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Between session reliability of intramuscular electromyography for segments of gluteus medius and minimus during gait and stepping tasks

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ABSTRACT

Between-session reliability of electromyographic data is important for confidence in interpreting the role of muscles in functional tasks but critical if these data are to be compared before and after an intervention that seeks to change pathological patterns of muscle activity. The gluteus medius (GMed) and minimus (GMin) are known to have functionally discrete segments that are highly active during stance phase of gait and stepping tasks. This study measured the between-session reliability of activity patterns, mean amplitudes and time to peak (TTP) activity of these muscle segments. Intramuscular electrodes were placed in 3 segments of GMed and 2 segments of GMin in 10 healthy young adults for each of two testing sessions held two weeks apart. Participants completed six repetitions of comfortable speed walking trials, step-up and step-down tasks with activity patterns for each muscle segment time- and amplitude-normalized and averaged across trials. Re-test reliability for was high for activity patterns (coefficient of mean correlation ranging from 0.890 to 0.998) across all tasks and muscle segments and only two pairwise comparisons showing differences in amplitude between sessions. With standardized data collection and analysis procedures, GMed and GMin muscle segment activity patterns show good between-session reliability for weightbearing tasks.

1. Introduction

Electromyography (EMG) is an commonly used technique to explore the phasic activity of muscles during complex functional tasks such as gait, allowing interpretation of the function of muscle segments. The value of EMG, particularly for examining muscle activity change over time, has been challenged, particularly for intramuscular electrodes (Murley et al., 2010, Kadaba et al., 1985). Re-test reliability is critical to monitor changes associated with clinical populations, particularly where the outcome of an intervention is being assessed. Most earlier investigations of between session reliability suggest that surface EMG has higher levels of reliability than intramuscular EMG (Kadaba et al., 1985, Buskirk and Komi, 1970, Jonsson and Komi, 1973). While the passage of time has seen significant advancement in the sophistication of EMG techniques and particularly computing power for data analysis, some (Bogey et al., 2003, Jacobson et al., 1995, Chapman et al., 2010), but not all (Murley et al., 2010) more recent studies have suggested that intramuscular EMG is as reliable as surface EMG. Although the potential for crosstalk from other muscles (Bogey et al., 2003, Semciw et al., 2014a) is reduced with intramuscular electrodes, reliability may be adversely affected by electrode movement during data collection, pain or muscle damage (Kadaba et al., 1985, Chapman et al., 2010). In addition, the selectivity of fine wire electrodes may also result in unique recordings during each testing session (Perry et al., 1981). It is possible that the use of strict protocols for data collection and data analysis (e.g., the same electromyographer inserting needles using standardized electrode placements and ultrasound guidance, all analysis using a single investigator, selection of trials without excessive artefact during analysis etc.) may enhance re-test reliability.

Recent evidence using intramuscular EMG for examining deep hip muscle stabilisers has identified functional differentiation in the gluteus medius (GMed) and minimus (GMin) (Semciw et al., 2014b, Semciw et al., 2013c). It has been suggested that this differentiation is absent in clinical populations, and may be related to functional deficits (Ganderton et al., 2017, Zacharias et al., 2019). Exercise-based rehabilitation programs may be able to restore normal muscle function in

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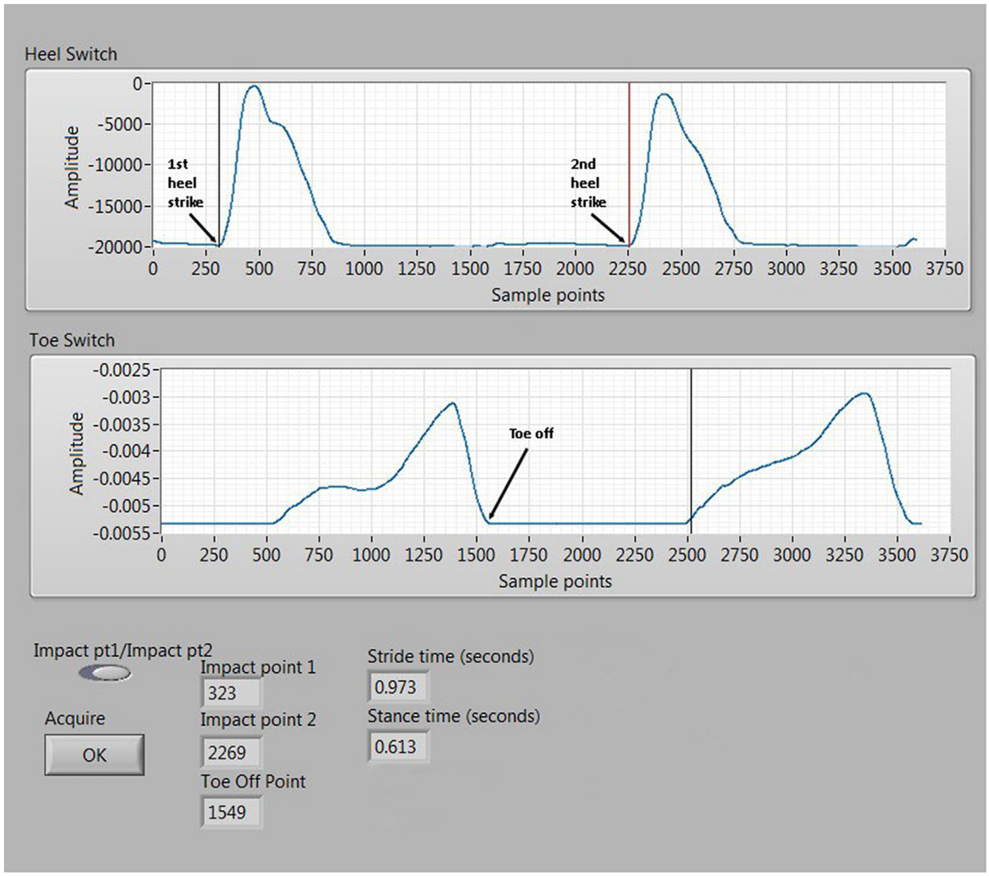

