Accelerometer use in young people with Down syndrome: A preliminary cross-validation and reliability study

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Running Head: Accelerometers in Down syndrome

Abstract

Abstract

Background: Inadequate physical activity is a problem for people with Down syndrome and objective monitoring using accelerometers may be inaccurate in this population.

Method: Cross-validation and reliability study comparing two tri-axial accelerometers (the SenseWear and RT3) to a criterion measure (the OxyCon Mobile) in 10 young people (mean age: 20±2) with Down syndrome. A ROC curve analysis was conducted to determine intensity thresholds from RT3 activity counts.

Results: During self-selected pace walking, the accelerometers overestimated energy expenditure and had large limits of agreement (SenseWear: -0.5-3.6METs; RT3: -0.2-2.7METs). At this pace SenseWear armband step counts were highly correlated with observed steps (r=.98) but underestimated steps by up to 12%. We developed RT3 thresholds that demonstrated good to excellent sensitivity and specificity in classifying physical activity intensity.

Conclusions: SenseWear steps and RT3 activity count thresholds can be used to monitor physical activity in young people with Down syndrome, though energy expenditure estimates should be used with caution in this population.

People with Down syndrome typically do not participate in recommended levels of physical activity (Shields, Dodd et al. 2009, Temple and Stanish 2009, Esposito, MacDonald et al. 2012). A lack of physical activity increases the risk of people with Down syndrome developing health conditions such as obesity, diabetes, cancer and Alzheimer's disease (Hermon, Alberman et al. 2001, Hill, Gridley et al. 2003, Zigman and Lott 2007). Risk factors for these chronic health conditions can be improved by participation in regular physical activity (Penedo and Dahn 2005).

Physical activity is an important component in weight and glycaemic control, and cardiovascular and cognitive health. Set-duration exercise interventions, as a structured form of physical activity, involving aerobic and/or resistance training, appear to improve cardiovascular fitness and muscle strength of people with Down syndrome (Dodd and Shields 2005, Mendonca, Pereira et al. 2010, Shields and Taylor 2010, Shields, Taylor et al. 2013). However, less is known about the effects of daily physical activity levels in this population. It is important to be able to accurately assess unstructured daily physical activity levels of people with Down syndrome to understand the longitudinal effects of physical activity on health status.

Self-reported physical activity levels are difficult to obtain in people with intellectual disability due to poor recall ability and non-compliance. Subjective reports are also typically inflated (Sallis and Saelens 2000, Pate, Freedson et al. 2002) making it important to measure physical activity objectively. Accelerometers are small, portable, lightweight and non-invasive devices that measure locomotor activity in terms of acceleration forces generated by body movement. The acceleration forces are combined to give the raw output termed activity counts. These counts are not comparable across devices due to different sensors, conversion parameters and amplification. Accelerometers can also give additional information on steps, estimated energy expenditure and gait characteristics (cadence, speed, distance travelled), which are derived from acceleration forces. By generating quantitative information on physical activity parameters (frequency, duration and intensity), accelerometers might be useful for longitudinal studies to determine the nature of any associations between physical activity dose and health consequences. Accelerometers could also be useful to evaluate the effectiveness of interventions designed to increase physical activity.

Few studies have objectively measured daily physical activity and energy expenditure using accelerometers in people with Down syndrome (Whitt-Glover, O'Neill et al. 2006, Shields, Dodd et al. 2009, Esposito, MacDonald et al. 2012). This may be because accelerometers have not been validated as providing accurate measures of energy expenditure for people with Down syndrome. People with Down syndrome have a number of physiological characteristics, such as inherent joint laxity, muscle hypotonia (American Academy of Pediatrics. Committee 2001), reduced muscle strength (Pitetti, Climstein et al. 1992), and atypical gait patterns (Agiovlasitis, McCubbin et al. 2009, Smith, Stergiou et al. 2011), that may affect the relationship between their metabolic rate and accelerometer output during physical activity. As a result, it cannot be assumed that energy expenditure estimates from accelerometers will be accurate for people with Down syndrome. It has been previously demonstrated that the prediction of energy expenditure derived from uniaxial accelerometer activity counts is less accurate in people with Down syndrome than in people without Down syndrome (Agiovlasitis, Motl et al. 2011). This might be because uniaxial accelerometers do not capture mediolateral body motion which is greater in people with Down syndrome (Agiovlasitis, McCubbin et al. 2009). As physical activity is important for people with Down syndrome to prevent chronic disease, physical activity needs to be accurately and reliably measured in this population. A device that can provide this accuracy and reliability needs to be identified.

