

Rücker, Lisa; Brombach, Johannes; Bengler, Klaus

Article — Published Version

Experimental study of standing and walking at work — What is compatible with physiological characteristics and human needs?

Zeitschrift für Arbeitswissenschaft

Provided in Cooperation with:

Springer Nature

Suggested Citation: Rücker, Lisa; Brombach, Johannes; Bengler, Klaus (2021) : Experimental study of standing and walking at work — What is compatible with physiological characteristics and human needs?, Zeitschrift für Arbeitswissenschaft, ISSN 2366-4681, Springer, Berlin, Heidelberg, Vol. 76, Iss. 3, pp. 333-343, <https://doi.org/10.1007/s41449-021-00288-1>

This Version is available at:

<https://hdl.handle.net/10419/287165>

Standard-Nutzungsbedingungen:

Die Dokumente auf EconStor dürfen zu eigenen wissenschaftlichen Zwecken und zum Privatgebrauch gespeichert und kopiert werden.

Sie dürfen die Dokumente nicht für öffentliche oder kommerzielle Zwecke vervielfältigen, öffentlich ausstellen, öffentlich zugänglich machen, vertreiben oder anderweitig nutzen.

Sofern die Verfasser die Dokumente unter Open-Content-Lizenzen (insbesondere CC-Lizenzen) zur Verfügung gestellt haben sollten, gelten abweichend von diesen Nutzungsbedingungen die in der dort genannten Lizenz gewährten Nutzungsrechte.

Terms of use:

Documents in EconStor may be saved and copied for your personal and scholarly purposes.

You are not to copy documents for public or commercial purposes, to exhibit the documents publicly, to make them publicly available on the internet, or to distribute or otherwise use the documents in public.

If the documents have been made available under an Open Content Licence (especially Creative Commons Licences), you may exercise further usage rights as specified in the indicated licence.



<https://creativecommons.org/licenses/by/4.0/>



Experimental study of standing and walking at work — What is compatible with physiological characteristics and human needs?

Lisa Rücker¹ · Johannes Brombach¹ · Klaus Bengler²

Accepted: 27 September 2021 / Published online: 10 November 2021
© The Author(s) 2021

Abstract

An experimental study with two scenarios S1 and S2 was conducted, in which the standing and walking proportions as well as movement dynamics were varied. Eleven participants have taken part in the study for 2.5h each (cycle time: 90s). By means of surface electromyography, the static and dynamic components of muscle strain as well as the muscle fatigue were recorded and compared with the results of water plethysmography and a structured subjective rating survey. The results of the EMG study showed significantly higher dynamic components of the EA at S2 compared to S1, while the static components for the same activities did not show any significant difference, as expected. S1 and S2 always led to an increase in volume of the lower leg. Standing with less walking (S1) resulted in a significantly higher increase than standing with a higher proportion of walking and stronger dynamic movements (S2). In scenario S2, compared to scenario S1, the participants reported weaker subjective complaints which were also reported later in time. The results on muscular fatigue indicated only partially significant differences between S1 and S2. The results make clear that the dynamics of movement are a decisive criterion for assessing standing activities.

Practical Relevance: To relieve strain during standing work, “real” walking movement must be integrated into the workflow. It could be shown that only a small step to the side or a few “shuffling” steps are not sufficient. In contrast, it is compatible with human physiological characteristics to make correct steps and dynamically activate the leg muscles.

Keywords Water plethysmography · Surface electromyography · Subjective complaints · Static/dynamic muscle strain

✉ Lisa Rücker, M.Eng.
ruecker.lisa@hm.edu

¹ Fakultät für Wirtschaftsingenieurwesen, Hochschule für angewandte Wissenschaften München, Lothstr. 64, 80335 München, Germany

² Lehrstuhl für Ergonomie, Technische Universität München, Boltzmannstraße 15, 85747 Garching bei München, Germany

Experimentelle Studie zum Stehen und Gehen bei der Arbeit – Was ist kompatibel mit physiologischen Eigengesetzlichkeiten und menschlichen Bedürfnissen?

Zusammenfassung

In einer experimentellen Studie mit zwei Szenarien S1 und S2 wurden die Steh- und Gehanteile sowie die Bewegungsdynamik variiert. Elf Probanden nahmen an der Studie von jeweils 2,5 h Versuchszeit teil (Zykluszeit: 90 s). Mit Hilfe der Oberflächen-Elektromyographie wurden statische und dynamische Komponenten der Muskelbeanspruchung und die Muskelermüdung erfasst und mit Ergebnissen der Wasserplethysmographie sowie einer strukturierten Befragung verglichen. Im Ergebnis der EMG-Untersuchungen zeigten sich signifikant höhere dynamische Komponenten der EA bei S2 gegenüber S1, während die statischen Anteile bei gleichen Tätigkeiten erwartungsgemäß keine signifikanten Unterschiede aufwiesen. Die Szenarien führten stets zu einer Volumenzunahme, und Stehen mit weniger Gehanteil (S1) zu einer signifikant stärkeren Zunahme als Stehen mit höherem Gehanteil und größerer dynamischer Bewegung (S2). Die Probanden gaben in Szenario S2 erst im späteren Zeitverlauf subjektive Beschwerden an, die zudem schwächer als in Szenario S1 waren. Die Ergebnisse zur muskulären Ermüdung zeigten nur teilweise signifikante Unterschiede zwischen S1 und S2. Die Ergebnisse verdeutlichen in Summe, dass die Dynamik der Bewegung ein ausschlaggebendes Kriterium zur Beurteilung bei Stehtätigkeiten ist.

Praktische Relevanz: Zur Entlastung bei Steharbeit müssen „reale“ Gehbewegungen in den Arbeitsablauf integriert werden. Es konnte gezeigt werden, dass nur ein kleiner Schritt zur Seite oder wenige „schlurfende“ Schritte hierbei nicht ausreichend sind. Kompatibel zu den menschlichen Eigenschaften ist es demgegenüber, richtige Schritte zu machen und die Beinmuskulatur dynamisch zu aktivieren.

Schlüsselwörter Wasserplethysmographie · Oberflächen-Elektromyographie · Subjektive Beschwerden · Statische/dynamische Muskelbeanspruchung

1 Current recommendations for work in a standing body posture

Occupational standing work is still widespread in industry. Employment surveys reveal that about each second employee in Germany spends the majority of his working hours in a standing position (Lück et al. 2019). It quite often results in damage to their health presenting as musculoskeletal complaints and venous disorders (Halim and Omar 2011; Halim et al. 2012; Waters and Dick 2014).