Fig. 1. Temporal data for 1st and 2nd heel strike and toe-off of the stance dominant limb (all inflection points determined using Labview algorithm) for a single stride in a gait cycle from Labview program using 2000 Hz time sample points.

clinical populations, but to assess changes in phasic muscle contractions during complex functional tasks such as gait, requires confidence in the between-session reliability of the activity of these muscle segments. Thus the primary aim of this study was to assess the between session reliability of segments of GMed and GMin during gait and stepping tasks. Given the paucity of previous data for gluteal muscle segments during stepping, a secondary aim was to report on the activity of these segments during the step-up and step-down tasks.

2. Methods

2.1. Participants

Ten healthy young adults (6 men and 4 women, 24.8 ± 3.1 yr, 176.9 ± 10.5 cm, 69.2 ± 11.7 kg) with no history of hip pain or pathology were recruited from a University population. All procedures were approved by the University Human Ethics Committee (HREC 14-087) and participants signed a written consent form prior to participation. Each participant attended two testing sessions conducted two weeks apart at approximately the same time of day.

2.2. Instrumentation and electrode insertions

Five bipolar stainless-steel Teflon® coated intramuscular electrodes were prepared according to the method of Basmajian and Stecko (Basmajian and Stecko, 1962) and inserted under sterile conditions using ultrasound guidance (HDI 3000; Advanced Technology Laboratories, Washington, USA) to confirm electrode placement. Participants were positioned in side lying with the hip and knee flexed to approximately 45° flexion while electrodes were inserted in the stance dominant limb into three segments of GMed (anterior, middle and posterior) and two segments of GMin (anterior and posterior) using surface landmarks identified in previously verified guidelines (Semciw et al., 2013a, Semciw et al., 2013b) and by the same electromyographer in each session. The stance limb was identified in session 1 as the limb that remained on the ground for two of three activities; kicking a ball, stepping up on to a block and stamping out an imaginary fire (Bullock-Saxton et al., 2001) and the contralateral limb was therefore defined as the skill limb.

Force sensitive resistors (Model: 402, Interlink Electronics, USA) were used as footswitches positioned under the plantar aspect of the heel and interphalangeal joint of the hallux to record temporal aspects of the gait cycle. Raw signals from the footswitches (148 Hz) and intramuscular electrodes (2000 Hz) were received by a Delsys Trigno Wireless EMG system (Delsys Inc., Boston, USA).

2.3. Experimental protocol

The experimental protocol was identical for both the first and second test sessions and involved three tasks; walking, stepping up and stepping down. After electrode insertion, participants completed several practice walking trials at a comfortable self-selected speed (Latt et al., 2008) to familiarize themselves with the protocol and establish a mean comfortable walking speed.

Participants then completed 6 walking trials on a 10 m walkway. Trials were repeated if they were greater than ± 5% of the comfortable walking speed established during the first test session. Following the walking trials, participants completed six repetitions each of a step-up onto and step-down from an 18 cm block. To maximize the muscular effort required from the hip abductors during stepping tasks, the step-ups were conducted with the stance limb (test limb) leading and step-downs with the skill limb leading.

