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RESEARCH ARTICLE

Exploring electromyography for assistive technology: feasibility, usability and performance of a dry sensor EMG switch

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ABSTRACT

Purpose: Switch access is a tool used by many individuals with physical disabilities. Switches used in assistive technology are typically electro-mechanical. Electromyography (EMG) has previously been suggested for assistive technology switch access but has been little explored.

Materials and Methods: An exploratory study aiming to investigate the feasibility, usability and performance of a dry sensor EMG switch when used by individuals with physical disabilities to control assistive technology was conducted.

Results: Twelve participants with a range of underlying conditions trialled a novel dry sensor EMG switch. Switch reaction performance data for both EMG and conventional switches and qualitative feedback from semi-structured interviews were collected and tabulated. Results showed that the EMG switch was feasible to use in a range of placements and with a range of individuals, that it was feasible in some situations where a conventional switch was not, and that it may be more appropriate for those with hypokinetic movement disorders. Some participants described use of the EMG switch as less effortful and fatiguing. Some participants had faster reaction times using the EMG switch compared to conventional switches, the fastest average reaction time reported in the study (483 ms) was using the EMG switch. More false positive activations occurred when using the EMG switch and participants described this as impacting on usability. Setup complexity was also noted as a key usability barrier.

Conclusions: This study highlights potential benefits of EMG switches but suggests further development is needed to improve ease of use and minimise false activations if EMG switches are to achieve broader adoption.

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Switch; MicroSwitch; assistive technology; EMG; electromyography

IMPLICATIONS FOR REHABILITATION

- EMG switches, using EPS dry sensor technology, may currently be appropriate as a switch access method for those with physical disabilities.
- It is likely that EMG switches may be more appropriate for those with hypokinetic movement disorders such as MND and DMD.
- It is likely that EMG switches may be more appropriate for those where no other switch access method can be found.
- EMG switches may offer some performance advantage in quicker reaction times which may provide benefit for some individuals, however EMG switches using current technologies may also result in users experiencing an increased rate of false positive activations.

Introduction

Switch access is used by a significant cohort of those with physical disabilities who use assistive technology. Switches are buttons which produce an on/off signal when pressed and are used by individuals who have physical and/or learning disabilities to control assistive technology equipment [1]. In its simplest implementation a switch may directly control a single device or function, for example a switch may toggle music to turn on and then off. Through the use of techniques such as switch scanning a single on-off switch can, however, be used to control an essentially infinite number of outputs, including control of computer operating systems, Environmental Controls (EC), or Augmentative and Alternative Communication (AAC) aids. Switch access has a long pedigree, arguably being the first non-pointing based method of alternative access to assistive technology [2].

The majority of current switches used in practice in assistive technology are electro-mechanical in design –

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i.e., they convert a mechanical activation into an electronic signal. These switches generally use an electronic component known as a snap-action switch (trademarked by Honeywell as the MicroSwitch™[1]) with some form of cover or lever to allow the user to operate the switch. Switches are also available that are purely electronic in design and which use forms of movement sensing technology such as capacitive sensing, infra-red or piezo-electronics.

Electromyography (EMG) is a technique which directly measures the electrical bio-signals produced by muscle activation. The electrical signals produced by muscle cells have been recorded with machines since the early twentieth century. Applications of EMG have predominantly been medical in nature, for example EMG is used in nerve conduction tests. EMG has also been used within the assistive technology field: for example in controlling prosthetics using residual limb muscles; and to trigger the electrical stimulation in functional electrical stimulation systems. EMG was also briefly used in early assistive human computer interaction systems: initial eye gaze technology used electro oculography (EOG) signals to estimate eye gaze [4], something that is still an area of research [5].

More recently EMG has been envisioned as a form of gesture recognition for (non-assistive) human computer interaction. Some products have appeared (and disappeared) which use EMG arm bands or similar to support gesture recognition, i.e., to allow in-air pointing or to recognise specific hand gestures that can be used control computers. See for example the work of Mendez et al. [6].

EMG can be recorded using surface sensors (placed on the skin above or near the muscle mass) or using intra-muscular sensors (using a needle electrode inserted into the muscle itself). Surface placed sensors are prone to electrical noise and are not as localised to specific muscles whereas intramuscular sensors allow signals from specific muscles and deep muscles to be recorded. Surface EMG (sEMG) is however, using current technologies, significantly less invasive and it is sEMG systems which are the focus of this article.

Initial sEMG technology used "wet sensor" systems: these sensors aim to minimise the electrical resistance between the skin and the sensor through the use of gels, typically composed of Silver/Silver Chloride (Ag/AgCl). Wet sEMG sensors pick up very small currents created in the skin between two sensors [7].

