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Effect of familiarization on the reproducibility of maximum isometric normalization contractions in a worker-specific sample

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ABSTRACT

The assessment of muscle activity (MA) via surface electromyography (sEMG) within a workplace setting offers valuable insights into workers' physical strain, but it encounters certain challenges. Particularly, the analysis of sEMG data presents difficulties when it requires normalization using maximal voluntary isometric contractions (MVIC). Given that familiarity with generating maximum forces cannot be assumed in samples from the field of occupational science, it becomes necessary to familiarize participants with the normalization task. This is crucial to ensure consistent and replicable performance of MVICs. This paper aims to investigate how familiarization can improve the capability of reproducing maximal voluntary force (MVF) of a high percentage (85% and 90%) and to assess its impact on the reliability of MA of lower leg (gastrocnemius medialis and tibialis anterior) and trunk muscles (obliquus externus abdominis) in MVICs, for a worker-specific sample. The results demonstrate that one or two familiarization days can enable a high degree of reproduction with a range of 85% of the absolute MVF and a low percentage of standard error of the mean (%SEM) in intra-day reliability of the sEMG amplitude. However, it is important to note that the reliability of sEMG varied among subjects and individual muscles, particularly for the trunk muscles. Still, our findings underscore the significance of familiarization sessions when utilizing MVIC normalization for a worker-specific sample.

Relevance to industry

With regard to the evaluation of the effectiveness of physical assistance systems, e.g. industrial exoskeletons, on muscle fatigue during occupational activity or comparison of workloads, it is of great relevance to conduct meaningful sEMG studies in a work environment and to achieve the highest possible standardization for MVIC normalization.

1. Introduction

A suitable method for the evaluation of physical strain during a workload is the determination of muscle activation (MA) using surface electromyography (sEMG). SEMG is often used in occupational studies to evaluate MA in work processes, the ergonomic design of workplaces and work equipment (Mathiassen et al., 1995). It represents a non-invasive method for direct assessment of MA and therefore allows conclusions to be drawn on muscle fatigue during occupational activity or comparison of workloads between different individuals, muscle groups and days (Besomi et al., 2020; Mahdavi et al., 2020).

The sEMG signal is affected by many intrinsic and extrinsic factors such as adhesive position of the electrodes, skin conductivity or sweat, especially in a work environment. Normalizing the signal can therefore reduce possible variability in the sEMG signal, to compare subjects, different muscles, or electrodes located on the same muscle but on different days (Merletti and Muceli, 2019). A common normalization method in ergonomics is the use of a maximal voluntary isometric contraction (MVIC) to generate a maximum sEMG amplitude (Burden, 2010). An MVIC involves isolated maximal isometric loads on a single joint with maximal force development against a fixed static resistance (Burden, 2010). Resulting maximum sEMG amplitude is used as a 100% reference value to normalize the sEMG data as the appropriate % of maximum MA. This normalization method is suitable for making measurements taken at different times comparable and has been used in numerous occupational science studies, including evaluation of loads on primary trunk muscles (Alemi et al., 2019; Jin, 2018; Lu et al., 2019; Kazemi et al., 2021), as well as upper and lower legs (Nicoletti and Läubli, 2018; Theurel et al., 2018; Renberg et al., 2020; Desbrosses et al., 2021).

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SEMG data expressed relative to the maximum (% MA) has physiological relevance, however, submaximal reference MA values are frequently used when MVIC's are limited by aging, pain or other symptoms (e.g. Dankaerts et al., 2004; Shamsi et al., 2017). In the context of occupational science long-term studies, MVICs allow for a direct and comparable measurement of %MA across different individuals, enabling data from various subjects to be placed on a consistent scale. Still, particularly when normalizing subsequent sEMG measurements on different days, it is crucial to standardize the measurements in order to obtain comparable normalization sEMG amplitudes (Merletti and Muceli, 2019). If these amplitudes on different days are not comparable, it significantly affects the validity and reliability of the measurements. An important prerequisite for this comparability is also the ability of subjects to achieve a consistent maximal voluntary force (MVF) at the time of MVIC data collection, because inexperience in producing high muscle forces (as it is typical e.g. for sports or strength training) limits the ability to reproduce MVF and related maximal MA (Frost et al., 2012; Amarantini and Bru, 2015; Salonikidis et al., 2021). As we can assume that in our case the user population of workers consists to a large extent of subjects without previous specific experience in maximum strength generation, this must be considered as a critical factor for the consistency and reproducible MVF (Buckthorpe et al., 2012; Tillin et al., 2010; Rodríguez-Rosell et al., 2018; Balshaw et al., 2019). Therefore, producing at least a high and consistent proportion of MVF is mandatory in sEMG studies, especially if day-to-day measurements require consistent daily maximal sEMG amplitudes for normalization.

It was shown that MVF can be as much as 20–40% lower than true absolute MVF in untrained subjects (Sodeberg and Knutson, 2000). However, familiarization with the MVIC task can optimize force production to reach the highest possible MVF value and MA of the selected muscle (Green et al., 2014; Chan et al., 2020; Reyes-Ferrada et al., 2022). Here, the number of familiarization sessions to reach the absolute MVF required for isometric contractions is usually measured for a 1-repetition maximum test and is reported as 2–3 sets (Green et al., 2014; Chan et al., 2020). Nevertheless, it is not clear whether a certain number of training sessions can subsequently lead to a consistent intra-day-reproducibility of MVIC signal outcomes over further measurement days.

The aim of this work is to analyze how familiarization can improve daily capability of MVF reproduction of a high percentage (90% and 85%) and to evaluate its effect on reliability of MA in MVICs for a worker-specific sample without previous experience in maximum strength generation.

