AN EMG PREPROCESSING PIPELINE AND A GUI FOR PARALYMPIC CROSS-COUNTRY SKIING SITTING POSITION ASSESSMENT

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An efficient sitting position and the sledge design are crucial for the success of para-athletes in cross-country sit skiing. However, there is a lack of studies on the effects of sitting positions on the performance of para-athletes. This study introduces an EMG preprocessing pipeline and a GUI to analyse and compare muscle activation in different sitting positions, as well as identify key factors to quantify the optimal sitting position. As desired by the coaches, this provides the opportunity to compare muscle activation during different sitting positions and conditions immediately after measurements. Test measurements were conducted with non-disabled athletes to validate the functionality of the EMG preprocessing pipeline and the developed GUI. This could allow coaches to quickly gain insights into the specific requirements of each athlete and make informed decisions on how the sitting position should be adjusted to improve performance and prevent injuries.

KEYWORDS: Paralympic sport, Sitting position, Performance, Sledge design.

INTRODUCTION: Cross-country sit skiing (XCSS) has been an official sport in the Paralympic Games since 1988 (International Paralympic Committee). It is an adaptive sport that enables individuals with physical disabilities to participate in a highly competitive and physically demanding activity. Athletes are classified by the Paralympic Committee into five categories based on specific criteria that reflect their functional capabilities, ensuring fair competition. In these categories, athletes propel themselves using a pair of poles while sitting in a sledge mounted on skis (Paralympic Committee (IPC) and World Para Nordic Skiing, 2017). Success in this sport necessitates correct categorization, effective training, and endurance. The design of the sleds and the resulting sitting position of athletes are also critical factors (Lajunen et al., 2020). The physiological differences between sitting positions in sit skiing are not yet fully understood. The upper body muscles play a crucial role in stabilizing the body and transferring the momentum generated by trunk extension and flexion to the poles, contributing to an effective forward drive (Holmberg et al., 2005). Additionally, EMG analysis can assist in identifying anomalies and asymmetries, minimizing improper activation of specific muscles, thereby reducing the risk of rapid fatigue and injury. To our knowledge, there are only a few studies that analyse and compare upper body muscle activation patterns in different sitting positions, with most of these studies being conducted on ergometers rather than on treadmills or in field settings(Karczewska-Lindinger et al., 2021; Lajunen et al., 2020; Valeria et al., 2018). Therefore, the objective of a collaborative project, which engaged coaches, biomechanics and neuroscientists, was to measure and analyse muscle activity of trunk and upper body muscles in various sitting positions on a treadmill. This information could be of great value to coaches and athletes, as it aids in identifying the most effective or optimal sitting position for enhancing performance. Specifically, in XCSS, a sport practiced by Para athletes with a variety of different impairments, an individualized approach is essential. This diversity of impairments requires individual consideration and adaptation to ensure that the sitting position is optimal for each athlete. Due to the variety of the stakeholders in this study one sub-goal of this project and the goal of this paper was to develop an EMG preprocessing pipeline and create a graphical user interface (GUI) that provides an intuitive and a quick way to upload, preprocess, and display the data measured, as well as to illustrate muscle activation patterns in different conditions and facilitate comparisons. This GUI enables trainers to analyse and compare sitting positions, to determine the most effective and economic position for the individual athlete.

METHODS: In the initial phase of this project, a pilot measurement protocol was created to develop the EMG preprocessing pipeline and the GUI. Five non-disabled athletes (2 females and 3 males, aged 25 ± 5 years) with experience in the double poling technique participated in the experiment. All tests were performed on a treadmill with an adjustable sled on wheels. Three positions of the sitting platform were defined: knee high (KH), neutral (NT) and knee low (KL), following the classifications in the Para Nordic guidelines for ski sitting (figure1). During the warm-up training at the beginning of the test, the participants were instructed to choose an individual speed that they could sustain. To ensure that all participants operated at a consistent intensity level, they were instructed to select the speed according to the value of 12 on the Borg Rating of Perceived Exertion (RPE) scale. The speed was tested during the warm-up phase with the NT sitting position. The protocol included both flat and uphill conditions. A condition with incline was included to highlight relevant performance differences more apparent on uphill slopes.

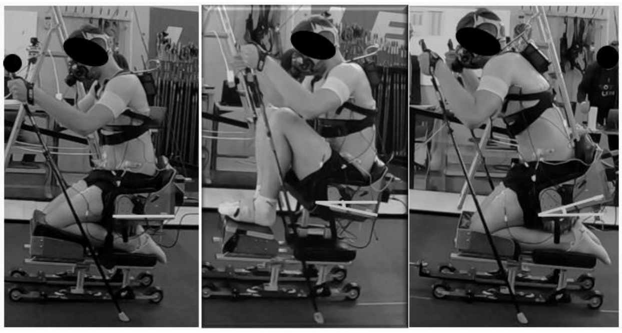

Figure 1 : The three sitting positions: neutral (NT), knee high (KH) and knee low (KL)

Force on the ski pole and bipolar surface electromyography (EMG) were simultaneously recorded on six muscles: the erector spinae (ES), rectus abdominis (RA), external abdominal oblique (EAO), triceps brachii (TB), latissimus dorsi (LD), and rectus femoris (RF). The RF muscle was measured solely as a control muscle making sure the able-bodied athletes exhibited the movement only in the upper body and will therefore not further be analysed. The recordings were conducted using the Sessantaquattro wireless system from OT Bioelettronica with a sampling frequency of 2000 Hz. Using the developed GUI, both the raw EMG data and force data were uploaded and prepared for further processing.