The SenseWear armband and RT3 activity monitors are tri-axial accelerometers that could be used to assess physical activity levels and energy expenditure in people with Down syndrome. To enhance the interpretability of accelerometer outputs, activity count thresholds can be applied to classify physical activity as low, moderate or vigorous intensity for comparison with physical activity guidelines. Previous research in Down syndrome (Whitt-Glover, O'Neill et al. 2006, Shields, Dodd et al. 2009, Esposito, MacDonald et al. 2012) has relied upon thresholds developed for healthy populations. Because of physiological differences and the altered relationship between energy expenditure and activity counts in people with Down syndrome for uniaxial accelerometers, it has been suggested that alternate thresholds for physical activity need to be developed in this population (Agiovlasitis, Motl et al. 2011).

Neither the SenseWear armband nor the RT3 activity monitor has been validated for people with Down syndrome, nor have RT3 activity count thresholds been developed for people with Down syndrome. Therefore the primary aim of this study was to assess the reliability and validity of the SenseWear armband and RT3 activity monitor in estimating energy expenditure of young people with Down syndrome. The secondary aims were: (1) to assess the reliability and validity of SenseWear armband in estimating steps taken and (2) to estimate activity count thresholds for physical activity intensity for the RT3 monitor.

Method

Design

This was a cross validation and reliability study with repeated measures. Ethics approval was received from the La Trobe University Human Ethics Committee (approval number 12-078). Written informed consent was sought from the next of kin (parent) for all adolescents (ages 14 to 17 years). Adolescents were also invited to provide their own written assent. For young adults with Down syndrome, (ages 18 years and over) competence to give consent was determined in conjunction with their parents. Where a young adult already in usual practice provides their own consent, they provided their own informed consent to participate in this study. Where a young adult was determined by their parents to not be cognitively able to provide their own consent, informed consent was sought from the next of kin and the participant was invited to provide written assent.

Participants

Adolescents and young adults (aged 14 years or older) with Down syndrome and mild to moderate intellectual disability were invited to participate. Participants needed to be able to follow simple verbal instructions in English and be deemed safe, as assessed by the Physical Activity Readiness Questionnaire (PAR-Q) (Canadian Society for Exercise Physiology 2002) to participate in physical activity. The PAR-Q is a screening tool designed to determine the safety of exercising based on answers to specific health history questions and has been used previously in Down syndrome (Shields, Taylor et al. 2013). Participants were required to get medical clearance from their family doctor prior to participating if any answers to the PAR-Q indicated safety concerns. Participants were excluded if they had an acute or concurrent medical condition rendering them unfit to participate (such as an acute knee injury) or a significant behavioural problem that would impact on their ability to participate (such as noncompliance or anxiety). A convenience sample of 10 young adults was recruited from a previous trial (Shields, Taylor et al. 2013).

Equipment

The SenseWear armband activity monitor[a] is a small device worn on the upper arm. It includes a tri-axial accelerometer to detect motion and body position and sensors that record galvanic skin response, skin temperature and heat flux. The information collected by the sensors is combined with the participants' sex, age, height and weight data in a proprietary algorithm to estimate energy expenditure reported in metabolic equivalent units (METs). METs report energy expenditure in multiples of the resting metabolic rate, where 1 MET is defined as the rate of oxygen uptake at rest. The SenseWear armband has been validated for healthy adults, young adults (Johannsen, Calabro et al. 2010, Wetten, Batterham et al. 2014) and children (Andreacci, Dixon et al. 2007), as well as clinical populations; such as people with stroke (Manns and Haennel 2012), cystic fibrosis (Dwyer, Alison et al. 2009) and children and adolescents with cerebral palsy (Koehler, Abel et al. 2015).