2. Materials and method

2.1. Subjects

Twenty-five subjects participated in the study, representing an average user population for the occupational sciences and worker-specific sample. We therefore recruited the participants from a subject list of the Federal Institute for Occupational Safety and Health including individuals of working age, mostly with either recreational or with no previous sport experience. They were twelve healthy men and thirteen women aged 19–41 years (age 29 ± 7 years, height: 175.0 ± 9.19 cm, weight: 70.9 ± 15.6 kg, BMI: 22.9 ± 3.19 kg/m^2), mostly recreational or with no previous sport experience. Subjects were asked to abstain from physical activity the day before and the day of the test to avoid the effects of cumulative muscle fatigue. All subjects signed an informed consent form before the test. Ethical approval was obtained from the local institutional ethics committee.

2.2. Experimental protocol

MVICs were performed on an isokinetic dynamometer IsoMed 2000 (D&R Ferstl GmbH, Hemau, Germany) on five familiarization days. Time interval between each examination was 48 h–72 h. On each familiarization day, we equipped the subjects with sEMG sensors, connected to a mobile sEMG system (Ultium, Noraxon).

Beforehand, skin was prepared to achieve stable electrode contact and high skin conductance by lowering the impedance. For this purpose, hair was removed from the skin positions to be covered with a disposable razor. The skin was cleaned with alcohol and treated with an abrasive gel. This method is suggested for clinical use (Hermens et al., 2000). Adhesive gel dual disposable electrodes served as sEMG electrodes; we placed these on each body side on the obliquus externus abdominis (OE), tibialis anterior (TA), and gastrocnemius medialis (GM) muscles according to SENIAM guidelines. We have chosen these muscles for several reasons. Firstly, they represent various tissue compositions, such as strength in wobbling mass or fat (abdominal muscles having more, calf muscles having less). Secondly, these muscles have been selected because they are highly relevant for a subsequent long-term study involving exoskeletons (Bär et al., 2021). We took care to place the electrodes on the midline of the abdominal area, perpendicular to the length of the muscle fibers between the muscle tendon junction and the nearest innervation zone.

After preparation, we fixed the subjects sequentially randomly on the isokinetic dynamometer in the following measurement positions.

- Prone position with the foot and toe attached to the adapter (Fig. 1). In addition, the subject's position was fixed with shoulder pads. Subjects were instructed to perform maximal plantar flexion (PlFlex) against the resistance of their fixed foot to activate GM.

- Supine position (2) with the foot fixed in the foot section of the isokinetic dynamometer (Fig. 2), with fasten shoulder pads. Maximum activation of the TA, while performing dorsal extension (DorEx) against the fixed resistance of the fixed foot was required.
- Seated position (3) with the pelvis firmly in the seat and the shoulder girdle fixed to the measuring bracket (Fig. 3). Isometric trunk rotations (TrRot) were performed against the established lever arm of the isokinetic dynamometer with maximal activation of OE.

All measurements started with a practice trial and were performed with both sides of the body, starting with each subject's dominant side. After completing the practice session, the subjects performed three consecutive trials of MVICs within a 5-s protocol, with a 60-s rest period between each MVIC. For further analysis, the last 3 s of the MVICs were utilized. The pause between measurements on different body sides and positions was 5 min. For all participants, sessions took place at approximately the same time of the familiarization day ±60 min. We made this precaution to minimize the influence of circadian rhythms on MVIC between participants (Douglas et al., 2021). We also took care to select measurement positions that could be implemented in the field trial (PlFlex and DorEx in standing, for example). We choose TrRot, because trunk flexion was not possible with the isokinetic dynamometer, but the TrRot position has also been described as suitable for normalizing the OE (Vera-Garcia et al., 2010; Roth et al., 2017).

2.3. Data acquisition and raw data processing

We recorded isokinetic data by the manufacturer computer software IsoMed analyze V.2.0 at 200 Hz and filtered it with a recursive 5th order Butterworth low-pass filter (6 Hz cutoff frequency). The rectified sEMG signal was set to a sampling rate of 2.000 Hz per channel and filtered using a fourth-order Butterworth filter with a bandpass of 20–500 Hz for GM and TA. We selected a bandpass of 2.5–100 Hz for the OE to remove heart rate artefacts (Drake and Callaghan, 2006; Vera-Garcia et al., 2010). Isokinetic data and sEMG were acquired time-synchronized using MyoSync (Ultium, Noraxon).

First, we determined the time of peak torque of the isokinetic data for

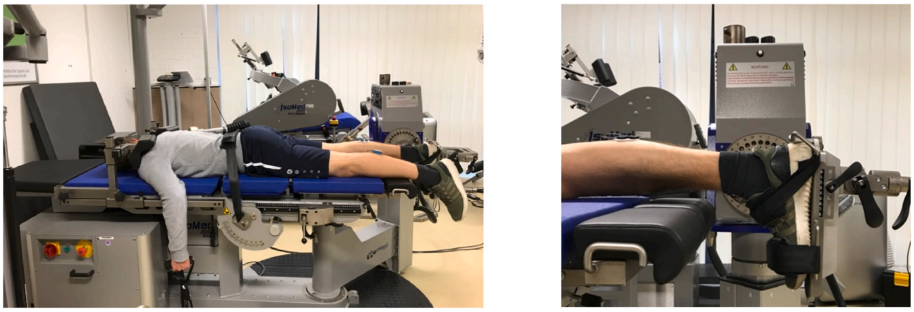

Fig. 1. PlFlex-position on the isokinetic dynamometer.

Fig. 2. DorEx-position on the isokinetic dynamometer.

Fig. 3. TrRot-position on the isokinetic dynamometer.

each MVIC trial and formed a 500ms interval around it (250ms before and after the respective peak torque). Afterwards we also extracted the time-corresponding 500ms intervals for the sEMG data. For sEMG and isokinetic data, the root mean square (RMS) value was calculated for the entire 500ms interval. To do this, the mean of the squares of all values within the 500ms interval was determined, and then the square root of the result was taken for both the isokinetic force values and the sEMG amplitude. The RMS serves as the primary parameter for all subsequent analyses and was also used to determine whether the individual reached the absolute MVF threshold of 85% or 90%.

