Title: Accelerometers-embedded Lycra sleeves to test wear compliance and upper limb activity in people with stroke: A feasibility study

Abstract

Background: To establish a possible effect of Lycra sleeves, accurate recording of wear time is critical. The aim of this study was to test whether an accelerometer-embedded Lycra sleeve can measure wear compliance and record upper limb (UL) movements/activity in people with stroke. **Methods**: A convenience sample of seven adults with stroke resulting in unilateral UL weakness were approached. Participants wore accelerometer-embedded Lycra sleeve on their affected arm for 8-10 hrs/day for 14 days and were prescribed four simple upper limb exercises. They completed a diary to record daily sleeve wear time and exercise times. Upper limb function, shoulder muscle strength, range of movement and pain were assessed at day 1 and 14. **Results**: **Seven participants were approached and** five participants (72±10 years) were recruited. **Mean time since stroke was 20 months.** Using an acceleration movement threshold of 0.01g (g=acceleration of gravity) and the constructed algorithm the sleeve donning and doffing time was identified. Mean accelerometer and diary recorded wear time were 11.64 hours/day (SD 2.64) and 11.27 hours/day (SD2.03) hours/day respectively. Individual spikes above threshold indicated UL activity but could not distinguish participant-recorded exercises from daily UL use. Arm function showed improvement in three out of five participants. **Conclusions:** Accelerometers provide a practical method to record wear-time of a Lycra sleeve, overcoming the necessity for patients to keep diaries, which can often be unreliable. A more sensitive accelerometer, which can detect the direction of the acceleration and movement should be considered in future study. **Clinical Relevance: Accelerometers provide accurate data on Lycra sleeve wear-time and may help with monitoring adherence.**

Key words: Accelerometers, Lycra Sleeves, Wear compliance, Upper limb Activity, Stroke

ABBREVIATIONS

AGT- Acromion-greater Tuberosity

g - acceleration of gravity

GHS – Glenohumeral subluxation

HSP – Hemiplegic shoulder pain

MRC - Medical Research Council

NPRS - Numerical Pain Rating Scale

ROM – Range of Movement

RMS - root mean square

UL- Upper Limb

UL MAS – Upper Limb Motor Assessment Scale

Introduction

Stroke is the leading cause of adult complex disability worldwide with up to 70% of stroke patients suffering loss of upper-limb (UL) function.[1,2] Common musculoskeletal complications include glenohumeral subluxation (GHS), hemiplegic shoulder pain (HSP) reported in 81% and 84% of people with stroke respectively that can **contribute** to poor UL function.[3,4]

A wide range of UL orthosis are prescribed to support the weak arm following stroke and a few are found to be effective in reducing GHS and HSP.[5] However, the majority of the available orthoses lack effectiveness and have designs that limit functional use of the arm, **potentially** contributing to learned non-use.[4,6] A Lycra sleeve fits from the wrist to the middle of the upper arm and provides a compressive and supportive effect. It is flexible, lightweight, and **allows** active movement when compared to its rigid counterparts,[7] hence it is referred to as dynamic. Lycra sleeve is found to be comfortable and acceptable for use by people with stroke.[8,9]

Previous studies have shown some clinical benefits of Lycra sleeve in people with stroke.[7,8,9] A recent study on chronic stroke (n=5), when ultrasound measurements of acromion-greater tuberosity (AGT) distance were taken from “sleeve off” on day one and compared with “sleeve on” on day 8, it showed a mean reduction of 0.27 cm suggesting reduction in GHS.[8] Three patients’ experienced decreased pain and one patient showed improvement in the upper limb function. In that study patients were advised to wear the sleeve for at least 7 hrs/day for seven days, which they confirmed relying on their memory.[8]

In contrast, in a recent feasibility randomised trial, patients in the intervention group wore the sleeve for 8 hrs/day for 8 weeks and were also asked to complete a diary to record daily frequency and duration of wear.[9] The study found a small margin of improvement in upper limb function in the intervention group over the control group at 8 weeks but this effect was reversed at 16 weeks. The study concluded that the outcome may reflect low wear compliance, as patient diaries were incompletely filled in and many participants abandoned them altogether.[9]

Reliability and validity of patient diaries is questionable[10] because they are inherently limited by person-error.[11] This limitation is more pertinent in the stroke population due to impaired hand function, increased cognitive and perceptual impairments.[12] To establish a possible effect of Lycra sleeves on UL impairments in people with stroke, accurate recording of wear time is critical.