The RT3 activity monitor[b] is a lightweight tri-axial accelerometer worn on a waistband at the hip. The RT3 provides raw data as activity counts by detecting acceleration in vertical, anteroposterior and mediolateral planes. The output is in vector magnitude (VM) per minute which is calculated as the square root of the sum of the squared activity counts for each dimension. These data are combined with information on the participants' sex, age, height and weight in a proprietary algorithm to estimate energy expenditure per minute expressed as calories. Estimation of energy expenditure by the RT3 has been validated for children (Hussey, Bennett et al. 2014) and young adults (Barreira, Kang et al. 2007). The RT3 has previously been used to measure physical activity in Down syndrome (Shields, Dodd et al. 2009, Shields, Taylor et al. 2013). Typically, VM count thresholds are applied to the output data to express the output as minutes spent in varying levels of physical activity to make it more interpretable. Count thresholds have been developed for typically developing children, adolescents and young men (Rowlands, Thomas et al. 2004, Vanhelst, Beghin et al. 2010) and children with cerebral palsy (Ryan, Walsh et al. 2014) but not for young adults with Down syndrome.

The OxyCon Mobile[c] is a portable, wireless metabolic system that is secured to the participants' chest with a harness and measures breath by breath gas exchange via a flow sensor unit connected to a face mask. The data are sent telemetrically to a base station connected to a computer and energy expenditure is expressed as volumetric oxygen uptake (VO_2) in ml/kg/min. Data are converted from VO_2 to METs using the equation: 1 MET = 3.5 VO_2 (ml/kg/min). Gas and volume calibration (reference gas tank: 16% O_2; 4% CO_2) were performed prior to testing using the built-in automated procedures. The OxyCon Mobile is a valid and reliable measure of metabolic variables when compared to the Douglas bag method (Rosdahl, Gullstrand et al. 2010) and the OxyCon Pro laboratory system (Akkermans, Sillen et al. 2012). The OxyCon Mobile has previously been used as the criterion measure for energy expenditure in children (Arvidsson, Slinde et al. 2007, Ryan, Walsh et al. 2014) and adults (Lee, Kim et al. 2014).

Testing protocol

Participants wore two SenseWear armbands (one on each upper arm), an RT3 monitor (on the waistband of their pants at their right hip) and wore the OxyCon Mobile equipment in a vest connected to a facemask during testing. Due to unavailability of monitors, if only one SenseWear monitor was available to be worn, the left arm was chosen a priori as per manufacturer guidelines. To increase adherence, verbal and written information (including pictures) was provided to participants at least two weeks prior to the testing session. On the day of testing participants were familiarised with the equipment by researchers explaining how each piece of equipment worked. The participants were also given time before the testing commenced to become comfortable wearing the equipment. A researcher recorded the participant's steps, distance walked or run, and rating of perceived exertion. Testing involved two 60-minute sessions, performed one week apart, which included the following activities: sitting, standing, walking, running and lying down (table 1). Duration of the walking tasks were randomised (range: 6 – 10 minutes) to provide a range of values for total steps taken to avoid a truncation effect in correlation. Rest periods of at least 10 minutes duration occurred between each walking task to allow participants to return to baseline resting state. Testing and re-testing were conducted by the same researchers and at the same times of day. The walking and running tasks were conducted indoors on a flat, 30 meter long hallway at the research centre.

[INSERT TABLE 1 ABOUT HERE]

Statistical analysis

Data were downloaded from the SenseWear armband (Steps and METs), the RT3 monitor (VM and calories) and OxyCon Mobile (METs) immediately after each testing session. Data from the SenseWear and RT3 are expressed per minute. The last 3 useable minutes of data for each activity (self-selected pace walking, fast pace walking and sitting) were extracted for analysis (table 1). At this time data were considered to be a true reflection of the activity performed. When only one set of SenseWear data were needed, the left SenseWear was chosen a priori. For validity and inter-monitor reliability, data from testing session 2 were chosen as participants were familiar with the procedure. RT3 calories were converted to METs using the equation: METs = Calories per minute x 200 / [3.5 x Weight (kg)] (Compendium of Physical Activities 2015).

Validity – SenseWear armband and RT3

Paired t-tests were conducted to assess differences in means and 95% confidence intervals between the accelerometers (SenseWear and RT3) and criterion measures (OxyCon Mobile and observer). Pearson's correlation coefficients (r) were calculated to assess the strength of association between: 1) the left SenseWear armband and the OxyCon Mobile for energy expenditure (METs); 2) the RT3 monitor and the OxyCon Mobile for energy expenditure (METs); and 3) the left SenseWear armband and observation for steps. The strength of the correlation was defined according to Munro (Munro 1993) as low (0.26-0.49), moderate (0.50-0.69), high (0.70-0.89) or very high (0.90-1.00). The coefficient of determination (r^2) was also reported to describe the amount of variability (%) in the criterion measure that the SenseWear and RT3 were able to predict (Howell 1992).