2.3.1. Reproducibility of MVF

To analyze the effect of familiarization on MVF reproducibility, we determined the highest RMS of all day isokinetic data per subject. Using this absolute MVF value, the remaining RMS values of the isokinetic data for each subject were normalized and converted to % of the absolute MVF.

To subsequently assess the quality of MVF reproducibility over time, we defined two threshold at 90% and 85% (<90%) absolute MVF. We subsequently established distinct MVF plateaus, referred to as "plateaus," by observing the consistent achievement of a threshold during all three trials of a familiarization day. Specifically, when a subject achieved an MVF exceeding 90% of their absolute MVF in three consecutive trials, we deemed this as successfully reproducing the MVF at the 90% MVF plateau. On the other hand, if all three trials in a single day fell within the range of 85% to less than 90%, we referred to it as the 85% MVF plateau. We calculated the MVF plateaus individually for each muscle (GM in PlFlex, TA in DorEx and OE in TrRot) and each side of the body (L/R). We also determined the day when the absolute MVF was reached for each MVIC task. Only subjects that were able to reach at least the 85%MVF plateau were included in the analysis. Mean and standard deviation (SD) was calculated over the included subjects.

2.3.2. Reliability of sEMG

In the next step, we determined the effect that familiarization with the normalization task had on the reproducibility of the MA and the sEMG. The Kolmogorov-Smirnov test for normality revealed that the data were normally distributed, allowing us to construct superimposed Bland-Altman plots of all muscles using IBM SPSS (Version 29). Showing the differences between trials one and two (1), two and three (2) and one and three (3) per familiarization day; the plots can be used to evaluate the measurement error of the sEMG data for each familiarization day. We derived from the scatter of the measurements the "limits of agreement" (LoAs) an average of the difference (AvDiff) ±SD. LoAs−/+95% were calculated summarized for differences of all three trials on one day LoAs−/+95% by AvDiff minus and plus 1.96 *SD (Atkinson and Nevill, 1998). We transferred the determined days of the 90% and 85%MVF plateau for each muscle to the plots as an indication of successful familiarization and standardizable repeatability, and marked the day of the absolute MVF as well. Subjects who were unable to achieve at least the 85%MVF plateau in a MVIC task were not included in the further sEMG examination for the corresponding muscle.

The reliability of the sEMG was furthermore assessed using the standard error of the mean (SEM) (Frost et al., 2012; Liljequist et al., 2019). To evaluate the intra-day reliability for each muscle, the SEM was calculated for each muscles and each day, and it was reported as the percentage of the mean for that specific day (%SEM). In the subsequent results, the sides of the body are abbreviated as L (left) and R (right).

3. Results

In total 23 subjects (twelve men and eleven women) completed the measurements on all five familiarization days. Only subjects that were able to reach at least the 85%MVF plateau were included in the analysis of the respective muscles absolute MVF. For example, if a subject reached the 85%MVF plateau in PlFlex for L, they were included in the absolute MVF evaluation for L, but at the same time if they did not reach the plateau for PlFlex for R, they were not included in the absolute MVF calculation for R. Fig. 4 shows the average number of familiarization days±SD for each MVIC task. For PlFlex the 90%MVF plateau was reached by 17 subjects for L and 19 subjects for R on session 3 ± 2.19 subjects achieved an 85%MVF plateau for L as well as R, after 3 ± 2 familiarization days, absolute MVF was reached from the remaining 19 subjects on day 3 ± 2.

In DorEx 21 subjects achieved a 90%MVF plateau on day 3 ± 1 (L and R). The 85%MVF plateau was reached for DorEx by all 23 participants on day 1 ± 1 (L) and day 2 ± 1 (R). Absolute MVF in DorEx was reached on day 3 ± 2. For TrRot, 13 (L) and 11 (R) subjects achieved 90%MVF plateau on day 3 ± 2 and day 1 ± 1.The 85%MVF plateau was achieved on day 2 ± 2 (absolute MVF on day 3 ± 1) and day 2 ± 1 (absolute MVF on day 2 ± 1) by 15 or 17 subjects.

3.1. sEMG reliability

The Bland-Altman plots (Fig. 5) illustrate the differences in the averaged sEMG between trials one and two (1), two and three (2), and one and three (3) for each familiarization day. The vertical axis represents the difference of averaged sEMG, while the horizontal axis represents the average of the averaged sEMG. The plots cover familiarization days one to five (Fig. 5) for L. The black solid line represents the average difference (AvDiff), and the dashed line represent.

The limits of agreement (LoAs) at ± 95%. The days on which the 85% and 90% MVF plateau and the absolute MVF were reached on average are indicated. Table 1 displays the %SEM values for both sides of the body for all muscles. It presents the %SEM of sEMG data (%) for the L and R on all familiarization days, for the GM, TA, and OE muscles, considering all three trials per day. The table also marks the average days of the 85% and 90% MVF plateaus and the absolute MVF. If 85% and 90%MVF plateaus were reached on the same day, they were marked only as 90% MVF plateau.

3.1.1. Lower leg muscles

On day 1 the AvDiff ± SD for the GM muscle on L and R is 0.5 ± 2.1 (LoAs −3.5/4.6) and 0.2 ± 2.2 (LoAs −4.0/4.4), while the %SEM of the measurement is 4.4% or 4.1%. On Day 2 the 85% MVF plateau is reached for R, with AvDiff of −0.1 ± 2.6 (LoAs −5.1/4.9), and 3.2% SEM. The 90% MVF plateaus is on day 3 with AvDiff ±SD values of 0.5 ± 2.5 (LoAs −4.4/5.3), and %SEM of 3.0% for L (including 85%MVF plateau), and AvDiff ± SD of −0.1 ± 1.9 (LoAs −3.9/3.7), with %SEM of 3.2% for R. In the subsequent days following the 90% MVF plateau and the absolute MVF, the AvDiff ±SD values continue to decrease, reaching 0.2 ± 2.7 (LoAs −5.1/5.4), and 0.2 ± 2.4 (LoAs −4.4/4.8), on day 5. The %SEM remains ≤3.3%.

