Statistical Parametric Mapping: SEMG analysis of shoulder muscle activations on traditional and pulling propulsion during manual wheelchair use

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Abstract

Introduction: Shoulder pain is a prevalent issue among manual wheelchair users (MWCU), often attributed to repetitive mechanical loading on shoulder tendons and joints during wheelchair propulsion. This comparative observational study aimed to assess the impact of a removable lever-assisted pull function (GO1) on muscle activation patterns surrounding the shoulder and upper body during wheelchair propulsion. **Methods**: Fifteen able-bodied participants underwent repeated measure testing, utilizing traditional (Trad) and pulling (Pull) propulsion techniques on a specialized treadmill. Surface electromyography (sEMG) data from bilateral recordings of six proximal muscles were analyzed using Statistical Parametric Mapping (SPM) to identify differences in muscle activation between Trad and Pull techniques during a complete propulsion cycle at average MWCU speed. **Results:** The SPM analysis revealed nuanced differences in muscle activation patterns between Pull and Trad propulsion techniques. Pull propulsion demonstrated significant lower activation ($p < 0.018$) in specific shoulder muscles, including the upper trapezius and deltoid anterior, compared to Trad propulsion through the cycle. Conversely, Trad propulsion exhibited lower activation levels in pectoralis major and lower trapezius ($p < 0.004$). **Discussion:** The observed differences in muscle activation patterns suggest the potential benefits of incorporating Pull propulsion into rehabilitation protocols to mitigate shoulder overuse injuries among MWCUs. These findings suggest variations in muscle activity which highlight the importance of exploring alternative propulsion techniques to reduce mechanical load. **Conclusion:** This study revealed the potential advantages of Pull propulsion in promoting more balanced muscle activation patterns and mitigating shoulder overuse injuries among MWCUs. Further research is warranted to investigate changes in muscle coordination, validate these findings and explore the long-term effects of alternative propulsion techniques on mobility efficiency.

Keywords: Muscular imbalance, treadmill testing, surface electromyography, average wheelchair speed

Introduction

Manual wheelchair users (MWCU) often experience shoulder pain with prevalence rates ranging from 36% to 76% (Gironda et al., 2004; Koontz, et al., 2014) and a general disengagement from physical activity due to excessive demands placed on their musculoskeletal system (Gutierrez et al., 2007; Hansen RK. et al., 2021). Given that MWCUs rely heavily on their upper limbs for daily function, preventing shoulder pain is crucial to preserving function, physical independence and quality of life (Gutierrez et al., 2007).

Findings lead to repetitive mechanical loads being one of the main factors in predicting pain regarding the shoulder tendons (Devkota and Weinhold, 2010; Minder et al., 2023; Lewis, 2010). Repetitive exhausting propulsion is a part of everyday wheelchair use as well as accumulation of fatigue, which causes the neuromuscular system to become susceptible to overuse injuries (Minder et al. 2023; Pol et al., 2019). Other findings emphasize that prolonged and repetitive loading on the shoulder joints, tendons, and muscles though wheelchair propulsion exacerbates wear and tear (Arnet, U. et al, 2022a; Arnet, U. et al, 2022b); Gellman et al., 1988). The consequences of repetitive shoulder loading in MWCUs are wide-ranging, encompassing physical, functional, and quality of life domains (Gutierrez et al., 2007). Moreover, pain can impede participation in social and recreational activities, thereby contributing to social isolation and diminished quality of life (Smith et al., 2014; Hansen RK. et al., 2021; McVeigh et al., 2009; Janssen et al., 1994). Studies state that repetitive mechanical loading of tendons alters the biochemical tissue (Porter et al., 2020; Pozzi et al., 2022) leading to decreased propulsion efficiency, reduced mobility (Curtis et al., 1995) and muscular imbalance (Burnham et al., 1993).

Muscular imbalance refers to an asymmetrical distribution of muscle strength, flexibility or activation patterns between agonist and antagonist muscle groups around a joint (Burnham et al., 1993). In the context of wheelchair use, muscular imbalance often arises due to the repetitive and unidirectional nature of propulsion, which primarily engages certain muscle groups while neglecting others (Burnham et al., 1993). In MWCUs, the muscles involved in traditional propulsion, such as the anterior deltoids, pectoralis major, and biceps brachii, tend to become overdeveloped and dominant, leading to shortened muscle fibers (Bossuyt et al., 2020; Boninger et al., 2005a; Boninger et al., 2005b). Conversely, the muscles opposing propulsion, including the rotator cuff muscles, rhomboids, and serratus anterior, may weaken and lengthen over time due to underutilization and disuse (Bossuyt et al., 2020; van Straaten et al., 2014). This imbalance in muscle strength and activation can predispose MWCUs to biomechanical inefficiencies, joint instability, and compensatory movement patterns, ultimately contributing to the development of shoulder fatigue and overuse injuries (Ambrosio et al., 2005; Finley et al., 2007; Heyward et al., 2017). Furthermore, neuromuscular imbalance may exacerbate existing shoulder pathologies, such as rotator cuff tears, impingement syndrome, and shoulder instability, by altering joint mechanics and increasing mechanical stress on vulnerable structures (Miyahara et al., 1998).

Assessment of muscular load in the shoulder region is pivotal for understanding the biomechanical intricacies of traditional manual wheelchair use and is best reflected using Statistical Parametric Mapping (SPM). SPM is recognized as the predominant method for characterizing muscle activation data (Friston et al., 1995). Instead of an enormous number of statistical tests used in order to identify changes in activation, the mass univariate approach of SPM embodied any arbitrary form for serial correlations among the error terms rendering it more conducive to diverse biomechanical profiles of dynamic movements (Pataky, 2010; Friston et al., 2007).