Ergonomic work organization should be compatible with human characteristics and needs (Strasser 2021). That means the adaptable technical components (in this case the organization of standing and walking periods) should take into account the human organism and the physiological background of work activities in a standing posture. The LV 50, a German instruction for action of the Committee for Occupational Safety and Safety Technology, offers recommendations for the ergonomic design of standing work (Berger et al. 2009). Berger et al. (2009, p. 14) define continuous standing work as “work in an upright position without the option of moving more than approximately 20 cm to the side, to the front or behind or without the ability to relieve strain temporarily by walking or sitting”. It classifies continuous standing work into different risk levels and recommends a certain ratio of “sitting to standing to walking”. For example, the standard provides a ratio

of “60:30:1” for risk level 1 with a low standing load (up to 2.5 h per working day).

When talking about static standing, in the same breath, it is often added that static standing leads to muscular fatigue (Carayon 2006; MacLeod 2012; Parker and Imbus 1992). The LV 50 defines that “as with all static postures, the *duration of staying still without any relief* is the criterion that results in discomfort and/or health impacts”, i.e. muscular fatigue (Berger et al. 2009, p. 14). However, what kind of relief is meant here? What kind of movement is compatible with physiological needs? The authors will address these questions in more detail in the discussion section.

The topic of static standing versus walking has been increasingly addressed in recent years (cp. Balasubramanian et al. 2009; Garcia et al. 2016; Wall et al. 2020). The study, presented in the following, evaluates the influence of dynamic movement on the occurrence of complaints during static standing and discusses the results.

2 Methods of an experimental study

A preliminary study (cp. Rucker et al. 2020) has already shown that, among other things, the repetition rate (timing of the work) and the type of dynamics (type of walking) have a strong influence on the physical and subjective strain. Different standing/walking parts and cycle times were considered in this study during an experimentation time of

45 min. Based on these results, two scenarios have been selected for the experiment and the experimentation times were extended to 2.5 h. In accordance with the preliminary study, the methodology focuses on the lower extremities (lower legs) using surface electromyography, water plethysmography and a structured questionnaire on the localization and intensity of subjective complaints.

2.1 Surface electromyography for the assessment of static and dynamic muscle strain

In surface electromyography (using a Noraxon EMG system), the muscle activity is logged by electrodes which are applied to the skin surface. The electromyographic activity (EA) was continuously recorded during the experimental procedure for three muscles of the lower leg (gastrocnemius lateralis/medialis and tibialis anterior). It was subsequently normalized to a so-called maximum voluntary contraction (MVC), per specific muscle. This data is used to consider and analyze static and dynamic muscle strain (Kluth et al. 2014; Strasser et al. 1989; Strasser 1996).

Fig. 1 illustrates static and dynamic muscle activities. The mean minima represent the muscle activity in the relaxation phase, while the mean maxima represent the contraction phase. The difference between mean maxima and mean minima is due to movement and is thus defined as the dynamic component of muscle strain. The mean minima represent the static muscle strain (Strasser 1996).

The study presented here had a strict timing of standing and walking parts within a cycle time of 90 s. Thus, it is possible to define each section with pure standing or pure walking during the whole experimental time of 2.5 h. The first and last five cycles were excluded due to, among others, reduced acclimatization effects (=90 cycles were analyzed). Fig. 2 illustrates the test setup (left side) and the analysis of the cycles (right side) with regard to the average static

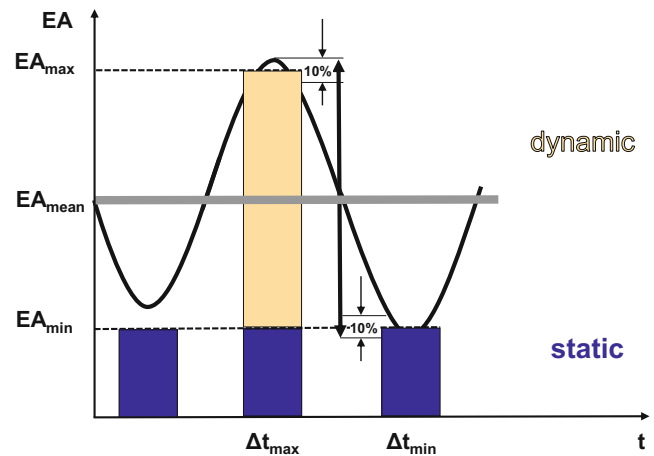


Fig. 1 Determination of the static and dynamic components of the EA (cp. Strasser 1996)

Abb. 1 Bestimmung der statischen und dynamischen Komponenten der EA (vgl. Strasser 1996)

standing and dynamic walking portions, exemplary for one muscle.

2.2 Water plethysmography

The so-called muscle pump is responsible for the removal of blood and tissue fluid from the lower leg towards the heart (Kirsch et al. 2011; Nüllen and Noppene 2010). Its function is limited during static activities (sitting, continuous standing), which is noticeable in a swelling of the lower legs and can lead to permanent pathological vein changes (Beebe-Dimmer et al. 2005; Berger et al. 2009; Wrona et al. 2015). Water plethysmography (WP) can be described as the current gold standard for measuring volume changes of the leg (Hartmann and Huch 2005; Kamusella and Schmauder 2019; Kauder et al. 2011; Rabe et al. 2010). It is based on the Archimedean principle of water displace-

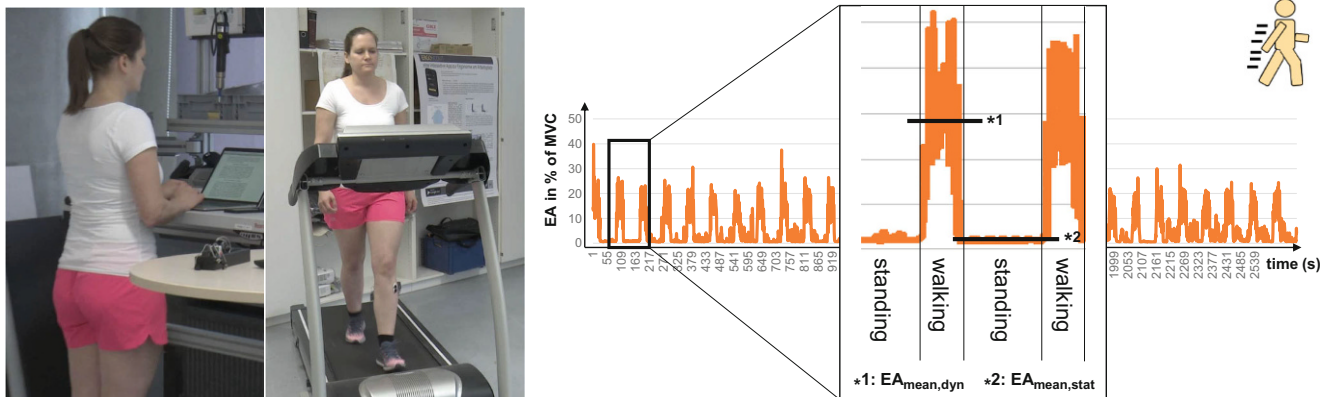


Fig. 2 Electromyogram of the clocked standing and walking components with the representation of the mean value formation

Abb. 2 Elektromyogramm der getakteten Steh- und Gehphasen mit der Darstellung der Mittelwertbildung

ment. Fig. 3 shows the specially developed measurement setup of the study.