Tibialis anterior's 85% MVF plateau is on day 1 for L and ranging from −4.1 ± 4.9 (LoAs −2.9/3.6), with a %SEM of 3.8%. For R it is on day 2 ranging from −5.1 ± 4.9 (LoAs −4.3/4.2), with a %SEM of 3.2%, including the 90% MVF plateau on this day. For L the 90% MVF plateau is reached on day 2 AvDiff −0.1 ± 2.2 (LoAs −3.9/4.5), with a %SEM of 3.3%. Throughout the familiarization period we observe a decreasing %SEM trend from day 1 onwards. However, on the day of the absolute MVF, the %SEM for the R side of the body shows a slight increase but remains below the initial value of 4.4% recorded on day 1.

3.1.2. Trunk muscles

For obliquus externus, the AvDiff ± SD is 0.2 ± 4.7 (LoAs −9.0/9.5), and 0.1 ± 3.2 (LoAs −6.1/6.3) on day 1, with a %SEM of 8.8/5.8%. On

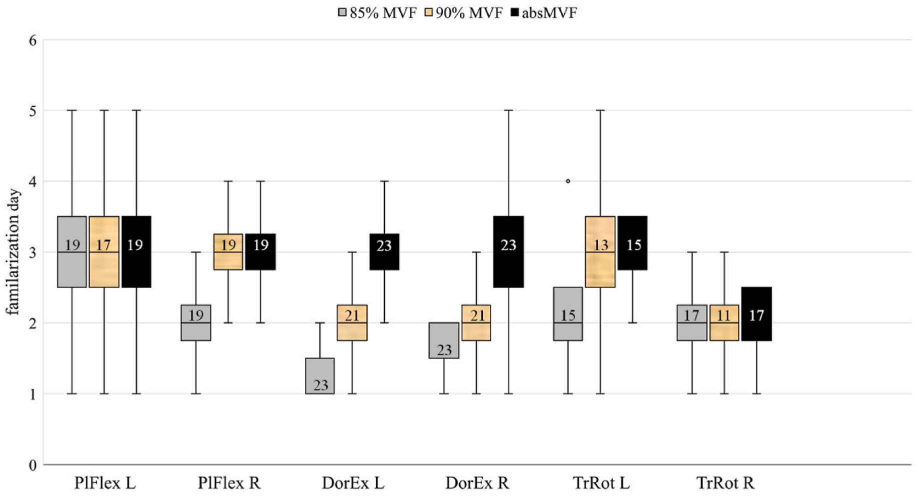

Fig. 4. Average measurement day or familiarization day required to reach absolute MVF and 90% and 85%MVF plateaus. Numbers in the boxes represent the number of subjects (n) included (only subjects that were able to reach at least the 85%MVF plateau were included in the analysis).

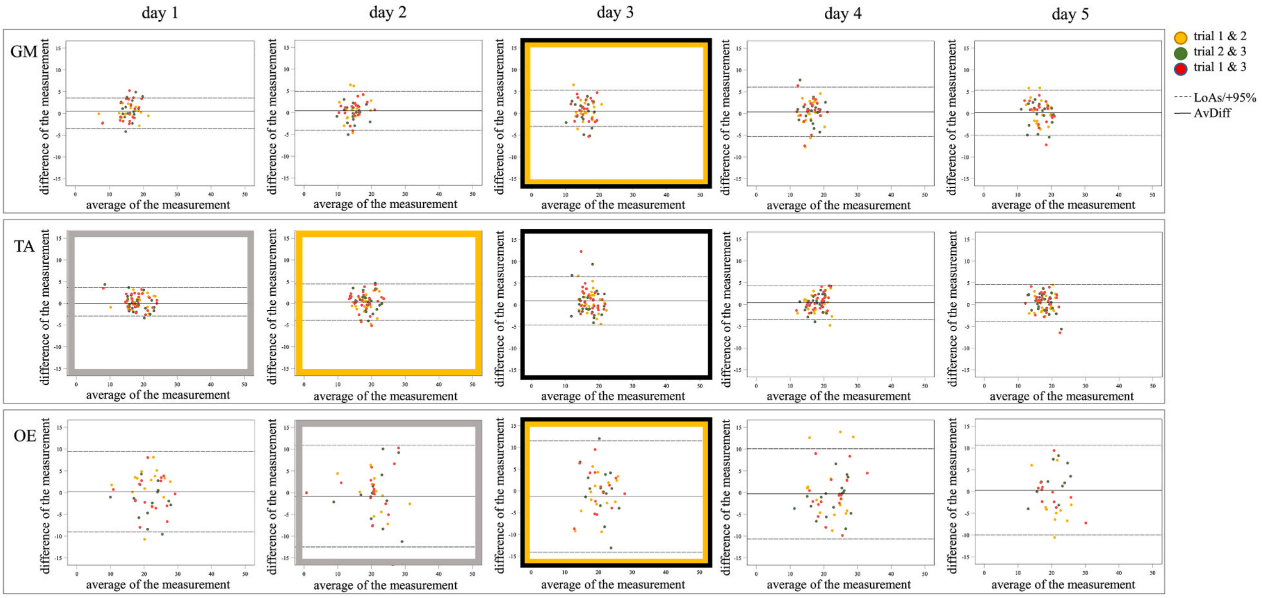

Fig. 5. SEMG data of L for GM, TA and OE. The plots show the differences between trials one and two with yellow dots, two and three with green dots and one and three with red dots per familiarization day, with difference on the vertical axis against the average of the measurements on the horizontal axis. AvDiff and LoAs−/+95% were calculated from the differences of all three trials per day, by mean minus and plus 1.96 *SD. The AvDiff is marked by the black solid line, the dashed line represents the upper and lower LoAs−/+95%. The black frames mark the day on which the absolute MVF was averaged achieved. Yellow and grey frames indicate the average day of 90%, and 85%MVF plateau. Missing grey borders indicate that the 80% MVF plateau was reached on the same day as the 90% MVF plateau.