Dry sEMG sensors developed more recently claim advantages over wet sensor systems in a number of ways: the lack of need for conductive gel and significant skin preparation; a lack of signal drift that is seen over time with wet systems (as the gel and skin-sensor contact degrades); and also in the lack of a need for a third "reference" electrode. There are a number of possible dry sensor technologies and the Electric Potential Sensors (EPS) developed by Prance et al. is the dry sensor technology used in the study reported here [7,8]. These sensors were commercialised by Plessey as the EPIC™ sensor. EPS are insulated sensors that have an ultra-high electrical impedance between skin and sensor. EPS detect the electric field created by the muscles during activation and this electric field induces a current in the capacitively coupled electrode within the sensor.

The properties of dry sEMG sensors make their use in assistive applications, where ease of use and use over extended periods are key design requirements, more feasible. The potential for EPS based EMG sensors to be used in assistive applications was highlighted by Prance et al. in 2009. Since then however there have been no studies evaluating the performance or feasibility of these sensors in assistive applications.

A commercial system based on EPS was developed and launched in 2016. This system, Emego™, was developed as part of UK Small Business Research Initiative (SbRI) Healthcare funded project. The Emego sensor was designed in a user centred way [9] to create a sensor that could be used in assistive technology applications but also with consideration of other potential applications, such as use in rehabilitation, where the same features may be relevant. Emego is designed to work as an assistive technology switch – i.e., when the device detects muscle activation over a certain threshold, an output signal is triggered.

The data reported here originated from a study funded as part of the SbRI project. The aims of the study were to evaluate the feasibility, usability and performance of an EPS EMG switch compared to conventional electro-mechanical switches, when used to control assistive technology by individuals with physical disabilities with a range of presentations resultant from a range of different medical conditions.

Usability and feasibility are well established constructs within the Assistive Technology field. As Arthanat et al. describe these constructs are underpinned by Assistive Technology conceptual models that relate to "the role of the user of AT device; the AT device; the activity; and the context" [10,p.237] such as HAAT [11] and MPT [12].

The characterisation of performance in terms of switch use in assistive technology is less well established in the literature. Hoppenbrouwers et al. [13] provide a review of the literature related to clinical switch assessment tools for children and did not find any validated and reliable tools. None of the tools included in Hoppenbrouwers' review included objective data collection, beyond logging of activity/use. Nguyen et al. [14] subsequently proposed and evaluated a clinical measure of switch access based on the observations of therapists.

Objective measures of switch performance allow for comparison across two switch methods used by the same individual. Nguyen et al. [14] provided an updated literature review on this topic and identified two papers, both by Koester et al. that discussed objective measures of switch performance. Koester et al. present two systems (Compass and Scanning Wizard) that characterise switch performance using a number of measures including: % error-free trials; total trial time; switch press time; switch release time and switch reaction time [15,16]. This work provides useful initial suggestions for meaningful measures of switch access performance, however there does not seem to be a clearly established accepted set of switch performance measures in the literature or practice.

In order to address the study aims, the following research questions were posed for this study:

- Can EMG, using EPS technology, be feasible as an assistive technology control method for a range of patients with different medical conditions and presentations?
- How well does an EMG switch perform as compared to conventional switches for those using assistive technology?
- How usable and acceptable is an EMG switch to users of assistive technology?

Study design and method

The study reported here was designed as a simple mixed methods evaluation of the EPS based Emego EMG switch for the application of switch control of assistive technology devices.

Participants were those who used, or were being assessed to use, a switch to control their assistive technology equipment (either an AAC device, EC system, or as part of a computer access setup). Participants trialled an Emego EMG switch alongside their conventional switch as part of the study.

A target sample size of 15 participants was chosen pragmatically based on the timeframes of the study and an estimation that this sample would achieve sufficient diversity of opinions and experiences. Recruitment was opportunistic and pragmatic – no sampling frame was used other than the inclusion criteria. Recruitment was carried out until the sample size was achieved.

The EMG switch used in the study was designed and manufactured by GSPK Design Ltd and was CE marked as a Class I medical device. The EMG switch consists of a Patient Unit, Base Unit and Windows™ software application. The Patient Unit communicates with the Base Unit using Bluetooth, has a size of 46 mm x 26 mm x 16 mm and can be affixed to the user using either a stretchy Velcro™ strap or a silicone pouch which is adhered to the skin. The switch output from the unit is either as a signal over USB into the computer/assistive device (as an HID Joystick fire button, the de-facto industry standard) or *via* a 3.5 mm jack connector. During the study the Base Unit was plugged into the researcher's laptop using USB and the switch signal converted using the Switch Driver 6 software (Smartbox Assistive Technology Ltd) into a keyboard spacebar press, for use as an input into the Scanning Wizard Tool [17].

Setting up the unit requires the sensor gain to be set and then a threshold value and signal conditioning timings set – any muscle signal higher than the threshold value that is sustained for the threshold time is accepted as a switch activation and the unit then outputs a switch signal (this signal has a minimum period of 50 ms).