In recent years, accelerometers have been found to be a reliable and valid way to monitor and gather physical activity data on gait, UL movements and functional tasks in people with stroke.[13,14] Accelerometers can continuously measure body movements based on accelerations over a long period in a home-based situation, and are generally perceived as user friendly.[13] More recent evidence suggests that wrist-worn accelerometers can distinguish between moderate and severe hemiparesis post-stroke with an accuracy of 91%, when participants are performing known movements.[15] Evidence suggests that accelerometers provide a feasible alternative to patient-reported measures,[11] and if used in conjunction with a Lycra sleeve, could provide reliable and valid information on both sleeve wear time and UL activity.

Limited low quality evidence suggests that the Lycra sleeve might be a useful treatment option for reducing GHS subluxation, pain and improve upper limb function in people with stroke.[7,8,9] To the best of our knowledge, no previous study has investigated electronic monitoring using accelerometers to determine wear compliance of Lycra sleeves. The aim of this study was to test the feasibility of using an accelerometer-embedded Lycra sleeve to measure wear compliance and record upper limb movements/activity in people with stroke.

Methods

Study Design:

This was a feasibility prospective cross-sectional study, and received ethical approval from the Research Ethics Committee, XXXXX XXXX XXXXX XXXXX, XXXXX. XXXXXXX (XXX REC REF HAS.20.01.101). Each participant gave informed written consent to take part. This study adhered to the guidelines of the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement.[16]

Participants

Due to a limited number of accelerometers available, the sample size was restricted to seven. People aged older than 18 years, with a stroke resulting in one-sided weakness, shoulder muscle strength ≥3 on the Medical Research Council (MRC) scale, medically stable and able to provide informed written consent were eligible to participate. People with other neurological or serious co-morbidities were excluded. Participants were recruited from the community via Bristol After Stroke, a voluntary organisation.

Apparatus

A triaxial accelerometer (Axivity AX3, Axivity Ltd, Newcastle upon Tyne, UK) was used to measure movement activity. Lycra arm sleeves (Jobskin Ltd UK), were used in this study. The accelerometers were inserted into pockets sewn into the Lycra sleeves, ensuring orientation of the accelerometers were consistent across all participants. Accelerometers were calibrated using Open Movement OMGUI software (available at www.github.com/digitalinteraction/openmovement/wiki/AX3-GUI), with an acceleration sensitivity between -8g and +8g and a sample rate of 50Hz. These settings were chosen as a balance between recording precision and maximising device battery life. **The maximum error seen in timing between samples is about 5%**

Prior to commencing the main study, pilot data was collected from a young, active person to provide derivation and testing of data processing algorithms for the main study. The subject wore the sleeve with an accelerometer for one day, precisely recording times when the sleeve was donned and doffed. Pilot data was also collected with the sleeve left unused for one day, and in the subjects backpack for another day. An algorithm based on Choi et al[17] was developed to determine whether the Lycra sleeve was being worn or not, and to estimate the daily wear time (Figure 1). The Lycra sleeve was donned at 09:25 and doffed at 17:25 by the subject. The root mean square (RMS) for total acceleration was found to be the most appropriate output. It was observed that during known 'non-wear' periods, the RMS acceleration value did not rise above 0.01g (g=acceleration of gravity, constant=9.8 m/s^2). Mirroring this, during periods of known 'wear', acceleration values were considerably larger than 0.01g for the majority of the time. Past research has shown that some periods of accelerometer inactivity are possible during the day, and that if these last less than 90mins they should still be considered ‘wear’.[17] As people with stroke may exhibit sedentary behaviours,[18] the chosen parameters prevent the misclassification of inactivity as non-wear.[17]

Insert Figure 1

Procedure

Baseline demographic data including age, gender, time after stroke and affected side were gathered from the participants as medical record access was not available. The following assessments were completed on day 1 and day 14. A standardized protocol was used and researchers practiced this on three colleagues before actual data collection. The following assessments were undertaken: 1) shoulder range of movement (ROM) using visual estimation, which is considered as effective as using goniometry[19]; 2) shoulder strength using the Medical Research Council (MRC) grading scale[20]; 3) shoulder pain using the Numerical Pain Rating Scale (NPRS).[21] 4) upper-limb function using upper-limb section (6, 7, 8) of the Motor Assessment Scale (UL-MAS).[22] 5) The ArmA is a patient-reported outcome score with two components.[23] The ArmA-A asks patients about their ability to care for their affected arm either themselves with their unaffected arm or by a carer or a combination of both of these. ArmA-B asks patients about how easy or hard it is to use the affected arm in activities of daily living.

Following this, according to the manufacturers' recommendations, the wrist circumference was measured for each patient and the correct size sleeve was

provided. The sleeve was worn superior to the wrist joint up to the insertion of the deltoid on the humerus, with the accelerometer on the lateral aspect of the humerus (Figure 2). Participants were instructed to wear the accelerometer-embedded Lycra sleeve for 8 to 10 hours a day during active waking hours for 14 consecutive days. Finally, the following upper limb exercises were demonstrated to the participants to be completed once daily with the affected arm: 1) shoulder flexion range of movement 2) shoulder abduction range of movement 3) moving an object from left to right side and return on a flat surface 4) reaching for two targets (higher and lower) in front. A wear diary was provided for participants to record Lycra sleeve don and doff times, and when exercises were completed. Participants were informed that accelerometer-embedded Lycra sleeve would capture movements of the upper limb undertaken during exercises and functional tasks.