Table 1
Standard error of the measurement (%SEM) of intra-day averaged sEMG of L and R for GM, TA and OE. The black frames mark the day on which the absolute MVF was averaged achieved. Yellow and grey frames indicate the average day of 90%, and 85% MVF plateau. Missing grey borders indicate that the 80% MVF plateau was reached on the same day as the 90% MVF plateau.

body side	Day 1	Day 2	Day 3	Day 4	Day 5
GM					
L	4.4	3.3	3.0	2.9	3.0
R	4.1	3.2	3.2	3.2	3.3
TA					
L	3.8	3.3	3.3	3.2	3.0
R	4.4	3.2	3.7	3.3	3.2
OE					
L	8.8	10.1	6.7	7.6	6.4
R	5.8	7.7	7.8	7.4	7.0

day 2, archiving the 85% MVF plateaus, the AvDiff ± SD is −1.3 ± 6.5 (LoAs −12.5/10.9), with 10.1%SEM and −1.1 ± 5.9 (LoAs −12.7/10.6), with a %SEM of 7.7%. For L the 90%MVF plateau is on day 3 AvDiff ± SD -1.3 ± 6.5 (LoAs −14.1/11.5), -while the 90%MVF plateau for R is included in day 2. These values decrease on the following familiarization days, for both sides of the body, to values ranging from LoAs −10.6/10.1 (L) and −8.5 to 7.8 (R) on day 4. The %SEM values also exhibit significant fluctuations and no clear reduction over time. The maximum %SEM for the OE muscle is reached on either day 2 or day 3.

4. Discussion

This study aimed to investigate the impact of familiarization on the daily ability to reproduce high percentages (90% and 85%) of maximum voluntary force and its effect on the reliability of muscle activity, presented in the sEMG amplitude, during MVICs in a sample of workers with no prior experience in generating maximum strength. Based on previous research (Buckthorpe et al., 2012; Tillin et al., 2010; Rodríguez-Rosell et al., 2018; Balshaw et al., 2019), we hypothesized that the characteristics of the target group play a crucial role in the consistency of maximum sEMG amplitude during MVIC normalization. Therefore, it was essential to achieve a high and consistent MVF and MA.

4.1. *MVF reproducibility*

In our initial step, we aimed to determine an acceptable percentage of absolute MVF for reproducibility. Considering previous studies indicating a reduction of 20–40% in MVF among untrained individuals (Sodeberg and Knutson, 2000), we defined a maximum deviation of 15% as acceptable for reproducibility. As a benchmark, we set the values of 90% and 85% MVF, with three daily follow-up measurements. Assuming that we consider an 85% MVF as acceptable for MVIC normalization in our sample, we can expect this value to be reached on day 2 or 3 for PlFlex and TrRot. However, for DorEx, our participants only require 1–2 days to safely reproduce 85% of their MVF. If we desire a higher degree of standardization for MVIC-normalization, such as a 90% MVF, this value was reached on day 2–3 for PlFlex, DorEx and TrRot. The 90% MVF plateau was typically achieved during the day of absolute MVF, meaning that individuals are capable of completing all three trials with at least 90% of their MVF.

4.2. *SEMG reliability*

Applying previous described understandings to the results of the sEMG measurement, we observe that the %SEM for the muscles GM and TA, activated by PlFlex and DorEx, decreases at day 2 and day 3 when reaching the 85% and 90% MVF plateau, respectively. It then remains at a low level in the following days. For OE in TrRot, these results are not conclusive but rather characterized by strong variations. Our results of GM and TA can be confirmed by Green et al. (2014) and Chan et al. (2020), who report that task familiarization was maintained over the three-day interval. The varying results regarding the reliability of sEMG amplitude of OE in TrRot differ from previous studies, such as the one reported by Vera-Garcia et al. (2010), Roth et al. (2017) and Juan-Recio et al. (2018), which found a very good intra-day reliability of isokinetic data in TrRot. We attribute our divergent results primarily to the differing characteristics of our study participants, as the aforementioned studies examined individuals with prior movement experience in strength training (Folland et al., 2014). This is a crucial point, especially when conducting TrRot, because the normalization-position seems to be a challenge in terms of technical execution for untrained subjects. Furthermore our results for MA in OE be due to the influence of abdominal fat, although several studies have found that fat has a filtering effect on the sEMG signal (Ptaszkowski et al., 2019; Lanza et al., 2020) and increases reliability. Our subject group has a particularly high proportion of wobbling mass, with an average fat fold thickness of 12.9 mm. The actual muscle signal could therefore have been distorted by wobbling fat.

The further interpretation of our results raises the critical question of whether the measured absolute MVF really represents the absolute maximum sEMG amplitude that subjects can achieve (Sodeberg and Knutson, 2000). This could be particularly relevant for GM and TA, as results from previous studies indicate that small muscles in particular, which are not consciously addressed in everyday life, tend to generate poorer reliability than others (Amarantini and Bru, 2015; Murley et al., 2010), and some test persons reported problems when performing the DorEx, as they found the MVIC task very unfamiliar. Especially in the implementation of MVIC normalization without those highly standardized positioning in an isokinetic dynamometer, e. g. in field investigations in occupational sciences, appropriate normalization positions must be identified and tested.