As the use of correlation alone can be misleading, methods described by Bland and Altman (Bland and Altman 1986) were used to assess the level of agreement in the units of measurement between the accelerometers (SenseWear and RT3) and the criterion measure (OxyCon Mobile) for each activity to improve interpretability. The difference between the two measures was plotted against the mean of the two measures to give the mean difference and limits of agreement between measurements. This allows the reader to determine whether the two methods agree sufficiently for one to replace the other.

Reliability – SenseWear armband and RT3

Intraclass correlation coefficient (ICC) and the 95% confidence interval (95%CI) and Bland-Altman tests to provide an estimate of reliability in the units of measurement, were used to assess reliability (Rankin and Stokes 1998). Re-test reliability of the SenseWear armband and the RT3 activity monitor between session 1 and session 2 was assessed using ICC (2,1) (Shrout and Fleiss 1979) for each activity. Inter-monitor reliability of two SenseWear armbands worn on the right and left upper arm of a participant in session 2 was assessed using ICC (3,1) (Shrout and Fleiss 1979).

Thresholds for activity – RT3 only

A Receiver Operating Characteristic (ROC) curve analysis was conducted to assess the ability of published thresholds, developed for typically developing children (Vanhelst, Beghin et al. 2010) and young men (Rowlands, Thomas et al. 2004), and children with cerebral palsy (Ryan, Walsh et al. 2014), to detect sedentary, low-intensity and moderate to vigorous intensity physical activity and determine new thresholds for young adults with Down syndrome. Sensitivity, specificity, and Area Under Curve (AUC) values of >0.9 were considered excellent, 0.8 to 0.89 were considered good, and 0.7 to 0.79 were considered fair.

Results

Participants

Ten young people with Down syndrome (5 females) with a mean age of 20 (SD 2, range 16 to 24) years took part (table 2). Four participants were classified as having normal weight according to body mass index (World Health Organization 2000), 2 as overweight, and 4 as obese. Their level of intellectual disability was classified by their parent as mild (n=5) or moderate (n=5). Four participants had a heart condition that did not limit their participation. Three participants had a small patent ductus arteriosus requiring no intervention and one participant had mild mitral valve regurgitation and a permanent pacemaker in situ. All participants completed 2 testing sessions each (20 sessions).

[INSERT TABLE 2 ABOUT HERE]

Compliance with the trial method

All activities in the protocol were completed in 19 out of 20 of the testing sessions. The running task was not completed on one occasion due to behavioural non-compliance. OxyCon Mobile recordings were not retrievable for one participant due to equipment malfunction (test 1); RT3 monitor data were not available for one participant due to battery failure (test 1); and on six occasions the right SenseWear armband was not worn due to unavailability of monitors (test 1: n=4, test 2: n=2). The mean self-selected walking speed was 1.1 (SD 0.2) m/s and the mean fast walking speed was 1.4 (SD 0.2) m/s. Walking speed did not differ between the two testing sessions (table 5). The running task was not maintained for 3 or more minutes by any participant therefore was not able to be analysed separately.

Validity

When assessing validity, data were available from the left SenseWear, RT3 and OxyCon from testing session 2 for all 10 participants. At rest, the SenseWear armband estimation of energy expenditure was not significantly different to the OxyCon Mobile and estimates were highly correlated (r=.72). Bland-Altman plot evaluation of limits of agreement demonstrated that energy expenditure could be estimated as 0.2 METs above or below the true value (figure 1a).Based on the coefficient of determination (r^2), 52% of the variability in the OxyCon Mobile measured energy expenditure at rest was predicted by the SenseWear armband (table 3).

When compared to OxyCon Mobile, the SenseWear armband significantly overestimated energy expenditure when participants walked at self-selected and fast pace (figure 1a). There was a moderate correlation between the measures at self-selected walking pace(r=.58) and a low correlation at fast walking pace (r=.35). This indicated between 12% and 34% of the variability in the OxyCon Mobile measured energy expenditure during walking was predicted by the SenseWear. Bland-Altman limits of agreement indicated that SenseWear could underestimate METs by 0.5 or overestimate METs by 3.6 for self-selected walking pace and underestimate by 1.2 METs or overestimate by 3.4 METs during fast walking.