Insert Figure 2

Data analysis

Statistical Package for the Social Sciences (SPSS) software, version 26.0 (IBM, Chicago, IL. USA) was used to generate descriptive statistics on participant demographics, clinical assessments, outcome measures and wear time (both accelerometer and self-reported). Data from accelerometers were extracted at one and two weeks after commencing collection. The week's datasets were processed by a Python software package, developed in partnership with Bristol Robotics Lab (BRL) (software and instructions are available at www.github.com/isopleth/kinetics). The outputs from this software contain aggregated accelerometer data for each minute and displayed in visual graphs. These graphs were sued to generate descriptive data on Lycra sleeve wear time and time the prescribed exercises were performed in the form of mean/ Median/ standard deviation. Data on participant-reported wear compliance (recorded in supplied wear diaries) is presented as mean wear time per day (time difference between donning and doffing) and total number of hours worn over 14 days period. **Individual patients' data on clinical outcomes (strength, range of movement, NRPS, ArmA and UL-MAS score) were reported**

Results

Seven participants were recruited. There was one incident of adverse-effect (allergy to Lycra, not requiring medical attention), and one drop-out due to poor sleeve fit. Five participants completed the study. Demographics are displayed in Table 1.

One participant was unable to wear the sleeve for one day due to illness, so this data was excluded from wear-time analysis. One diary was completed incorrectly (don/doff times were not recorded), so was not included in diary-calculated wear-time. The mean accelerometer and diary wear-times were 11.64 (SD 2.64) and 11.27 (SD 2.03) hours per day respectively. Median participant-recorded exercise time was 15:00 **hours** (range = 08:00 to 22:00 **hours**) with a mean time of 20 mins /day spent on exercises.

Insert Table 1

Application of the algorithm to participant data allowed calculation of wear-time. RMS acceleration values were examined until the first incidence of threshold (>0.01g) data (excluding movement artefact) was observed. This was labelled sleeve 'donning'. Following this, where the RMS acceleration value dropped below threshold (<0.01g) for at least 90mins, the last preceding timestamp where a threshold value appeared was taken as sleeve ‘doffing’. Wear-time per day was the difference in time between donning and doffing, including any sub-threshold periods of less than 90mins. Table 2 shows a sample period of participant data to demonstrate how these rules are applied to identify sleeve donning **(09.00)** and doffing (19.30) times.

Graphs were generated from accelerometer data using the Python scripting language. An annotated example can be seen in figure 3, which also includes diary recorded donning, doffing and exercise times superimposed onto the graph. Individual spikes above threshold indicate ‘movement events’ and reflect a minute in which movement of the upper limb occurred. ‘Wear’ periods are noted by consistent movement events, with few readings below threshold. At the participant-reported exercise time, there is no obvious change to the pattern of recorded movement events.

Insert Figure 3

For one participant who was unable to attend the second session, ARM-A follow-up was taken over the phone and other outcome measures were unable to be obtained. Two participant’s UL-MAS scores improved, and two remained unchanged. All participants noted an improvement in passive hand/arm function (Arm-A subscale-1), with three also noting improvements in active arm/hand function (Arm-A subscale-2). OMs data are displayed in Table 3.

Insert table 3

Discussion

This study aimed to test the feasibility of using an accelerometer to measure Lycra sleeve wear-time in participants with stroke. Results suggest it is possible to identify Lycra sleeve wear-time from data, and to view movement activity via graphs. Average wear-time was 11.64 hrs/day. Similarly, wear-time recorded in diaries was 11.27 hrs/day, however, errors were made with diary use.

Wear-time calculations were possible due to the identification of a threshold for movement. A threshold of 0.01g RMS acceleration was used in our study. In contrast, Van der Pas *et al.*[14] used peak accelerometer motion over one minute periods with movement threshold reported as 0.05g. Also, that study positioned the accelerometers at the wrist in contrast to the upper arm in our study which may have an effect on the accelerometer recordings. As our threshold was empirically chosen, there may be a range of threshold values which yield similar wear-times. Several other studies used more sophisticated processing techniques for the accelerometer data[24,25,26] and should be considered to improve accuracy in future studies, particularly with individuals with very limited UL use.