4.2.1. *Bland-Altman plots*

Additionally, in the Bland-Altman plots we can't observe any significant trend of development or reduction in LoAs, but rather continuous unspecific variation in the range of 5–10% for GM and TA. For OE in the range up to 20%, even at the level of the 90% and 85%MVF plateaus. AvDiff values approach zero, but also show variation in the plus and minus range. We explain the ambiguous results of our Bland-Altman plots by a possible co-activation of the agonist-antagonist muscle pair, which can increase while generating MVF, in subjects without specific experience in strength training (Amarantini and Bru, 2015). This leads to lower measured MVF values, which are not directly reflected in the sEMG values of the observed muscle. With rising number of familiarization days, MVF increases with constant MA, by the improvement of intermuscular coordination through familiarization, leading to less co-activation of the surrounding muscles (Young, 2006; Balshaw et al., 2019; Santos et al., 2021), so mainly affects the level of MVF achieved, but less so the maximum sEMG amplitude of the observed muscles. We can therefore assume familiarization to change the relation between MVF and MA, and thus also influence the results of the MVIC normalization.

4.3. *Limitation*

This study is accompanied by some limitations. Firstly, our participant population is heterogeneous, with variations in age, body height and body composition. These factors can impact the ability to perform an MVIC and contribute to intra-individual variability in force development, potentially influencing our results. Considering the demographic shift towards an older working population and the known decline in motor skill adaptation and strength capacity with age (Van Dijk et al., 2007), especially the factor age should be kept in mind and conclusions regarding a generalization of the results must be made with great caution. Secondly, the level of sports experience among participants is to consider (Salonikidis et al., 2021). Although we confirmed that none of the participants had prior strength training experience, it is possible that they had varying levels of general movement experience, which could influence the inter-individual results. Thirdly, despite our efforts to ensure comparable measurement conditions by conducting them at the same time of day, we cannot exclude the influence of extrinsic factors, such as increased physical activity or dietary habits prior to the measurements, as well as intrinsic factors like changing motivation over five consecutive days (Merletti and Muceli, 2019). Additionally, conducting measurements over five consecutive days places increased demands on the attachment of sEMG sensors, which was ensured in our study through a high level of measurement standardization. However, it is also crucial to allow sufficient time between test sessions to allow for skin regeneration. Otherwise, skin changes and irritations can potentially affect the sEMG signal. Fourthly, the transferability of our results beyond the abdominal and lower leg muscles is likely limited, although these muscle groups exhibit different connective tissue structures and fat content. As evidenced by the high inter-individual variability for the different muscle observed in our study, it needs further research to extrapolate these findings to other muscle groups, as various factors clearly influence the inter-individual MVIC capacity of different muscles. Moreover, the transferability of our results to MVICs performed under less standardized field conditions poses a challenge for result generalization, due to differing environmental and measurement conditions, and should be considered in future studies conducted in workplace settings.

6. Conclusion

The results of this study highlight the importance of familiarization with the MVIC task to achieve a high level of standardization in MVIC normalization for a worker-specific sample. The findings demonstrate that with a one-day familiarization period, a range of 85% reproduction of absolute MVF and low percentage standard error of the mean (%SEM) in intra-day reliability of sEMG amplitude can be achieved. A two-day familiarization period can result in 90% reproducibility of absolute MVF, while maintaining comparable intra-day reliability of sEMG. Applying the knowledge of this study to MVIC normalization in occupational studies can lead to more reliable sEMG values across different measurement days. It is crucial for investigators to determine the appropriate level of standardization necessary for their respective study, taking into account intra-individual factors and considering the normalized muscle groups that contribute to result variability. Further investigations should address this aspect and explore the optimal level of MVIC familiarization required for conducting MVICs in field investigations with less standardized conditions.

Author statement

We are pleased to revise our manuscript titled " Effect of familiarization on the reproducibility of maximum isometric normalization contractions in a worker-specific sample " for consideration for publication in the International Journal of Industrial Ergonomics. The primary objective of our study was to investigate how familiarization can enhance the capability to reproduce maximal voluntary force (MVF) at high percentages (85% and 90%) and assess its impact on the reliability of muscle activity in lower leg (gastrocnemius medialis and tibialis anterior) and trunk muscles (obliquus externus abdominis) during MVICs within a worker-specific sample. Through our research, we aimed to shed light on the effectiveness of familiarization in achieving reliable and consistent measurements of muscle activity. Our findings indicate that one or two familiarization sessions enable a high degree of force reproduction, encompassing a range of 85% of the absolute MVF, along with a low percentage of standard error of the mean (%SEM) in intra-day reliability of the sEMG amplitude. It is important to note that the reliability of sEMG varied among subjects and individual muscles, particularly in the case of trunk muscles. Nonetheless, these results emphasize the significance of familiarization sessions when utilizing MVIC normalization for a worker-specific sample. The relevance of our study extends to the industry, especially in evaluating the effectiveness of physical assistance systems, such as industrial exoskeletons, in mitigating muscle fatigue during occupational activities or comparing workloads. The standardization of MVIC normalization through meaningful sEMG studies conducted in a work environment becomes crucial to ensure reliable and valid assessments. We believe that our study contributes to the existing body of knowledge by addressing an important aspect of sEMG analysis in the context of occupational science. The findings have implications for improving the accuracy and reliability of muscle activity assessments, particularly in the field of workplace ergonomics and the development of effective interventions for reducing physical strain. We confirm that this manuscript has not been previously published and is not under consideration for publication elsewhere. All authors have read and approved the final version of the manuscript. We declare no conflicts of interest related to this work.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Julia Riemer reports a relationship with Technische Universität Dortmund that includes: non-financial support.

Data availability

The authors do not have permission to share data.

References

Alemi, M.M., Madinei, S., Kim, S., Srinivasan, D., Nussbaum, M.A., 2019. Effects of two passive back-support exoskeletons on muscle activity, energy expenditure, and subjective assessments during repetitive lifting. Hum. Factors. https://doi.org/10.1177/0018720819897669.