Traditional exercise modalities such as wheelchair propulsion recreational activities, while beneficial for cardiorespiratory fitness, primarily engage the anterior shoulder musculature, increasing the risk of underutilization and dysfunction of the posterior shoulder muscles (Gutierrez et al., 2007; van Straaten et al., 2014; Wilbanks S. et al. 2016). Rowing, an exercise modality involving both aerobic and strength components for the posterior muscles, has garnered attention as a potential intervention for MWCUs (Hansen RK. et al., 2021). Studies exploring the usability of custom-made adaptive rowing machines have demonstrated that upper-body exercise sessions performed on ergometers are enjoyable and effective with no exacerbation of shoulder pain (Hansen RK. et al., 2021). Therefore, exercises focusing on pull motions, targeting the relatively weaker posterior muscles and a well-shifted muscle activation change, potentially reducing high biomechanical loading causing pain and muscular imbalance (Burnham et al., 1993).

Attempts to change the propulsion system of the wheelchair into a reverse or pulling alteration has been made by ROWHEELS (Madison, Wisconsin, USA), where standard drive wheels are swapped with custom drive wheels. This study regarding the alternative system observed significant differences in shoulder kinematics, kinetics, and muscular activity during reverse manual wheelchair propulsion compared to traditional propulsion (Haubert et al., 2020). The study indicated statistically significant increase in the range of motion (ROM) at the shoulder joint and higher levels of activation of lower trapezius and reduced activation of pectoralis major during reverse propulsion (Haubert et al., 2020). However, the reverse propulsion system exposes a future threat of muscular imbalance as ROWHEELS' system are clutched one-way and not combining both pulling and pushing to create forward movement. Therefore, a different propulsion system that combines the pulling motion (Hansen RK. et al., 2021) for forward propulsion with the option of using the push-motion would be preferable to minimize muscular imbalance. One innovative solution addressing this issue is the GO1 product by Pull & GO (Aalborg, Denmark), a comprehensive patent-pending assistive device enabling MWCUs to alternate between pulling and pushing motions. This unique feature with removable levers aims to minimize muscular imbalances in the shoulder region by engaging both anterior and posterior muscle groups during everyday propulsion.

The aim of this study was to investigate whether a removable lever-assisted pull function (GO1) changes the level of activation of six posterior and anterior muscles surrounding the shoulder and upper body. I compared pulling (Pull) with traditional (Trad) wheelchair propulsion at average MWCU propulsion speed using SPM. We hypothesize a shift in muscle activity when utilizing Pull, with decreased anterior and increased posterior muscles level of activation.

Methods

Study design and participants

In this comparative observational study, data from 15 (sex; 4 females, 11 males, age; 27.1 ± 2.0 years, height; 175.2 ± 7.2 cm, BMI; 25.1 ± 2.5 kg/cm^2) participants was presented. The sample included asymptomatic participants at the time of enrollment. In order to obtain a larger sample size and greater generalizability, able-bodied participants were recruited to participate. Written informed consent was obtained from all parts prior to the one hour testing session, which took place in the Sector B, Movement Laboratory at the physiotherapist education's professional room (UCN Aalborg, Denmark). Participants were instructed to avoid strenuous exercise 48 hours before the testing day. After 15 minutes of familiarization with the testing wheelchair, several assessments in terms of exertion measurements were conducted before and after the propulsion test. The standardized procedures prior to the propulsion cycles test included completion of demographic characteristics, a combined wheelchair propulsion warm up session and preparations for sEMG before starting the test.

