lt; .001</td>
</tr>
<tr>
<td>Shoulder angle</td>
<td>UT</td>
<td>232263.2</td>
<td>2.0</td>
<td>114973.1</td>
<td>123.7</td>
<td>&lt; .001</td>
</tr>
<tr>
<td></td>
<td>AD</td>
<td>324283.9</td>
<td>2.6</td>
<td>124180.4</td>
<td>378.5</td>
<td>&lt; .001</td>
</tr>
<tr>
<td></td>
<td>ES</td>
<td>26312.5</td>
<td>1.4</td>
<td>18430.1</td>
<td>11.7</td>
<td>.001</td>
</tr>
<tr>
<td></td>
<td>RF</td>
<td>11686.5</td>
<td>2.7</td>
<td>4315.6</td>
<td>5.3</td>
<td>.001</td>
</tr>
<tr>
<td></td>
<td>RPE</td>
<td>1702.7</td>
<td>1.4</td>
<td>1235.0</td>
<td>79.8</td>
<td>&lt; .001</td>
</tr>
<tr>
<td>Back angle x Shoulder angle</td>
<td>UT</td>
<td>24158.9</td>
<td>2.9</td>
<td>12345.9</td>
<td>11.7</td>
<td>&lt; .001</td>
</tr>
<tr>
<td></td>
<td>AD</td>
<td>29442.0</td>
<td>5.6</td>
<td>5246.3</td>
<td>22.1</td>
<td>&lt; .001</td>
</tr>
<tr>
<td></td>
<td>ES</td>
<td>17325.1</td>
<td>3.8</td>
<td>4554.4</td>
<td>6.9</td>
<td>&lt; .001</td>
</tr>
<tr>
<td></td>
<td>RF</td>
<td>6508.7</td>
<td>6.8</td>
<td>959.6</td>
<td>1.2</td>
<td>.296</td>
</tr>
<tr>
<td></td>
<td>RPE</td>
<td>226.3</td>
<td>6.1</td>
<td>37.1</td>
<td>9.7</td>
<td>&lt; .001</td>
</tr>
</tbody>
</table>

![Fig. 2.](image)

Fig. 2. Interaction effect on averaged RPE across subjects according to a) shoulder angle x back angle b) back angle x shoulder angle.

![Fig. 3.](image)

Fig. 3. Interaction effect on averaged sEA of anterior deltoid across subjects according to a) shoulder angle x back angle b) back angle x shoulder angle.

RPE and muscle activity of RF, r_{RF} = .009, p < .853.

3.3. EMG amplitude

Interaction effects of back angle and shoulder angle on the AD revealed significance (p < .001). Fig. 3 displays interaction effects of back angle and shoulder angle on the AD. Overall shoulder angle influences sEA for all investigated back angles. For greater back angles, small shoulder angles barely influence sEA. Marginal difference in sEA could be found for greater back angles at greater shoulder angles. As we can see from Fig. 3b in general, sEA decreases for almost every shoulder angle with increasing back angle. Only for a shoulder angle of 0° can an
approximately constant course of sEA be detected. For a shoulder angle of 120°, sEA increases for an increasing back angle from 0° to 20°.

Interaction effects of back angle and shoulder angle on the UT revealed significance (p < .001). Details are given in Fig. 4. For back angles of 40° and above, an increasing shoulder angle from 0° to 30° barely decreases the sEA of the UT. For a back angle of 80°, a further increase of shoulder angle up to 60° decreases sEA slightly. For all investigated back angles, an increasing shoulder angle of more than 60° increases sEA considerably up to 90% sEA. Fig. 4b indicates for all shoulder angles an overall decreasing sEA of the UT for increasing back angles. Overall, the sEA of the UT for a shoulder angle of 120° is exceptionally greater for all back angles than the sEA of the UT for all other investigated shoulder angles.

Interaction effects of back angle and shoulder angle on the ES revealed significance (p < .001). As evident from Fig. 5a, the sEA of the ES for back angles of 0° is noticeably smaller than the sEA for all other investigated back angles. For back angles of 60° and 80°, a small decrease in sEA can be recognised for a shoulder angle increasing from 0° to 30°. As displayed in Fig. 5b, the sEA of the ES increases appreciably for all shoulder angles for an increasing back angle from 0° to 20°. A further increase in back angle causes a decrease in the sEA of the ES for all shoulder angles except for a shoulder angle of 0°.

