Evaluating Test-Retest Reliability of surface electromyography (sEMG) in Measuring Fatigue in Adolescents Through Prolonged Activity

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2. Background

Muscle fatigue is a multifaceted physiological phenomenon, characterized by a decline in muscle performance during sustained or repeated activities (Cifrek et al., 2009). It results from a combination of central and peripheral mechanisms, ultimately leading to a reduced ability to maintain force or perform tasks. Adolescents engaged in prolonged physical activities, such as sports and dance, may experience fatigue, which has the potential to impair performance and could contribute to an increased risk of injury (Ratel et al., 2006). Understanding and accurately assessing muscle fatigue is therefore essential for optimizing performance, preventing overtraining, and reducing injury risk in this population.

Surface electromyography (sEMG) is a non-invasive technique that measures the electrical activity of muscles during contraction (Cao et al., 2017). This method has proven to be effective in detecting muscle fatigue by capturing changes in muscle electrical activity that occur as fatigue progresses (McManus et al.2020). Typical sEMG changes associated with fatigue include increases in signal amplitude, such as the root mean square (RMS) and integrated EMG (iEMG) indicate muscle activation intensity (Sun et al., 2022) and decreases in the mean and median frequencies of the sEMG power spectrum (Gál-Pottyondy et al., 2023), reflecting alterations in muscle fiber conduction velocity. These sEMG characteristics have been widely studied in adults, but their application and reliability in adolescents, especially during prolonged activities, remain underexplored.

Adolescents, due to their unique physiological development, present specific challenges for muscle fatigue assessment (Patikas et al., 2018). Given their ongoing growth, differences in muscle fiber composition, and varying levels of physical maturity, muscle fatigue patterns in adolescents may differ from those in adults (Bontemps et al., 2019). It is crucial to establish reliable tools for assessing muscle fatigue in this age group, as subjective fatigue reporting may be inconsistent or inaccurate. Reliable objective measures like sEMG could provide critical insights into fatigue management and performance optimization for young athletes.

To be a valuable tool in fatigue assessment, sEMG must demonstrate both test-retest and inter-rater reliability. Test-retest reliability refers to the consistency of measurements over time when the same participants are tested under similar conditions on different occasions (Lynn et al., 2018), while inter-rater reliability examines the consistency of measurements when different raters conduct the assessments (Mchugh, 2012). Establishing both forms of reliability is essential to ensure that sEMG can be reliably used to assess muscle fatigue in adolescents without being influenced by measurement error or variability introduced by different assessors.

Aims

To determine the test-retest reliability of surface electromyography (sEMG) outcomes in detecting levels of fatigue among healthy adolescents. This study will examine the consistency of sEMG readings across repetition of the exercises and assess how these measurements correlate with performance metrics and subjective fatigue assessments.