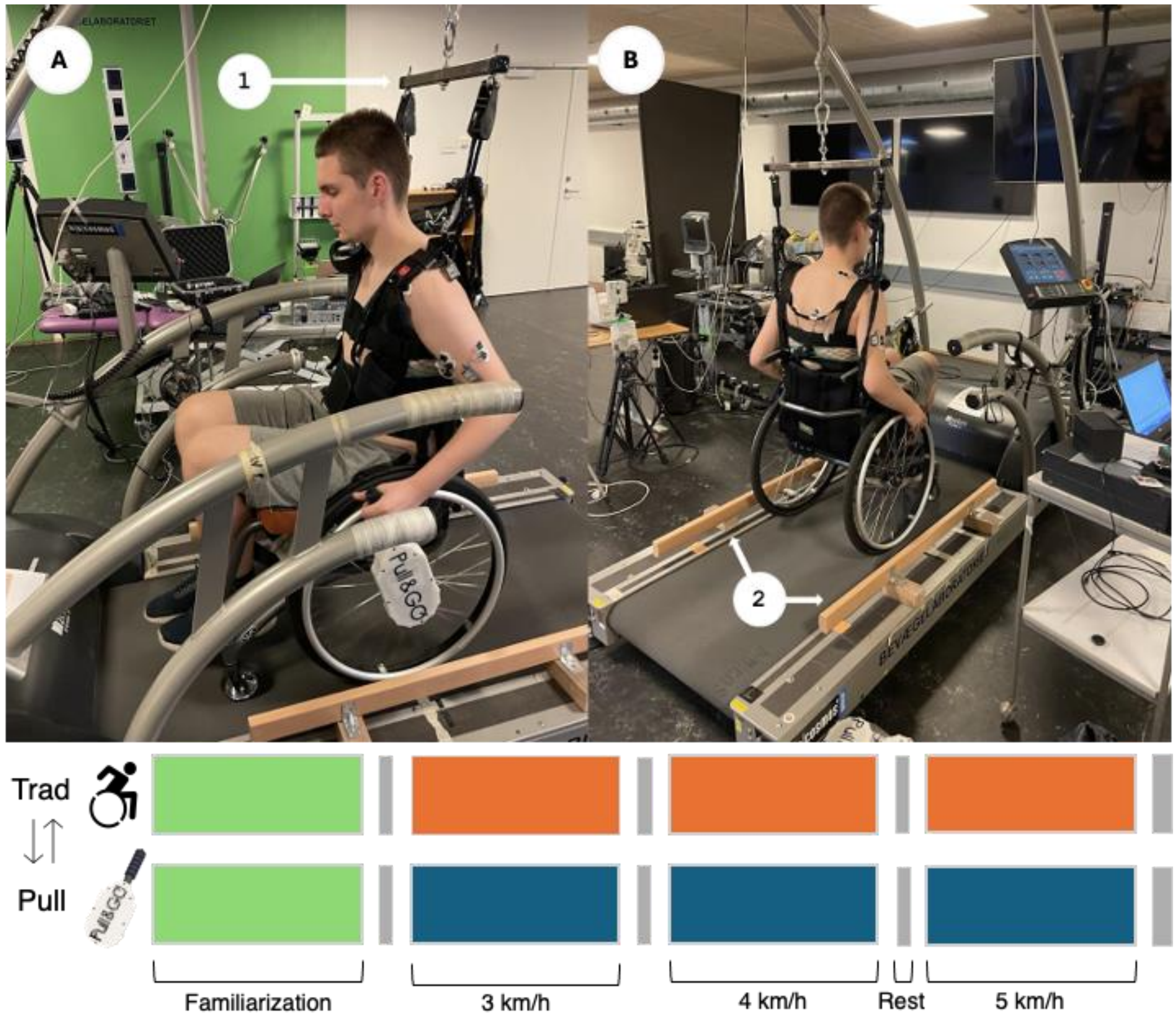


Figure 1: Safety procedures included (1) safety catch and (2) skip-assisted skirts to prevent derailing. SEMG samples on A; pulling (Pull) and B; traditional (Trad) propulsion techniques were recorded in randomized order over 10 completed cycles (blue and orange) following a metronome. Moreover, the observer obtained rate of perceived exertion and heart rate measurements to assess exertion before and after completed cycles. The full amount of cycles were performed three times at three speed settings (3, 4 and 5 km/h). After completing the cycles at all speed settings, the protocol was restarted and the opposite propulsion technique was used.

Propulsion protocol

The protocol for MWCUs compared the traditional propulsion (Trad) technique to pulling propulsion (Pull) on a specialized treadmill (Zebris RehaWalk®, Germany) with harness equipment ensuring participant safety (Fig. 1). The repeated measures protocol involved a randomized balanced design wherein participants were randomly assigned to start with either the traditional propulsion technique or the GO1. For participants commencing with the Pull, the protocol was initiated by adjusting the treadmill speed to 3 km/h. Participants subsequently executed 10 complete pulling propulsion cycles at this speed. Following a brief pause to manage exertion, the treadmill speed was increased to 4 km/h for another 10 cycles. Finally, the speed was further elevated to 5 km/h for the last 10 cycles before transitioning to the alternate propulsion technique. Speed setting was outlined by Continho et al., (2013), which reported average cruising speeds among MWCUs ranging from 20 m/min to 100 m/min (approximately 1.5 to 6.0 km/h) in various everyday environments and where middle values were selected, which additionally aligned with previous studies (Copper et al., 2008; Oyster et al., 2011; Tolerico et al., 2007). Afterwards, the participants changed propulsion technique following the same protocol and speed order. Participants were to utilize a semicircular propulsion technique outlined by Slowik et al., (2016) and Curi et al., (2020) to ensure better efficient energy utilization and less stress on the shoulder region (appendix). To counter dissimilarities in length of the propulsion cycle and sEMG recording a metronome was utilized and paired with the speed setting order (3km/h, 40 BPM; 4km/h, 55 BPM; 5km/h, 66 BPM) (Konrad, P., 2006). Simultaneously, heart rate (HR) and the rate of perceived exertion (RPE) (Borg, 1990) were monitored before and after completion of the propulsion cycles at each speed setting to track physiological responses. Participants were to maintain very light changes in heart rate (<120 bpm) (Janssen et al., 1994) and RPE (<12) (Qi et al., 2015) before each phase to ensure consistency in measurements, no exertion shift in movement pattern and a general comparability to average propulsion speed (Vanlandewijck et al., 1994; Slowik et al., 2016). After completing the protocol, a rest period of 5 minutes was provided between the two propulsion mode recordings, as aligned with the former protocol (Gossey et al., 2000).

Surface EMG measurement

The methodology comprised the acquisition of sEMG signals originating from proximal muscles bilaterally. Proximal muscles encompassed of six muscles: M. biceps brachii (BB), M. triceps brachii (TB), M. pectoralis major pars sternalis (PM), M. deltoideus anterior (DA), M. upper trapezius (UT) and M. lower trapezius (LT).The non-dominant and dominant side were monitored equivalent to a total of 12 sEMG channels to observe handiness variations. These muscles were selected in accordance with the SENIAM guidelines (Hermens et al., 2000) and previous study (Król et al., 2007; Minder et al, 2023).

Before electrode placement, necessary procedures, including shaving and cleaning with alcohol swabs, were carried out to reduce skin-electrode impedance. Extra adhesive tape was used to affix the electrodes to prevent the disconnection of the electrodes or leads and reduce the electrode motion on the skin surface (Cömert A. & Hyttinen J., 2014). Bipolar Ag–AgCl surface electrodes, 22 mm in width (Ambu Neuroline 720), were positioned adhering to anatomical landmarks with an inter-electrode spacing of 20 mm, in accordance with established protocols (Bavdek et al., 2018). SEMG signals were obtained utilizing a Telemyo wireless EMG system (Noraxon USA Inc., USA), featuring signal amplification of 500 times, band-pass filtration ranging from 10–500 Hz (1st order), a sampling rate of 1.5 kHz, and digitization employing a 16-bit analog-to-digital converter. The sEMG signals were digitally band-pass filtered [5-500 Hz] using a 4^{th} order Butterworth filter selected due to its capability to preserve signal characteristics while attenuating noise (Mello et al., 2007). In addition, a low-pass Butterworth filter (4th order) with a cutoff frequency of 6 Hz was used to obtain the activation profiles of the sEMG (Criswell E., 1998). Ten propulsion cycles were visually inspected by the observer to discern the initiation and cessation points of completed cycles activation. Following this visual assessment, the data were normalized into 100 data points to achieve a standardized representation of a complete propulsion cycle, thereby facilitating comparative analysis across all cycles (McMarcus et al., 2020).