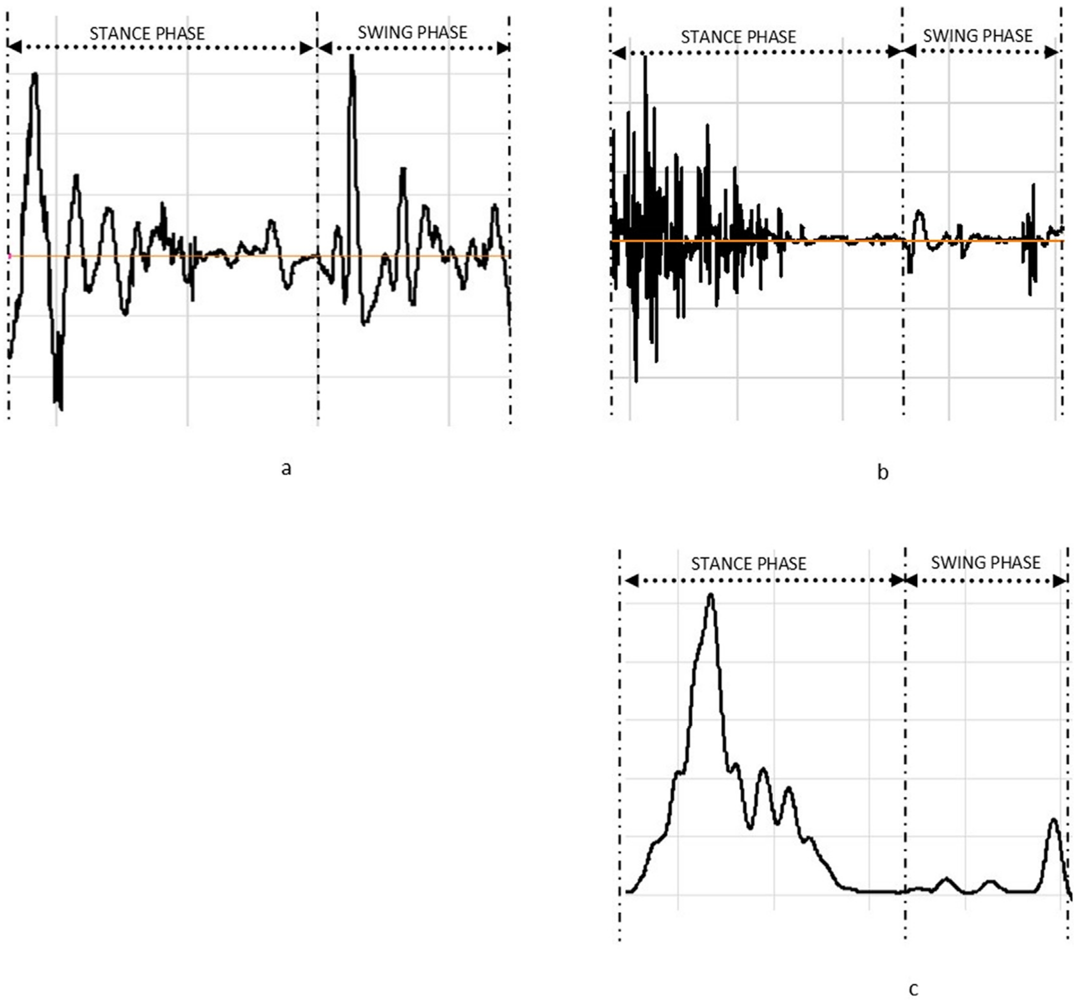

Fig. 2. Raw EMG data from a single gait cycle collected in two separate trials. The first shows significant artefact in both stance and swing phase (a) and was discarded from the analysis, whereas the second shows predominantly typical EMG activity during the stance phase (b) and is subsequently processed to produce a linear envelope of EMG activity for inclusion (c).

2.4. EMG data processing

Raw EMG signals collected by the Delsys EMGworks Acquisition software (CMRR > 80 dB at 60 Hz; gain of 1000; band pass filtered 20–900 Hz) were sampled at 2000 Hz. EMG activity was exported as spreadsheet files containing all raw data and subsequently analysed using custom-written LabVIEW software (National Instruments, Austin, USA). The software imports raw EMG data files from a single trial and displays signals in separate graphs to allow for data inspection. Once the user defines a specific data interval based on two time points from footswitch graphs (Fig. 1), the software simultaneously processes all EMG data. EMG signals were high pass filtered (4th order Butterworth, 50 Hz cut-off) to reduce low frequency movement artifact (Semciw et al., 2013c), then full wave rectified and further processed with a low pass filter (4th order Butterworth) at a cut off frequency of 6 Hz to generate linear envelopes. Finally, analysed data were saved into .csv files for further analysis.

EMG signals for each muscle segment were normalised to the respective peak muscle activation recorded during the gait cycle (%max) (Yang and Winter, 1984). This method of amplitude normalization is the most reliable in terms of providing information about the pattern of activity during a particular task (Chapman et al., 2010). EMG signals were time normalised to 100-points (% of the gait cycle). Similarly for step-up and step-down tasks, EMG data were normalized to the respective peak muscle activation recorded during that task and were time normalized to 100-points (% task cycle). For the step-up, the task cycle was deemed to commence at initial contact of the stance foot on the step and cease at initial contact of the skill limb onto the same step since previous research has shown activity of the gluteus medius only in the stance phase of this task (McFadyen and Winter, 1988). For the step-down, the task cycle was deemed to commence at toe-off from the step for the skill limb and cease at toe-off from the step for the stance limb. All data for each task (gait, step-up, step-down) were analyzed by a single investigator and where a trial had significant artefact for a particular muscle segment that data was excluded from the analysis (Fig. 2).

For each gait trial, a single stride in the middle of a 10 m walkway (to avoid periods of acceleration or deceleration) was analysed making a total of 6 gait cycles for each participant in each session. For each participant, an ensemble average of muscle activity was created for each muscle segment (anterior GMed, middle GMed, posterior GMed, anterior GMin and posterior GMin) and each task (gait, step-up and step-down) in each testing session. A grand ensemble for each muscle segment, task and session was obtained by calculating the average activation across all participants. Variability of muscle segment activation for each task and each participant within a testing session was calculated using the coefficicent of variation (CV) for each repetition of the task in that session (Kiss et al., 2012).

