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Site-to-site variation of muscle activity and sensitivity in the human anterior temporalis muscle: Implications for contingent stimulation

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Abstract

Objective. To evaluate variation of electromyographic (EMG) activity and sensitivity between different sites of anterior temporalis (AT) muscle. ***Materials and methods.*** Sixteen healthy subjects (eight men: 28.8 ± 5.2 year old and eight women: 29.1 ± 3.9) participated in one experimental session. EMG activity during masticatory muscle contraction was recorded from nine sites at the AT muscle in a 3 × 3 grid with 1 cm between. The subjects maintained steady 30% of maximal voluntary contraction (MVC) using visual feedback. The surface EMG electrode was moved sequentially between these nine test sites and the contractions were repeated. One site was tested four times to assess test–re-test variability. The sensory threshold to electrical stimulation and impedance was also measured at the same sites as the placement of EMG electrodes. ***Results.*** The 30% MVC force values did not differ between sites ($p = 0.863$) or within the same site ($p = 0.995$) due to the feedback. The EMG activity during 30% MVC was highest at the anterior–superior site ($p < 0.05$) with a marginal difference within the same site ($p = 0.044$). Impedance was higher at the posterior–superior, posterior–middle and posterior–inferior sites ($p < 0.05$). The sensory threshold was highest at the posterior–superior site ($p < 0.05$). ***Conclusions.*** These findings showed that electrodes close to the hairline have higher impedance and sensory thresholds and should be avoided. The anterior–superior site produces the highest EMG activity and lower sensory thresholds and can be recommended as the optimal site to place the electrode for contingent stimulation.

Key Words: *biofeedback, contingent stimulation, electromyography, sleep bruxism, temporalis muscle*

Introduction

According to the International Classification of Sleep Disorders, sleep bruxism (SB) is defined as a sleep-related movement disorder characterized by grinding and clenching of the teeth during sleep [1]. The prevalence of SB is reported by 8% of the general population without gender difference [2] and declines from childhood (10–20%) to the elderly (3%) [2,3]. SB has been associated with a multitude of effects such as tooth wear (attrition), fracture and/or failure of fillings, restorations and implants, muscle hypertrophy, pain in teeth, jaw muscles and the temporomandibular joints and temporomandibular disorders (TMD) [4]. Many different treatment options for SB have been suggested, for example occlusal appliances [5], pharmacological therapy [6], biofeedback or contingent stimulation [7–11], hypnotherapy [12], massed practice [13] and muscle relaxation [14].

Biofeedback can be described as the process of becoming aware of various physiological functions (e.g. heart rate, brain waves, muscle tone or skin conductance) using physiological monitoring equipment [15]. For a system to be suitable for treatment of sleep bruxism, it should not wake up the patient, i.e. the patient shall be unaware of the stimulation taking place. Hence, we prefer to use the term ‘contingent stimulation’ about the system that activates subconscious inhibitory reflex to stop muscular activity. So far, various stimuli have been used, e.g. auditory [7], electrical [10,11], vibratory [9] and taste [8]. There is evidence that contingent electrical lip stimulation or auditory feedback can be used to suppress SB events [7,10]. A recent study also reported [11] that the use

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of contingent electrical stimulation on the temporalis muscle caused a reduction of 54–55% jaw muscle EMG events per hour of sleep and that the reduction lasted for some days, even when the stimulator was turned off.

Surface EMG recording is normally used for the assessment of SB [16]. This method can provide objective and non-invasive information on muscle properties and has been widely used for the analysis of jaw-closing muscles and facial muscles. Although polysomnography recordings in a sleep laboratory [17] remain the golden standard for assessment of SB, ambulatory single-channel EMG recordings may offer some advantages because of ease of use, low costs and multiple night recordings [18]. Furthermore, ambulatory EMG recording systems may be suitable for contingent stimulation devices. The masseter and temporalis muscles are normally selected for the EMG recording to assess SB [11,17]. The masseter muscle is the most powerful of the jaw-closing muscles and the EMG activity can be easily recorded, although facial hair will compromise the skin contact. The temporalis muscle may have the advantage that placement of the surface electrode is more comfortable compared to the masseter muscle, especially during sleep. The temporalis muscle can be divided into three parts: anterior, middle and posterior. The anterior part usually has been used to measure surface EMG activity, because this part is not influenced by hair, which again gives poor connection between the skin and the electrodes. For the anterior temporalis (AT) muscle, the placement of electrodes is generally based on the muscle belly by palpation during clenching and anatomical landmark as reference [19]. However, no studies have reported characteristics of AT muscle EMG activity at different electrode positions.