The RT3 also significantly overestimated walking energy expenditure (figure 1b), but there was a high correlation with the OxyCon Mobile at self-selected walking pace (r=.82) and a moderate correlation at fast pace walking (r=.52) (table 3). This indicated between 27% and 67% of the variability in OxyCon Mobile energy expenditure could be predicted by the RT3.

SenseWear armband step counts were very highly correlated with observed steps at self-selected (r=.98) and fast pace walking (r=.91), and indicated between 83% and 96% of variation in observed steps could be predicted by the SenseWear armband. However, the SenseWear armband underestimated steps during fast walking (figure 1c).

[INSERT FIGURES 1a – 1c ABOUT HERE]

[INSERT TABLE 3 ABOUT HERE]

Inter-monitor reliability

When assessing inter-monitor reliability there were complete left and right SenseWear armband data from 8 participants from testing session 1 used for analysis. There was good inter-monitor reliability of the left and right SenseWear armbands with no significant differences between energy expenditure estimates from the left and right armbands at rest or during walking (table 4). The monitors were highly correlated at rest (ICC=.86), self-selected walking pace (ICC=.97), and fast walking pace (ICC=.88).

For steps, left and right SenseWear armbands were highly correlated at self-selected (ICC=.88), but not fast pace (ICC=-.32) walking. It was observed that during fast pace walking, participants became concerned with the movement of the equipment and either tried to hold the OxyCon Mobile vest and/or pulse oximeter still with one hand. This may have resulted in asymmetrical movement and different right and left armband recordings.

[INSERT TABLE 4 ABOUT HERE]

Re-test reliability

Full data from the first and second testing sessions were available for 10 participants for the SenseWear, 9 participants for the RT3, and 9 participants for the OxyCon Mobile. At rest, there were no significant differences in energy expenditure estimates between the SenseWear armbands between testing sessions (re-test) and high re-test reliability (ICC=.81). There was very high re-test correlation for the RT3 estimated energy expenditure at rest (ICC =.90) (table 5).

For walking tasks, re-test measures of SenseWear estimated energy expenditure were highly correlated (self-selected ICC=.80; fast pace ICC=.72). Similar re-test results were seen for OxyCon Mobile data. However, re-test correlation was poor to moderate for the RT3 during walking tasks (self-selected ICC=.61; fast pace ICC=.46).

For steps, there was good re-test reliability between sessions with very high correlation between the two testing sessions for self-selected (ICC=.96) and fast pace (ICC=.90) walking.

[INSERT TABLE 5 ABOUT THERE]

RT3 activity count thresholds

For walking tasks, increases in METs recorded by the OxyCon Mobile correlated with increased RT3 activity counts (self-selected pace r = 0.82). ROC curve analysis identified the optimal threshold of 52 counts per minute from the RT3 to differentiate between sedentary and light physical activity with excellent sensitivity (1.0) and specificity (.94). The threshold for moderate intensity physical activity was identified as 1389 counts per minute with excellent sensitivity and specificity with an AUC of .94 (95%CI .88 to 1). The ROC curve derived threshold for vigorous intensity physical activity was 2448 counts per minute with excellent sensitivity and specificity with an AUC of .92 (95%CI .84 to 1). The resulting ranges of counts per minute are: sedentary ≤52, light >52 to ≤1389, moderate >1389 to ≤2448 and vigorous >2448. Previously published thresholds for RT3 activity counts were acceptable for differentiating between sedentary and low intensity physical activity; and moderate and vigorous intensity physical activity; but not low and moderate intensity physical activity for young people with Down syndrome in this study (table 6).

[INSERT TABLE 6 ABOUT HERE]

Discussion

Results from this study indicate that the SenseWear armband and the RT3 activity monitor were valid and reliable measures of energy expenditure at rest for young people with Down syndrome. However, during walking tasks, both monitors were not valid measures as they overestimated energy expenditure. During walking, the SenseWear armband demonstrated good inter-monitor and test re-test reliability for energy expenditure while the RT3 monitor had poor to moderate test re-test reliability. The SenseWear armband was a valid measure of steps taken and had high test re-test reliability but poor inter-monitor reliability during fast pace walking. We developed RT3 thresholds that demonstrated good to excellent sensitivity and specificity in classifying physical activity intensity.

