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JSAMS-1304; No. of Pages 5
ARTICLE IN PRESS
Journal of Science and Medicine in Sport xxx (2016) xxx–xxx
Contents lists available at ScienceDirect
Journal of Science and Medicine in Sport
journal homepage: www.elsevier.com/locate/jsams

Original research

Feasibility of a Chest-worn accelerometer for physical activity measurement

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ARTICLE INFO

Article history:
Received 27 October 2015
Received in revised form 19 February 2016
Accepted 10 March 2016
Available online xxx

Keywords:
Measurement
Activity monitors
Actigraph
Wrist worn
Treadmill
Objective monitoring

ABSTRACT

Objectives: A “proof-of-concept” study to examine the feasibility of wearing an Actigraph GT3X+ at the Chest (resembling a neck pendant) for physical activity measurement.
Design: A convenience sample of 45 healthy adults (23 male, mean age 20.0 ± 4.5 years) was included in data analysis.
Methods: Participants simultaneously wore three GT3X+ accelerometers, on the Waist, Wrist, and Chest and completed 8 bouts of slow (.67, .89, 1.11 m/s), average (1.33, 1.56, 1.78 m/s) and fast (2.00, 2.22 m/s) walking on a treadmill. Paired *t*-test, correlations and absolute percentage errors (APE) of accelerometer output (vector magnitude, VM) were computed for the key pairs: Waist–Wrist; and Waist–Chest.
Results: The Wrist-site overestimated VM to a greater extent at all speeds in comparison to the Chest. Pearson’s r correlations were weaker for Waist–Wrist (<.80) in comparison to the Waist–Chest (>.85). The APE’s were much lower (i.e. higher agreement) for the Chest (9.23–15.5%) compared to the Wrist (19.7–54.9%). Participants also felt the Chest-site was more acceptable than the Waist-site.
Conclusions: PA measurements recorded by a Chest worn GT3X+ more closely resembled PA measurements recorded at the traditional Waist site than when compared to the Wrist site. When combined with high Chest site preference, the findings of our study suggest that the Chest is a feasible site for accelerometer wear.

1. Introduction

There is an increasing use of wearable monitors in the objective assessment of physical activity (PA). Accelerometers have frequently been selected as the device-of-choice because of their small size and ability to characterize the intensity and duration of PA over long periods of time.

The traditional wear-site of an accelerometer is on the Waist, but this site has caused compliance issues. As low as 25% of participants provided the requested 7 days of data, citing reasons of discomfort or inconvenience of wearing a device on the waist over long periods.[1] Similar problems were also found in children and youth studies.[2–4] Consequently, when the “wrist-worn accelerometer” was adopted by the NHANES, participant compliance increased substantially from 40–70% in the 2003–2004 cycle (Waist-wear) to 70–80% in the 2011–2012 cycle (Wrist-wear). However, the validity and reliability of a Wrist-worn device remains debatable.[5] The NHANES attempted to overcome this limitation by using raw acceleration data and log transformations instead of activity counts in its data analyses. Yet data processing of Wrist accelerometry data remain challenging and much more complex than the Waist data because of the Wrist gesticulation and variability in movement,[6] which often requires high computational costs and sophisticated analytic skills[7] to achieve comparable accuracy to the Waist. This heightens the need for an alternative wear-site.

Recently, there has been a growing interest in Chest-worn accelerometers (directly attached to the participant’s skin or via a chest-strap). Cleland et al.[8] showed that an accelerometer placed at the Chest performed better in correctly detecting daily activities using various machines learning algorithms than an accelerometer placed at the wrist. Moreover, Altini et al.[9] showed that a single accelerometer at the Chest together with a combined activity-specific estimation method was very accurate for EE estimations. These studies have emphasized on the feasibility of a Chest-worn device in activity-specific measurements (i.e. posture recognition, fall detection) as opposed to levels of PA measurement. It is therefore worthwhile to investigate whether a Chest-worn accelerometer is applicable for the measurement of PA.

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http://dx.doi.org/10.1016/j.jsams.2016.03.004

Please cite this article in press as: Zhang JH, et al. Feasibility of a Chest-worn accelerometer for physical activity measurement. *J Sci Med Sport* (2016), http://dx.doi.org/10.1016/j.jsams.2016.03.004

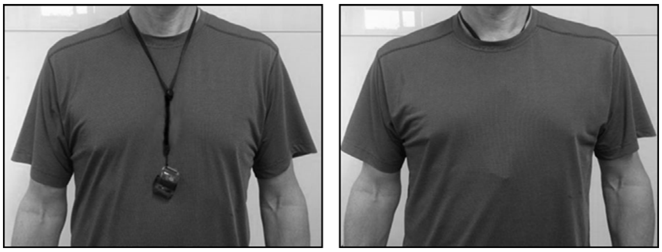

Fig. 1. Illustration of the Chest accelerometer necklace and positioning above and beneath (normal site) clothing.

The aim of this study was to determine whether participants would be more likely to agree to wear a commonly-used research accelerometer at the Chest, without significantly compromising measurement agreement when compared to other traditional sites. Thus this paper was a "proof-of-concept" study examining the feasibility of wearing the GT3X+ at the Chest for the measurement of PA by examining both the initial site preference, as well as the comparability of measurements made at the Chest, Wrist and Waist.