Amarantini, D., Bru, B., 2015. Training-related changes in the EMG–moment relationship during isometric contractions: further evidence of improved control of muscle activation in strength-trained men? J. Electromyogr. Kinesiol. 25 (4), 697–702. https://doi.org/10.1016/j.jelekin.2015.04.002.

Atkinson, G., Nevill, A.M., 1998. Statistical methods for assessing measurement error (reliability) in variables relevant to sports medicine. Sports Med. 26 (4), 217–238, 0112-1642/98/0010-0217/$11.00/0.

Balshaw, T.G., Massey, G.J., Maden-Wilkinson, T.M., Lanza, M.B., Folland, J.P., 2019. Neural adaptations after 4 years vs 12 weeks of resistance training vs untrained. Scand. J. Med. Sci. Sports 29 (3), 348–359. https://doi.org/10.1111/sms.13331.

Bär, M., Steinhilber, B., Rieger, M.A., Luger, T., 2021. The influence of using exoskeletons during occupational tasks on acute physical stress and strain compared to no exoskeleton–A systematic review and meta-analysis. Appl. Ergon. 94, 103385 https://doi.org/10.1016/j.apergo.2021.103385.

Besomi, M., Hodges, P.W., Clancy, E.A., Van Dieën, J., Hug, F., Lowery, M., Tucker, K., 2020. Consensus for experimental design in electromyography (CEDE) project: amplitude normalization matrix. J. Electromyogr. Kinesiol. 53, 102438 https://doi.org/10.1016/j.jelekin.2020.102438.

Buckthorpe, M.W., Hannah, R., Pain, T., Folland, J.P., 2012. Reliability of neuromuscular measurements during explosive isometric contractions, with special reference to electromyography normalization techniques. Muscle Nerve 46 (4), 566–576, 0.1002/mus.23322.

Burden, A., 2010. How should we normalize electromyograms obtained from healthy participants? What we have learned from over 25 years of research. J. Electromyogr. Kinesiol. 20 (6), 1023–1035. https://doi.org/10.1016/j.jelekin.2010.07.004.

Chan, J.P.Y., Krisnan, L., Yusof, A., Selvanayagam, V.S., 2020. Maximum isokinetic familiarization of the knee: implication on bilateral assessment. Hum. Mov. Sci. 71, 102629 https://doi.org/10.1016/j.humov.2020.102629.

Desbrosses, K., Schwartz, M., Theurel, J., 2021. Evaluation of two upper-limb exoskeletons during overhead work: influence of exoskeleton design and load on muscular adaptations and balance regulation. Eur. J. Appl. Physiol. 121 (10), 2811–2823. https://doi.org/10.1007/s00421-021-04747-9.

Douglas, C.M., Hesketh, S.J., Esser, K.A., 2021. Time of day and muscle strength: a circadian output? Physiology 36 (1), 44–51. https://doi.org/10.1152/physiol.00030.2020.

Drake, J.D., Callaghan, J.D., 2006. Elimination of electrocardiogram contamination from electromyogram signals: an evaluation of currently used removal techniques. J. Electromyogr. Kinesiol. 16 (2), 175–187. https://doi.org/10.1016/j.jelekin.2005.07.003.

Folland, J.P., Buckthorpe, M.W., Hannah, R., 2014. Human capacity for explosive force production: neural and contractile determinants. Scand. J. Med. Sci. Sports 24 (6), 894–906. https://doi.org/10.1111/sms.12131.

Frost, L.R., Gerling, M.E., Markic, J.L., Brown, S.H., 2012. Exploring the effect of repeated-day familiarization on the ability to generate reliable maximum voluntary muscle activation. J. Electromyogr. Kinesiol. 22 (6), 886–892. https://doi.org/10.1016/j.jelekin.2012.05.005.

Green, L.A., Parro, J.J., Gabriel, D.A., 2014. Quantifying the familiarization period for maximal resistive exercise. Appl. Physiol. Nutr. Metabol. 39 (3), 275–281. https://doi.org/10.1139/apnm-2013-0253.

Hermens, H.J., Freriks, B., Disselhorst-Klug, C., Rau, G., 2000. Development of recommendations for SEMG sensors and sensor placement procedures. J. Electromyogr. Kinesiol. 10 (5), 361–374. https://doi.org/10.1016/S1050-6411(00)00027-4.

Jin, S., 2018. Biomechanical characteristics in the recovery phase after low back fatigue in passive and active tissues. Int. J. Ind. Ergon. 64, 163–169. https://doi.org/10.1016/j.ergon.2018.01.014.

Juan-Recio, C., López-Plaza, D., Barbado Murillo, D., García-Vaquero, M.P., Vera-García, F.J., 2018. Reliability assessment and correlation analysis of 3 protocols to measure trunk muscle strength and endurance. J. Sports Sci. 36 (4), 357–364. https://doi.org/10.1080/02640414.2017.1307439.

Kazemi, Z., Mazloumi, A., Arjmand, N., Keihani, A., Karimi, Z., Ghasemi, M.S., Kordi, R., 2021. A comprehensive evaluation of spine kinematics, kinetics, and trunk muscle activities during fatigue-induced repetitive lifting. Hum. Factors, 0018720820983621. https://doi.org/10.1177/0018720820983621.

Lanza, M.B., Ryan, A.S., Gray, V., Perez, W.J., Addison, O., 2020. Intramuscular fat influences neuromuscular activation of the gluteus medius in older adults. Front. Physiol. 11 https://doi.org/10.3389/fphys.2020.614415.

Liljequist, D., Elfving, B., Skavberg Roaldsen, K., 2019. Intraclass correlation–A discussion and demonstration of basic features. PLoS One 14 (7), e0219854.