The aim of this study was, therefore, to investigate the variability of EMG activity and sensitivity to afferent stimulation at different electrode locations on the skin over the AT muscle and between repeated measurements of the same location. This knowledge is important to establish if contingent stimulation can be considered a realistic treatment option for SB.

Materials and methods

Subjects

Sixteen healthy subjects; eight men (mean ± SD: 28.8 ± 5.2 years old) and eight women (29.1 ± 3.9) participated in this study. All subjects were in good health and had full dentition (28 teeth). When asked, none of the subjects reported being aware of having sleep bruxism, but they were not further investigated for this condition. The experimental protocol of the present study was in accordance with the Declaration of Helsinki and approved by the local ethical committee. Informed consent was obtained from all subjects.

Study design

Subjects sat on a comfortable dental chair and were asked to bite on a force transducer with their first molars on the same side as the surface EMG electrode and to perform a maximal voluntary contraction (MVC). A 30% MVC level was calculated and, then, the subjects were asked to bite at this level for 3–4 s with the use of visual feedback. EMG activity during masticatory muscle contraction was recorded from nine sites at the AT muscle. One site was measured four times. The surface EMG electrode was moved systematically between these nine test sites (Figure 1). The

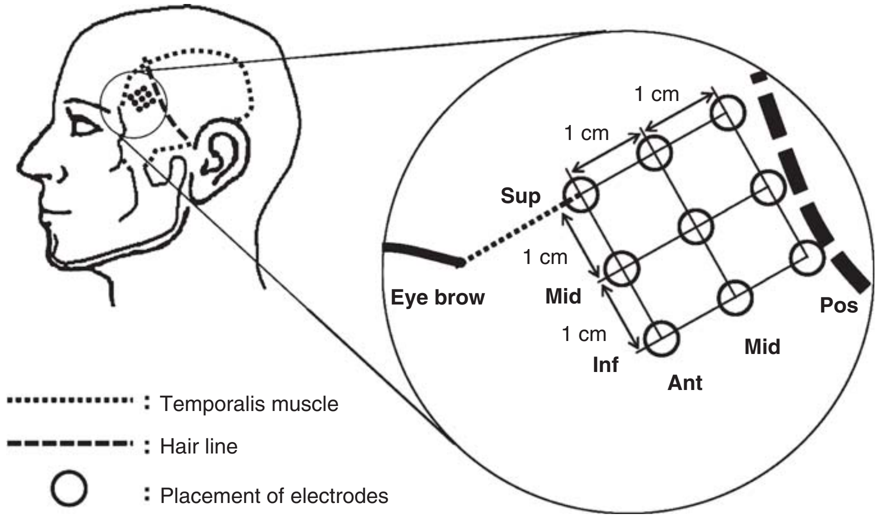

Figure 1. Schematic presentation of the placement of electrodes. The AT muscle was divided into nine sites in a 3 × 3 grid with 1 cm between: anterior–superior, middle–superior, posterior–superior, anterior–middle, middle–middle, posterior–middle, anterior–inferior, middle–inferior, posterior–inferior.

sensory threshold to electrical stimulation and impedance was measured at the same sites as the placement of EMG electrodes.

EMG recordings

EMG activity was recorded unilaterally (the side of recording was determined by the flip of a coin) from the AT muscle with a portable EMG device (Grindcare3™, Medotech A/S, Herlev, Denmark). The device has a single electrode assembly, with three electrode contacts. The placement of the electrode was divided into nine sites, which were a 3 × 3 grid spacing of 1 cm. The AT muscle sites were located as follows; 1: anterior–superior, 2: middle–superior, 3: posterior–superior, 4: anterior–middle, 5: middle–middle, 6: middle–posterior, 7: anterior–inferior, 8: middle–inferior and 9: posterior–inferior (Figure 1). The locations of recording positions were marked by black ink. The electrode was placed vertically with the middle of the three electrode contacts placed on each site after ethanol wipe. The EMG activity was recorded through the amplifiers (×800-times) and filters (250–610 Hz) in the device and digitized and stored on a portable PC through an A/D converter (USB-6216, National Instruments, Austin, TX).