The participant has to immerse the right lower leg into the measuring apparatus while standing. A mark on the bottom of the measurement setup and a holder for the thigh ensure an exact posture of the leg during repeated measurements. The displaced water is collected via the large overflow and weighed directly in ml. Wave movements during immersion are eliminated by a plexiglass pane positioned in front of the overflow. The water temperature during the measurements is always between 28.5 and 30.0 °C. Due to the large overflow, a measurement time of 1.5 min is sufficient and comparatively short (cp. Wall et al. 2017). Two measurements could be taken immediately before and two measurements immediately after the experimental procedure.

2.3 Structured questionnaire for the assessment of intensity and localization of subjective complaints

In addition to objective criteria, subjective discomfort was also considered. To determine subjective complaints, a structured questionnaire for the assessment of the intensity and localization of subjective complaints was used, with a numerical scale of 0–10 (0 = no complaints; 5 = moderate complaints; 10 = maximum complaints) (cp. Lips 2017). The following areas were queried: upper back, lower back, hips, thighs, knees, lower legs, and feet. In addition, participants evaluated physical discomfort and the urge to sit down or to move. The questioning began with the start of the experimentation time and was repeated at intervals of 15 min (a total of eleven surveys per participant and scenario).



Fig. 3 Measurement setup for water plethysmography in the laboratory

Abb. 3 Messaufbau der Wasserplethysmographie im Labor

2.4 Analysis of muscle fatigue

It is often asserted that muscle fatigue is the main problem of static standing (Berger et al. 2009; Opfermann et al. 2008), therefore, it was also considered in this study. A possible approach to analyze muscle fatigue is provided in Luttmann et al. (1996). In this case, the temporal graphs of the EA amplitude and the median/center frequency (MF) are considered in parallel (Kluth et al. 2013). Physiologically, an increasing force and a decreasing frequency are typical for fatigue. The so-called Joint Analysis of Spectrum and Amplitude method (JASA) of Luttmann et al. (1996; 2000) uses simultaneously the graphs of the amplitude and frequency spectrum of the EMG, and defines four state ranges (fatigue, recovery, force increase, force decrease). The results from the regression lines of the amplitude and frequency spectrum are embedded in a four-quadrant coordinate system (cp. Fig. 4). As discussed, fatigue therefore occurs with an increasing amplitude of the EA and a simultaneous drop in the median/center frequency (Luttmann et al. 1996; Rucker et al. 2018). Luttmann et al. (1996) evaluated this representation according to the number of value pairs in their respective quadrants.

In the first step, the value pairs of the regression lines over the whole testing time per participant were analyzed and plotted in the JASA coordinate system.

In two and a half hours, both fatigue and recovery can occur over time in standing and walking activities and predominant components of fatigue or recovery might even vary over time. In order to be able to look at time plots, regression lines were then created in units of five cycles each. As the cycles include static and dynamic sections, moving averages were used. So, for each second the regression lines of the following five cycles (=450 s) have been analyzed with regard to fatigue or recovery.

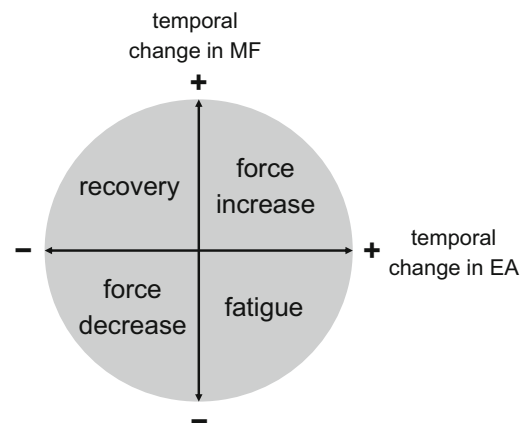


Fig. 4 Schematic representation of the Joint Analysis of Spectrum and Amplitude method (JASA) (Luttmann et al. 2000)

Abb. 4 Schematische Darstellung der Joint Analysis of Spectrum and Amplitude Methode (JASA) (Luttmann et al. 2000)

A cumulative value is formed by adding “1” in case of fatigue and subtracting “1” in case of recovery. In other words, it is defined that “+1” represents a phase of 450s that is predominantly in the fatigue sector of the JASA quadrants (cp. Fig. 4 with increasing amplitude and decreasing frequency). A corresponding phase of relaxation is represented by a value of “-1”.

In the last step, the results of each muscle were cumulated to one value as a complete package for the lower leg. The data was first analyzed by viewing the graphs and then in pairs using the mean values of the accumulated data.

3 Study design and research hypotheses

3.1 Study design

The study consisted of two test days of 2.5 h each with two scenarios in random order. A cycle time of 90s with varying standing and walking portions (scenarios S1 and S2) were chosen. The 90s represent typical conditions in industry where people operate machines in a work cycle. The participant group ($MV_{age} = 44.1$ years; $SD_{age} = \pm 13.3$ years) comprised five women and six men. During the standing components of the experiment, the participants pursued self-selected PC tasks. The test setup and the portions of standing and walking of both scenarios are shown in Fig. 5. The test day proceeded as follows: the participants arrived at the laboratory, were instructed and then seated for five minutes while the EMG electrodes were placed on the left lower leg. Subsequently they were doing specific exercises to measure the maximum voluntary contraction for each muscle. The participants then walked during five minutes on the treadmill to get familiar with the apparatus and to practice getting up and down from the treadmill. The lower leg volume was measured at least twice via water plethysmography. Finally, the test time started with continuous recording of the EMG

and the assessment of subjective complaints. At the end of the test time, the water plethysmography was repeated twice.

Fig. 5 specifies scenario one (S1) on the left and scenario two (S2) on the right side in detail. In S1 the participants had to stand for 87s and then walk for 3s. In S2 they first stood for 63s and then walked for 27s. The compliance with the clock of 90s was controlled and ensured by a programmed timer and a supervisor.

In scenario S1 with a low portion of walking of three seconds, the participant switched between WP1 and WP2 (cp. Fig. 5). Similar situations can occur e.g. at pre-assembly workstations, where the worker only takes a few steps to the side during the progression of their work. To standardize the walking speed during scenario S2 with a portion of walking of 27s, a treadmill (TM) was used. The participant switched between WP1 and the treadmill. The selected speed of 3.2 km/h corresponds to a step frequency of about one step per second and is in line with the step frequency of the workplace change in S1. An average speed of three to five km/h can be regarded as typical (BAuA 2019). Scenario S2 could serve as an example for activities in logistics or on assembly lines with “real” walking motions and recognizable step sequences.