Furthermore, to mitigate potential biases, the observer was blinded to the propulsion technique being analyzed. Propulsion techniques were labeled as "X" for Trad and "Y" for Pull propulsion to ensure unbiased data interpretation and finally revealed at the end of data analysis.

Visual estimation of onset and offset
In this study, the visual estimation method was employed to determine the propulsion onset and offset of muscle activation in the lower trapezius (right side) during both Trad and Pull cycles. Onset indicated start of muscle contraction, while offset indicated returning to start of muscle activation. The selection of lower trapezius activation as the focus of analysis was predicated on its pivotal role in scapular stabilization during both Trad and Pull propulsion maneuvers among MWCUs (Micoogullari M. et al., 2023). Additionally, lower trapezius was chosen due to its relatively lower susceptibility to noise interference, enhancing the reliability of the acquired sEMG signals (McMarcus et al., 2020).

To enhance the reliability of the visual estimation method, the Intraclass Correlation Coefficient (ICC) was calculated for intra-rater reliability (Koo & Li, 2016). The ICC values (ICC = 0.90, on 15% repeated measurements) determined high consistency of onset and offset estimations across repeated trials, thereby increasing the method's reliability (Koo & Li, 2016) (appendix).

The identification of potential outliers in the sEMG signals was conducted by identifying data points that deviate from the mean by more than two times the standard deviation (2xSTD). This method is selected based on its effectiveness in distinguishing outliers in signal processing, as described in previous studies (Grønlund K. et al., 2009; Dunn, P. K., 2021). Grønlund et al. (2009) demonstrated that employing statistical measures such as the standard deviation provides an efficient way to monitor and evaluate signal quality enabling identification of signal anomalies.

Statistical Parametric Mapping
Statistical Parametric Mapping (SPM) was used to identify regionally specific effects in sEMG data by comparison between Trad and Pull propulsion (Friston K., 2007; Martinkovic et al., 2014). SPM offers the benefit of treating the signal comprehensively and provides outcomes directly within the original sampling framework (Pataky, 2012). SPM procedure involved comparing the time-series data of muscle activations across different cycles. Specifically, two-sample t-tests were applied to compare the sEMG signals of the respective muscles (appendix).

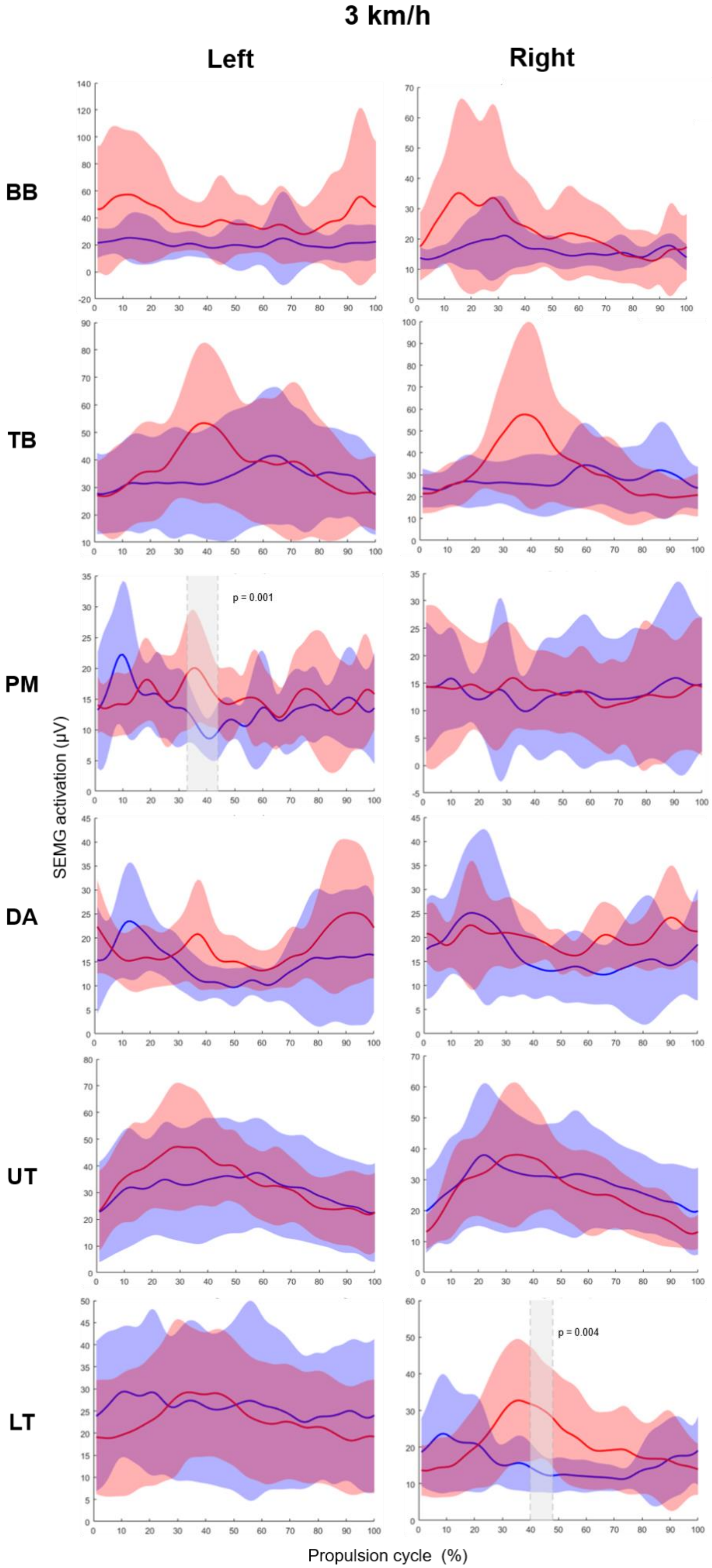
Statistical analysis
Normality of data distribution of participant characteristics, RPE and HR was carried out using a Shapiro–Wilk test in Statistical Package for the Social Sciences (SPSS Statistics 27, IBM). All SPM analyses were implemented and analyzed in MATLAB (The MathWorks, Inc, Massachusetts, USA, version R2024A) including tests for the sEMG activation data normal distribution. Potential outliers were excluded prior to any subsequent analyses. These computations and data preprocessing steps were executed using MATLAB, ensuring rigorous handling of outlier data to maintain the integrity of the statistical analysis. In the SPM graphs, the gray-shaded areas denoted the intervals wherein notable variations between the propulsion techniques were detected, underscoring the temporal regions with significant differences in neuromuscular activity (Pataky, 2010; Pataky, 2012). SPSS analysis involving determination of significance in exertion measures was analyzed using a

Repeated Measure ANOVA (RM-ANOVA) test. The within-subject factors were propulsion technique (Trad and Pull) and speed (3 km/h, 4 km/h, and 5 km/h). In accordance with observed significant values, a post-hoc Bonferroni analysis was conducted to determine where the significant differences lie. All p-values below 0.05 were considered as significant.