A U-shaped force transducer, with a bite-area 7 mm high, 1.1 cm × 1.1 cm area, coated with elastic tube (Durasoft™, Scheu GmbH, Iserlohn, Germany), developed at University (Aalborg University, Aalborg, Denmark), was placed between the first molars in the same side as the electrode and the subjects were asked to bite on the force transducer as hard as they could for 5 s in order to obtain the MVC [20]. The subjects were then asked to clench their teeth at 30% MVC for 3–4 s guided by visual feedback from the digital display of the bite force meter. These submaximal contractions were repeated for all electrode positions, in the following order: 1-2-3-1-4-5-6-1-7-8-9-1, i.e. one recording from each location, except for location 1, which was recorded four times (Figure 1).

Sensory thresholds to electrical stimulation

The portable EMG device (Grindcare3™) has the ability to apply electrical stimulation through the same electrodes as are used for EMG recording. This method of applying electrical stimulation when specific events appear in the EMG signal is defined as contingent stimulation. The stimulus consisted of a train of current-controlled, square, bi-phasic electrical pulses (450 ms long and a pulse rate of 230 Hz). The amplitude of the pulses within the pulse train rose linearly from 0 to a final level which was adjustable in nine steps from 0–7 mA, i.e. the whole pulse train was 'triangular' in shape, with an overall adjustable amplitude. Sensory threshold values were found for each electrode application at the nine test sites. This was done for each site by applying single pulse-trains, starting at level 0 and gradually increasing the stimulus intensity until the subject reported the slightest sensation, i.e. sensory threshold. This procedure was repeated three times and the average was used for further analyses.

Impedance measurements

The portable EMG device (Grindcare3™) also has a built-in impedance measurement function. This is done by applying a constant current sine wave across the two outer electrode contacts in the electrode assembly (the same ones as are used for recording of the EMG signal). The sine wave has a frequency of 610 Hz and is amplified through the amplifier, sampled and stored along with the EMG signal. As the current is constant, the sampled voltage at 610 Hz is a direct expression of the impedance. Offline analysis of the recorded signals could thus extract the electrode impedance at any time during the experiments. The method was calibrated using known resistors within the same range as the electrode impedance.

Statistics

The results are presented as mean ± standard deviation (SD). Repeated measures analysis of variance on ranks (Friedman ANOVA) was used to test 30% MVC, the EMG activity, impedance and the sensory threshold between sites (9 levels). The test–retest data were also analysed with a Friedman test (4 levels). Post-hoc tests were performed with Tukey tests. The level of significance was set at $p < 0.05$.

Results

Site-to-site variability

Figure 2 shows the data of 30% MVC, the EMG activity, impedance and the sensory threshold from the nine test sites at the AT. The 30% MVC force values did not differ between sites (Figure 2A, $p = 0.863$), i.e. any difference seen in EMG activity was not caused by variation in force levels. EMG activity significantly differed between sites ($p < 0.001$) with the highest values at the anterior–superior site and with significantly lower values at the anterior–inferior, middle–inferior and posterior–inferior site compared with the anterior–superior site (Figure 2B, Tukey, $p < 0.05$). Impedance was significantly influenced by sites ($p < 0.001$) with the highest values at the posterior–middle site and significantly higher values at the posterior–superior, posterior–middle and posterior–inferior site compared with the anterior–superior site (Figure 2C, Tukey,