3.2 Research hypotheses

From the results of a preliminary study (cp. Rucker et al. 2020) with varying cycle times and parts of standing/walking, the following hypotheses are examined in the study:

H1: Statistically significant differences in movement patterns (static/dynamic) can be determined with EMG measurements.

Fig. 5 Study design with the paths of both scenarios (S1/S2) between two workplaces (WP1/WP2) and a treadmill (TM) and the temporal timing of the standing/walking components in proportion and in seconds

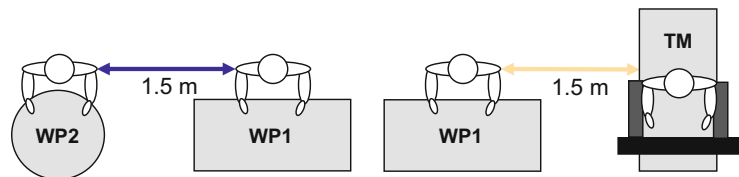
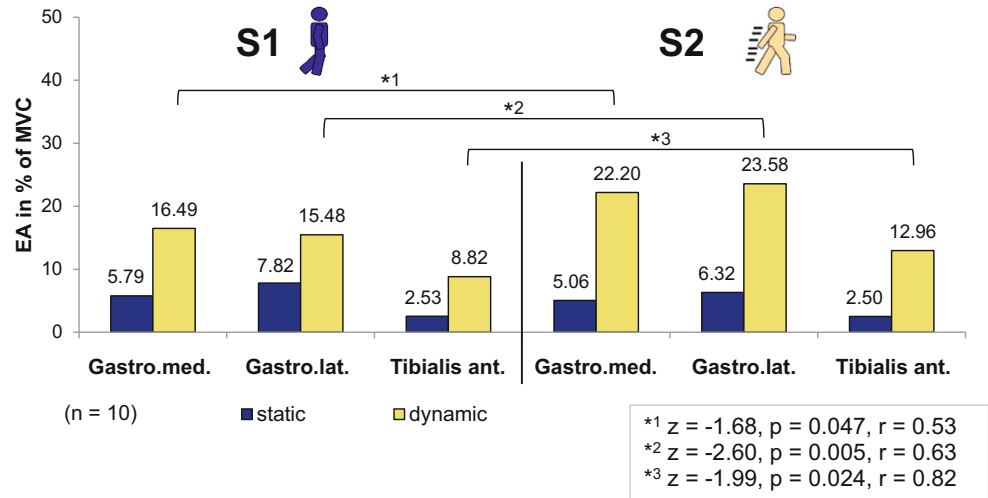


Abb. 5 Studiendesign mit den Gehwegen beider Szenarien (S1/S2) zwischen zwei Arbeitsplätzen (WP1/WP2) und einem Laufband (TM) sowie der zeitlichen Abfolge der Steh-/Gehphasen im Verhältnis und in Sekunden

Scenario	S1	S2
Standing : walking ratio	30 : 1	70 : 30
Standing : walking in seconds	87s : 3s	63s : 27s

Fig. 6 Representation of the mean values of the static and dynamic components for three muscles (gastrocnemius medialis/lateralis and tibialis anterior) for S1 (left) and S2 (right) for ten participants

Abb. 6 Darstellung der Mittelwerte der statischen und dynamischen Phasen für drei Muskeln (Gastrocnemius medialis/lateralis, Tibialis anterior) für S1 (links) und S2 (rechts) für zehn Probanden



H2: Static standing with components of little movement leads to earlier and higher subjective complaints than static standing with more movement components.

H3: Higher static standing proportions lead to a swelling of the lower legs. This swelling is more pronounced with static standing with components of little movement than static standing with more movement components.

H4: Static standing with components of little movement leads to more muscle fatigue than static standing with more movement components.

4 Results of the study

4.1 Static and dynamic components of muscle strain

The evaluation is based on ten separate data sets, since the EMG recording of one muscle failed for one participant during the test. Fig. 6 shows the mean values of the static standing components and dynamic walking components of the EA (% of MVC) for S1 (left) and S2 (right) of the three examined muscles (gastrocnemius medialis/lateralis and tibialis anterior). The data refers to 90 cycles of the total experimental time (=100 cycles).

The static task involves the same situation for the participant. As expected, the EA values of the static components for S2 do not differ significantly from S1 (e.g. gastrocnemius medialis $z = -0.764, p = 0.223, n = 10$). However, all three muscles examined for scenario S2 compared to S1 show a significantly higher EA value of dynamic movement (e.g. gastrocnemius medialis $z = -1.68, p = 0.047, r = 0.53$, cp. Fig. 6). The increased values range from approx. 35% (gastrocnemius medialis) to 52% (gastrocnemius lateralis), respectively.

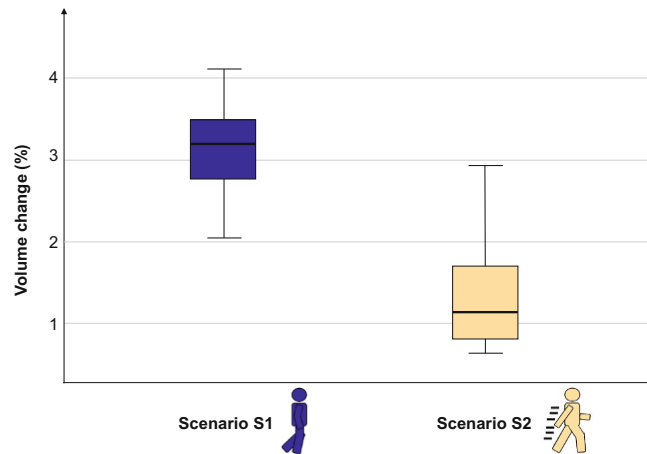


Fig. 7 Results of the water plethysmography with volume changes of scenarios S1 and S2 ($n = 11$)

Abb. 7 Ergebnisse der Wasserplethysmographie mit den Volumenveränderungen der Szenarien S1 und S2 ($n = 11$)

4.2 Volume increases of the lower leg

Volume increases always occur in the before/after comparison for both S1 and S2. The results are plotted in Fig. 7. On average in S1 with little movement, the volume increased by 3.19% (~140.0 ml) and in S2 with more movement by 1.15% (~41.5 ml). Statistically, they differ significantly from each other ($z = -2.934, p = 0.002, r = 0.88$).