Interaction effects of back angle and shoulder angle on muscle activity of RF could not show significance (p = .296). However, separate univariate ANOVAs on muscle activity of RF revealed no significance for back angles (p = .428) but for shoulder angles (p < .001). As shown in Fig. 6a, the sEA of the RF is nearly constant for all back angles for increasing shoulder angles. As we can see from Fig. 6b, the sEA of the RF for a shoulder angle of 120° is slightly greater than the sEA of all other shoulder angles for all back angles.

3.4. Correlation between OWAS, RPE and muscle activity

Among working postures assumed by participants, there are five with an OWAS AC 1 and 20 with an AC 2. In order to investigate the correlation of OWAS ACs with muscle activity and RPE Spearman’s correlation coefficient was calculated. There was a significant positive correlation between OWAS ACs and RPE, r_{RPE} = .250, p < .001. Muscle activity of AD was significant negative correlated with OWAS ACs, r_{AD} = -.131, p = .007. There was no significant relationship between muscle activity of UT and OWAS ACs, r_{UT} = -.040, p = .414. Muscle activity of ES was significant positive correlated with OWAS ACs, r_{ES} = .461, p < .001, muscle activity of RF was also significant positive correlated with OWAS ACs, r_{RF} = .104, p = .032.

A graphical overview of the relationship between OWAS ACs and muscle activity is provided in Fig. 7.

4. Discussion

Several methods for the ergonomic analysis of working postures are currently used in manufacturing practice. An overall risk score is calculated by using such methods to estimate risk levels of health impairments, such as MSDs. However, the current lack of consideration of interaction effects of body segments may lead to inaccurate assessment of overall risk scores (DIN EN 1005-4, 2009; ISO 11226, 2000; Lim et al., 2011). Therefore, our study investigated interaction effects of shoulder flexion angle and back angle on RPE and muscle activities. MANOVA revealed that there is a significant interaction effect of back angle and shoulder angle on the muscle activity of four muscles.
4.1. Interaction effects

4.1.1. Anterior deltoid

In line with the results of Kong (2014), we found a drastic increase in muscle activity of the AD with increasing shoulder angle. However, back angle must be considered for the interpretation of workload brought about by working posture. The described drastic increase in muscle activity could only be proven for smaller back angles. Furthermore, regardless of back angle size, a far higher level of muscle activity was identified for greater shoulder angles. These findings extend those of Lim et al. (2011), who did not report a significant influence of back angle on upper limb muscle activity of the AD. This non-conformity can be explained by a greater deflection of back angles up to 80° investigated in our study in contrast to a maximum back angle of 45° investigated by Lim et al. (2011). Since the AD is employed for abduction and flexion of the arm (Perotto and Delagi, 2011), we expected to see increasing muscle activity with increasing shoulder angle. On the contrary, the described influence of back angle on muscle activity in the AD would appear not to be trivial. Admittedly, a hypothesis explaining decreasing muscle activity in the AD with an increasing back angle could be a reduced height of the arm through an increasing back angle since an increased blood flow in upper limb muscles resulting from reduced arm height can reduce muscle metabolisms (Lin et al., 2010), which results in reduced muscle activity for greater back angles. A biomechanical explanation of increasing muscle activity brought about by increasing shoulder angles is an increased lever arm of the load. For this case the lever arm is positioned between the hand and the shoulder joint. For small shoulder angles AD is employed at a small level, whereas an increasing shoulder angle increases the lever arm of the load and consequently, the torque in the shoulder joint (Jäger and Luttmann, 1989). However, an increasing back angle will decrease the lever arm even for higher shoulder angles. This causes a decreasing muscle activity in AD with an increasing back angle even for higher shoulder angles.

4.1.2. Trapezius pars descendes

A quiet similar course of muscle activity in the AD related to back angle and shoulder angle could be observed in the UT muscle. The similarities between muscle activity in the AD and the UT can be explained by a similar function of these muscles, which enable flexion of the arm. For a flexion of the arm, rotation of the scapula is essential. Rotation of the scapula is performed by the UT (Perotto and Delagi, 2011). Similarly to Bosch et al. (2007), Lim et al. (2011) and Kong (2014), we proved an increase in muscle activity in the UT due to an increasing shoulder angle. The influence of decreased blood flow accompanied by an increased shoulder angle and increased arm height is apparent. Beyond that, a significant influence in back angle has to be taken into consideration. One explanation for decreasing muscle activity in the UT along with an increase in back angle could be that an increase in back angle reduces the height of the arm, which enables an increased blood flow in upper limb muscles. In addition, the lever arm of the load decreases with an increasing back angle, which supports a decrease of muscle activity in UT.

