Table 1. Within-session variability (CV%; mean ± SD) of the length of excitation across 10 excitation bursts during running, cycling and squatting exercise for traditional surface and textile EMG electrodes.

		Traditional surface EMG electrodes	Textile EMG electrodes
Run	Gluteals	14.2 (4.2)	11.6 (4.9)
	Vasti	17.3 (6.0)	18.9 (6.1)
	Hamstrings	12.3 (4.5)	17.4 (6.6) *
Cycle	Gluteals	17.2 (5.9)	15.6 (5.0)
	Vasti	11.8 (3.8)	14.2 (7.9)
	Hamstrings	14.5 (4.3)	16.2 (6.2)
Squat	Gluteals	10.8 (5.3)	8.7 (3.8)
	Vasti	7.0 (2.4)	6.4 (1.6)
	Hamstrings	9.2 (2.5)	7.7 (2.9)

* denotes higher variability in the textile vs. traditional surface EMG electrodes

Table 2. Within-session variability (CV%; mean ± SD) of the normalized average rectified EMG signal across 10 excitation bursts during running, cycling and squatting exercise for traditional surface and textile EMG electrodes.

		Traditional surface EMG electrodes	Textile EMG electrodes
Run	Gluteals	16.5 (6.5)	14.4 (4.6)
	Vasti	20.3 (7.7)	16.5 (5.8)
	Hamstrings	13.4 (4.2)	12.6 (5.5)
Cycle	Gluteals	17.4 (6.8)	16.7 (5.7)
	Vasti	13.7 (5.4)	15.1 (5.9)
	Hamstrings	13.2 (4.1)	17.4 (6.8) *
Squat	Gluteals	13.7 (5.2)	12.5 (5.5)
	Vasti	9.8 (4.4)	8.3 (3.3)
	Hamstrings	8.8 (4.7)	10.4 (4.6)

* denotes higher variability in the textile vs. traditional surface EMG electrodes

Table 3. Intraclass correlation coefficients of the normalized average rectified EMG signal across 10 excitation bursts during running, cycling and squatting exercise for traditional surface and textile EMG electrodes.

		Traditional surface EMG electrodes	Textile EMG electrodes
Run	Gluteals	.46	.81
	Vasti	.44	.64
	Hamstrings	.58	.96
Cycle	Gluteals	.83	.89
	Vasti	.51	.87
	Hamstrings	.73	.92
Squat	Gluteals	.77	.87
	Vasti	.46	.94
	Hamstrings	.49	.83

for a longer period of time collectively, compared with traditional surface EMG. This highlights an important consideration and limitation of the current textile-embedded electrodes, which relates to the inability to measure precise muscles (e.g. vastus lateralis) within the overall muscle group (e.g. the vasti). Additionally, the differences in temporal resolution between the systems or the signal processing that is internal to the textile electrode system could also contribute to these differences.

In line with previous findings during isometric exercise (Finni et al., 2007), there appeared to be similar within-session (Table 2) and day-to-day reliability for the normalized average rectified EMG (Figure 7) and excitation burst length (Figure 6) measured via traditional surface and textile electrodes. However, during the more dynamic activities (i.e. running) the hamstrings and gluteal muscle excitations appeared more variable in the textile electrode trials compared with the traditional electrode trials. This perhaps indicates a loss of contact between the shorts and the participant's skin, which is likely to introduce variability through the detection of non-physiological signals. This problem has been raised previously for isometric tasks (Finni et al., 2007) and for treadmill walking and running (Tikkanen et al., 2014), and the need for the shorts to tightly fit the participant remains a potential drawback to this method as garments are limited to a small range of sizes.