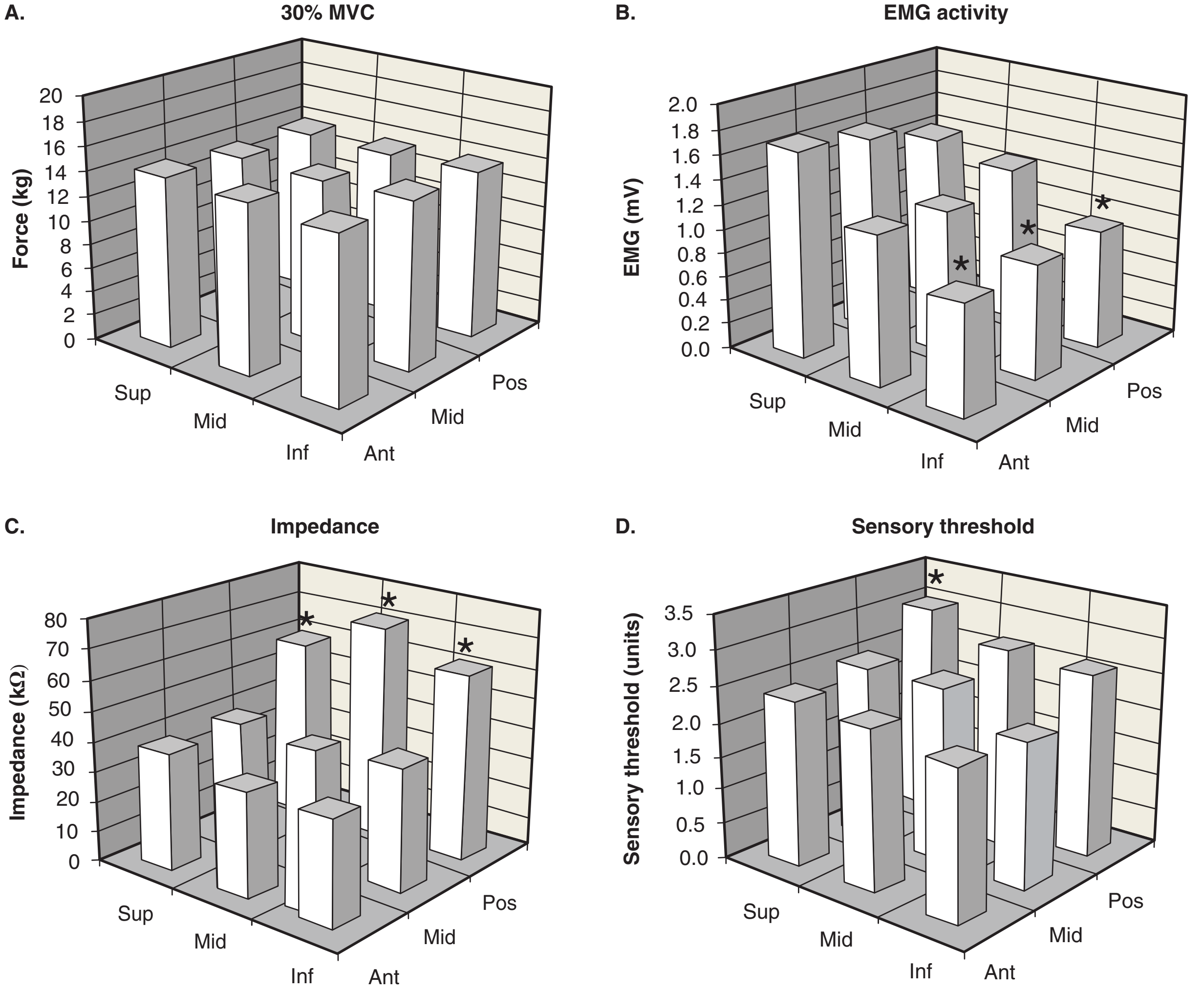

Figure 2. The bar chart showing the mean scores obtained from the measurement in each site. Ranges of SD are given in parentheses; (A) 30% MVC did not show any differences between the test sites (SDs: 4.4–4.9), (B) the EMG activity shows a significant difference at the anterior–inferior, middle–inferior and posterior–inferior site compared with the anterior–superior site (Tukey: $*p < 0.05$) (SDs: 0.4–1.3), (C) impedance shows a significant difference at the posterior–superior, posterior–middle and posterior–inferior site compared with the anterior-superior site (Tukey: $*p < 0.05$) (SDs: 8.3–28.9) and (D) the sensory threshold shows a significant difference at the posterior–superior site compared with the anterior–inferior and middle–inferior site (Tukey: $*p < 0.05$) (SDs: 0.7–1.3).

$p < 0.05$). Also the sensory threshold significantly differed between sites ($p < 0.001$), with significantly higher values at the posterior–superior site compared with the anterior–inferior and middle–inferior site (Figure 2D, Tukey, $p < 0.05$).

Test–re-test variability

Figure 3 shows the test–re-test data of 30% MVC, the EMG activity, impedance and the sensory threshold at the anterior-superior site (i.e. location 1—the only location used for repeated testing). Again, the 30% MVC force values did not differ between tests ($p = 0.995$). The EMG activity had a marginal difference ($p = 0.044$), but post-hoc tests could not identify between which tests (Tukey, $p > 0.05$). Impedance and the sensory threshold were not significantly influenced by repeated tests ($p = 0.807$ and $p = 0.351$, respectively).