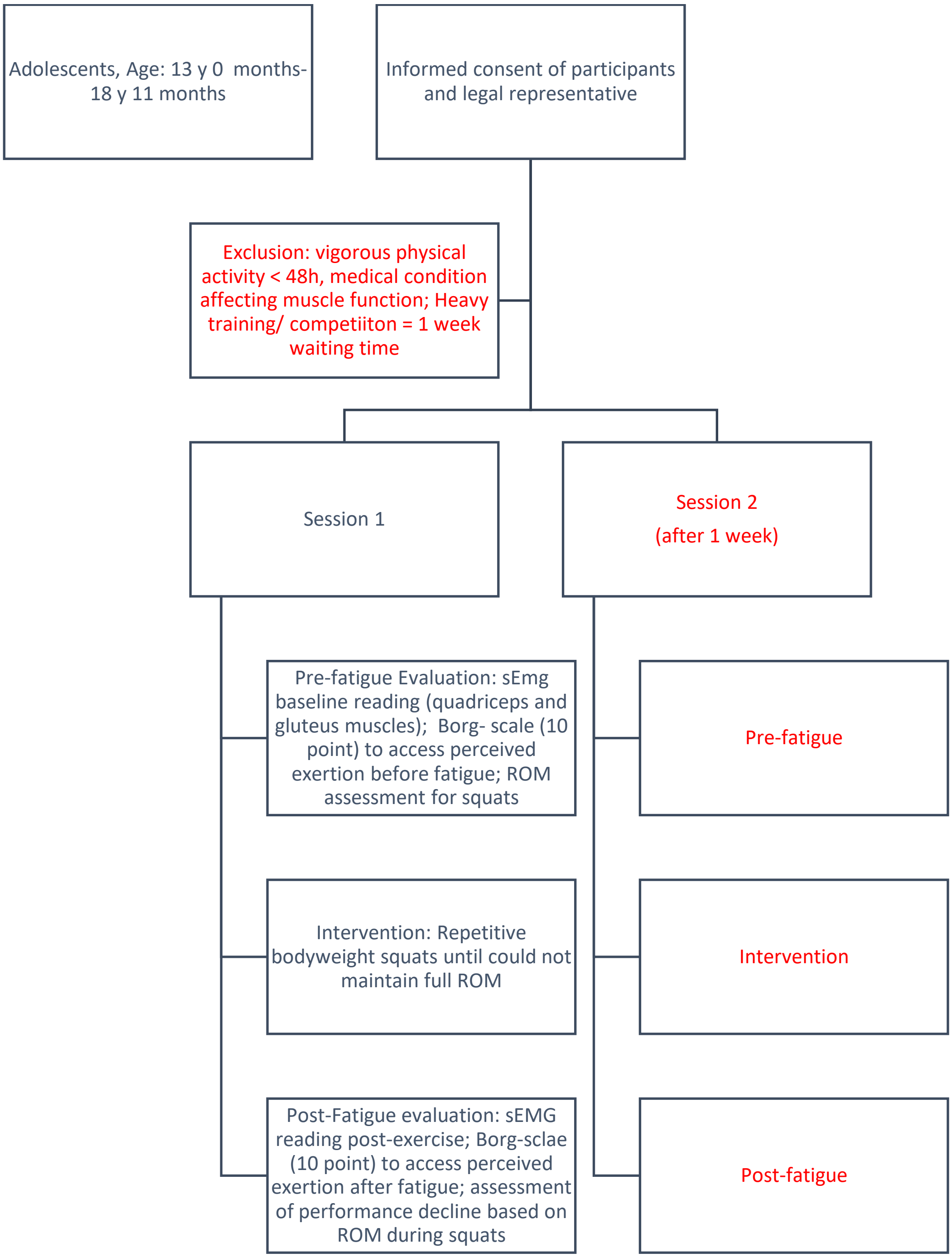
We formulate the following hypotheses:

1. sEMG will demonstrate **high test-retest reliability** in measuring fatigue levels across two sessions of prolonged activity in healthy adolescents, demonstrating its consistency as a tool for fatigue assessment.
2. The patterns of fatigue detected by sEMG will correlate with subjective measures of fatigue and performance decline, supporting the tool's **construct validity** in capturing the multifaceted nature of fatigue in this population.

3. Method

Cross-sectional study with test- retest design

Duration: one week per participant.



Figuur 1: Schematische weergave van het verloop van de studieA

1. *Participants and recruitment:*

- Population: Healthy adolescents aged 13.0-18.9 years will be recruited for the study. To be included, participants can have no known neuromuscular disorders or conditions that could affect muscle function. Participants can be physically active for up to 60 minutes per day, on average (Piercy et al., 2018) but cannot be involved in any specific, rigorous training programs towards elite competition sports. Adolescents will be recruited from local schools, sports clubs, and among the children of University of Antwerp staff members.