Data generated from the study were quantitative and also qualitative and so this study can be considered to be a simple mixed methods study [18]. Quantitative data were in the form of measures of the performance of the EMG switch when used by patient participants. Qualitative data consisted of feedback from participants about the feasibility and usability of the EMG switch and were collected *via* a short semi-structured interview. Researcher notes relating to the study questions and aims were also recorded after each session, researcher notes also documented the process of placement of the EMG switch and the participant's history of prior and current switch use.

Interviews were recorded and transcribed by the researcher and recorded against the interview questions in a spreadsheet table. Researcher notes were also recorded against the same questions in the table. The interview questions were designed to relate to the research aim and explore the participant's perceptions of use of the switch. The topic guide questions were as follows: What did you think of the EMG switch; How might you use it?; What are the potential benefits?; What are the potential disadvantages?; When might you use it?; What would you change about the switch you tested?; What ideas do you have?; What constraints did you have related to wearing the device?; Would the EMG switch be acceptable for you to use if you could use it to control your device?; Do you think that EMG switch could be used at different muscle sites? Would you like to share any more ideas or thoughts?

Quantitative data were collected using the Scanning Wizard tool [17]. This is an online tool which provides a switch reaction and scanning performance test and exports summary data as well as detailed timing data [15]. The switch reaction timing element of this test used in this study requires the participant to activate the switch after a prompt (a green "Go" circle) appears on the screen. There are three trial phases where the user is asked to press the switch once, twice and three times following the prompt. The Scanning Wizard tool is described more fully by Koester & Simpson [15].

Quantitative data from the single switch press trial were tabulated for all cases to allow comparison of basic descriptive statistics of switch performance across and within cases. No additional descriptive information relating to the study aims of switch performance or feasibility were provided by the additional switch press trials and so these were not tabulated. The single switch press reaction time, number of switch presses per trial and standard deviation (SD) were tabulated. The reaction time and switch press number are averaged over the eight trials of the test. The error-free result for the average number of switch presses per trial is thus 1. Reaction times included the time to activate and release the switch.

The quantitative switch performance data were exported from the Scanning Wizard tool as an excel file. The relevant measures were then collated, using a simple spreadsheet table, alongside the qualitative data.

The research questions of this study were exploratory and did not aim to test a hypothesis about the use of EMG switches. The study was interventional in that it introduced the use of the EMG switch. The study method could thus overall be considered as a single-arm exploratory uncontrolled interventional study, or case series [19]. Data were thus treated as descriptive, rather than analytic and collation of these data into the spreadsheet table was the primary method of analysis. Analysis was supplemented by the creation of a series of case descriptions that assisted in synthesising and reporting the results.

Ethical approval for this study was granted by the Yorkshire & The Humber Leeds West Research Ethics Committee of the UK Health Research Authority, reference 16/YH/0470.

Participant recruitment

The population of interest was individuals who might benefit from an alternative EMG based switch for control of assistive technology. All individuals in this population will have a physical disability that severely affects their movement and/or control of their limbs but will have some volitional control over a muscle. The population is not defined by aetiology and may include those who may have a range of medical conditions including: brain stem stroke, high spinal cord injury, motor neurone disease, cerebral palsy or other disabilities.

As such, inclusion criteria were defined as individuals who:

- have, or are being considered for, a switch access method that they use to control a communication aid or environmental control system (including computer access);
- are able to give informed consent and to actively take part in the interviews;
- are over 12 years old.

Participants were recruited from two assistive technology services based in the North of England that provided specialised AAC and/or EC interventions.

Potential participants were identified by review of caseloads for those currently using a switch and through review of referrals to the services during the recruitment period. Potential participants were initially approached by the investigator on each site to tell them about the study and ask if they would like to find out more. Potential participants who showed an interest in the study were then posted a study invitation pack containing a letter of invitation, a participant information sheet, a consent form and a stamped addressed envelope. The letter of invitation was followed after one week with a telephone call from the researcher to offer to discuss the study in more detail, at this call if the potential participant stated they were unable to send the consent form back then initial consent was taken by the researcher over the phone and an initial visit arranged to obtain formal informed consent. Where potential participants were children or young people ascent was obtained from the child or young person themselves and consent was obtained from parents or legal guardians.

Data collection

Data collection was carried out by researchers in the participant's preferred setting such as their home. Data collection was carried out over two stages: an initial stage where the EMG switch was setup and initial measures taken and a review stage where the measures were repeated. Each stage took either one or two visits, depending on the needs of the participant (e.g., due to fatigue). The review stage was booked for two weeks after the end of the initial phase, when participants were not available the next mutually convenient date was booked.

The initial data collection stage consisted of the researcher taking or confirming informed consent and then working with the participant to setup the EMG switch. This process involved discussing potential muscle sites that the participant could use to trigger the switch and trialling these with the EMG switch. EMG switch positioning was generally achieved by placing the switch on the appropriate muscle and then using the accompanying software to display the EMG signal so that the participant and researcher could see volitional movements reflected in real-time in the signal and adjust the positioning of the switch if needed.

