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SHORT COMMUNICATION

Wrist activity monitor counts are correlated with dynamic but not static assessments of arm elevation exposure made with a triaxial accelerometer

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There is evidence in the literature of a link between workplace arm elevation exposure and atraumatic shoulder injuries. However, there are several methods that can be used to assess this exposure. The goal of the present study was to compare the outcomes of an activity monitor attached to the wrist and a triaxial accelerometer mounted on the humerus. Twenty-one workers wore both sensors over the course of a full workday. While the activity monitor data was not significantly correlated with any static humeral parameters, it was strongly correlated with all dynamic parameters. The use of a simple, commercially available activity monitor might offer an inexpensive alternative for the assessment of a large number of subjects over multiple workdays to determine the relationship between dynamic motion and occupation shoulder injuries in the future.

Practitioner Summary: Arm overuse has been linked to occupation-related shoulder injuries. An activity monitor attached to the wrist and a triaxial accelerometer mounted on the humerus were compared in a field trial. The results demonstrate that, under certain conditions, a commercially available activity monitor might be a useful tool for exposure assessment.

Keywords: shoulder; exposure; accelerometers; overuse injuries

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1. Introduction

According to the National Occupational Research Agenda, work-related musculoskeletal disorders of the upper extremities in the United States account for over $2 billion in workers' compensation costs (1996), with total direct medical costs of $4 billion annually (Melhorn 1998). In recent years, there has been a dramatic rise in the number of occupational shoulder injuries (Sommerich *et al*. 1993), with the Bureau of Labor Statistics (2010) reporting that, for the most recent year available, there were over 86,000 reported occupational injuries of the shoulder involving days away from work, representing 13% of all musculoskeletal injuries. The prevalence of shoulder pain in the working population is approximately 12% (Miranda *et al*. 2005) but ranges from 26% to 81% in high-risk populations (Oberg and Oberg 1993, Pope *et al*. 2001, Leclerc *et al*. 2004). There is now a preponderance of evidence, from both cross-sectional (Ohlsson *et al*. 1995, Pope *et al*. 2001, Svendsen *et al*. 2004a, Miranda *et al*. 2005, Silverstein *et al*. 2008) and prospective studies (Miranda *et al*. 2001, Harkness *et al*. 2003, Leclerc *et al*. 2004), of a link between overuse and workplace shoulder injuries. This was confirmed in a comprehensive report by the National Institute for Occupational Safety and Health (NIOSH; Bernard 1997) as well as a recent systematic review by Van Rijn *et al*. (2010).

A review of the literature reveals that the de facto standard technique for directly assessing occupational overuse exposure at the shoulder is with an accelerometer mounted on the humerus. This methodology has gone through several lab-based validation studies (Hansson *et al*. 2001, 2006, Bernmark and Wiktorin 2002, Luinge *et al*. 2007, Coley *et al*. 2008, Amasay *et al*. 2010) and has been used in field-based studies by a great number of investigators (Wiktorin *et al*. 1995, Fernstrom and Ericson 1996, Vasseljen and Westgaard 1997, Sporrong *et al*. 1999, Paquet *et al*. 2001, Moller *et al*. 2004, Svendsen *et al*. 2004a, Jonker *et al*. 2009, Hansson *et al*. 2010). An alternative approach for assessing general ambulatory arm movements has been to use a commercially available system that converts acceleration data to arbitrary units of movement 'counts' using threshold crossings, maximum values or integration algorithms (Chen and Bassett 2005). Although originally developed to serve as surrogate measurements of energy expenditure (Trost *et al*. 2005), this methodology has been adapted for assessing movement of the upper extremity by placing a sensor on the wrist. This approach has mainly been used to examine arm usage in patients with neurological conditions (Schasfoort *et al*. 2003, Uswatte *et al*. 2005, Vega-Gonzalez and Granat 2005, Lang

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et al. 2007). However, Estill *et al*. (2000) have also demonstrated that this methodology was also able to detect differences in occupational upper extremity activity levels between workers known to have different hand usage patterns.

While placing a sensor on the humerus provides a more direct assessment of shoulder activity, measuring activity counts with a commercially available sensor on the wrist has many advantages, such as ease of use, multiday recording capability and the availability of companion software. However, to our knowledge, there have been no studies that have directly compared these two approaches. Therefore, the goal of the present study was to perform a field-based study in workers to compare the outcomes from these two approaches. We hypothesised that the activity counts as measured from the wrist would be correlated with the assessments of dynamic humeral motion parameters, but not static parameters.