4.1.3. Erector spinae

In good agreement with the results of Lim et al. (2011), we observed a moderate increase in muscle activity in the ES for an upright working posture (back angle 0°) and an increasing shoulder angle. Maximum muscle activity for a back angle of 0° can be found at a shoulder angle of 90°. Overall muscle activity of the ES for a back angle of 0° and all shoulder angles is smaller than muscle activity for all other investigated back angles in combination with all shoulder angles. It seems plausible
that increasing shoulder angles in combination with increasing back angles result in an increased lever arm of the back. Thus, a greater muscle contraction in the ES is necessary to keep the trunk in an upright position, which leads to a greater muscle activity in the ES.

However, interaction effects of back angles and shoulder angles on muscle activity of the ES are evident. As we could prove, muscle activity in the ES for all shoulder angles shows an increase for increasing back angles up to 40°. A further increase in back angle reduces muscle activity in the ES for all shoulder angles except a shoulder angle of 0°. These results are compatible with the findings of Jäger and Luttmann (1989), who introduced a biomechanical model for analysing spinal load at various back angles. Maximum spinal load and therefore maximum muscle activity in the ES is not found at a back angle of 90°, but for slightly smaller back angles. Jäger and Luttmann (1989) stated a dorsal offset of the reference point of force application relative to the longitudinal trunk axis as the explanation for the maximum shift of spinal load.

4.1.4. Rectus femoris

The main task of RF is to extend the leg and the knee joint (Bridger et al., 1989; Perotto and Delagi, 2011). Therefore, an increase of muscle activity in RF with an increasing shoulder angle was not expected. RF was measured as primary muscle of the leg and to get a complete insight into muscle activity of all body segments as considered by OWAS. A significant effect of shoulder angle on muscle activity in RF may be explained by an increase of whole body tension during abnormal working postures like 120° in shoulder angle, which is especially apparent in combination with a high back angle. However, investigations of the leg and muscle activity in RF were not the primary aim of this study. Therefore, a systematic variation of leg posture was not part of the study design. Hence, future studies are necessary to investigate effects of working postures on muscle activity in RF.

4.1.5. RPE

RPE were at a near constantly high level for increasing back angles and shoulder angles of 30° to 120°. For increasing back angles, RPE increased rapidly for small shoulder angles only but was at a constantly high level for back angles of 20° to 80°. These findings are analogous to Hagberg (1981), who identified a considerable increase in RPE for increasing shoulder joint torque. RPE is dependent on central factors like the cardiovascular system and local factors like muscle activity or muscle fatigue (Pandolf, 1978). However, cognitive processes have to be considered for an interpretation of RPE due to physical work tasks. Karwowski et al. (1999) discovered significant relationships between RPE and cognitive appraisal of weights. In consideration of the findings of Karwowski et al. (1999) an influence of psychosocial factors on RPE especially for greater back angles and shoulder angles investigated in this study cannot be ruled out. Spearman's correlation coefficients showed higher values between muscle activity in upper limb muscles (AD, UT) and upper body (ES) and RPE than between muscle activity in the lower limbs (RF) and RPE. This may explain a consistently high level of RPE for shoulder angles of 30° to 120° and back angles of 20° to 80°, which cause a high workload in the upper body and the upper limbs.

4.2. Correlation of OWAS action categories with RPE and muscle activity

The second aim of this study was to investigate the agreement of workload assessed by OWAS and by RPE as well as objective measures like electromyography. A low significant positive correlation between OWAS ACs and RPE was revealed by applying Spearman's correlation analysis. This indicates that working postures which are perceived as more exerting tend to be assigned to higher OWAS ACs. In contrast to the results of Olendorf and Drury (2001), we could not find a strong correlation between OWAS ACs and RPE. Olendorf and Drury (2001) investigated 84 different postures, which covered all different OWAS postures (four back postures, three arm postures, and seven leg postures) in combination with two different weights (1.1 kg and 10.1 kg). The disagreement of our results to the results of Olendorf and Drury (2001) could be explained by the fact that our study only covered four different OWAS postures (two back postures and three arm postures) in combination with one weight. However, the great scatter of RPE values for each OWAS AC, which can be seen in Fig. 7a, has also been observed by Olendorf and Drury (2001).