Once an acceptable EMG switch placement was found the participant was asked to complete the Scanning Wizard tool activity using the EMG switch and also their conventional switch (if the participant was an established conventional switch user). During this stage the researcher also discussed the participant's history of switch use.

The participant was asked to use the EMG switch as they felt appropriate between visits. The review data collection stage involved the researcher repeating the quantitative measures and also carrying out the short semi structured interview to explore the participant's experience of using the switch.

Results

16 participants were recruited to the study (Table 1). Four participants withdrew from the study prior to data collection. Four participants completed only the initial data collection visit and this included one participant (P2) who passed away between the two data collection phases. One participant (P12) passed away during the second data collection phase having completed the quantitative data collection but not completed the interview. Thus full quantitative data were collected from eight participants and partial data from 12.

Participants had a range of medical conditions: Motor Neurone Disease (MND, $n=5$), Cerebral Palsy (CP, $n=3$), Duchene Muscular Dystrophy (DMD, $n=3$), Brain Stem Stroke (BSS, $n=2$), Multiple Sclerosis (MS, $n=2$) and Traumatic Brain Injury (TBI, $n=1$). Looking at Table 2 it can be seen that no participants with Cerebral Palsy completed data collection with two withdrawing prior to initial data collection and the remaining participant only completing initial data collection; the participant with Traumatic Brain Injury withdrew prior to any data collection; and only one of the two participants with MS completed data collection. 13 of the 16 participants in this opportunity sample were Male (10 of the 12 from who data were collected).

Table 1. Participant information.

ID	Medical condition	Gender	Existing switch	Existing switch location	EMG switch location
P1	MND	M	Small Click Switch	Left hand	Forearm
P2	MND	M	Medium Click Switch	Right hand	Forearm
P3	DMD	M	Small Click Switch (array)	Right hand	Thumb
P4	DMD	M	Small Click Switch (array)	Right hand	Calf
P5	CP	M	Small Click Switch	Head	Jaw
P6	MND	F	N/A	N/A	Calf
P7	MS	M	Sip/Puff	Breath	Eyebrow
P8	MS	M	Medium Click Switch	Head	Forearm
P9	CP	M	Medium Click Switch	Head	Forearm
P10	CP	F	Small Click Switch	Head	Forearm
P11	DMD	M	Small Click Switch	Finger	Thumb
P12	MND	F	Small Click Switch	Arm	Forearm
P13	MND	M	Medium Click Switch	Foot	Forearm
P14	BSS	M	EMG Switch	Thumb	Thumb
P15	BSS	M	N/A	N/A	Forearm
P16	TBI	M	N/A	N/A	N/A

Table 2. Participant recruitment.

	Count
MND	5
Complete	3
Initial Data Collection Only	1
Initial Data Only (Passed Away)	1
CP	3
Withdrawn	
Initial Data Collection Only	1
DMD	3
Complete	2
Initial Data Collection Only	1
BSS	2
Complete	2
MS	2
Complete	1
Withdrawn	1
TBI	1
Withdrawn	1
Grand Total	16

Participants existing switch use and activation location is tabulated in Table 1. Seven participants used a conventional small circular click switch (approx. 25 mm) or medium circular click switch (approx. 50 mm) – i.e., a snap-action based switch. Three participants did not currently use a switch. One participant was an existing EMG switch user and one was a sip-puff (breath in and out) switch user.

Performance of EMG and conventional switches

The switch performance reaction task results have been tabulated in Table 3. All participants completed all three trials of the switch performance test.

Table 3. Switch performance data. (+), (-) indicates EMG performance better/worse than conventional switch. Bold values indicate the min/max range values in each column.

		Conventional switch			EMG switch		
		Mean reaction time (ms)	SD reaction time (ms)	Mean switch presses	Mean reaction time (ms)	SD reaction time (ms)	Mean switch presses
P1	Visit 1	873	49	1	843 (+)	136 (-)	1.625 (-)
P1	Visit 2	733	71	1	625 (+)	55 (+)	1.25 (-)
P2	Visit 1	–	–	–	1167	233	1.25
P2	Visit 2	–	–	–	–	–	–
P3	Visit 1	990	168	1	965 (+)	426 (-)	1
P3	Visit 2	–	–	–	–	–	–
P4	Visit 1	771	**412**	1	635 (+)	125 (+)	1
P4	Visit 2	–	–	–	787 (-)	466 (-)	1.125 (-)
P5	Visit 1	587	**24**	1	875 (-)	615 (-)	**2.857** (-)
P6	Visit 1	–	–	–	1745	866	1
P6	Visit 2	–	–	–	–	–	–
P7	Visit 1	**1127**	139	1	1213 (-)	757 (-)	1
P7	Visit 2	–	–	–	1141 (-)	311 (-)	1
P11	Visit 1	567	89	**1.125**	**483** (+)	110 (-)	1.25 (-)
P11	Visit 2	**558**	85	1	506 (+)	78 (+)	1
P12	Visit 1	–	–	–	**1881**	**1317**	1
P12	Visit 2	–	–	–	1285	645	1
P13	Visit 1	741	125	1	640 (+)	170 (-)	1
P13	Visit 2	660	50	1	636 (+)	89 (-)	1
P14	Visit 1	–	–	–	1655	718	1.125
P14	Visit 2	–	–	–	1211	391	1.5
P15	Visit 1	803	56	1	648 (+)	**50** (+)	1
P15	Visit 2	869	56	1	1006 (-)	137 (-)	1.625 (-)

