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Monopolar electromyographic signals recorded by a current amplifier in air and under water without insulation

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ABSTRACT

It was recently proposed that one could use signal current instead of voltage to collect surface electromyography (EMG). With EMG-current, the electrodes remain at the ground potential, thereby eliminating lateral currents. The purpose of this study was to determine whether EMG-currents can be recorded in Tap and Salt water, as well as in air, without electrically shielding the electrodes. It was hypothesized that signals would display consistent information between experimental conditions regarding muscle responses to changes in contraction effort. EMG-currents were recorded from the flexor digitorum muscles as participant's squeezed a pre-inflated blood pressure cuff bladder in each experimental condition at standardized efforts. EMG-current measurements performed underwater showed no loss of signal amplitude when compared to measurements made in air, although some differences in amplitude and spectral components were observed between conditions. However, signal amplitudes and frequencies displayed consistent behavior across contraction effort levels, irrespective of the experimental condition. This new method demonstrates that information regarding muscle activity is comparable between wet and dry conditions when using EMG-current. Considering the difficulties imposed by the need to waterproof traditional bipolar EMG electrodes when underwater, this new methodology is tremendously promising for assessments of muscular function in aquatic environments.

1. Introduction

Electromyography (EMG) is used by researchers and clinicians to understand and assess motor control in human movement, with much of this work being performed using bipolar surface EMG methodologies (Cram et al., 1998). Despite limitations with respect to penniform muscles (Dimitrova et al., 1999; Mesin et al., 2011; von Tscharner et al., 2013), bipolar electrodes are used extensively due to their apparent advantage of reducing noise by sampling the potential difference across the electrodes (Cram et al., 1998). Another major limitation of bipolar electrodes is the fact that skin resistance is not large enough to prevent some lateral current flow across the skin between the electrodes (von Tscharner et al., 2013). The presence of sweat and water on or around the skin and electrodes, therefore, will only exacerbate this 'short-circuit' effect, making the detection of muscle activity difficult or impossible.

When one considers voltage potentials on the skins surface during immersion in water, it is reasonable to conclude that the surface potential becomes equipotential. It can also be concluded that the actual surface potential on the skin does not affect the muscles capacity to work. The primary task of a muscle is not to create a surface potential; similarly the primary task of a surface potential is not to elicit muscle activity. Nonetheless, in normal dry conditions a surface potential builds up. Rather than allowing these charges to build on the surface, it is possible to remove them by measuring them as currents (von Tscharner et al., 2013). As shown in von Tscharner et al. (2013), currents reflect the muscle activity equally well as the potentials created at the surface of the skin. Therefore it is a logical step to hypothesize that if the skin surface and the electrodes are at the same potential one could record an EMG current while immersed in water.

Although distilled water is a poor electrical conductor (electrical conductivity is <10 μS/cm) due to its lack of ions (APHA et al., 2012), water found in most aquatic environment is considerably more ion rich. For instance, the electrical conductivity of drinking water is in the order of magnitude of 10 times greater than that of distilled water at approximately 100 μS/cm (APHA et al., 2012). This presents an enormous challenge to researchers and clinicians who

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are interested in understanding neuromuscular activity during human movement in aquatic environments such as pools or even the ocean. The electrical conductivity of non-saline and saline pool water approximates 650–1200 μS/cm and 8000 μS/cm, respectively (APHA et al., 2012; Rainoldi et al., 2004). Ocean water however, has an average salinity of 35 g/L, resulting in vastly higher conductivity that approximates 60,000 μS/cm (APHA et al., 2012). Therefore, it is important to understand the effects of the range of conductivity levels found in different aquatic environments if one is to attempt the recording of surface EMG signals underwater. Furthermore, due to the obvious prevalence of water-based sports such as swimming, and the explosion in water-based activities and therapies for clinical populations such as those with cardiac diseases (Fernhall et al., 1992), obesity (Gappmaier et al., 2006) and osteoarthritis (Golightly et al., 2012), investigating neuromuscular activity underwater is an area with enormous potential for research using EMG.

Numerous researchers have investigated the application of standard bipolar electrodes in aquatic settings (Carvalho et al., 2010; Rainoldi et al., 2004). They collected bipolar surface EMG signals from the biceps brachii during isometric contractions under water and in the air. These studies showed that despite no difference in force production between contractions in air and underwater, the amplitude of the signals collected in water was reduced by as much as 95% (Carvalho et al., 2010; Rainoldi et al., 2004). Not only was signal amplitude affected, but artefact from water movement was shown to alter spectral power substantially in the 0–20 Hz range (Rainoldi et al., 2004). Furthermore, by using an experimental condition with waterproof tape, it was demonstrated that the amplitude and frequency spectra were only comparable between data collected in air and underwater when one takes such precautions (Carvalho et al., 2010; Rainoldi et al., 2004). As a result, researchers have relied upon waterproof tape in order to assess EMG activity in studies to date that involve human movement underwater.