2. Methods

2.1. Subjects

Twenty-one healthy individuals (9 males and 12 females) with a mean age of 37 (SD 13) years, a mean body mass of 78 (SD 18) kg and a mean height of 170 (SD 9) cm agreed to participate in this study (Table 1). According to the Edinburgh Handedness Inventory (Oldfield 1971), 19 subjects were classified as being right handed and 2 were left handed. To be included in this study, subjects were required to be employed and be able to participate on an 8-h workday that was representative of at least 3 days of their work week. Subjects were asked about the health of their shoulders and any subject that reported a past or present shoulder injury was excluded. Prior to testing, all subjects read and signed an informed consent form approved by the Institutional Review Board at the University of Oregon. There were originally 26 subjects, but 2 were excluded because they slept for part of the day and 3 were excluded because they returned to the lab with one of the devices having been removed.

2.2. Data collection

Data from the arm were collected bilaterally with the MSR145WS triaxial accelerometer (MSR Electronics GmbH, Henggart, Switzerland), which measures 20 mm × 15 mm × 61 mm and has a mass of 23 g. This device is completely self-contained, with a lithium-polymer internal battery and the capability of recording two million measurement parameters. We have found that the accuracy of this device is similar to other triaxial

Table 1. Subject demographics. Self-reported activities were summarised from the most common activities reported on the activity logs.

Occupation	Self-reported activities	Sex	Age
Library circulation manager	Computer use, shelving journals	F	53
Computer programmer	Reading, computer use, driving	M	38
Computer-aided designer	Computer use, phone calls	M	23
Researcher (computer)	Computer use, writing	F	25
Personal assistant	Computer use, driving, physical labour	M	49
Computer-aided designer	Computer use, mechanical set-up	M	54
Computer worker	Computer use, reading, relaxing	M	38
Nutritional consultant	Reading, computer, phone	F	52
Supervisor at coffee shop	Working register, cleaning, making and serving coffee	F	26
Childcare	Shopping, playing with kids, reading	F	25
Nurse's assistant	Patient care, paperwork, computer	F	22
Housekeeping	Clean houses, driving	F	46
Cashier	Cashier work, cleaning	F	20
Lab technician	Computer use, working in hood, washing	F	34
Resource development	Writing, computer use	M	25
Web designer	Computer use, computer repair	M	43
Retail sales	Helping customers, register work, folding clothes	F	20
Postal clerk	Computer use, lifting parcels	M	60
Emergency medical technician	Washing ambulance, data entry, ambulance call	M	46
Data entry (computer)	Computer use	F	38
Office worker	Paperwork, computer use, phone calls	F	34

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accelerometers we have tested (Amasay *et al*. 2009). The subject was instructed to maintain a seated upright posture while holding a 1-kg weight. Direction was given to perform lateral trunk flexion, which resulted in a perpendicular orientation of the arm to the floor (Hansson *et al*. 2006, Acuna *et al*. 2010). During this alignment procedure, the triaxial accelerometer was connected to a computer so that the acceleration parameters could be observed in real time. The device was oriented vertically by positioning the device until the long-axis accelerometer read as close as possible to 1 g. At this point, it was attached to the lateral side of the humerus, just proximal to the deltoid tuberosity, with double-sided tape. The area of skin surrounding the triaxial accelerometer was outlined for observation of possible displacement during the experiment. It was then programmed to record raw *x, y* and *z* accelerometer data automatically for a designated 8-h time period at 10 Hz, and was then disconnected from the computer. This procedure was performed for both upper extremities.

Following the placement of both triaxial accelerometers, an Actical physical activity monitor (Philips Respironics, Bend, USA) was placed on each wrist. This device measures 28 mm × 37 mm × 11 mm and has a mass of 16 g. Unlike the triaxial accelerometer, the activity monitor uses a uniaxial accelerometer to calculate cumulative 'activity counts' for a given epoch, which was set to 15 s for the present study. These counts are provided through the companion software for this product. The general algorithm to determine these counts is detailed in the next section. The placement of the activity monitor was on the wrist with the use of an adjustable Velcro strap. The activity monitor was programmed to start recording at the same time as the triaxial accelerometer.

Subjects arrived in the lab at least 1 h prior to the start of their workday for placement of the devices. Each device was programmed to start data collection at the start of the subject's workday, so that the time in the lab and commuting time were not included in data collection.