Table 3 highlights the variation in the data. Looking at the eight participants where EMG and conventional switch data were collected five participants demonstrated quicker reaction times using the EMG switch over the conventional switch. Of the other three participants: P15 had split results (one test where the EMG switch outperformed the conventional switch and one where the conventional switch reaction time was quicker) and P7 and P5 had poorer performance with the EMG switch. P5 in particular had a slower reaction time and a higher number of false positives and did not continue to the second data collection stage.

The conventional switch matched or outperformed the EMG switch in terms of accidental additional switch presses (false positives) in all cases – with the rate of false positives being higher for two of the eight participants, split (one test higher and one the same) for three participants and the same for the other three. It is not possible to determine if these false positive responses were due to the EMG switch performance or the user's actions.

In four cases the standard deviation (SD) of the switch timings was larger for the EMG switch than the conventional switch, whereas for the other four cases there was a split result.

Looking across all the cases it can be seen that P11 achieved the fastest average reaction time using the EMG switch (483 & 506 ms). The longest reaction time for the EMG switch was P6 with a 1744 ms average reaction time across the trial, this was achieved with full accuracy (i.e., no additional switch presses). P14, who uses the EMG switch functionally and extensively for switch scanning daily, also had a relatively long reaction time of 1211 and 1654 ms. The range of average reaction times for conventional switches was from 558 ms to 1126 ms.

Feasibility of EMG switch use

Table 1 lists the placement of the switch for the 12 participants who trialled the EMG switch. The majority of placements were on the forearm and picked up finger movements. Other placements were over the thumb, jaw, eyebrow and calf muscles. The EMG switch was successfully setup in all these locations to capture signals from the relevant muscles. An example EMG placement (Figure 1) and signal (Figure 2) are provided for P14 for whom a case description is also included as supplemental material.

Some participants discussed or trialled choosing between muscle flexion or extension for activation. P11 for example discussed this in terms of choosing between a thumb up versus thumb to palm movement.

> So moving it up means it's less likely to get accidental ones, but potentially more likely to miss some. (P11)

Of the 11 participants providing interview feedback, seven participants stated that they would either continue to use the EMG switch or would find the EMG switch acceptable to use as a switch for control of their assistive technology equipment. Three of the four participants who withdrew from the study did so during the initial session when the EMG switch was demonstrated and it thus likely that this sample is skewed towards those more likely to accept the EMG switch as feasible.

Complexity of setup of the EMG switch was a common theme both for those who found the EMG switch to have utility as well as for those who did not. Specific factors discussed were the need for carer support to setup the switch, the time taken to set it up initially, and the technical complexity of the setup process for carers and family members (who may not be particularly technical). The setup was described as the critical reason for not finding the EMG switch appropriate for one participant. P14 who uses the EMG switch daily described needing someone skilled to setup the device and then adjust it throughout the day as P14's thumb strength altered and thus the threshold needed altering (see also case description in supplemental material).

Figure 1. Placement of EMG switch, P14.

> The most obvious drawback over a conventional switch would be the sensitivity to positioning and the slight trial and error nature it required. (P15)

Attaching the sensor, particularly in locations that the sensor could not be strapped to (i.e., not arms or legs) was also described as problematic by participants. The switch was successfully mounted on the head using this method during the study but this was not considered a long-term solution by the participants who tried this.

> Attaching the sensor with sticky back on my head was a problem as I need to keep changing it every day. Each batch runs out after a few weeks. (P7)

Strapping was used by a majority of participants as the means of attaching the sensor. Strapping was used