Outcome variables included time to peak activity (TTP) and mean amplitude (% peak amplitude) for early and late phases for each

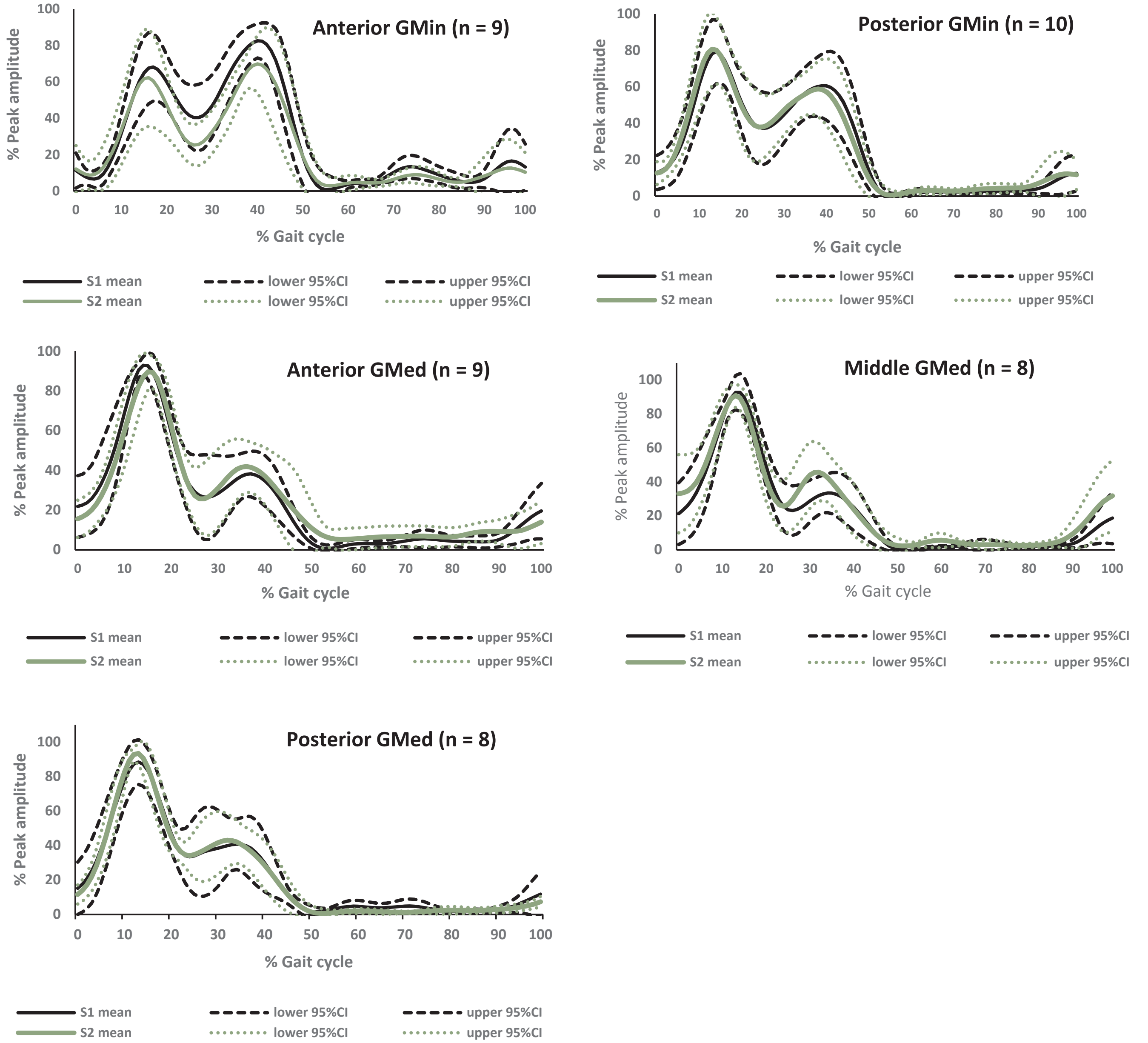

Fig. 3. Grand ensemble EMG average data with 95% confidence intervals across the gait cycle for anterior (a) and posterior (b) GMin and anterior (c), middle (d) and posterior (e) GMed.

activity. Consistent with previous EMG studies analysing muscle activity during gait (Zacharias et al., 2019) early and late were defined as 0–30% and 31–60% respectively as stance phase is the major period of muscle activity. As the muscle segments were active throughout the stepping tasks early and late were defined as 0–50% and 51–100% respectively.

2.5. Statistical analysis

Reliability for EMG studies can be considered to be whether a consistent muscle activation pattern is observed for the same movement task on different occasions and this has been assessed previously using coefficient of multiple correlation (CMC) (Reed et al., 2015; Wattanaprakornkul et al., 2011; Kadaba et al., 1989). Where waveform patterns are similar between sessions it is expected that correlation coefficients will approach 1. Coefficient of variation (CV = standard deviation/mean activity) was compared between sessions as measure of within session variability. CV for each participant was determined for each of the 100 data points across all included repetitions in each session for each muscle segment and task. Outliers were defined as 3 times the median absolute deviation and were removed (Leys et al., 2013) before averaging the remaining data points for each muscle segment, task and participant. Assumptions of normality were assessed using the Kolmogorov-Smirnov (K-S) test. The test-retest reliability of CV, mean amplitude and TTP data was assessed using a paired *t*-test (or Wilcoxon matched-pair signed-rank test for non-normal data) to compare each variable between session 1 and session 2.