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2.3. Data analysis

Once the subject returned to the lab, data were downloaded for analysis with custom written LabView (National Instruments, Austin, USA) programs. For the activity monitor, we used the activity counts as reported by the companion software. For the triaxial accelerometer, first the raw accelerometer data were converted to elevation angles with respect to gravity (Amasay *et al*. 2009), and then a series of static and dynamics parameters were calculated. The static parameters included the per cent time above a threshold elevation angle (30°, 60° and 90°; Svendsen *et al*. 2004a) and the 50th, 90th and 99th percentiles of arm elevation (Hansson *et al*. 2010). The dynamic parameters included the 50th, 90th and 99th percentiles of arm velocity (Svendsen *et al*. 2004a), jerk time (Moller *et al*. 2004) and a parameter similar to activity counts (Acuna *et al*. 2010). Arm velocity was calculated by differentiating the elevation angle data set using the central difference method. In order to calculate jerk time, the entire data set was run through an algorithm that looked for the number of adjacent data points contained within a single 10° bin (e.g. 0–10 and 10–20). If the number of points within that bin represented a time of less than 1 s, the points were classified as dynamic; otherwise, they were classified as static. The jerk time was defined as the number of dynamic points divided by the total number of points. A parameter based on the algorithm for calculating activity counts used by the Actical activity monitor was developed. First, the magnitude of the resultant acceleration vector was calculated using data from all three accelerometers. The resultant data were then run through a second-order band pass Butterworth filter (0.5–3 Hz), rectified and integrated over the entire trial to calculate the area under the acceleration (*g*)–time (s) curve. Finally, the counts were normalised by the data collection time, which was 8 h (28,800 s) for all subjects. The resulting parameter, termed the dynamic acceleration, represents the average non-gravitational acceleration in *g*'s units.

2.4. Statistical analysis

A separate linear regression analysis was performed between each of the triaxial accelerometer parameters and the activity counts as recorded by the activity monitor. When the data were analysed separately for the dominant and non-dominant sides, there were no significant differences between the correlation coefficients for any of the parameters ($p > 0.39$). The data were therefore averaged across sides. Analyses were run with SPSS version 17 (SPSS, Chicago, IL). For all analyses, an α level was set at 5%.

3. Results

There was a general trend towards a reduction in all static parameters as the activity monitor counts increased (Figure 1). While this is further verified by the negative correlation coefficients, as high as -0.36 for $>30^{\circ}$ and -0.38 for 50th percentile, none of these relationships demonstrated statistically significant (Table 2).

There was a significant ($p < 0.0001$) positive correlation between all of the dynamic triaxial accelerometer parameters and the activity monitor counts (Table 2 and Figure 2). The r-values for the velocity percentiles ranged from 0.81 for the 99th percentile to as high as 0.97 for the 50th velocity percentile. Similarly, the jerk analysis ($r = 0.93$) and dynamic acceleration ($r = 0.86$) also demonstrated a strong correlation with activity monitor counts (Table 2).