For instance, researchers taped over the electrodes when investigating differences between treadmill walking on land and underwater (Masumoto et al., 2004; Masumoto et al., 2007). Similarly, Bressel et al. (2011) used waterproof tape when determining the differences between trunk muscle activity during land and water-based exercise. Other researchers have used waterproofing techniques such as taping and spray plaster in order to investigate EMG activity underwater during fin swimming (Marion et al., 2010), deep-water running (Kaneda et al., 2008, 2009) and manual muscle testing (Silvers and Dolny, 2011). Nonetheless, despite the best efforts of researchers in these areas, waterproofing techniques are fallible with one investigation revealing that 10 out of 11 techniques failed during testing (Benfield et al., 2007). Considering the difficulties imposed by the need to waterproof bipolar EMG electrodes in aquatic environments and the knowledge that any water leakage leads to a serious decrease in the quality and validity of the signals (Carvalho et al., 2010; Rainoldi et al., 2004; Veneziano et al., 2006), it is imperative that we investigate alternative technologies for their effectiveness.

It was recently proposed and demonstrated that one can use current (or trans-impedance) amplifiers with a monopolar electrode setup, instead of potential amplifiers, to record EMG-currents (von Tscharner et al., 2013). A current amplifier captures or injects the charges in such a way that the potential under the electrode remains at the potential of the ground electrode. As a consequence, no lateral currents occur. It is postulated that if the electrodes are pressed against the skin the current amplifiers will actively compensate the movements of charges at the location of the electrode; thereby eliminating the need to isolate or shield the electrode from the environment.

Therefore, the purpose of this study was to determine whether EMG-currents can be recorded in Tap and Salt water, as well as in air, without electrically shielding the electrodes. The main hypothesis was that EMG-current signals derived from the flexor digitorum muscles would display consistent responses (trends in magnitude and frequency) to changes in contraction efforts between experimental conditions. More specifically, we also hypothesized the following:

H1. It would be possible to measure EMG-currents without electrical shielding of the electrodes.
H2. The overall signal intensity would increase monotonically in each experimental condition with increases in contraction effort.
H3. The mean frequency of the EMG-current would follow the same trend in each experimental condition with increasing contraction effort.

2. Methods

2.1. Participants

Thirteen healthy individuals participated in this study (1 female, 12 male; age 30 ± 10 years, mass 78 ± 11 kg, height 179 ± 7 cm, mean and SD). All gave written informed consent in accordance with the University of Calgary's policy on research using human subjects. The protocol was approved by the Conjoint Heath Research Ethics Board at the University of Calgary (Ethics ID: 24485).

2.2. Electrode placements and EMG signal recording

Prior to placement, electrode sites were shaved, abraded and washed with alcohol. In order to enhance signal conductivity, a very thin layer of electrode gel (Spectra 360, Parker Laboratories, Inc. NJ. USA) was applied between the skin and the electrodes. A custom monoploar electrode (machined silver (Ag) disc; 7.38 mm diameter; 99.99% purity) was placed in the approximate center of the muscle bellies for the flexor digitorum muscles by palpating during activation. A similar custom silver reference electrode was placed on the styloid process of the radius. The electrodes were secured by non-waterproof, air permeable cover-roll stretch tape (Fig. 1). In order to activate the flexor digitorum during palpation, participants were asked to flex their carpo-metacarpal and metacarpo-phalangeal joints by squeezing their fingers into the palm of their hand. Surface

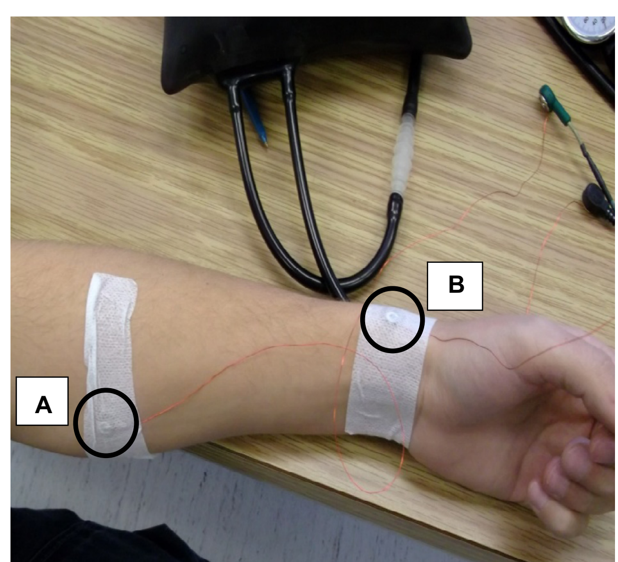

Fig. 1. Illustration of placements for the surface EMG monopolar electrode (A) and the reference electrode (B).