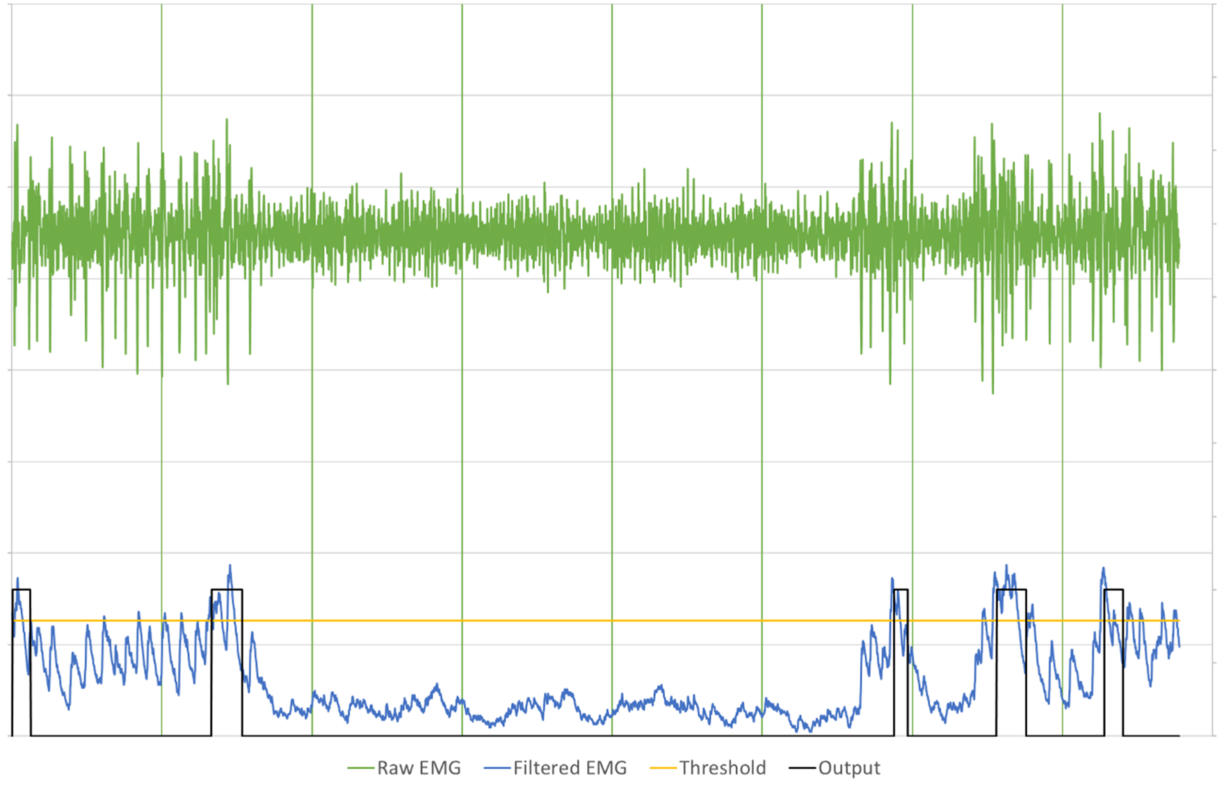

Figure 2. P14 EMG data sample: EMG (green), algorithm (blue) and switch output (black) data. Threshold (yellow). Units omitted as these are not absolute units.

successfully although over tightening of the strap was described as problematic and causing discomfort and/or issues with setup by P4 and P6.

A number of participants felt that fitting the sensor would be easier if it were smaller. The idea of multiple sensors, of a smaller form factor was discussed by P13 as a way of more easily locating the muscle activation site. A number of participants wanted to be able to stick the sensor easily to different locations on their body, such as their face.

Experience of use of EMG switch

A number of participants experienced the use of the EMG switch as being less tiring, and for some quicker, than a conventional switch.

> I found it much faster and less tiring than the switches with my thumb" … "I use it all the time now and even in my bed occasionally for some games, which was not possible with the other switches. (P4)

As can be seen in the quantitative performance data, some participants experienced false activations and discussed the ease of accidental activations when using the EMG switch. P13 for example attributed this to the nature of the EMG switch as being a sensor switch.

> It's because it's not physical. It's easy to press an error (P13)

As a body mounted switch some participants also noted that there was benefit to being able to use the EMG switch in a range of positions. A number of participants discussed other parts of the body where they might try or want to use an EMG switch, with leg/calf and jaw/facial muscles suggested by participants.

> Opens up new locations (e.g., couch/bed) other than my wheelchairs to use switches. (P5)

Participants all suggested design improvements when discussing the experience of use of the device.

Mounting and form factor, were discussed by a number of participants in the context of potential improvements in design (and as above, in terms of limitations to the feasibility of the use of the device in its current form factor). P13, for example, discussed aspirations for the device to be similar to small coin shaped glucose monitoring patches that P13 had seen and which attached to the skin for a day or a few days.

Charging and batteries were raised with practicality of charging the Patient Unit (which charged wirelessly when placed one way up on the Base Unit) raised by some participants. Participants also suggested that the battery indication on both devices should be clearer and give more warning when either unit was on low battery and when fully charged.

The receiver Base Unit design was raised by some participants with P11 and P13 both suggesting that this could be eliminated and that the patient unit should connect directly to the target assistive technology device. These participants also both linked this to envisioning adjusting the threshold and other settings of the sensor *via* an app.