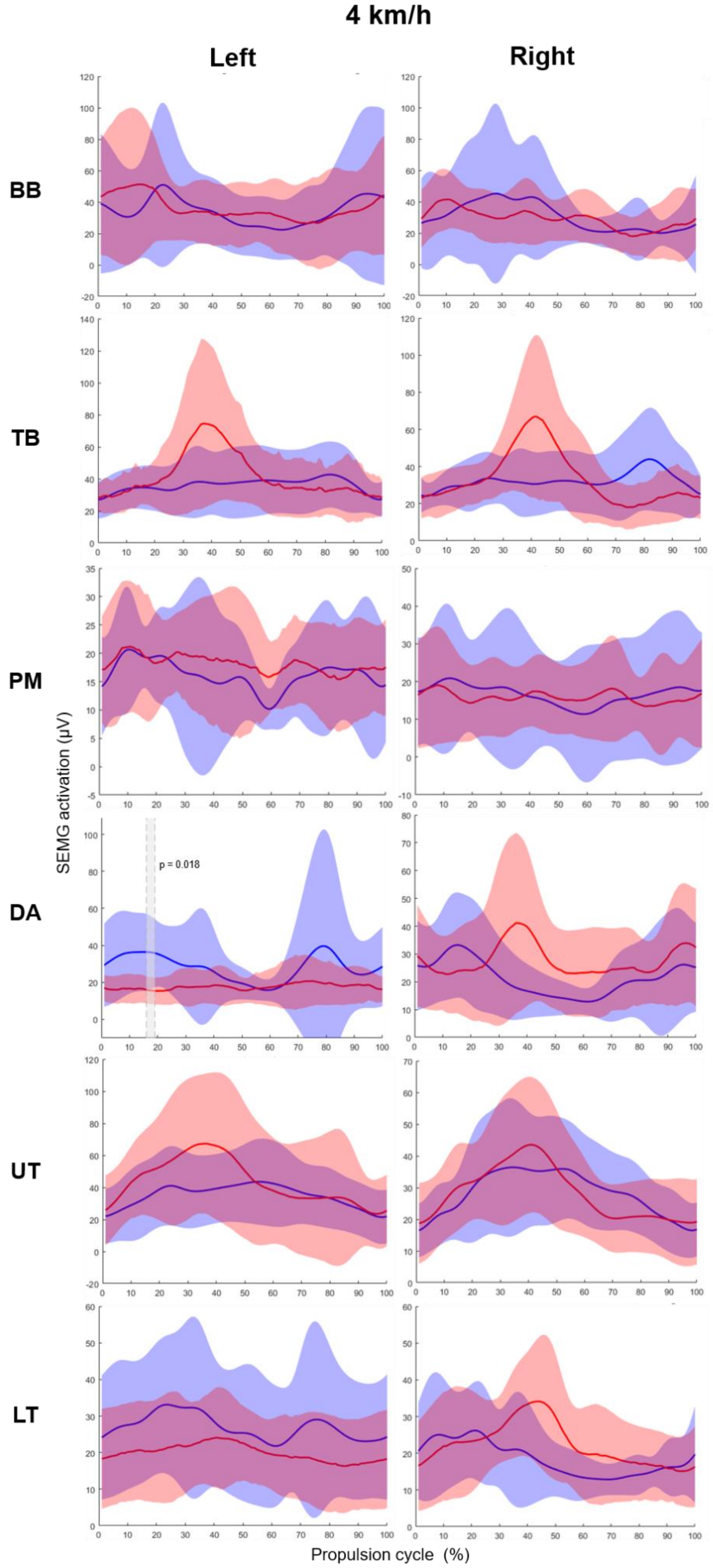
Results

The sEMG data did not adhere to a normal distribution ($p = 0.000$) while RPE and HR data did adhere to normal distribution ($p = 0.23$, $p = 0.10$). Non-normality in the distribution of data resulted in non-parametric tests for accurate interpretation of the sEMG signals. The percentage of excluded outliers extended to a total of 18.2%.

SPM results showed no significant differences ($p > 0.05$) in all assembled comparisons of muscle activation. However, individual muscle activation significance was observed ($p < 0.05$). Figure 2-3-4 presents muscle activity profiles including significant SPM observations. The profiles illustrate the amplitude and temporal patterns of muscle activation for each propulsion mode.