2. Methods

Participants were recruited from the neighbourhood of The University of Hong Kong by convenience sampling, including word of mouth and distribution of posters and leaflets. Inclusion criteria of the study were (1) apparently healthy adolescents/adults (≥15 years but <60 years) with BMI < 30 kg/m^2 and (2) individuals free of any type of walking aid/impediment. All participants read and signed an informed consent form, with the study protocol and ethics being approved by the Human Research Ethics Committee for Non-Clinical Faculties of the University of Hong Kong.

Testing was conducted in a laboratory at the Institute of Human Performance, the University of Hong Kong. Prior to testing, height (m) and weight (kg) of participants were measured using a stadiometer (Seca 213) and a Body Composition Analyzer (Tanita Model TBF-410), respectively. For height and weight measurements participants were asked to remove shoes, heavy clothing and belongings. The usual formula of body mass (kg) divided by height squared (m^2) was used to compute the BMI for each participant.

To determine site preference, pictures of how each monitor is sited on the Waist, Wrist and around the neck (Chest) along with its corresponding accessory (Waist belt, Wrist strap and necklace) were first placed on a table in front of interviewees in no particular order. Interviewees were asked to rank the wear-sites according to how convenient and user-friendly they were perceived and prior to participation in the treadmill tests. For statistical analyses, a chi-square test of independence was performed to examine the relationship between wear-site and preference.

Upon completion of anthropometric measurements, instructions and assistance for simultaneously wearing three GT3X+ accelerometers on the Waist (located on the right waist in the mid-axillary line using a waistband), Wrist (located on the non-dominant wrist with a wrist-strap) and Chest (located around the neck using a soft nylon necklace, length was adjusted to ensure the GT3X+ was near the xiphisternum underneath clothing, Fig. 1) were given to participants.

Participants performed 8 bouts of slow (.67, .89, 1.11 m/s), average (1.33, 1.56, 1.78 m/s) and fast (2.00, 2.22 m/s) walking/jogging on a preprogramed treadmill (Woodway, UK) in a controlled laboratory environment. Participants ambulated at each speed for 4-min with 1-minute break between each bout.

The Actigraph GT3X+ accelerometer (Actigraph, Pensacola, FL, USA) was used throughout, it is a lightweight (19 g), small (4.6 cm × 3.3 cm × 1.5 cm) tri-axial activity monitor that records dynamic accelerations in a magnitude range of ± 6 G's over extended periods of time. The device then quantifies the detected accelerations as an arbitrary unit called activity counts (a count is registered each time the magnitude of acceleration of the activity exceeds a given threshold) in three dimensions (axis 1 = vertical, axis 2 = horizontal right to left plane and axis 3 = horizontal front to back plane). A summative score $(x^2 + y^2 + z^2)^{0.5}$ of the three axes is termed "vector magnitude (VM)", it is a common parameter for the estimation of PA (i.e. energy expenditure, activity intensity threshold) by capturing multidirectional movements.[10] Therefore this parameter (VM) was selected as the outcome variable to be compared between the 3-sites. This approach is consistent with other recent studies aimed to examine intermonitor reliability of the GT3X+ accelerometers at hip, Wrist and Ankle sites during activities of daily living[11] and to compare accelerometer output of different accelerometer models.[12–14]

All accelerometers were synchronized in time and initialized to collect data at a sampling rate of 100 Hz. Data were downloaded using 1 s epochs and analyzed using Actilife version 6 software (Actigraph, Pensacola, USA). To compare monitor output, the first and forth minutes were removed and the middle portion of "matching" data were analyzed.

The statistical analyses were performed using SPSS version 20.0 (SPSS Inc., Chicago, IL) and MedCalc version 12.5 (MedCalc Software, Ostend, Belgium) for Windows. As the Waist-site is often considered as the traditional wear-site of accelerometers and has shown to be better at estimating energy expenditure[15] (from its activity count output), as well as identifying activity intensity thresholds than the Wrist-site,[16] it is therefore most logical to utilize measurements made at the Waist as the "referential criterion" for a proof-of-concept study as such. Hence all analyses were conducted for comparison pairs: Waist versus Wrist (Waist–Wrist), and Waist versus Chest (Waist–Chest) to examine comparability of measurements. Dependent *t*-tests and Cohen effect sizes (*d*)[17] were used to examine the size and magnitude of difference in VM scores between wear-sites at each speed bout. Pearson product–moment correlations were performed to quantify the relationship between VM scores recorded at each wear-site at each speed bout. Finally, absolute percentage errors (APE) were calculated for each comparison pair and Bland–Altman-type[18] plots were generated using MedCalc to numerically and graphically illustrate the variability (magnitude and direction) of the error. All statistical tests were performed with a p-value of <0.05.

3. Results

Forty-five healthy young-adults (23 male) participated in the study (age: 20.0 ± 4.5 years; body mass index (BMI): 20.5 ± 2.9 kg/m^2). All participants had complete accelerometer and questionnaire data.

Table 1 displays comparisons of VM scores. Across all speeds, statistically significant differences in VM scores were observed, with the absolute differences between the Waist–Wrist pair being much larger than the Waist–Chest pair. When compared to the Waist, statistically significant overestimation of VM at the Chest and Wrist were constantly observed with one exception, where the Chest significantly underestimated VM at slow walking speeds. The Cohen effect sizes for mean differences were considerably smaller (confirming higher agreement) for Chest–Waist comparison than the Chest–Wrist. Moreover, for average and fast walking speeds, Pearson's correlations were stronger for the Waist–Chest pair (>.85) compared to the Waist–Wrist pair (<.80). APE's were much lower (again confirming higher agreement with the Waist) for the Chest-site (9.23–15.5%) when compared to the Wrist-site