3. Results

The requirement that participants have data for a particular segment for both test sessions to be included in the re-test reliability analysis reduced the median number of participants for each of the gait (Fig. 3; anterior GMin n = 9; posterior GMin n = 10; anterior GMed n = 9; middle GMed n = 8 and posterior GMed n = 8), step-up (Fig. 4; anterior GMin n = 6; posterior GMin n = 9; anterior GMed n = 9;

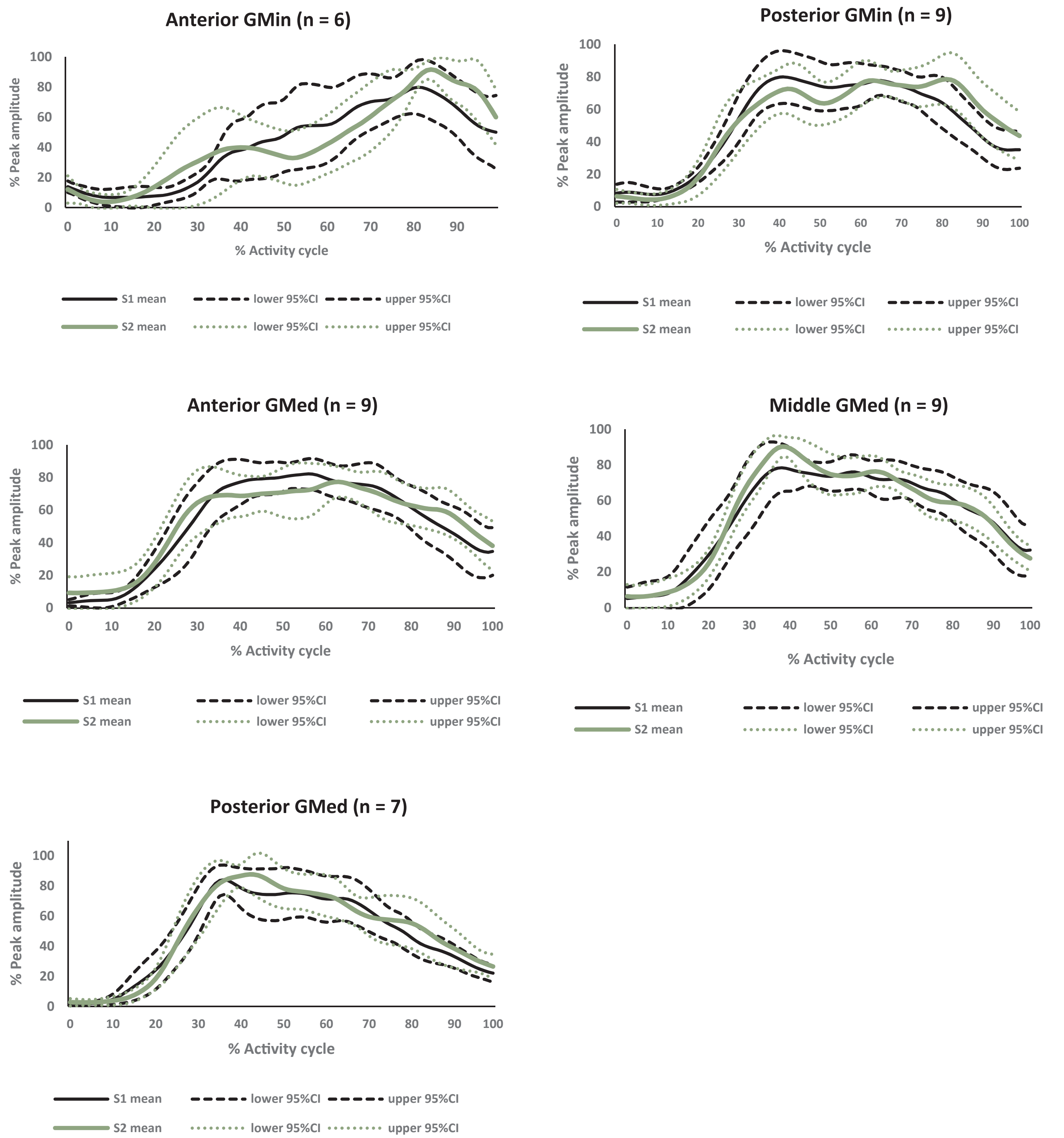

Fig. 4. Grand ensemble EMG average data with 95% confidence intervals during a single step-up for anterior (a) and posterior (b) GMin and anterior (c), middle (d) and posterior (e) GMed.

middle GMed n = 9 and posterior GMed n = 7) and step-down (Fig. 5; anterior GMin n = 6; posterior GMin n = 9; anterior GMed n = 9; middle GMed n = 7 and posterior GMed n = 7) tasks.

Coefficients of mean correlation were all very high, ranging between 0.89 and 0.99, indicating similar waveform patterns for all muscle segments in session 1 and session 2 (Table 1, Figs. 3–5). Within session variability was reduced for middle GMed ($t(7) = 2.614$, $P = 0.035$) in the second session of the gait trials (Table 2). Outliers comprised < 1% of CV data points for the step-down task, < 3% for the step-up task but 9% for gait. There were no differences in TTP data between testing sessions (Table 3) and very few differences in mean amplitude data between sessions, with no differences for the step-up and step-down activities but in the later part of stance phase the anterior GMin and middle GMed segments displaying a higher and lower mean amplitudes respectively in the second session (Table 4).