- Sample Size: 27 participants to account for potential dropouts and ensure robust statistical power. For the sample size of this study, we selected the intraclass correlation coefficient (ICC) value of 0.7 as the target for reliability analysis, based on the "consensus-based cut-off point for sufficient reliability" (Mokkink et al., 2023). The sample size determination was performed using an alpha level of 0.05 and a medium effect size of 0.25 (Huang et al., 2023), which reflects a moderate relationship between test sessions.

The power analysis indicated that 21 participants would provide a statistical power of 0.80 to detect significant test-retest reliability, according to the COSMIN Checklist (Mokkink et al., 2023). However, to account for a 20% potential dropout rate, the final target sample size has been increased to 27 participants. This calculation assumes two repeated measurements per participant and a single group design. As ICC estimation generally requires a smaller sample size, this is appropriate for our pilot study, where test-retest reliability is being assessed in an initial, limited participant pool (Tan et al., 2013).

- Inclusion Criteria: Healthy adolescents with no known neuromuscular disorders. They should be engaged in regular physical activity, defined as participating in normal physical activity for up to 60 minutes per day, and must not be involved in any specific or rigorous training programs for elite sports.

- Exclusion Criteria: Adolescents with any medical condition affecting muscle function, or those currently on medications influencing muscle performance. Additionally, participants who have engaged in intense physical activities within the 48 hours prior to the study will be excluded. If participants have taken part in heavy training or competition, they will be required to wait a minimum of one week before being eligible to complete the second session of the study.

2. *Intervention*

To induce muscular fatigue, participants will perform a repetitive bodyweight squat until 1) the squat cannot be performed over the full range of motion for 2 consecutive repetitions and 2) physical exertion occurs (10-point Borg scale). Squats were chosen as they effectively engage both muscle groups (quadriceps and gluteus muscles) and have been proven to induce fatigue over time. The exercise will be performed at a predefined tempo using a metronome to maintain a consistent repetition rate, ensuring controlled and uniform movement across participants. The squats will continue until participants are unable to achieve the full range of motion (ROM) for two consecutive repetitions or are unable to maintain the tempo set by the metronome.

During the activity, sEMG measurements will be taken to assess muscle activation and fatigue levels in the quadriceps and gluteus muscles. The combination of objective sEMG data and subjective fatigue ratings will allow for a comprehensive assessment of fatigue.

Each participant will visit the laboratory twice over the course of the study. During the first visit, participants will complete a pre-fatigue evaluation, which includes baseline sEMG recordings, ROM-assessment, and perceived exertion measured via the Borg scale. The intervention (squats) will be performed following these initial assessments. Post-intervention, another evaluation will be conducted, including sEMG recordings, ROM reassessment, and post-exercise Borg scale ratings to assess performance decline and perceived fatigue.

Participants will undergo a second session one week later to evaluate the test-retest reliability of sEMG in assessing muscle activation patterns and fatigue levels. The second session will replicate the first, with sEMG measurements taken continuously to assess the consistency of muscle activation patterns, performance decline, and perceived fatigue across the two sessions. This data will be used to verify the high test-retest reliability of sEMG and to evaluate intra-rater reliability, ensuring minimal variability in measurements between different assessors and across sessions.

Throughout both sessions, sEMG readings will be recorded continuously to evaluate the consistency of muscle activation patterns and their relationship to performance decline and perceived fatigue levels. The collected data will be analysed to verify the high test-retest reliability and intra-rater reliability of sEMG as hypothesized, with minimal variability across sessions.

3. *Evaluation*

Duurtijd: 90 – 120 minuten

1.1. Anamnese

During the initial assessment, participants will be asked a series of questions to gather information about their general health status and relevant background. The following aspects will be covered:

- Age: Participants will be asked to provide their age and date of birth, to ensure they fall within the inclusion criteria of 13.0-18.9 years.

- Height and Weight: Basic anthropometric measurements, including height, weight and leg length will be recorded to assess the participants' physical characteristics.