4.3 Intensity and localization of subjective complaints

Significant differences between S1 and S2 are illustrated in Fig. 8. While stress on the back and feet tended to create similar strain, the “urge to move” and the “strain on the lower leg” differed significantly ($z = -2.81, p = 0.003, n = 11, d = 0.85; z = -2.94, p = 0.002, n = 11, d = 0.89$). Addi-

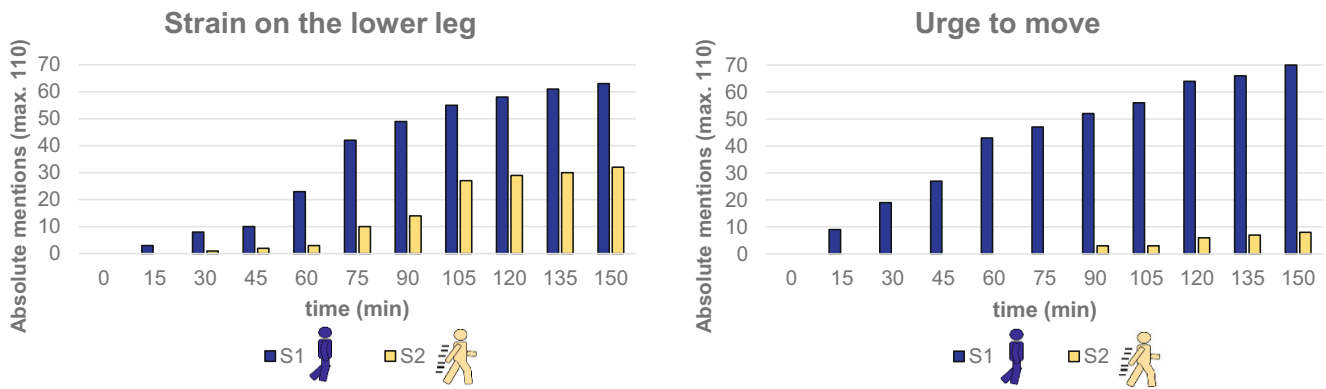


Fig. 8 Absolute motions of the characteristics “strain on the lower leg” and “urge to move” over time ($n = 11$)

Abb. 8 Absolute Nennungen der Merkmale „Beanspruchung des Unterschenkels“ und „Bewegungsdrang“ über die Versuchszeit ($n = 11$)

tionally, these two characteristics occurred significantly earlier over time at S1 than at S2. For the characteristic “urge to move”, it was already significant after 30 min ($z = -2.06$, $p = 0.020$, $n = 11$, $d = 0.62$) and for the “strain on the lower leg” after 60 min ($z = -2.68$, $p = 0.004$, $n = 11$, $d = 0.81$). At the end of the experiment, the characteristic “urge to move” reached an average value of 6.36 for S1 and 0.73 for S2, and the characteristic “strain on the lower leg” reached a value of 5.73 for S1 and 2.91 for S2. All participants rated the “strain on the lower leg” for S1 at least as a “medium load”, 36% of them rated it as “moderate strong to strong”. The “urge to move” was classified for S1 with at least “medium load” by the end of the test time. For this characteristic as much as 55% rated with “moderate strong to strong”.

4.4 Muscle fatigue

The results of the Joint Analysis of Spectrum and Amplitude of Luttmann et al. (1996) were first collected from the regression lines over the entire experimental period, excluding the first and last five cycles (cp. Fig. 9).

For all three muscles, the value pairs of the fatigue quadrant decreased from S1 to S2 (i.e. S1: 5, S2: 2), while the value pairs of the recovery quadrant increased from S1 to S2 (i.e. S1: 3, S2: 6). According to Luttmann et al. (1996), initially the graphs of EA and MF amplitude after 2.5 h were compared. Due to the different walking proportions in both scenarios S1 and S2, there is the assumption that fatigue can build up and also decrease again within the test time.

In order to examine temporal effects during the test, the observation was carried out — as described — in steps of five cycles using moving averages. Fig. 10 illustrates an example of the temporal lines of the cumulated values of the muscle gastrocnemius medialis of one participant. For each second of the experimentation time, the regression lines over the following five cycles were analyzed with occur-

ring fatigue “+1” or recovery “-1” in cumulation, excluding the first and last five cycles. Fig. 10 shows that within the 2.5 h (90 cycles), as a cumulative representation, components of predominant fatigue are represented by a positive slope. In contrast, a predominant recovery is represented as a decreasing or negative curve. Indeed, a variation of components predominantly in the fatigue and in the relaxation area of the JASA quadrants can be seen in both scenarios.

Comparatively, for the gastrocnemius medialis, eight out of ten participants had on average higher accumulated values in S1 than in S2. For the gastrocnemius lateralis, the ratio was seven out of ten and for the tibialis anterior it was nine out of ten. In addition, all three muscles were examined simultaneously. Fig. 11 shows the curves of the cumulated values for all three muscles of each participant for the scenarios S1 (left) and S2 (right). The thick black curve illustrates the average of the ten participants. The graphical representations of the individual muscles show similar progressions.

Here, for nine out of ten participants, S1 had comparatively higher accumulated values than S2 regarding the combination of all three muscles.

Table 1 Statistical results of the mean values of the cumulated data (fatigue “+1”, recovery “-1”) for each muscle and all three muscles in cumulation (Wilcoxon)

Tab. 1 Statistische Ergebnisse der Mittelwerte der kumulierten Daten (Ermüdung „+1“, Erholung „-1“) für jeden Muskel und alle drei Muskeln kumuliert (Wilkoxon)

Muscle	Pair	Z	p (two-sided)
Gastrocnemius med	S2–S1	-2.293 ^a	0.022^c
Gastrocnemius lat	S2–S1	-1.784 ^a	0.074
Tibialis anterior	S2–S1	-2.599 ^a	0.009^c
Three muscles (cum)	S2–S1	-2.599 ^a	0.009^c