The muscle activity patterns during gait for all segments were biphasic during the stance phase with minimal activity during swing phase (Fig. 3). The activity patterns for step-up were somewhat similar to the gait cycle with an earlier peak of activity for posterior segments of both GMed and GMin followed by a later peak in anterior GMin

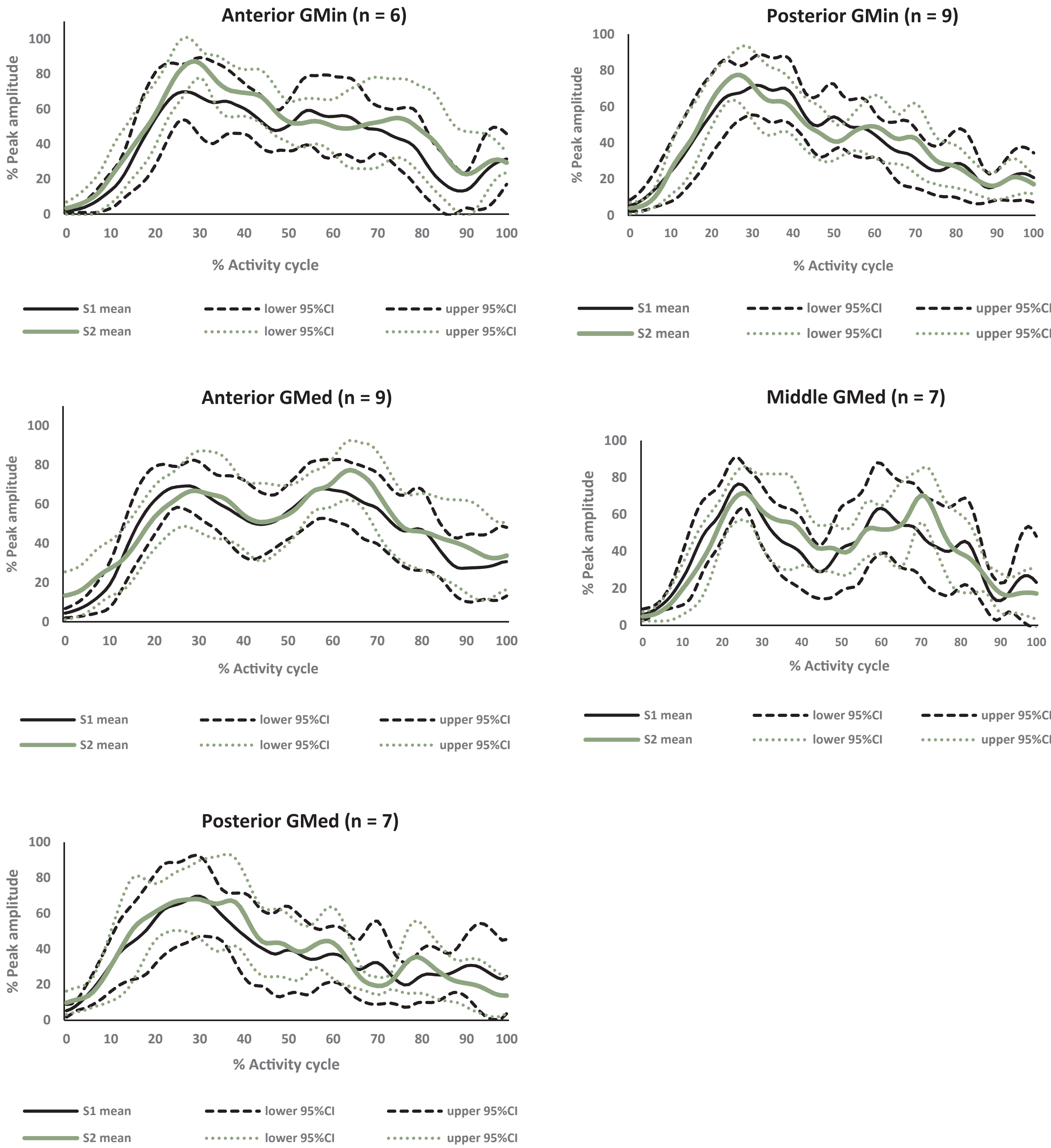

Fig. 5. Grand ensemble EMG average with 95% confidence intervals during a single step-down for anterior (a) and posterior (b) GMin and anterior (c), middle (d) and posterior (e) GMed.

(Fig. 4, Table 4). In the step-down task, posterior segments of both muscles appeared to peak early in the task cycle with a subsequent rapid reduction in activity levels in the later part of the task cycle, whereas more sustained activity was observed in anterior segments of both muscles and middle GMed (Fig. 5, Table 4).

4. Discussion

This is the first study to report between session reliability for intramuscular EMG activity of functional segments of the GMed and GMin during gait, step-up and step-down tasks. High levels of test-re-rest reliability were identified in this study indicating similar patterns of activity for these muscle segments across the task cycle during each session. Similarly there were very few differences in mean amplitude or TTP data between sessions.