The GUI was developed using the App Designer in MATLAB (figure 3). In the first step, it facilitates the uploading and associating of individual measurement data for specific conditions and sitting positions. Additionally, it ensures a uniform mapping of individual muscles. Following this, the data is uniformly stored and processed using the developed EMG processing pipeline as part of the data preprocessing. Using the developed pipeline, both the raw EMG data and force data were uploaded and prepared for further processing. The EMG data was filtered using a digital Butterworth filter of the 4th order. This is a digital zero-phase filter with an infinite impulse response and limits ranging from 10 Hz to 350 Hz, where the EMG activity is located. In addition, a second-order recursive digital notch filter was used to suppress 50 Hz and all harmonics, which are interfering frequencies. Subsequently, a Root Mean Square (RMS) envelope with a smoothing window of 100 milliseconds was calculated. In addition to the filtering of the EMG signal, the signal from the force sensor was also filtered for smoothing using a recursive digital low-pass filter of the 4th order with a cut-off frequency of 20 Hz. The filtered EMG data were then segmented based on the force data in individual cycles. For this purpose, an automatic segmentation method using the Otsu method was applied. This method automatically finds the threshold at which the poles touch the ground. The Otsu method is a commonly used technique for threshold determination in image processing and was adapted for the present case in this study. The method is based on minimizing the variance within a class and maximizing the variance between classes (Otsu, 1979). First, the signal's histogram is calculated, representing the frequency of signal amplitudes. Subsequently, the probability for each amplitude is determined by dividing the histogram by the total number of samples. Based on these probabilities, the weighting for each class is calculated, indicating the percentage of data contained in each class. Next, the mean amplitude for each class is computed. These means are then used to calculate the variance within each class. The variance is calculated by squaring the deviations from each value in the dataset to the mean and then dividing by the number of data points in the class. The total variance is computed as the sum of the variances within each class, weighted by the number of data points in each class. Finally, the threshold is chosen as the value that minimizes the variance within each class while simultaneously maximizing the variance between classes (Otsu, 1979). After identifying the threshold at which the poles touch the ground, these time points were used to segment the EMG and force data into individual poling cycles. To ensure all cycles have the same sampling points, each cycle was resampled for consistency, making all cycles equal in length. Following this, mean values and standard deviations were calculated for each condition, preparing the data for visualization. All the steps of the developed preprocessing pipeline are summarized in Figure 2.

Figure 2: Pipeline for the preprocessing of the Force and EMG data

RESULTS AND DISCUSSION: The developed GUI allows an easy and user-friendly way to the direct upload, filtering, and segmentation of raw data after measurements. The filtering effectively removes unwanted frequencies and artifacts while preserving the essential signal. This was tested during the development of the pipeline by comparing filtered and unfiltered data in both the time and frequency domains. Additionally, it is possible to visualize and compare the Force and EMG mean and standard deviation of different muscles in various sitting positions and under different conditions (figure 4). Importantly, the user does not need to specify filter frequencies or thresholds during the use of the GUI; all processes are automated and can be employed by non-specialized personnel (Figure 3).

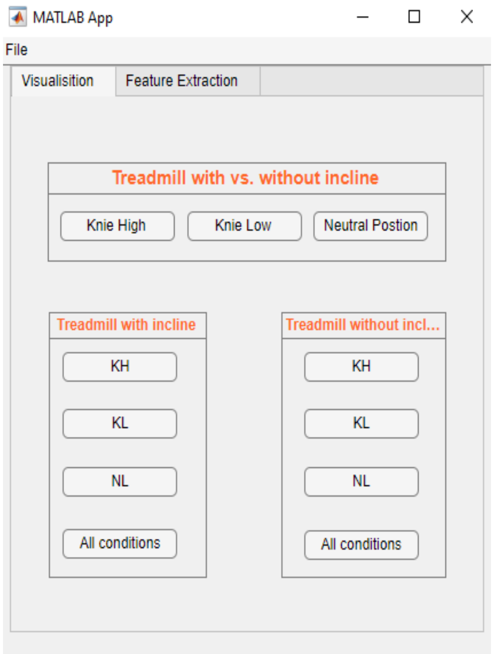

Figure 3: Visualisation panel of the developed GUI to selected EMG features to compare.