^abased on positive ranks

^bbased on negative ranks

^cindicates significant values $\alpha = 0.05$

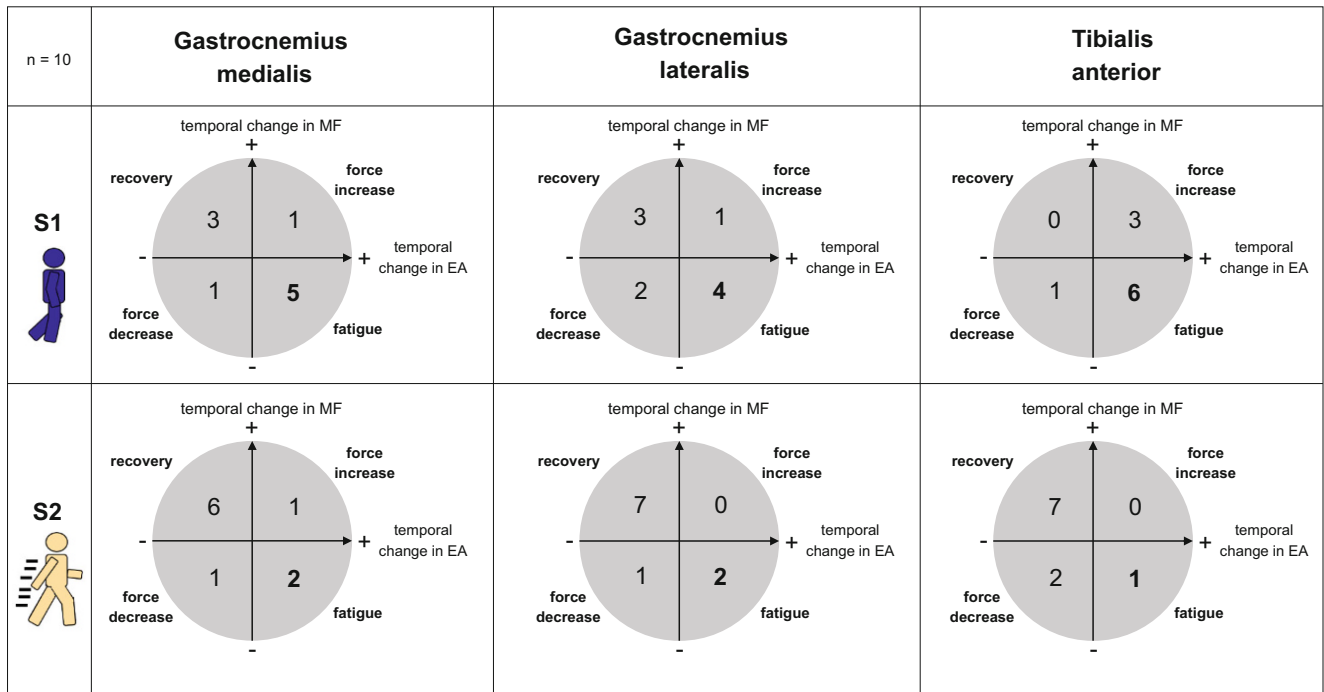
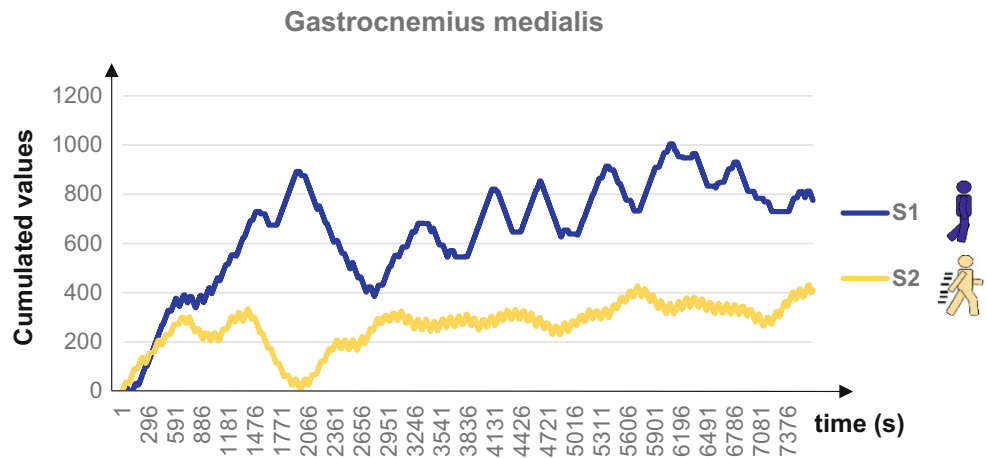


Fig. 9 Results of the JASA method (Luttmann et al. 1996) for S1 and S2, three muscles each for an experimental period of 2.5h (90 cycles), $n = 10$
Abb. 9 Ergebnisse der JASA-Methode (Luttmann et al. 1996) für S1 und S2 für drei Muskeln über eine Versuchsdauer von 2,5h (90 Zyklen), $n = 10$

Fig. 10 Temporal lines of the cumulated values of the muscle gastrocnemius medialis, exemplary for one participant (cumulated values over time: fatigue “+1” and recovery “-1”)
Abb. 10 Zeitlicher Verlauf der kumulierten Werte für den Muskel Gastrocnemius medialis, beispielhaft für einen Probanden (kumulierte Werte über die Zeit: Ermüdung „+1“ und Erholung „-1“)



In order to check whether the curve of S1 shows on average more fatigue components than the curve of S2, the mean values of the cumulative lines of the individual muscles and all three muscles in cumulation were examined statistically (cp. Table 1). There are significant differences for the gastrocnemius medialis, the tibialis anterior and the combined view of all three muscles.

5 Discussion

Although the two scenarios (S1/S2) of the investigation were based on realistic conditions, they are deliberately borderline. The strict timing of the test time (cycles of 90s) allowed the desired standardization in the laboratory environment. The combined view on the examined parameters (cp. summary in Fig. 12) shows consistent and significant results.

The results of the static and dynamic components make clear that EMG measurements can be used to determine statistically significant differences in movement patterns (H1),

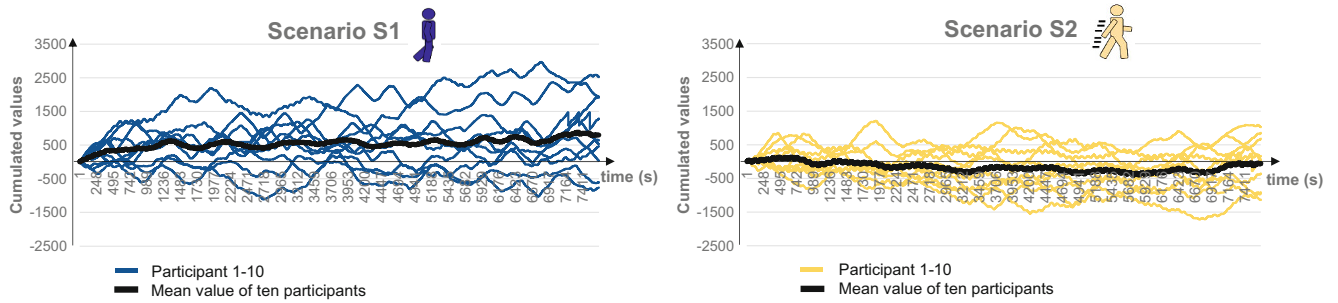


Fig. 11 Temporal lines of the cumulated values of the ten participants for all three muscles and as an averaged value over all participants (*thick black line*) for S1 (*left*) and S2 (*right*)

Abb. 11 Zeitliche Verläufe der kumulieren Werte der zehn Probanden für alle drei Muskeln und als gemittelter Wert über alle Probanden (*dicke schwarze Linie*) für S1 (*links*) und S2 (*rechts*)

Fig. 12 Summary of the results of the present study

Abb. 12 Zusammenfassung der Ergebnisse der vorliegenden Studie

Results of the study

- First representation of the microstructure of the movement of the lower leg muscles (static/dynamic): **Dynamics**
- Survey on strain: **Subjective complaints**
- Improved water plethysmography: **Volume change**
- EA amplitude/MF spectrum: **Muscle fatigue**



S1	<	S2
S1	>	S2
S1	>	S2
S1	≠	S2

because for all three muscles examined, the dynamic components of the EMG for S2 are significantly (35 to 52%) higher than for S1. The structured survey provides significantly higher complaints for scenario S1 compared to S2. Thus, for the characteristics “strain on the lower leg” and “urge to move” for S1 compared to S2, subjective complaints occur significantly higher during the duration of the experiment and significantly earlier (H2), respectively. The water plethysmography always showed an increase in volume in the course of the test time, which is significantly more pronounced in S1 with less movement than in S2 with more movement (H3). The results of the water plethysmography are consistent with similar studies (Lips 2017; Wall et al. 2020). E.g. Wall et al. (2020) showed an increase in the volume of the lower leg of 3.60% for pure static standing and 0.03% for pure walking, each over a time of 275 min (interrupted by two breaks). A direct comparison of the static and dynamic parts of the EA is not possible due to different test designs.