The high levels of test-re-test reliability reported in this study for a re-test interval of 14 days are similar to those reported previously for a range of lower limb muscles during cycling in elite athletes (Chapman et al., 2010) but higher than those reported for leg muscles during gait (Murley et al., 2010). Chapman et al reported that test-retest reliability

Table 1
Coefficients of mean correlation (CMC) for time-normalized EMG activity between two sessions of three functional tasks for segments of GMed and GMin.

Muscle segment	Gait cycle	Step-up	Step-down
Ant GMin	0.984**	0.909**	0.943**
Post GMin	0.993**	0.944**	0.956**
Ant GMed	0.987**	0.978**	0.949**
Mid GMed	0.978**	0.988**	0.890**
Post GMed	0.998**	0.985**	0.931**

** $p < 0.000$.

of muscle activation patterns was higher when amplitude was normalized to the maximum of the muscle activity during the task and also when the re-test interval was greater than 10 days as this minimises the effects of intramuscular damage following the initial test (Chapman et al., 2010). The importance of data inspection and screening has also been emphasized (Chapman et al., 2010) and may account for the high levels of re-test reliability in the current study. High levels of re-test reliability for GMed during stepping tasks have also been reported using a single surface electrode (French et al., 2015).

The activity patterns during the gait cycle (Fig. 3) were similar to those previously reported with a biphasic burst pattern during stance phase and minimal activity during swing phase for all segments of both muscles (Semciw et al., 2014b, Semciw et al., 2013c). For GMed, all segments showed a higher amplitude during the first burst in early stance phase consistent with roles including pelvic stabilization, stabilization of the head of femur and possibly a contribution to contralateral rotation of the pelvis for the anterior segment of GMed (Semciw et al., 2013c). For GMin, the data from this study is again consistent with previous reports in that the posterior segment peaks during the first burst in early stance phase whereas the anterior segment typically peaks in the second burst (Semciw et al., 2014b). The current findings again confirm the role of the posterior segment of GMin as a femoral head stabilizer during early stance, while its anterior segment may minimize anterior hip forces during hip extension in the latter part of stance phase.

Previous reports of gluteal muscle activity patterns during stepping tasks have only used a single surface electrode on the middle segment of GMed (Boudreau et al., 2009, Joseph and Watson, 1967, McFadyen and Winter, 1988) and some reported only period(s) of activity (Joseph and Watson, 1967) or average activity across the whole task (Boudreau et al., 2009). In this study, the step-up task show similarities to the patterns of activity during the gait cycle. For GMed, the posterior and middle segments appear to peak earlier than the anterior segment, and for GMin the posterior segment appears to peak before the anterior segment (Fig. 4). This is consistent with the fact that both the stance phase of the gait cycle and the step-up task involve initial flexion of the stance limb followed by flexion of the contralateral limb, albeit followed by a reduced extension phase (not going beyond neutral) for the stance limb in the step-up. For the step-down task (Fig. 5), the anterior GMin activity appears to change significantly with an earlier peak and this is likely to be related to the change in the task. The contralateral limb is initially flexed to step-down so the relative extension of the stance limb occurs early in the task cycle. The posterior segment of GMin shows a less sustained contraction during the step-down, which is again consistent with the task, where the stance limb is only ever in relative extension, the activity in this segment is quickly curtailed. A similar pattern is evident in the posterior fibres of GMed in the step-down task. The anterior and middle segments of GMed are more active throughout the step-down in a somewhat biphasic pattern, which is similar to a previous report of GMed using a single surface electrode (McFadyen and Winter, 1988). The sustained activity in these muscle segments may be due to the demands of stabilizing the pelvis during the eccentric flexion of the stance limb in the step-down task.

The levels of intra-session reliability as measured by CV were all < 1, a result that is similar to those reported previously for the same muscle segments in a previous study (Ganderton et al., 2017). Low levels of intra-session variability suggests reproducible patterns of activity when these tasks are performed under controlled circumstances in a laboratory situation. The finding that one muscle segment showed a reduction in variability in the second session of the gait task suggests that either there was a practice effect in the second session or that the person conducting the analysis improved at selecting only trials that did not exhibit excessive artefact. The absence of a similar effect in the step-up or step-down tasks suggests that it may relate to data analysis and this potentially reinforces the need for standardized procedures and training for researchers undertaking EMG data analysis.

There were some missing data for particular muscle segments, particularly anterior GMin in the step-up and down activities and these are consistent with slightly wider confidence intervals (Figs. 3 and 4). This resulted in slightly lower between session reliability (Table 1) for these segments but because the study design only included participants with data for both sessions for each muscle segment, the correlations are still high (> 0.89). While the number of statistical tests performed in this study was large, the decision was made to not adopt a correction factor to the significance level so that we are more likely to see any changes between testing sessions. The fact that so few variables showed a difference between sessions again suggests that the procedures adopted to ensure that only artefact-free trials were included in the analysis is likely to result in more reliable data.

5. Conclusion

The high levels of between session reliability are important for studies involving an intervention, for example a rehabilitation program, whereby the investigators are attempting to modify activity of a particular muscle. The results of this study suggest that if standardized procedures are adopted for EMG data collection and analysis, then the re-test reliability is good and therefore any changes in muscle activity patterns between sessions may be attributed to real changes in muscle segment activity.

Table 2
Within session variability expressed as coefficient of variation (CV, mean ± sd) for amplitude normalized EMG activity between two sessions of three functional tasks for segments of GMed and GMin.