The day-to-day variability of the textile electrodes measured during dynamic activities in the current study was greater than that previously measured during isometric knee extensions (Finni et al., 2007). Additionally, the current study revealed muscle excitation during the slowest velocity movement (squatting) to be the most reproducible out of all three functional exercises (Figures 6 and 7). Previous findings suggest the reliability of EMG measurements is higher for squat jumps compared to countermovement jumps (Ball and Scurr, 2010). Moreover, muscle excitation during isometric or low velocity contractions have consistently been found to be more repeatable than those during dynamic, higher velocity tasks. For example, using traditional surface EMG electrodes, within-session coefficients of variation of 18 to 27% have been demonstrated for the vasti excitation during isometric contraction (Finni et al., 2007) and 11 to 22% for hip abductor muscles during low velocity rehabilitation exercises (Bolgla and Uhl, 2007). Conversely during running, Guidetti et al. (1996) found mean intra-individual variability of the EMG profiles to range from 42 to 66%. It is likely that these higher velocity movements involving impacts (such as the running in the current study) are less repeatable than lower velocity movements (for example the squatting exercise) due to the introduction of movement artefact, which is considered to be the most troublesome source of noise in EMG signals (De Luca et al., 2010). Alternatively, as the squatting exercise was conducted last and the running was first in the sequence of exercises in the current study, it may be that there was improved conductivity between the skin and electrodes (the importance of which has previously been highlighted, Finni et al. (2007)) during the latter exercises due to the participant sweating. It is of course also possible that some of the between-day variation observed could be attributed to genuine differences in muscle excitation due to day-to-day variation in the movement coordination. However, as these movements are reasonably closed motor skills which the participants were well-accustomed to, and the data were averaged across 10 excitation bursts, it is perceived that the variation identified in the current study is predominantly measurement error.

The observed high ICCs for certain measures in the current study may be perceived to indicate good agreement between repeated tests for both the textile (ICCs ranged from 0.64 to 0.96) and the surface EMG electrode (ICCs ranged from 0.46 to 0.83), as shown in Table 3. However, the typical error of the measurements are considerable in some cases. This demonstrates the importance of quantifying the likely error magnitude (typical errors) rather than solely using correlational analyses, which can appear artificially high if the spread of data is wide, as suggested by Weir (2005). In fact, the high reliability observed in previous studies (ICCs of 0.73 to 0.97, for example) could be explained in part by the wide variation in the observed normalized EMG patterns during daily tasks (Tikkanen et al., 2013).

The length of excitation bursts certainly appears to be more reproducible than the magnitude of the excitation bursts themselves (Figures 6 and 7, respectively). However, it is important to note that no output variable for either EMG collection method displayed high reliability, particularly in comparison to other methods routinely used to analyze the execution of movement. For instance, Ball and Scurr (2010) previously showed physical performance test outputs (sprint times, squat jump height and one-repetition maximum strength) to be considerably more reliable to that of the EMG signals collected during those tests. In fact, it has long been acknowledged that EMG data are inherently variable and substantial measurement errors are present (Yang and Winter, 1983), particularly when recorded during dynamic conditions (Guidetti et al., 1996; Karamanidis et al., 2004; Smoliga et al., 2010). These previous findings, alongside those of the current study, highlight the importance to carefully consider the design of studies which look to assess for differences in EMG signals between groups or changes in muscle excitation across time. Specifically, researchers should take into consideration the fact that large sample sizes, multiple trials and/or very large effects or changes are required in order to confidently detect true, clear differences in normalized average rectified EMG during dynamic tasks.

Conclusions

Textile electrodes embedded in shorts appeared to provide comparable lower limb muscle excitation data to traditional surface EMG, especially when the recorded excitation levels were lower. Additionally, the textile electrodes seem to provide similar reproducibility to the traditional surface EMG in most cases. As surface EMG is a widely accepted method to assess muscle excitation in both clinical and sporting settings, the textile electrodes appear to provide a practical alternative to acquiring muscle excitation data. Thus, textile-embedded electrodes can potentially provide opportunities to study movement control outside of controlled laboratory conditions. However, particularly when collected in dynamic situations, experimental artefacts are likely to influence the data acquired which appears to be inherently variable, regardless of the measurement technique adopted. This warrants consideration when interpreting differences between groups or changes in muscle excitation across time to ensure that signal is not confused with noise and that the correct conclusions are drawn.

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Key points

- Muscle excitation (normalized average rectified EMG) during functional tasks was generally comparable across the textile EMG and traditional surface EMG systems
- Excitation lengths tend to be longer when collected using textile electrodes compared with traditional surface electrodes
- Reproducibility is similar across the two systems
- Textile EMG electrodes can provide a practical alternative to traditional surface EMG, which may allow greater opportunity to collect muscle excitation information in externally-valid, field-based environments, such as normal training situations

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