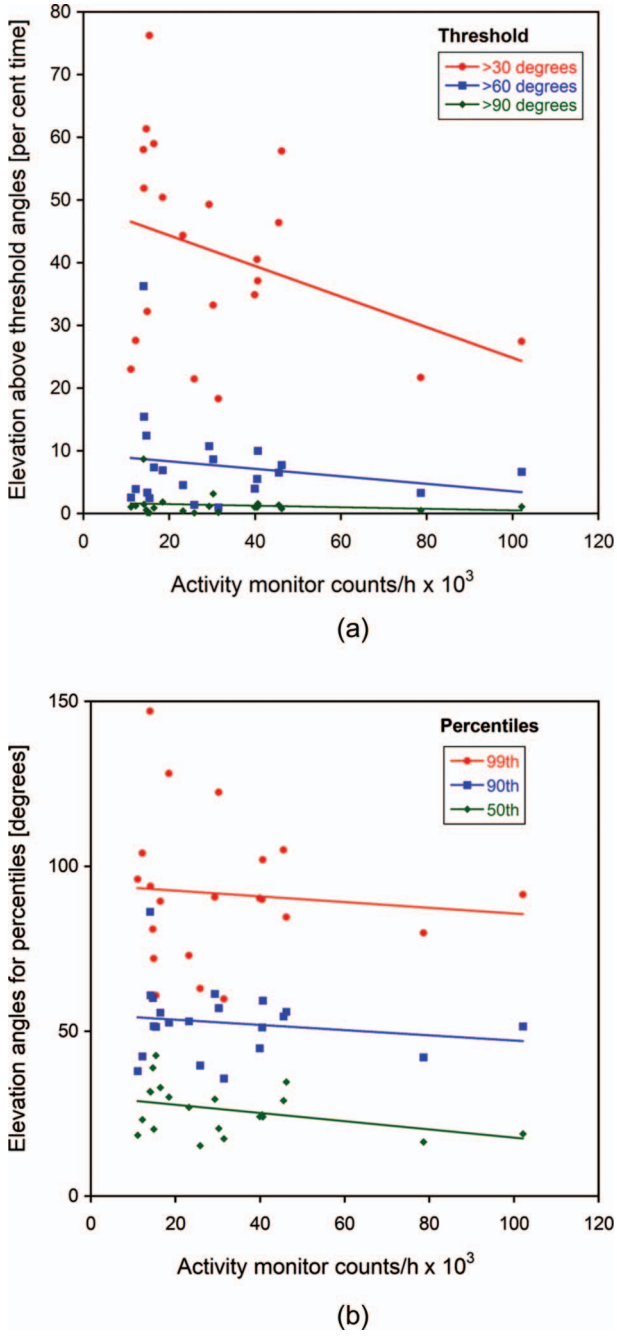

Figure 1. Correlation between static triaxial accelerometer parameters and activity monitor counts: (a) per cent time above a threshold elevation angles of 30°, 60° and 90° and (b) 50th, 90th and 99th percentiles of arm elevation. While there is a general negative relationship for all of these parameters, none were found to be statistically significant.

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Table 2. Results of the correlation analyses between the triaxial accelerometer parameters and the activity monitor counts. The parameters from the triaxial accelerometer have been separated into those that are based on static vs dynamic conditions. The static parameters included the per cent time above a given elevation angle (30°, 60° and 90°) and the 50th, 90th and 99th percentiles of arm elevation. The dynamic parameters included the 50th, 90th and 99th percentiles of arm velocity, jerk time and dynamic acceleration, respectively.

			r-Value	*p*-Value
Static parameters	Thresholds	>30°	−0.36	0.11
		>60°	−0.18	0.43
		>90°	−0.15	0.51
	Elevation percentiles	50th	−0.38	0.09
		90th	−0.17	0.47
		99th	−0.09	0.69
Dynamic parameters	Velocity percentiles	50th	0.97	<0.0001
		90th	0.92	<0.0001
		99th	0.81	<0.0001
	Jerk analysis		0.93	<0.0001
	Dynamic acceleration		0.86	<0.0001

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4. Discussion

There have been many studies that have demonstrated a link between arm elevation exposure and occupational shoulder injuries. While some have relied upon self-report data (Pope *et al*. 2001, Harkness *et al*. 2003, Leclerc *et al*. 2004, Miranda *et al*. 2005), others have used observational techniques (Ohlsson *et al*. 1995, Punnett *et al*. 2000, Silverstein *et al*. 2008). To our knowledge, only Svendsen *et al*. (2004a, 2004b, 2005) have demonstrated a link between these injuries and direct measurements of arm exposure. In that set of studies, the authors only considered the static 'per cent time above' parameters presented in the current paper. However, as suggested by Hansson *et al*. (2010), one of the major problems with assessing physical workload exposure from a continuous workday assessment is that 'a virtually infinite number of summary (exposure) measures can be derived'. Therefore, the importance of all of these other parameters as assessments of shoulder exposure is still debatable.

Consistent with our first hypothesis, there was no significant correlation between the activity monitor counts and any of the reported triaxial accelerometer static parameters. This is not surprising, given that working at a higher elevation does not necessarily require workers to adopt a more dynamic movement pattern. In fact, while these correlations are not significant, they all have negative *r*-values, indicating a trend towards more static movements at higher elevation angles. Hannson *et al*. (2010) observed this trend for the 50th percentile but not for the 90th and 99th percentiles of humeral elevation.

Our second hypothesis was also supported, as there was a strong correlation between the activity monitor counts and all of the reported triaxial accelerometer dynamic parameters. Although it might not be surprising that these parameters are related, it is the strength of these correlations that is impressive, with *r*-values ranging from 0.81 up to 0.97. These results are consistent with the high correlation ($r = 0.92$) reported by Hannson *et al*. (2010) between median angular velocities of the wrist and humerus. While that study used the same techniques for these measurements, in the present study, there were different sensors positioned at different positions on the upper extremity. Also, with the exception of dynamic acceleration parameter, the data were analysed with very different algorithms, since the activity monitor data simply uses the linear acceleration of the sensor along a single axis, while the triaxial accelerometer data were used to reconstruct angular positional data. One could image several scenarios in which these relationships would not be strong, such as motions that were primarily at the elbow or whole body motions that did not involve angular displacement of the upper extremity.