3 km/h
Left
Right
BB
TB
PM
DA
UT
LT
p = 0.001
p = 0.004
SEMG activation (µV)
Propulsion cycle (%)


4 km/h
Left
Right
BB
TB
PM
DA
UT
LT
SEMG activation (µV)
p = 0.018
Propulsion cycle (%)

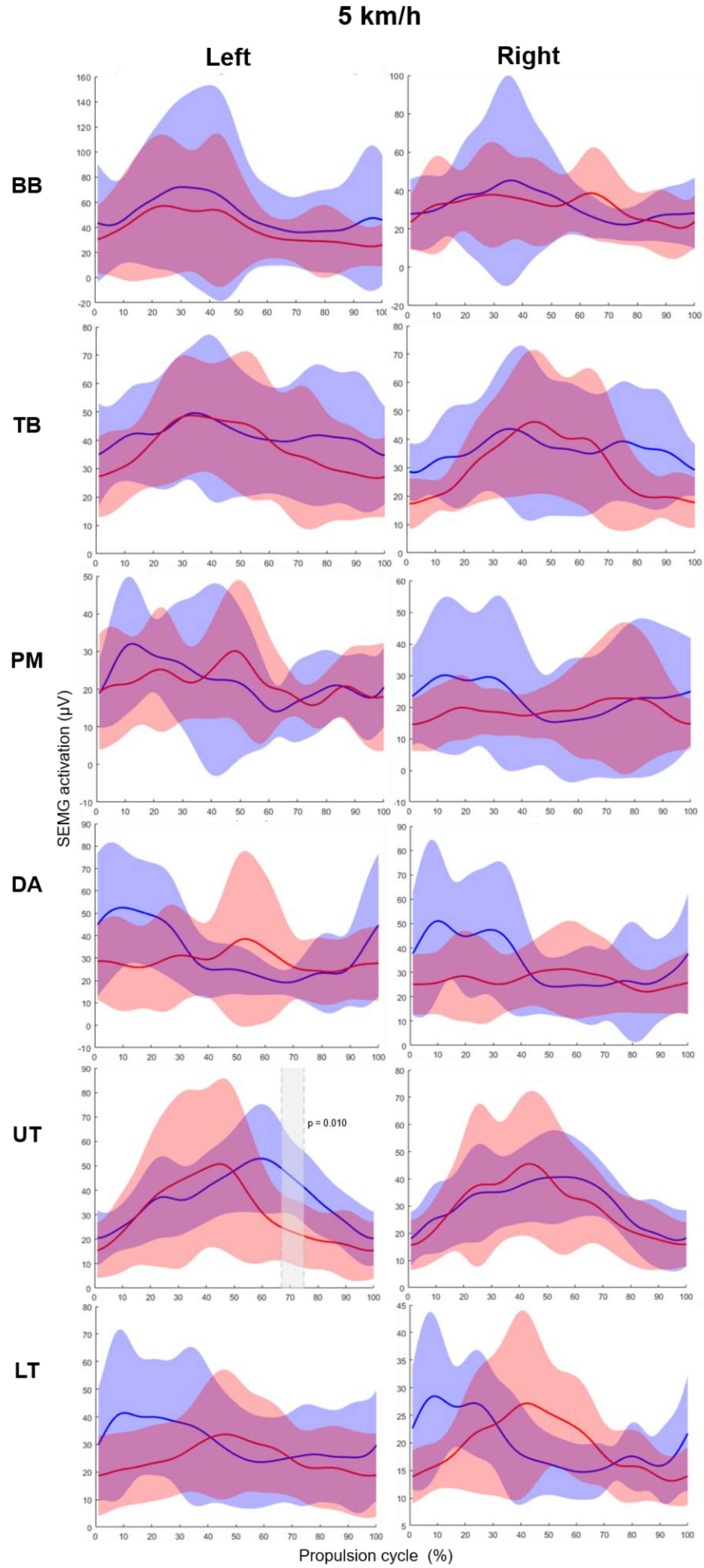


Figure 3-4-5: The Statistical Parametric Mapping analysis results (t-statistics) were calculated using the Trad (blue) and Pull (red) propulsion techniques on a treadmill. These results depict the mean and standard error muscle activity (sEMG) for both the right and left sides of biceps brachii (BB), triceps brachii (TB), pectoralis major (PM), deltoid anterior (DA), upper trapezius (UT), and lower trapezius (LT) for all participants. The gray-shaded areas indicate the windows in which a significant difference ($p < 0.05$) was observed between the propulsion techniques. n=15.

The analysis of muscle activity profiles revealed a few statistical differences between Pull and Trad, particularly notable at lower velocities. Despite yielding comparable overall patterns of muscle activation, discernible differences in both amplitude and timing were found. The analysis identified four significant differences in muscle activity between Pull and Trad. Specifically, Pull exhibited significantly higher activity than Trad in the left pectoralis major (PM) at 3 km/h (p = 0.001) and right lower trapezius (LT) at 3 km/h (p = 0.004) throughout percentages of the propulsion cycle. Conversely, Trad demonstrated significant higher levels of muscle activation compared to Pull in the left upper trapezius (UT) at 5 km/h (p = 0.010) and left deltoid anterior (DA) at 4 km/h (p = 0.018) across propulsion cycle phases.

Further examination of the temporal distribution underscored disparities and heightened significance particular in left muscle activation. Both left UT (5 km/h) and left DA (4 km/h) muscles displayed significant deviations in muscle activation patterns for 8% and 3% of the propulsion cycle. Conversely, left PM at 3 km/h exhibited the largest significant variations for a total of 11% of the cycle. Moreover, right LT at 3 km/h exhibited significant alterations in muscle activity for 8% of the cycle. Exertion measurements are shown in figure 5.