Discussion

The main finding in this study was that the highest EMG activity and lower sensory threshold to electrical stimulation were observed at the anterior–superior site in the AT muscle compared with the other eight sites. Furthermore, the test–re-test variability is acceptable with only minor differences in EMG activity between repeated tests.

Submaximal contractions using EMG feedback from anterior temporalis muscle

In this study we used the term MVC consistent with the terminology in general muscle physiology, although previous dental studies sometimes prefer terms like maximal bite force or maximal voluntary occlusal force. Nevertheless, MVC was used to establish a reference value and determine and standardize

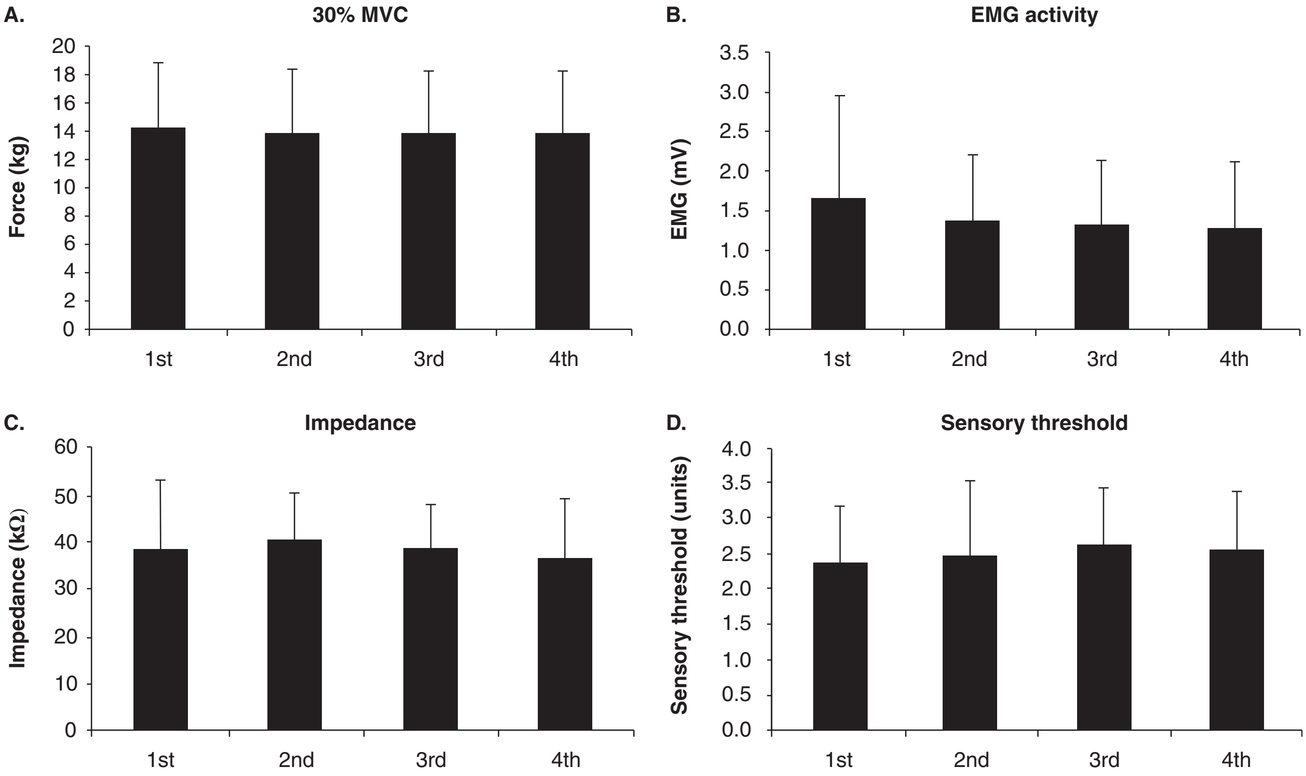

Figure 3. The bar chart showing the mean scores (±SD) of each measurement obtained from repeated test at the anterior-superior site. (A) 30% MVC, (B) the EMG activity, (C) impedance, (D) the sensory threshold.

the submaximal contractions. Subjects were asked to clench their teeth at 30% MVC at each site with the use of feedback. Therefore, it is not a big surprise that the force values were constant across the nine different sites and within the same site. A positive linear relationship has been shown to exist between bite force and EMG activity of jaw-closing muscles during isometric contractions [21]. We therefore believe that the variation between EMG activity measured at different sites represent true regional differences in activation of motor units within the AT. Such heterogeneity of the jaw muscles have also been described previously using motor unit action potentials [22,23].