A low significant negative correlation was found between OWAS ACs and muscle activity in AD. No significant correlation could be found between OWAS ACs and muscle activity in UT. Nevertheless, data of UT also show a decreasing trend for increasing OWAS AC. The main function of AD is forward elevation of the arm (Perotto and Delagi, 2011). The main function of the UT is elevation of the scapula, therefore UT has a supporting function to elevate the arm over shoulder level (Perotto and Delagi, 2011). Working postures with back bent forward are assigned to OWAS AC 2. With an increasing back angle the angle between the arm and perpendicular is decreasing, even for greater shoulder angles. Therefore, the more the back is bent forward, the less the arms are flexed in relation to the perpendicular. This leads to a smaller muscle activity in AD and UT in OWAS AC 2 compared to OWAS AC 1. Nevertheless, our findings are in contradiction to the study by Nevala-Puranen et al. (1996), who examined the correlation between muscle activity in the UT and postural load assessed using OWAS and found significant positive correlation between muscle activity in the UT and OWAS ACs. The reason for this disagreement can be found in the fact that Nevala-Puranen et al. (1996) investigated dynamic activities lasting one to two hours, containing only short static work periods.

A high significant correlation between OWAS ACs and muscle activity in the ES indicates a high level of accuracy of OWAS to evaluate exposure of the back, which is in line with the findings of Burdorf et al. (1991) who investigated risk factors for developing back pain in manufacturing work using OWAS. Finally, a low significant relationship between OWAS ACs and muscle activity in RF could be found. This demonstrates that increasing muscle activity in RF can be reflected by OWAS ACs.

4.3. Limitations

Nevertheless, our study was conducted under controlled laboratory conditions, so it is not possible to generalise findings to an unlimited extent. One limitation of the study is found in the choice of investigated muscles regarding the shoulder. Movements of the shoulder are carried out by several muscles, including infraspinatus, trapezius, deltoid and supraspinatus (Iridiastadi et al., 2008). Thus, we obtained EMG data from more than one muscle, but there are arguments for and against obtaining EMG data for shoulder movement from these muscles. Although we investigated isometric muscle contractions for several working postures, dynamic muscle contractions were excluded from this study. Consequently, our results are transferable to ergonomic assessment methods like OWAS on a limited basis only. Thus, future work should focus on dynamic muscle contraction.

Although our hypotheses were supported statistically, the number of participants in our study is small. However, statistically significant effects could be proofed even by this sample size. Therefore a framework for investigation of interaction effects could be presented and should be succeeded in future work.

Additionally, the average age of our participants was relatively low. So far, nobody has suffered from MSD and they were in good physical condition. However, discrepancies between young participants and industrial workers are conceivable (Iridiastadi and Nussbaum, 2006).

Finally, studies conducted to date can be seen as a first step towards understanding the interaction effects of working postures on muscle activity. Future studies are necessary to develop comprehensive models of interaction effects, which have to be integrated into ergonomic
assessment methods used in practice.

5. Conclusion

This study sought to describe interaction effects of back angle and shoulder flexion angle on RPE and muscle activity. One of the main findings was that interaction effects are evident and are important in the assessment of working postures. Therefore, an investigation of postural load based on an isolated consideration of back angle and shoulder angle may lead to an inaccurate assessment of risk scores. Since interaction effects appear to be complex, future work should seek to integrate findings of interaction effects into ergonomic assessment methods used in practice. Additionally, we examined the correlation between OWAS ACs, muscle activity and RPE, which yielded a strong correlation of muscle activity of the ES with OWAS ACs and a low correlation of the RF and RPE with OWAS ACs as well as a negative correlation between OWAS ACs and AD in contrast to muscle activity in the UT which was not significantly correlated to OWAS ACs. Thus, the risk of an inaccurate assessment of workload by using an entire risk score like OWAS, as it was stated by Lim et al. (2011), is evident for the upper limbs but not for the back. Nevertheless, assessment methods appear to meet the needs of practitioners who wish to estimate a general risk score. However, consideration of interaction effects can help increase the accuracy of workload assessment (Li and Buckle, 1999).

Due to technical innovations, e.g. the use of range sensors in observation based assessment methods, it is possible to achieve user-friendly integration of interaction effects into assessment methods as well as integration into a daily personal plan according to workload (Brandl et al., 2016). This outcome supports the option of integrating interaction effects into ergonomic assessment methods.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.jergon.2018.06.006.

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