> I think I said the other week about it being direct Bluetooth to the device it's controlling. So if that could go straight into your iPad for example (P13)

Extending this idea some participants also raised the aspiration to not need to set a threshold. Participants suggested having an algorithm or learning phase that allowed the threshold to be set and then adjusted in session if needed. P11 also discussed aspirations for the device to automatically ignore movements which were not switch activations, e.g., the longer muscle activations associated with moving P11's hand to make it comfortable.

Discussion

The aim of this study was to explore the feasibility, usability and acceptability of an EMG switch in comparison to conventional electro-mechanical switches for control of assistive technology devices.

Feasibility

The study demonstrates that EMG switches are feasible to be used in a range of placements: the EMG switch was used to acquire signals from a range of participants' muscles. Signals were acquired from muscle activations which would be impossible or challenging to use with an electro-mechanical switch such as facial muscles. Signals were also acquired from extension or abduction movements that are less commonly captured with electro-mechanical switches, such as thumb abduction.

Participants with a range of medical conditions participated and where able to achieve signal acquisition. In this study those with MND, DMD and BSS appeared to find the switch most feasible: the retention rate within the study was highest for these participants and their performance data and qualitative feedback was generally more positive. One of the two participants with MS completed the study but with poorer performance results that the conventional switch. The participant with CP who completed the initial data collection visit was able to acquire a signal with the sensor placed to pickup facial muscles, but when using the EMG switch in this location the participant experienced a large number of false positive activations. The data from this study may thus suggest that the EMG switch currently has more potential for those with hypokentic movement disorders. These findings can only be considered indicative at best though: as an exploratory study the study method did not aim to test specific hypothesis or evidence an effect for specific cohorts of assistive technology users. These data suggest that EMG switching may not currently be feasible for those with hyperkinetic movement disorders but further work should be carried out to explore this more fully. Equally these findings may suggest that technical development exploring the potential of these switches in these cohorts is warranted: machine learning approaches to distinguish between intended and unintended movements and calibrate the system may offer great potential to overcome many of the issues experienced by participants.

P14 demonstrates the feasibility and acceptability of use of the switch in more extreme situations. In this situation there were no observable movements but the EMG switch allowed acquisition of muscle signals, demonstrating that despite the lack of visible movement, there was some innovation of a small number of muscle fibres. Comparing the EMG signal from P14 (Figure 2) with that from P11 (Figure 4, in Supplemental Material) it can be seen that P11's signal is clearer and less noisy, resulting in a lower baseline signal from the Emego algorithm and more clearly defined signal peaks.

Performance

For some participants in this study the EMG switch also appeared to offer potential performance advantages over conventional electro-mechanical switches with faster reaction times being recorded for five of the eight participants. This is despite participants having minimal exposure to the EMG switch, i.e., without extensive training and learning of the device operation which might be expected to improve performance. These data cannot be generalised and it is likely that these performance gains will not alter the acceptability of these switches to the majority of those who use switches, however "marginal gains" may well have a significant impact for some individuals or when used in high performance environments such as gaming.

In addition to performance improvements a number of participants reported that the EMG switch was less effortful to use than their conventional electro-mechanical switch. Again, this cannot be generalised and is unlikely to be a factor that will affect the acceptability of use of EMG for the majority of those using switches, but could be a key factor for some where stamina and fatigue are an issue.

Usability

These data suggest that the acceptability of current EMG switches is limited beyond the situations where EMG may be the only option or where it offers performance improvements. In their current form EMG switches are unlikely to be widely adopted as a replacement for electro-mechanical switches. Participants listed the false-positive rate and usability issues as being the main reasons for this.

Key usability issues related to the device setup and the demands this placed on those supporting participants. Participants wanted the device setup to be simpler or require no specific setup. Two key components of usability participants felt present design challenges: positioning and mounting of the device and calibration.

This study provides a roadmap for those developing EMG systems that might overcome acceptability and usability issues and drive uptake. These data suggest that development of future EMG systems should aim to:

- Remove the need to setup and calibrate the threshold and eradicate false positive activations, e.g., through the use of machine learning to filter out unintentional and non-switch activation muscle activations.
- Remove the need for accurate placement, e.g., through the use of a matrix of sensors – for example as demonstrated by Ma et al. [20].
- Increase the feasibility of placement of the sensor, e.g., through smaller form factor devices or through technologies such as micro-needle patches or tattoos – for example as described by Fu et al. [21].

Switch performance data

The study gathered switch reaction time performance data from participants using conventional electro-mechanical switches as well as the EMG switch. There is a paucity of data published around switch reaction times for those who use assistive technologies. Koester & Simpson [15] provide an evaluation of the Scanning Wizard tool with participants who used switches for assistive technology and report text entry rates but not reaction times. In a study related to the design of their innovative Nomon scanning system Bonaker et al. [22] simulated the switching performance of assistive technology users and used switch reaction times of approximately 300 ms to 1200 ms as the basis of this simulation. Bonaker et al. stated that these data were obtained from the studies reported in Koester & Simpson [15,23] however these data were not reported in the original papers and were plotted, not tabulated, by Bonaker et al. Beyond these papers, and despite the significance of switch access as an access method, little or no other empirical quantitative data appears in the literature about switch performance in this population.