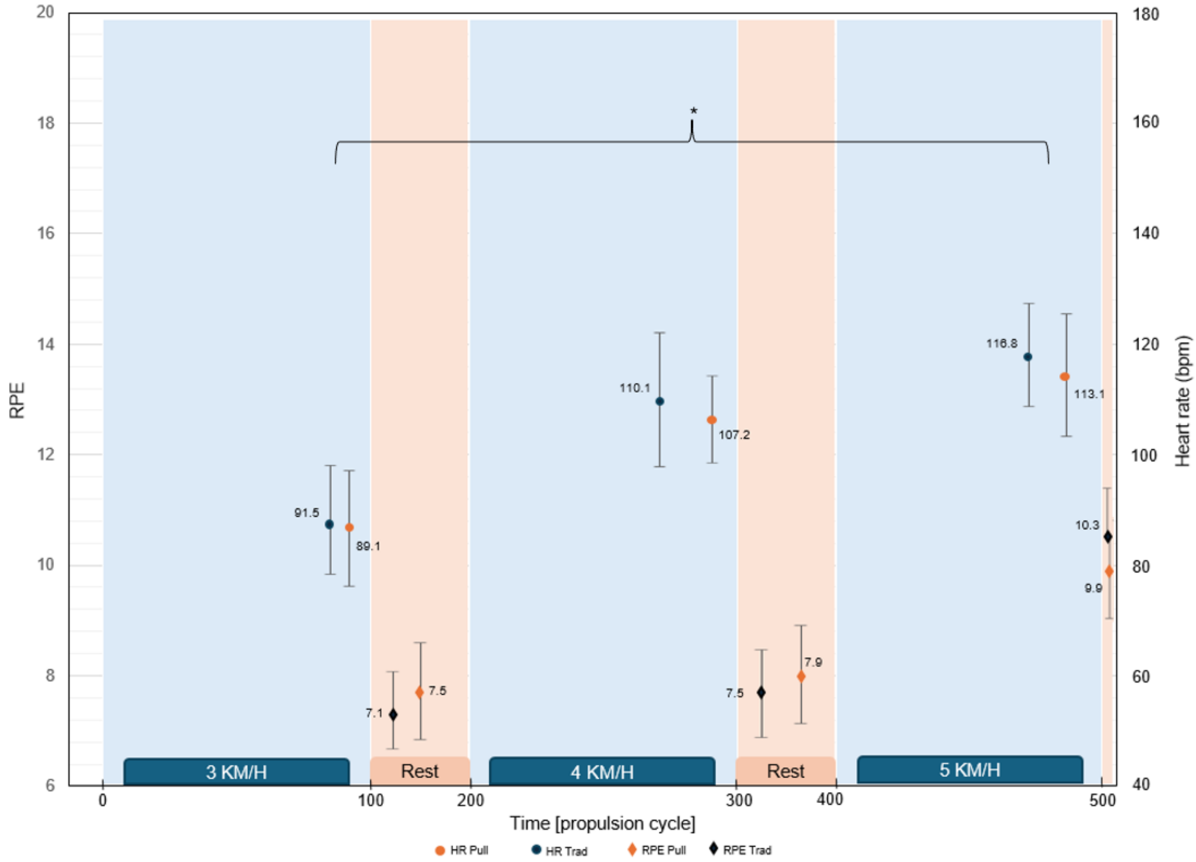


Figure 5: This figure presents the heart rate (HR) and rate of perceived exertion (RPE) means ± SD of the completed propulsion cycle. HR values were obtained throughout the completion of the propulsion cycles, while RPE was gathered after each ended propulsion sequence. * illustrate RM-ANOVA analyzed values of significance at speed variations. n=15.

Through RM-ANOVA analysis, no significant differences were observed in either group, speed or the interaction (group x speed) for RPE with lowest observed p-values being group (F = 2.50, p = 0.125). Mean and SD values for RPE increased at all speed variations (3 km/h, 4 km/h, and 5 km/h), as participants reported the highest level of exertion at 5 km/h. Comparable to Pull, the highest RPE values were observed during Trad at 5 km/h with an assembled 0.4 difference between the two propulsion techniques. RM-ANOVA analysis of HR indicated statistically significant differences across the different speeds ($F = 4.70$, $p = 0.014$) while no significance observed in interaction or group. Based on the Bonferroni-corrected analysis, the significant difference in speed was observed between 3 km/h and 5 km/h ($p < 0.001$). The similar patterns were noted in the visual presentation of heart rate measurements, with diminished HR values registered during Pulling in contrast to Traditional propulsion at matched velocities, as the pinnacle of HR values was documented during Trad at 5 km/h with a small absolut difference of 2.9 bpm.

Discussion

The main purpose of this comparative observational study was to investigate the dynamic nature of muscle activation patterns during different wheelchair propulsion modes utilizing SPM. I investigated for the first time the changes in muscle activity among proximal muscle pairs from the upper extremities in a population of able-bodied people conducting MWCU. In line with the hypothesis, the main findings demonstrated that Pull compared with Trad, had a tendency to reveal higher muscle activation in posterior muscles, particularly right lower trapezius, and Trad with higher level of anterior muscle activation, the anterior part of deltoid.

These findings align partially with those reported by Haubert et al. (2020), who investigated the effect of reverse (pull) manual wheelchair propulsion on muscular activity in individuals with paraplegia. Haubert et al. (2020) found that reverse propulsion resulted in different muscle activation patterns, specifically noting higher activation levels in the lower trapezius and reduced activation in the pectoralis major during reverse propulsion compared to traditional forward propulsion (Haubert et al., 2020). Our study corroborates these findings by demonstrating increased activation in the right lower trapezius (LT) during Pull propulsion. Similarly to the previous study, the findings from Requejo et al. (2008) who compared lever-activated versus pushrim wheelchair propulsion in individuals with spinal cord injury reported increased muscular demand on the rhomboids and triceps, while the anterior deltoid and pectoralis major exhibited reduced activity (Requejo et al., 2008). Our results showed a consistent trend where Pull propulsion led to lower activation in the left anterior deltoid (DA) compared to Trad, supporting the notion that pulling motions redistribute muscular demand favorably across different muscle groups. However, an opposite significance was found in pectoralis major, which may indicate high activation of the muscle in the recovery phase of the pulling propulsion. An explanation for this difference could be attributed to the distinct movement patterns, as the pull function primarily engages the pectoralis major during the later arm pull though (Mazzone T., 1988), whereas traditional propulsion relies on the pectoralis major during the early contact phase (Curi et al., 2020; Slowik et al., 2016). These significant differences observed in this study highlight the promising option of alternating different propulsion techniques to may reduce muscular imbalance.

Furthermore, no significant difference was found in BB and TB although tendencies toward higher activation of triceps was observed at lower velocities (3 km/h, 4 km/h) in Pull. Previous studies have shown that while changes in propulsion techniques can significantly influence certain shoulder and upper back muscles due to their role in stabilizing and guiding the movement, BB and TB, being the main drivers, tend to have more consistent activation levels (Koontz et al., 2009). For instance, Koontz et al. (2009) found that muscle activation in the biceps and triceps showed less variation between propulsion techniques compared to other muscles, such as the deltoids and pectoralis major. Additionally, these muscles are typically composed of a higher proportion of fast-twitch fibers, which are capable of handling repetitive and high-intensity activities common in wheelchair propulsion (Burnham et al., 1993). This could lead to a more uniform response to different propulsion modes.