	Gait cycle		Step-up		Step-down	
Muscle segment	Session 1	Session 2	Session 1	Session 2	Session 1	Session 2
Ant GMin	0.57 (0.14)	0.57 (0.15)	0.63 (0.06)†	0.56 (0.22)†	0.49 (0.12)	0.58 (0.18)
Post GMin	0.42 (0.11)	0.48 (0.12)†	0.50 (0.14)	0.45 (0.11)	0.64 (0.15)	0.62 (0.16)
Ant GMed	0.51 (0.15)	0.56 (0.16)†	0.47 (0.19)	0.47 (0.15)	0.55 (0.15)	0.50 (0.16)†
Mid GMed	0.54 (0.18)*	0.43 (0.12)*	0.47 (0.08)	0.46 (0.15)	0.63 (0.21)	0.58 (0.15)†
Post GMed	0.56 (0.22)†	0.45 (0.11)	0.61 (0.25)	0.45 (0.13)	0.68 (0.15)	0.65 (0.13)

† Data not normally distributed, comparison conducted using non-parametric test.
* $p < 0.05$.

Table 3
Time to peak EMG activity (expressed as % of activity cycle) for two sessions (S1 & S2) of three functional tasks for segments of GMed and GMin and and significance (p) of paired t-tests for between session reliability.

Muscle segment	Gait cycle		Step-up		Step-down	
	S1 mean (sd) S2 mean (sd)	p	S1 mean (sd) S2 mean (sd)	p	S1 mean (sd) S2 mean (sd)	p
Ant GMin	33.3 (12.8) 30.2 (14.5)	0.352†	76.3 (18.3) 76.8 (22.3)	0.970	40.0 (17.6) 43.3 (21.3)	0.736
Post GMin	20.0 (11.4) 17.1 (9.6)	0.230†	53.8 (17.8) 63.1 (17.9)	0.094	33.3 (13.1) 34.0 (18.3)	1.000†
Ant GMed	15.7 (5.3) 18.2 (10.2)	0.733†	48.4 (15.8) 49.2 (20.7)	0.937	49.7 (19.8) 54.1 (23.3)	0.642
Mid GMed	12.6 (2.9) 11.1 (4.5)	0.141†	39.8 (13.2) 42.4 (8.7)	0.859†	54.7 (27.9) 49.3 (22.6)	0.724
Post GMed	17.8 (9.2) 12.5 (2.0)	0.112†	45.3 (11.3) 42.4 (8.4)	0.537	41.9 (24.5) 27.7 (9.5)	0.118

† Data not normally distributed, comparison conducted using non-parametric test.

Table 4
Mean amplitude for early and later segments of activity cycle (mean (sd) of peak amplitude) for two sessions of three functional tasks for segments of GMed and GMin and significance (p) of paired t-tests for between session reliability.

Muscle segment	Activity phase#	Gait			Step-up			Step-down		
		Session 1	Session 2	p	Session 1	Session 2	p	Session 1	Session 2	p
Ant GMin	early	38.1 (12.3)	32.9 (20.3)	0.315	19.6 (11.3)	22.0 (17.0)	0.819	43.6 (11.1)	52.3 (7.8)	0.198
	late	44.6 (7.8)	36.9 (12.5)	0.030*	64.1 (9.3)	63.8 (9.6)	0.968	39.3 (10.9)	43.7 (17.8)	0.693
Post GMin	early	46.1 (14.8)	47.4 (15.3)	0.741	40.1 (9.8)	36.0 (12.1)	0.180	48.0 (12.8)	47.5 (7.1)	0.919
	late	34.1 (15.6)	31.9 (15.5)	0.393	62.5 (10.0)	68.6 (11.1)	0.195	31.4 (16.1)	32.6 (12.8)	0.845
Ant GMed	early	51.1 (12.0)	47.8 (6.4)	0.433	40.3 (12.1)	41.6 (14.5)	0.953†	45.7 (9.8)	46.4 (18.5)	0.917
	late	18.8 (7.2)	23.3 (15.7)	0.449	64.2 (13.9)	64.7 (9.9)	0.914	48.4 (13.7)	53.5 (18.0)	0.378
Mid GMed	early	50.3 (11.2)	52.0 (12.3)	0.681	43.0 (12.1)	46.2 (3.5)	0.516	41.5 (12.5)	42.2 (8.5)	0.913
	late	14.4 (8.0)	18.0 (9.4)	0.050*	61.1 (11.5)	60.0 (8.4)	0.839	40.5 (18.5)	41.2 (8.3)	0.941
Post GMed	early	50.8 (17.2)	51.2 (5.6)	0.943	41.6 (6.8)	42.8 (7.8)	0.729	44.6 (14.1)	48.4 (9.2)	0.623
	late	18.6 (8.7)	18.2 (6.9)	0.867	53.1 (14.0)	56.1 (12.4)	0.637	29.4 (16.3)	28.4 (13.8)	0.908

Gait; early = 0–30%, late = 31–60%. Step-up and step-down; early = 0–50%, late = 51–100%.
† Data not normally distributed, comparison conducted using non-parametric test.
* $p < 0.05$.

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Declaration of Competing Interest

The authors report no conflict of interest in relation to the above manuscript

Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jelekin.2019.05.015.

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