For example, through the analysis of the diagrams visualized with the GUI for the three different sitting positions of a test person, users such as trainers or accompanying orthopaedic technicians can derive the following results (figure 4). The KL position exhibited the highest muscle activation amplitude and the shortest duration of activation during the poling phase, particularly for LD, TRI, and abdominal muscles. The ES muscle remained active throughout the entire cycle, reaching its maximum at the end of the poling phase. Force analyses showed that the KL position enabled the highest force production, while the KH position had the lowest. The KL position was characterized by a shorter poling time, interpreted as more economical. The biomechanical advantages of the KL position were supported by the optimal alignment of the upper body during the poling phase. In the KH position, more intense TRI muscle activities and an extended poling phase were observed, leading to higher workload in these muscles. Overall, it can be concluded that the KL position optimally utilizes the upper body's capacity for force production. The TRI muscle was more activated in the KH position, while it was more pre-activated in the KL position and more relaxed during the recovery phase.

Using the GUI, trainers and accompanying orthopaedic technicians can identify which muscle groups are most engaged in a specific sitting position and how this varies based on impairment. Based on this information, targeted training programs can be developed, and sitting positions can be adjusted to optimize muscle activity and enhance performance.

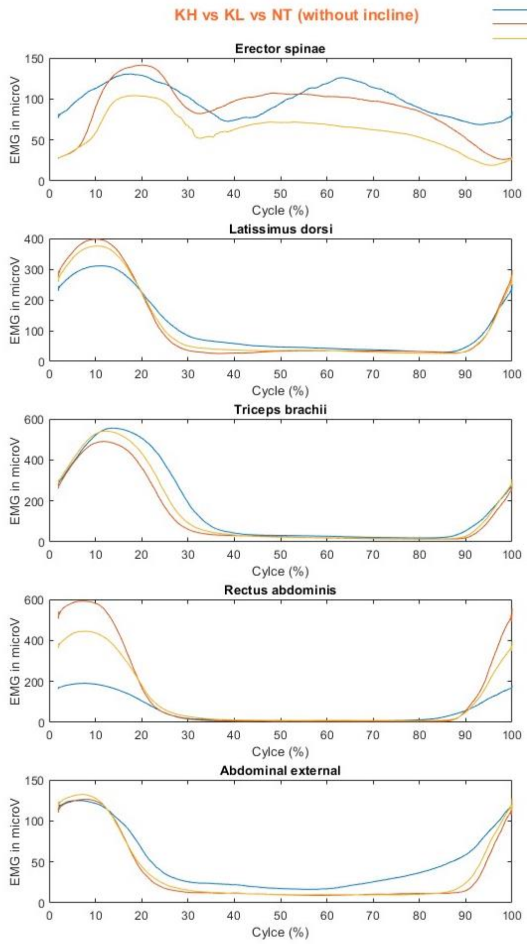

Figure 4 Comparison of EMG activation patterns of Participant P05 in the sitting positions KH (blue), KL (orange) and NT (yellow) using the developed GUI.

CONCLUSION: In summary, the developed GUI could play a supportive role in examining muscle activation patterns during sit skiing. The GUI facilitated the visualization and comparison of muscle activation across various sitting positions, while the EMG preprocessing pipeline carefully prepared the data for a meaningful analysis. The GUI provides a user-friendly way to visualize and analyse the Force and EMG data. It facilitates a clear representation of the data, making it easier to discern individual differences and patterns in muscle activity. This allows trainers to quickly gain insights into the specific requirements of each athlete and make informed decisions on how the sitting position should be adjusted to improve performance and prevent injuries. The GUI can serve as an efficient tool for planning regular measurements and adjusting based on the results. In this way, trainers and orthopaedic technician can continuously optimize the sitting position and enhance performance while considering the individual needs and differences of the athletes.

REFERENCES:

Holmberg, H.-C., Lindinger, S., Stöggl, T., Eitzlmair, E., & Müller, E. (2005). Biomechanical analysis of double poling in elite cross-country skiers. Medicine and Science in Sports and Exercise, 37(5), 807–818. https://doi.org/10.1249/01.mss.0000162615.47763.c8.

International Paralympic Committee. HISTORY OF PARA NORDIC SKIING. https://www.paralympic.org/nordic-skiing/about

Karczewska-Lindinger, M., Linnamo, V., Rosso, V., Gastaldi, L., Rapp, W., Vanlandewijck, Y., & Lindinger, S. (2021). Force Generation Profiles of Para-Nordic Sit-Skiers Representing Different Physical Impairments. Journal of Science in Sport and Exercise, 3(3), 281–291. https://doi.org/10.1007/s42978-021-00117-1

Lajunen, K., Rapp, W., Ahtiainen, J. P., Lindinger, S. J., & Linnamo, V. (2020). Effect of Sitting Posture on Sit-Skiing Economy in Non-disabled Athletes. Frontiers in Sports and Active Living, 2, 44. https://doi.org/10.3389/fspor.2020.00044

Otsu, N. (1979). A Threshold Selection Method from Gray-Level Histograms. IEEE Transactions on Systems, Man, and Cybernetics, 9(1), 62–66. https://doi.org/10.1109/TSMC.1979.4310076