The results of the data on muscular fatigue show partially significant differences between the scenarios S1 and S2. In this study, in order to take the temporal aspect into account, a different method was deliberately chosen. However, these results should be treated with caution. As Fig. 11 illustrates, the curves of all ten participants have a wide range. A comparison of the curves S1 and S2 of individual participants partly shows that both curves are in the recovering range (below 0) or even have opposing effects. To what extent fatigue really occurs in S1 cannot be answered with

certainty, as for individual participants it may occur and for others not. It must be mentioned that the test design has reached its limits. It cannot be ruled out that the participants take countermeasures against fatigue, e.g. in the form of arbitrary or not actively perceived small movements of the muscles (stretching knees, more powerful steps in scenario S1 between the two workstations, muscle relaxation and tension). Due to the test design (using water plethysmography), only the EA of the left leg was measured. Lastly, it should be mentioned that averaging over time plus averaging over the muscles can mask effects, so that the authors would like to specify a derivation in the result of only tententially higher fatigue in S1 compared to S2 (H4).

A comparison of similar studies showed the following results using different approaches. Garcia et al. (2016) evaluated static standing on a hard floor or antifatigue mat, or walking on a treadmill with an experimentation time of 275 min interrupted with two breaks (110 min standing or walking, 35 min seating break, 110 min standing or walking, 10 min seating break, 55 min standing or walking). They found no evident alterations in muscle twitch force (used as an indicator for fatigue) during the first 110 min of static standing or walking on a treadmill. Wall et al. (2020) investigated static standing or walking on a treadmill with the same test procedure as Garcia et al. (2016). They reported meager changes in twitch amplitude and duration after 110 min of standing work. Balasubramanian et al. (2009), on the other hand, detected a faster rate of fatigue of the lower extremity muscles during a stationary standing

posture (one workplace) compared with a dynamic posture (six workplaces) after one hour working on a mechanical assembling task.

In summary, measuring fatigue and comparing it to the present results is difficult. Unfortunately, in the studies mentioned above, the type of dynamic movement is not presented in a sufficiently comparable manner. Activities that must be performed predominantly while standing and which include only little movement may lead to fatigue. In summary, walking activities lead to less or no fatigue in the experimental designs. However, it remains unclear — in the literature mentioned — which parts of the walking have an effect on recovery. As a result, it might not be surprising that in the author's experimental design with standing and walking in combination, which was based on real activities in industry, the difference in fatigue was only detectable tentatively. Since the other results of the study consistently show that scenario S2 causes significantly lower complaints compared to S1 (WP and survey, cp. Fig. 12), the question arises whether the previous approaches are insufficient or whether muscle fatigue does not play the essential role for strain as assumed before.

A comparison of the results of the present study with the specifications of the LV 50 (Berger et al. 2009) leads to the question as to whether the standing parts of the present study can be defined as standing stress within the meaning of this definition at all. The LV 50 defines that “standing with the possibility of moving freely is not defined as work in a continuous standing position” (Berger et al. 2009, p. 14). However, in both cases (S1 and S2) walking portions (of at least 1.5 m) occurred within the 90 s cycles. How a company practitioner grades the definition of the LV 50 in this situation is not very predictable. In addition, the LV 50 only defines time units, which can also be misleading (60:30:1). This, too, can lead to misinterpretations. Thus, in industrial practice, the impression could arise that short walking portions (often only “shuffling” movements), as they occur in scenario S1, are already seen as a relief and no complaints are to be expected.

The LV 50 also defines that “as with all static postures, the *duration of staying still without any relief* is the criterion that results in discomfort and/or health impacts” (Berger et al. 2009, p. 14). Physiological aspects of long-lasting standing (missing muscle pump) are described in the LV 50 in a comprehensible way, i.e. a restricted metabolic exchange of tissue cells, inter alia, as a consequence of the reduced blood flow to the muscles due to static muscle strain (oxygen supply and disposal of waste products) (Berger et al. 2009; DGUV 2013). However, unfortunately, this can no longer be found in the specifications in which only time shares are stored. Other recommendations also only rely on the length of standing as a decisive factor, i.e. the risk assessment with the key indicator method (BAuA

2019) considers standing in the context of constrained postures with a classification of the duration of static standing.

The present study suggests that the structure of movement has a significant influence on the physical comfort of the participants. So, the duration is not the only criterion to evaluate strain in continuous standing situations. As a result, the scaling of the static and dynamic areas allows an assessment of the situation based on the movement structure. Dynamic components prove to be very effective in reducing loads. As a practical result, it becomes clear that workplaces with standing work and only an occasional step to the side are not compatible to the physiological characteristics of the human body, and can therefore not be recommended. The type of walking (“real” walking vs. “shuffling gait”) is a decisive factor. The specifications should therefore be at least more focused on the dynamics, i.e. the type of movement. From the results of the present study, the company practitioner is recommended not to misconstrue a step to the side as “real” walking parts. Finally, it can be summarized that actual walking is compatible with physiological characteristics and human needs!

Funding Open Access funding enabled and organized by Projekt DEAL.

Open Access This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit <http://creativecommons.org/licenses/by/4.0/>.