P14 again provides an interesting case example as the switch reaction time and false positive rate that P14 achieved in the switching task may be considered by practitioners to rule out P14 from functional use of switches for scanning. Indeed the "Switching Difficulty Score" provided by the Scanning Wizard software used in this study placed P14 in the "amber" or "red" zone where the advice issued is "the current switch setup may not allow for effective use of scanning" [17]. P14, however, is an established switch scanner using the EMG switch with the inbuilt switch scanning of an IPad™ operating system. This discrepancy could be explained in a number of ways: it may be that outside of the test environment P14 may achieve more better performance; that P14 has strategies to cope with false positives; that the scanning system P14 uses is able to adapt to relatively error-full input; or that P14 tolerates this level of performance as it still provides utility compared to P14's alternative partner-assisted method. P14 again highlights the limited empirical evidence about switch use, switch scanning and strategies of use within this population.

These data suggest that reaction times of between 500 ms and 1500 ms might be a reasonable range to assume for those using switches for assistive technology and this concurs broadly with Bonaker et al. [22]. It might be assumed that the large range of switch reaction timings are linked to the underlying conditions of those using switches however these data suggest a more complex picture: for example the participant with CP (P5) was able to achieve a reaction time of 587 ms using their conventional switch and this is comparable to the participant who achieved the fastest conventional switch reaction time (P11, 558 ms) who had DMD. These data contribute to, but also demonstrate the paucity of, current empirical performance data and highlight the need for further data collection from new and established switch users to create a better understanding of switch performance in the population of those who use assistive technology.

Future directions for switch access

EMG is one of a possible range of technologies that has been used or is being developed with the aim of improving on conventional switch access for those using Assistive Technologies.

Brain Computer Interface technology is often cited as another potential technology that may also offer potential for improved or alternative switch access *via* techniques such as motor imagery or evoked potentials [24]. BCI technology is, in both invasive and non-invasive types, relatively intrusive and also requires learning of a new mode of control that is not something naturally acquired or experienced in everyday life.

Sensor based technologies, such as pressure sensors, capacitive sensors and InfraRed sensors offer the ability to detect small movements, however these sensors are often complex to setup and not body-worn. Other innovative sensors have been investigated to take advantage of other movements of muscles whose control may be retained in a wide range of conditions, for example tongue movement [25] or the inner ear tensor tympani muscle [26].

Camera based detection of movements is another well-established assistive technology access method [27] and one which promises future improvements, particularly with the advent of machine learning of gestures. These systems however tend to require significant image processing – i.e., need to run on a computer – and also require a camera to be positioned to see the user/the interaction site.

Comparing EMG against conventional switches and these other potential access methods suggests that EMG has potential to offer a high performance, relatively intuitive, body worn and standalone assistive technology switch. This study suggests that, alongside development of these other potential assistive access methods, EMG systems warrant further development and evaluation.

Limitations of this study

This was an exploratory descriptive study that aimed to investigate the performance, feasibility and usability of a novel EMG switch. Recruitment to this study was opportunistic and did not include a control arm. As such the findings from this study cannot be generalised to the wider population of those who use assistive technology. The study method did not include analysis of the raw EMG data and this might provide further useful insights in a future study. This study does however provide indicative data which points towards the utility of future studies and development relating to EMG switches.

A number of participants withdrew from the study after the first visit and although the reason for withdrawing was not recorded it is likely that this skewed the sample towards those more likely to find the EMG switch acceptable.

Switch performance data collected in this study was collected with the purpose of exploring the novel EMG switch and not with the aim of characterising switch performance data in this population and again as such these data cannot be generalised. Despite these limitations these data, both for the conventional and EMG switch, might be considered to provide some useful foundational indicative switch performance data.

Conclusions

The current study suggests that EMG switches are feasible to use for assistive technology control for a range of participants who use assistive technology. The study suggests that currently these switches may be most suited to those with minimal hypokinetic movements who are well supported by those who are able to configure and setup the EMG switch. The study suggests that EMG use may have particular utility in situations where electro-mechanical switches cannot be used or where performance or fatigue is a key issue.

This study also provides empirical data about the performance, namely the reaction time, of individuals using assistive technology switches and EMG switches. These data suggest that EMG switches can out-perform conventional electro-mechanical switches when used by individuals who use assistive technology living with a variety of conditions. This study also suggests that the reaction times of those using assistive technology switches can vary across a relatively large range with a range from 483 ms to 1881 ms recorded in these data.

There are a number of technical developments that need to happen before EMG switches might be more widely adopted as an assistive technology control method. This study highlights the potential for future EMG switch development and suggests that this could yet have a transformational impact on switching access to assistive technology.

Note

1. Indeed, historically within the literature the term MicroSwitch has often been used to refer to assistive technology switches (3).

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