Lu, S.-Y., Liu, C.-C., Lee, C.-L., Lin, Y.-H., 2019. Vertical vibration frequency and sitting posture effects on muscular loads and body balance. Int. J. Ind. Ergon. 74, 102860 https://doi.org/10.1016/j.ergon.2019.102860.

Mahdavi, N., Dianat, I., Heidarimoghadam, R., Khotanlou, H., Faradmal, J., 2020. A review of work environment risk factors influencing muscle fatigue. Int. J. Ind. Ergon. 80, 103028 https://doi.org/10.1016/j.ergon.2020.103028.

Mathiassen, S.E., Winkel, J., Hägg, G.M., 1995. Normalization of surface EMG amplitude from the upper trapezius muscle in ergonomic studies – a review. J. Electromyogr. Kinesiol. 5, 197–226. https://doi.org/10.1016/1050-6411(94)00014-X.

Merletti, R., Muceli, S., 2019. Tutorial. Surface EMG detection in space and time: best practices. J. Electromyogr. Kinesiol. 49, 102363 https://doi.org/10.1016/j.jelekin.2019.102363.

Murley, G.S., Menz, H.B., Landorf, K.B., Bird, A.R., 2010. Reliability of lower limb electromyography during overground walking: a comparison of maximal-and sub-maximal normalisation techniques. J. Biomech. 43 (4), 749–756. https://doi.org/10.1016/j.jbiomech.2009.10.014.

Nicoletti, C., Läubli, T., 2018. Leg and back muscle activity, heart rate, performance and comfort during sitting, standing, and using a sit-stand-support with different seat angles. Int. J. Ind. Ergon. 67, 73–80. https://doi.org/10.1016/j.ergon.2018.04.011.

Ptaszkowski, K., Wlodarczyk, P., Paprocka-Borowicz, M., 2019. The relationship between the electromyographic activity of rectus and oblique abdominal muscles and bioimpedance body composition analysis-A pilot observational study. Diabetes, Metab. Syndrome Obes. Targets Ther. 12, 2033. https://doi.org/10.2147/DMSO.S215982.

Renberg, J., Wiggen, Ø.N., Tvetene, P.Ø.S., Færevik, H., Van Beekvelt, M., Roeleveld, K., 2020. Effect of working position and cold environment on muscle activation level and fatigue in the upper limb during manual work tasks. Int. J. Ind. Ergon. 80, 103035 https://doi.org/10.1016/j.ergon.2020.103035.

Reyes-Ferrada, W., Chirosa-Rios, L., Martinez-Garcia, D., Rodríguez-Perea, Á., Jerez-Mayorga, D., 2022. Reliability of trunk strength measurements with an isokinetic dynamometer in non-specific low back pain patients: a systematic review. J. Back Musculoskelet. Rehabil. 35 (5), 937–948. https://doi.org/10.3233/BMR-210261.

Rodríguez-Rosell, D., Pareja-Blanco, F., Aagaard, P., González-Badillo, J.J., 2018. Physiological and methodological aspects of rate of force development assessment in human skeletal muscle. Clin. Physiol. Funct. Imag. 38 (5), 743–762. https://doi.org/10.1111/cpf.12495.

Roth, R., Donath, L., Kurz, E., Zahner, L., Faude, O., 2017. Absolute and relative reliability of isokinetic and isometric trunk strength testing using the IsoMed-2000 dynamometer. Phys. Ther. Sport 24, 26–31. https://doi.org/10.1016/j.ptsp.2016.11.005.

Salonikidis, K., Papageorgiou, K., Meliadis, A., Arabatzi, F., 2021. Force steadiness during submaximal isometric plantar and dorsiflexion in resistance training: experienced vs non-experienced individuals. Central European Journal of Sport Sciences and Medicine 34, 5–13, 0.18276/cej.2021.2-01.

Santos, P.D., Vaz, J.R., Correia, P.F., Valamatos, M.J., Veloso, A.P., Pezarat-Correia, P., 2021. Intermuscular coordination in the power clean exercise: comparison between olympic weightlifters and untrained individuals—a preliminary study. Sensors 21 (5), 1904. https://doi.org/10.3390/s21051904.

Shamsi, M., Sarrafzadeh, J., Jamshidi, A., Arjmand, N., Ghezelbash, F., 2017. Comparison of spinal stability following motor control and general exercises in nonspecific chronic low back pain patients. Clin. BioMech. 48, 42–48. https://doi.org/10.1016/j.clinbiomech.2017.07.006.

Sodeberg, G.L., Knutson, L.M., 2000. A Guide for use and interpretation of kinesiologic electromyographic data. Phys. Ther. 80, 485–498. https://doi.org/10.1093/ptj/80.5.485.

Theurel, J., Desbrosses, K., Roux, T., Savescu, A., 2018. Physiological consequences of using an upper limb exoskeleton during manual handling tasks. Appl. Ergon. 67, 211–217. https://doi.org/10.1016/j.apergo.2017.10.008.

Tillin, N.A., Jimenez-Reyes, P., Pain, M., Folland, J., 2010. Neuromuscular Performance of Explosive Power Athletes versus Untrained Individuals. https://doi.org/10.1249/MSS.0b013e3181be9c7e.

Van Dijk, H., Mulder, T., Hermens, H.J., 2007. Effects of age and content of augmented feedback on learning an isometric force-production task. Exp. Aging Res. 33, 341–353. https://doi.org/10.1080/03610730701319194.

Vera-Garcia, F.J., Moreside, J.M., McGill, S.M., 2010. MVC techniques to normalize trunk muscle EMG in healthy women. J. Electromyogr. Kinesiol. 20 (1), 10–16. https://doi.org/10.1016/j.jelekin.2009.03.010.

Young, W.B., 2006. Transfer of strength and power training to sports performance. Int. J. Sports Physiol. Perform. 1 (2), 74–83. https://doi.org/10.1123/ijspp.1.2.74.