References

- Balasubramanian V, Adalarasu K, Regulapati R (2009) Comparing dynamic and stationary standing postures in an assembly task. *Int J Ind Ergon* 39:649–654
- Beebe-Dimmer JL, Pfeifer JR, Engle JS, Schottenfeld D (2005) The epidemiology of chronic venous insufficiency and varicose veins. *Ann Epidemiol* 15(3):175–184
- Berger H, Caffier G, Schultz K, Trippler D (2009) Bewegungsergonomische Gestaltung von andauernder Steharbeit (LV 50). Länderausschuss für Arbeitsschutz und Sicherheitstechnik LASI (ed), Potsdam
- BAuA, Bundesanstalt für Arbeitsschutz und Arbeitsmedizin (ed) (2019) MEGAPHYS. Mehrstufige Gefährdungsanalyse physischer Belastungen am Arbeitsplatz. Abschlussbericht vol 1. BAuA, Dortmund
- Carayon P (2006) Handbook of human factors and ergonomics in health care and patient safety. CRC Press, Boca Raton
- DGUV, Deutsche Gesetzliche Unfallversicherung (2013) Lernen und Gesundheit – Stehberufe – Eingeschränkter Stoffwechsel. Universum, Wiesbaden

- Garcia M-G, Wall R, Steinhilber B, Läubli T, Martin BJ (2016) Long-lasting changes in muscle twitch force during simulated work while standing or walking. *HFES* 58(8):1117–1127
- Halim I, Omar AR (2011) A review on health effects associated with prolonged standing in the industrial workplaces. *IJRRAS* 8(1):14–21
- Halim I, Omar AR, Saman AM, Othman I (2012) Assessment of muscle fatigue associated with prolonged standing in the workplace. *Saf Health Work* 3(1):31–42
- Hartmann S, Huch R (2005) Response of pregnancy leg edema to a single immersion exercise session. *Acta Obstet Gynecol Scand* 84(12):1150–1153
- Kamusella C, Schmauder M (2019) Steharbeitsplätze mit Lasthandhabung: Einfluss des Belastungswechsels auf Muskelbeanspruchung, Beschwerdeempfinden und Beinvolumenänderung. *Z Arb Wiss* 73:78–89
- Kauder S, Strölin A, Adamczyk A, Krug M, Häfner HM (2011) Image 3D zur Unterschenkelvolumenbestimmung im Vergleich mit der Wasserplethysmographie. *Phlebologie* 40(6):337–342
- Kirsch J, May CA, Lorke D, Winkelmann A, Schwab W (2011) Taschenlehrbuch Anatomie. Thieme, Leipzig, pp 40–52
- Kluth K, Göbel M, Bopp V, Strasser H (2014) Anwendung der Oberflächen-Elektromyographie zur Beanspruchungsermittlung bei der arbeitsphysiologischen Beurteilung von Arbeitsplätzen und Arbeitsmitteln. *Zbl Arbeitsmed* 63:286–292
- Kluth K, Steinhilber B, Anders C, Jäger M, Läubli T, Luttmann A, Rieger MA, Scholle H-C, Schumann N-P, Seibt R, Strasser H (2013) S2k-Leitlinie Oberflächen-Elektromyographie in der Arbeitsmedizin, Arbeitsphysiologie und Arbeitswissenschaft. Deutsche Gesellschaft für Arbeitsmedizin und Umweltmedizin e. V. (DGAUM) (ed), München
- Lips O (2017) Erfassung des Unterschenkelvolumens und subjektive Beschwerden bei mehrstündiger Stehexposition auf hartem Untergrund sowie einer Anti Ermüdungsmatte. Dissertation. Universität, Tübingen
- Lück M, Hünefeld L, Brenscheidt S, Bödefeld M, Hünefeld A (2019) Grundausswertung der BIBB/BAuA-Erwerbstätigenbefragung 2018. Vergleich zur Grundausswertung 2006 und 2012, 2nd edn. Bundesanstalt für Arbeitsschutz und Arbeitsmedizin, Dortmund
- Luttmann A, Jäger M, Laurig W (2000) Electromyographical indication of muscular fatigue in occupational field studies. *Int J Ind Ergon* 25:645–660
- Luttmann A, Jäger M, Sökeland J, Laurig W (1996) Electromyographical study on surgeons in urology. II. Determination of muscular fatigue. *Ergonomics* 39(2):298–313
- MacLeod D (2012) The rules of work: a practical engineering guide to ergonomics, 2nd edn. CRC Press, Boca Raton
- Nüllen H, Noppeney T (2010) Varikose: Diagnostik – Therapie – Begutachtung. Springer, Berlin
- Opfermann R, Streit W, Tannhauer J, Pernack E-F, Pangert R (2008) Arbeitsstätten. Loseblattsammlung – Arbeitswissenschaftliche Erkenntnisse – Steharbeitsplätze. Hüthig Jehle Rehm, Heidelberg
- Parker KG, Imbus HR (1992) Cumulative trauma disorders: current issues and ergonomic solutions. CRC Press, Boca Raton
- Rabe E, Stücker M, Ottillinger B (2010) Water displacement leg volumetry in clinical studies — a discussion of error sources. *BMC Med Res Methodol* 10:5
- Rücker L, Brombach J, Bengler K (2018) Einfluss verschiedener Beinpositionen auf die Muskelaktivität/-ermüdung bei Steharbeit. In: Gesellschaft für Arbeitswissenschaft (ed) Arbeit(s). Wissen. Schaff(f)t Grundlage für Management & Kompetenzentwicklung. GfA-Press, Dortmund
- Rücker L, Brombach J, Bengler K (2020) Einfluss von gehenden Bewegungsanteilen bei statischer Steharbeit. In: Gesellschaft für Arbeitswissenschaft (ed) Digitaler Wandel, digitale Arbeit, digitaler Mensch? GfA-Press, Dortmund
- Strasser H (1996) Elektromyographische Beurteilung dynamischer Muskelarbeit: Methoden – Ergebnisse – Anwendungsmöglichkeiten. In: Strasser H (ed) Beanspruchungsgerechte Planung und Gestaltung manueller Tätigkeiten – Elektromyographie im Dienst der menschengerechten Arbeitsgestaltung, 1st edn. ecomed, pp 35–72
- Strasser H (2021) Compatibility as guiding principle for ergonomics work design and preventive occupational health and safety. In: Kompatibilität – Themenheft der Zeitschrift für Arbeitswissenschaft. Springer, Berlin
- Strasser H, Keller E, Müller KW, Ernst J (1989) Local muscular strain dependent on the direction of horizontal arm movements. *Ergonomics* 32(7):899–910
- Wall R, Garcia M-G, Läubli T, Seibt R, Rieger MA, Martin B, Steinhilber B (2020) Physiological changes during prolonged standing and walking considering age, gender and standing work experience. *Ergonomics* 63(5):579–592
- Wall R, Lips O, Seibt R, Rieger MA, Steinhilber B (2017) Intra- and inter-rater reliability of lower leg waterplethysmography, bioelectrical impedance and muscle twitch force for the use in standing work evaluation. *Physiol Meas* 38(5):701–714
- Waters TR, Dick RB (2014) Evidence of health risks associated with prolonged standing at work and intervention effectiveness. *Rehabil Nurs* 40(3):148–165
- Wrona M, Jöckel K-H, Pannier F, Bock E, Hoffmann B, Rabe E (2015) Association of venous disorders with leg symptoms: results from the Bonn vein study I. *Eur J Vasc Endovasc Surg* 50(3):360–367