The EMG recordings were performed four times at one site. A previous study has shown large variability of EMG activity exhibited between subjects although they performed identical tasks [24]. In the present study, there was a marginal difference of EMG activity within the same site during an identical task. Although post-hoc test could not identify between which tests there should be differences, the mean values were larger for the first trial compared to the subsequent three trials. The reasons for this are not clear, but perhaps minor variation in the actual placement of the electrode within the specified site could play a role. It might also be because a new gel was applied on the electrode just before application to the first recording site, but the same gel was used for the following sites and tests. Overall, the data suggest that repeated submaximal contractions measured with the same surface EMG electrode within the anterior–superior part of the AT is sufficiently reproducible to allow repeated assessment.

Effect of location in the surface EMG recording

To our knowledge, this is the first report to systematically investigate the variability of EMG activity and sensitivity to afferent stimulation in different sites of the AT muscle. Previous studies reported that surface EMG recordings were influenced by location of the electrodes over the muscle, inter-electrode distance, body posture and psychological factors [25–27]. The electrode location has a large influence, especially on characteristics of the recorded EMG signal. Some methods were developed to accurately place the electrode on the AT muscle. Ferrario and Sforza [19] placed the electrode vertically along the anterior margin of the muscle (approximately at the coronal suture). They specified the location using anatomical landmarks. In another study, the electrode was placed 1–1.5 cm from the anterior border of the AT muscle based on manual palpation of the muscle borders [28]. Linear and bi-dimensional arrays have also been applied to standardize the electrode location [29]. Linear arrays comprise a series of electrodes along a line at a fixed distance between each other. Bi-dimensional arrays consist of electrodes located in a grid. The influence of location can be reduced with the use of standardized methods. In this study, we used a standardized electrode, which had three electrode contacts with fixed inter-electrode distance. EMG recording was performed in similar conditions and only the location of the electrode was changed. EMG activities and sensory threshold to electrical stimuli were different depending on the placement of electrode, despite the same absolute force being produced. This indicates that the location of the electrode in AT muscle influences the EMG signal during muscle contractions.

Influence of impedance

The electrode–skin impedance is one of the main elements of artefact in surface EMG recording and electrical stimulation intensity [30,31]. The skin at the temple over the AT muscle was divided into nine sites which were a 3 × 3 grid in this study. The posterior area is located near the hair line. The hair line can cause poor connection between gel pads and skin and as a result higher impedance may occur. Adequate electrode adhesion to the skin is important for maintaining EMG signal quality and sensory threshold to electrical stimulation. Skin abrasion, electrolytic gel interfaces and pressure on the electrode surface have been recommended to reduce impedance and hold the electrode in place [30]. This study showed that impedance and sensory threshold was higher at the posterior area compared to the anterior and middle areas. The reason for this is likely to be the proximity of the hair line. So, it is not recommended to measure EMG activity and use contingent stimulation at the posterior area of the AT muscle.

Influence of innervation zone

The innervation zone and muscle fiber length may have implications on the quality of surface EMG data [32]. Innervation zone is defined as 'the location where nerve terminations and muscle fibers are connected' P 38 [33]. The location of the innervation zone has been identified by multi-channel surface EMG using the linear electrode array [34]. The optimal electrode location is considered between the innervation zone and the tendon region [35]. In this location, surface electrodes detect the propagation of the motor unit action potentials. However, the AT muscle has short fibers and scattered innervation zones, a previous study therefore reported that it was impossible to identify an optimal position of surface EMG electrodes between innervation zone and tendon in AT muscle [34]. High EMG activity was observed at the anterior–superior site in this study. This finding suggests that this position may have some advantage related to the location of the innervation zones. Further studies are needed to investigate this point.

Conclusions

This methodological study showed that the anterior–superior site had the highest level of EMG signal quality and sensitivity to afferent stimulation. Based on previous studies [11,36] and the present findings, we propose that the anterior–superior site can be recommended as the optimal site to place the electrode for contingent electrical stimulation paradigms.

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Declaration of interest: The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

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