Moreover, Kwarciak et al., 2012 explored the effects of propulsion training on muscle activation patterns. They demonstrated that training could optimize muscle use and prevent overuse injuries. My study's findings, that Pull propulsion results in significantly lower activation of the left DA and UT, along with higher activation of the right lower trapezius (LT) ($p = 0.004$), suggest that incorporating Pull propulsion into training regimens could promote more advantageous muscle activation patterns. This could potentially balance muscle use and reduce the propensity for muscle overuse injuries, resonating with Kwarciak et al.'s conclusions on the positive impact of targeted training (Kwarciak et al., 2012). Although this study's findings indicate minimal differences in RPE and HR, the tendency of lower exertion values in the Pull group at higher speeds suggests potentially beneficial future outcomes. However, future studies should implement a more generalizable demographic to verify these significant findings and the suggestion of alternating different propulsion strategies.

Strength and limitations

Using able-bodied individuals to simulate MWCU in a wheelchair protocol aimed at investigating muscle activation differences can be a contentious but methodologically feasible approach. Such a decision necessitates a thorough justification rooted in both practical and methodological considerations. Firstly, the recruitment of able-bodied individuals as surrogate wheelchair users offers practical advantages, notably in terms of ease of recruitment and accessibility (MacGillivray et al., 2017). Able-bodied individuals are readily available and typically exhibit fewer logistical challenges compared to recruiting individuals with disabilities (MacGillivray et al., 2017). Similar to previous sEMG analysis in MWCUs, muscle activity amplitudes in able-bodied participants increased with intensity, paralleling the response observed in MWCUs (De Luca, 1997). However, other sEMG analysis delineating muscle coordination like synergy analysis and normalized mutual information showed differences in spinal cord injury categorisation with people with tetraplegia having higher EMG intensity and duration for most muscles (Mulroy et al., 2004). This discrepancy in activation intensity indicates several considerations when determining paralleling responses in MWCUs.

Moreover, employing able-bodied individuals also presents certain limitations and challenges indicating dissimilarities in comparison. Primarily, the resting metabolic rate among MWCUs tends to be lower than in able-bodied individuals, potentially causing challenges in exertion measurement within the current protocol, as evidenced by the absence of notable differences (Buchholz et al., 2003). This may alter the observed significance in higher HR across various speeds. These limitations may also be the inherent difference in propulsion technique between able-bodied individuals and actual MWCUs. The traditional biomechanics patterns involved in wheelchair propulsion are likely to differ between the two groups. Comparing a traditional propulsion method to a newly developed one using a wheelchair can result in biased results as motor strategies in the shoulder girdle depend on the level of experience (Madeleine et al., 2003). This comparison disagreement could potentially confound the results and limit the generalizability of findings to the target population of MWCU. To mitigate this limitation, participants were instructed to utilize a semicircular propulsion technique, which minimizes shoulder strain and energy expenditure (Curi et al., 2020; Slowik et al., 2016). This standardized instruction and the equal state regarding the novel pulling mode aims to approximate the propulsion technique commonly employed by MWCUs, thereby enhancing the ecological validity of the study outcomes. Despite these efforts, it is essential to acknowledge that the able-bodied participants may have exhibited a propulsion pattern deviation in the contact phase during higher speed that did not entirely mirror the population (Curi et al., 2020). Further studies should investigate a perfect approximation of MWCU population.

This study employed time normalization for the sEMG data, similar to methods used in gait studies (Robinson et al., 2015; Patoz et al., 2022), to account for variations in movement cycles. However, amplitude normalization, typically done relative to maximal voluntary contraction, was not utilized, thus this time normalization ensures that data from different phases of the propulsion cycle are comparable across participants. In addition, the high percentage of outliers could be attributed to noise along with potential disconnections during the dynamic movement, as the safety catch overlapped the electrodes potentially unfastened them. Additionally, inaccuracies in the estimation of onset and offset detection may have contributed to the exclusion of these data samples. Addressing these issues through improved artifact reduction techniques and more robust detection algorithms could enhance data quality and reduce the number of outliers. This method of identifying muscle activation based on observed sEMG signals can introduce subjective biases and errors due to human interpretation, which may vary between observers and even within the same observer over time (Trinler et al., 2018). Despite these potential limitations, this study has shown that visual estimation can achieve high levels of reliability with ICC of 0.90, indicating excellent agreement among the same observer in determining muscle activity onset and offset (Koo & Li, 2016). Although the percentage of repeated measures remained stunted. However, other studies suggest that under controlled conditions and with trained personnel, visual estimation can be a reliable method for identifying muscle activation periods (Koo & Li, 2016). Future studies should include synchronous recording of video or kinematics to ease onset detection to minimize subjective biases.

In conclusion, this study revealed the nuanced differences in muscle activation patterns between Pull and Trad propulsion techniques among MWCUs. Pull propulsion demonstrated lower activation in specific shoulder muscles, potentially offering a promising alternative to mitigate high level of activity and shoulder overuse injuries. These findings underscore the importance of exploring and integrating alternative propulsion methods into rehabilitation protocols to enhance musculoskeletal health and optimize mobility efficiency in MWCUs. Further research is warranted to validate these findings across diverse MWCU populations and explore long-term effects on shoulder health.

Ethics statement

The University of Aalborg (Denmark) approved this study involving testing in humans. The study was conducted in accordance with the local legislation and institutional informed consents.

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Conflict of interest

The author's involvement raised concerns regarding a conflict of interest. To address these concerns and enhance the study's validity, all laboratory visits were conducted with external test personnel in order to remove the author from actively defrauding results in data collection. Moreover, blinding the author when conducting SPM analysis' helped eliminate potential sources of bias associated with the involvement.

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