The accelerometer and diary average wear-times were similar in our study. This disputes previously noted inaccuracies in diary recording.[9] Variance may be partially attributed to the 'Hawthorne effect', whereby people intentionally perform better when they know they are being observed.[27] Our participants may have been more likely to comply with the procedures of this study because they were already motivated to attend an exercise group and knew that the accelerometer in the sleeve was recording their movements.

The results from our study indicate average wear-time in this study was above the recommended target of 8-10hrs/day. Morris *et al*.[9] found an average wear-time of 8hrs/day over 56 days. Variance between our findings and past research may be attributed to shorter time-period of our study, which may have increased usage. Accelerometers and sleeves may serve as an external cue, whereby participants may utilise the monitored limb more than normal.[11] The sleeves and accelerometers may have also been a novel experience for participants, therefore, coupled with the short intervention period, wear-time identified in our study may not reflect a participant's typical day. However, if UL use can be increased by accelerometers and sleeves, this may enhance recovery of the affected UL as they may utilise it more during ADLs.

Statistical analysis was not performed due to small sample size, however, interestingly, all participants' ARM-A section A (passive arm function) improved, and three noted improvements in ARM-A section B (active task ability). This could be attributed to increased use during the 14 days period, which may have been encouraged by the sleeve and accelerometers.[28] Two participants reported reductions in ARM-A section B (active task ability), **and a reduction in active function.** UL-MAS scores stayed the same (n=2) or increased (n=2), signifying little or no change in function. This is not surprising, as these two participants scored highly at baseline and the intervention period was short.

Higher accelerations represent quicker movements, which are associated with greater strength.[29] Therefore, from our data it may be possible to infer that participants with greater accelerations may have greater strength. This is supported by another study that concluded identifying the highest amplitude per second was a valid method to assess UL activity post-stroke.[14] However, speed alone cannot give information on the quality of movement, for example control or co-ordination, nor differentiate between active (e.g. functional) versus passive movements (e.g. limb swing during gait, car travel).[11] Consequently, speed on its own may be insufficient to make clinically meaningful inferences regarding UL use.

Graphs were visually examined to identify prescribed exercises by corresponding the timestamp as recorded in diaries. It was not possible to identify any notable changes in patterns or size of accelerations occurring at this point. Unsuccessful activity recognition may be attributed to methodological differences. In our study, majority of the participants had a relatively highly functional arm and we used only one sensor to monitor the activity. In addition, due to software and time limitations, activity recognition was conducted visually from reviewing graphs, which is prone to human-error. In contrast, other accelerometer studies used machine learning based pattern recognition techniques to identify actions, used multiple sensors on different limbs[30] and created a 'blueprint' by supervising a set of exercises before identification from real-time wear.[15] The clinical viability of these methods may be limited due to time, resources, knowledge of algorithms and variability in people. Successful activity recognition would be of use in future studies on Lycra sleeves in order to confirm compliance with treatment. Furthermore, successful activity recognition, particularly if used in conjunction with meaningful information on UL use, could allow future trials to identify those at risk of deterioration,[15] or for helping guide the individualization of treatment plans.[30]

This study has several limitations. Firstly, a small convenience sample was selected which was prone to selection bias, limiting generalizability. Secondly, data analysis was primarily conducted manually, which is time consuming and prone to human error. Third, the effect of walking on UL activity was not addressed in this study. It is important to acknowledge that the accelerometer is also sensitive to general activity, such as arm swing whilst walking, and so accelerometer data must be interpreted cautiously. A more sensitive accelerometer, which can also record the direction of the acceleration, should be considered in future study to gather information on direction of movement. Finally, bilateral accelerometers to identify activity of the paretic limb in relation to the non-paretic limb would be highly beneficial to create a ‘ratio’ between the two to give an indication of relative affected upper limb use or disuse and function.

Conclusion

In conclusion, it is feasible to use accelerometers to measure hours of usage of Lycra sleeve. This will help improve the quality of future trials investigating the effect of Lycra sleeves on UL function, by overcoming the need for tedious and unreliable participant-recorded diaries. This study was unable to differentiate UL exercises from daily UL use, therefore if activity recognition is desired, accelerometers with directional information and advanced machine learning analysis techniques are required.

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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 article.

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Suppliers

a. Jobskin Limited UK, Unit 13a Harrington Mill, Leopold St, Long Eaton, Nottingham NG10 4QG

b. Axivity AX3, Axivity Ltd, Newcastle upon Tyne, UK

c. IBM UK, Business Analytics - SPSS, 2 New Square (B32S), Bedfont Lakes, Feltham, Middlesex TW14 8HB, UK.

Figure Legend:

Figure 1: An Algorithm to determine sleeve wear time based on Choi et al (2011)

Figure 2: Application position of the Lycra sleeve on the arm. The accelerometer in its pocket next to the label.

Figure 3 Example data on Lycra sleeve wear for one participant over 24 hours period