As can be observed in Figure 2, there were two subjects that have large values for their dynamic parameters. One worked as a cashier and the other worked at a coffee shop (and indicated that she performed a lot of repetitive motion the day of testing). However, upon reviewing their activity logs, we found no indication that these subjects were doing anything unusual that might have corrupted their data. In order to determine whether these potential outliers could have skewed our results, we re-ran the correlations after removing these subjects. Although there were small changes in *r*-values, the removal of these subjects did not change the fact that all triaxial accelerometer static parameters were not significantly correlated with the activity monitor counts and that all dynamic parameters were significantly correlated.

There are some limitations of the present study that need to be addressed. While workers were recruited from a wide variety of occupations, most were not involved in work that has been found to be associated with shoulder

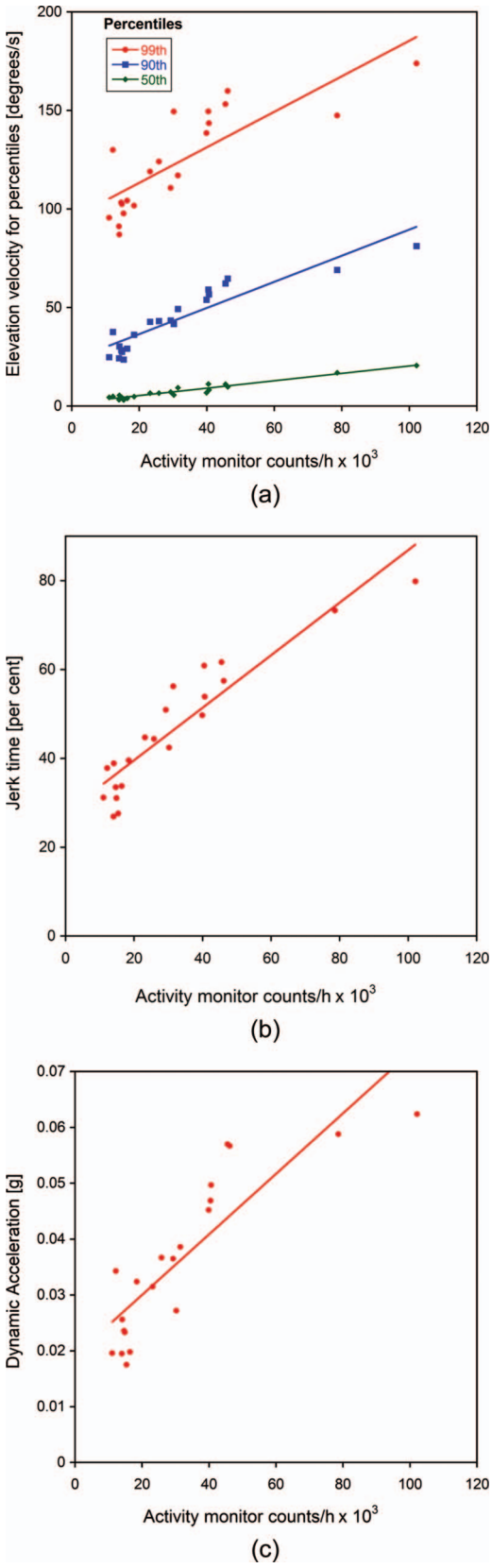

Figure 2. Correlation between dynamic triaxial accelerometer parameters and activity monitor counts: (a) 50th, 90th and 99th percentiles of arm velocity; (b) jerk time or per cent time spent under dynamic conditions and (c) dynamic acceleration, as defined by a similar algorithm as for the activity monitor counts.

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injuries. It may be that the correlations observed would not be as strong in workers involved in more dynamic activity, such as construction workers or house painters. Additionally, subjects were not observed over the course of the day, so it is difficult to determine exactly what they were doing. Although, subjects filled out hourly activity logs and these were consistent with the self-reported occupations.

Triaxial accelerometers and activity monitors are both commercially available devices that are completely self-contained and therefore ideally suited for workplace exposure assessment. With the triaxial accelerometer, researchers have more control over the kinds of parameter they can assess. However, the activity monitor is easier for a worker to place on by themselves and can collect data for longer periods of time. Although there is some indication that high levels of repetitive motion are detrimental (Moriguchi *et al*. 2011), to our knowledge there have been no studies demonstrating that dynamic parameters are predictive of overuse injuries of the shoulder. So in conclusion, while activity monitors cannot be used as a surrogate for static postures, they may be useful in further investigating the relationship between dynamic motion and occupational shoulder injuries.

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