- Sports Participation: Participants will be asked using physical activity questionnaires for adolescents (PAQ-A) questionnaires about the types of physical activities they are engaged in, including the frequency and duration of participation in sports, dance, or other physical activities. This will help confirm that they meet the requirement of engaging in normal physical activity and are not involved in any structured or rigorous training programs.

- Health Status: A series of health status questionnaires will be asked to determine whether participants have any known neuromuscular disorders, medical conditions, or injuries that could affect muscle function. Participants will also be asked if they are currently taking any medications that might influence muscle performance.

1.2. Surface electromyography protocol

- Baseline Assessment: Setup and calibration of sEMG sensors will be conducted on the identified muscle groups, placed bilaterally on both the left and right sides of the body. The primary lower limb muscles to be monitored include the gluteus medius, rectus femoris, vastus lateralis (quadriceps), biceps femoris (hamstrings), tibialis anterior, and gastrocnemius medialis (calves). This setup fully utilizes the 16-channel sEMG system by monitoring each muscle group bilaterally to capture comprehensive data on muscle activity and fatigue. Before the intervention, participants will undergo a baseline evaluation that includes sEMG recordings of muscle activation and an assessment of ROM during squats.

- Activity Measurement: sEMG measurements and perceived exertion using the Borg Rating of Perceived Exertion scale will be taken during the fatigue-inducing exercises (full-bodyweight squats). Immediately after the squats, participants will walk for a short duration to assess post-fatigue muscle activity. sEMG measurements will be taken during this walking phase to capture immediate post-fatigue muscle activation in the quadriceps and gluteus muscles.

- Follow-Up Measurement: The entire protocol will be repeated after a recovery period of a week, under identical conditions. This will allow for the assessment of the test-retest reliability of the sEMG data, ensuring that muscle activation patterns, as well as the overall protocol, remain consistent and reliable across different testing sessions.

4. *Outcome measures*

Descriptive parameters

Demographics: age (years), gender, PAQ-A score
Anthropometric data: height (cm), weight (kg), BMI, leg length (cm)

Primary Outcome measure: sEMG median power frequency (MPF) and root mean square (RMS)

Secondary Outcome measures: Borg RPE score

The statistical analyses for this study will be conducted using IBM SPSS Statistics 29 with G*Power 3.1, allowing for comprehensive data analysis, including descriptive statistics, reliability testing, and inferential statistics to explore the relationships between variables of interest and to compare outcomes across sessions and groups.

- *Descriptive Statistics*: These will summarize participant characteristics and sEMG outcome measures, including means, standard deviations (SD), and ranges. We'll calculate means and standard deviations for sEMG median power frequency (MPF) and root mean square (RMS) at each trial and visualize sEMG patterns across the gait cycle using ensemble averages and standard deviation.

- *Inferential Statistics*: The ICC analysis will provide a statistical measure of how consistent the sEMG readings are between sessions (e.g., test and retest) for each. A two-way mixed effect, absolute agreement, multiple raters/measurements ICC model will be used, with ICC values ≥ 0.75 indicating good to excellent reliability and values between 0.6-0.74 indicating good reliability. Confidence intervals for ICC estimates will also be calculated. Additionally, Bland-Altman plots will be used to identify any systematic bias and outliers in test-retest measurements.

4. Data management

The data obtained from the various tests are coded (pseudonymised) and processed with Matlab, Excel, SPSS and JMP to design tables (.xlsx) and figures (.pdf, .eps, .bmp, .pptx). Encrypted data is also entered into a REDCap database via an eCRF. Data that is stored for a long time (in the secure institutional repositories) contains only encrypted data. Data protection procedures according to the GDPR (including GCP) will be applied to comply with national and EU legislation on the protection of the processing of personal data.

5. Relevance of the research

This research aims to enhance the understanding of how muscle fatigue can be reliably measured using sEMG in adolescents. Findings could lead to improved protocols for monitoring and managing fatigue in young athletes, potentially influencing training routines and performance enhancement strategies.

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