The SenseWear armband significantly overestimated energy expenditure during walking. The limits of agreement were large relative to what was being measured, with the SenseWear armband potentially overestimating energy expenditure by as much as 103% during walking at self-selected pace compared to the criterion measure. Overestimation of energy expenditure during walking tasks by the SenseWear armband has previously been demonstrated in other validation studies in healthy adults (Fruin and Rankin 2004, King, Torres et al. 2004) and in adults with Down syndrome (Mendonca 2008). It has been suggested that exercise specific algorithms need to be developed to increase the validity of SenseWear estimating energy expenditure (Jakicic, Marcus et al. 2004).

Similar to the SenseWear armband, the RT3 monitor consistently overestimated energy expenditure during walking tasks but had a higher correlation with the criterion measure. The limits of agreement were still large indicating that the RT3 should also not be used to estimate energy expenditure in young people with Down syndrome as it could overestimate energy expenditure by as much as 83% during fast pace walking. Previously published activity count thresholds for differentiating between light and moderate intensity physical activity (Rowlands, Thomas et al. 2004, Vanhelst, Beghin et al. 2010, Ryan, Walsh et al. 2014) appeared to be too low as they incorrectly identified low intensity physical activity as moderate in participants of the current study. This would result in an over-estimation of the physical activity levels of young people (aged 16 to 24 years) with Down syndrome in our study. Use of thresholds developed in this paper may be a more accurate way of classifying physical activity intensity based on the RT3 activity monitor data for this population.

The SenseWear armband was a valid measure of steps at self-selected and fast pace walking and had very high re-test reliability at both speeds. There was high inter-monitor correlation between the left and right SenseWear armbands at self-selected walking pace, but not at fast walking pace. The low correlation at fast pace walking may be attributable to participants changing their movement patterns due to OxyCon Mobile equipment movement at faster walking speeds. This may have clinical implications for physical activity monitoring with an armband if a person is carrying an object while walking. It also demonstrates some issues with the OxyCon Mobile equipment at fast pace walking in this population, as they were unable to ignore the equipment movement. Even though correlations were high, Bland-Altman limits of agreement show that the SenseWear armband could underestimate steps by as much as 18% during fast pace walking.

Accelerometers are designed to measure acceleration. The indirect estimation of energy expenditure from accelerometer data uses proprietary algorithms and a number of assumptions to convert raw accelerometer activity counts to energy expenditure. These assumptions may contribute to error in the estimation of energy expenditure for people with Down syndrome. Raw activity counts (which are directly derived from accelerations) and steps (which are more closely related to acceleration) appear to be more accurate than energy expenditure estimates and therefore appropriate to use in this population.

The overestimation of energy expenditure during walking in young adults with Down syndrome by both tri-axial accelerometers may also partially be explained by the inefficient movement patterns of people with Down syndrome. People with Down syndrome have inherent joint laxity, muscle hypotonia (American Academy of Pediatrics 2001), reduced muscle strength (Pitetti, Climstein et al. 1992), and atypical gait patterns (Smith, Stergiou et al. 2011) which appear to result in greater movement variations during gait (Agiovlasitis, McCubbin et al. 2009). Exaggerated movements may result in larger body accelerations and subsequently higher SenseWear and RT3 activity counts. When compared to adults without Down syndrome, instrumented gait analysis shows that adults with Down syndrome have greater mediolateral movement during gait (Agiovlasitis, McCubbin et al. 2009). At most walking speeds however, the vertical and anteroposterior movements are not different between people with and without Down syndrome, but were more variable for people with Down syndrome (Agiovlasitis, McCubbin et al. 2009). This might help to explain the differences between this current study and the study by Agiovlasitis (Agiovlasitis, Motl et al. 2011) that used a uniaxial accelerometer that only measures acceleration in the vertical direction. That study found that published activity count thresholds for the Actigraph were too high for people with Down syndrome whereas in the current study, published RT3 thresholds appeared to be too low. The uniaxial accelerometer used in that study would not detect mediolateral movement and therefore may underestimate activity. The tri-axial accelerometers used in this current research would pick up the increased mediolateral movement. Because algorithms that convert activity counts to estimated energy expenditure were developed in healthy populations, the increased mediolateral activity counts may be overly weighted in the algorithm which may cause an overestimation of energy expenditure by the tri-axial accelerometers above the true increase in energy expenditure measured by the OxyCon Mobile.

Energy expenditure during rest and walking has been previously measured for people with Down syndrome with conflicting results. Some research suggests that people with Down syndrome may have a lower resting metabolic rate than people without Down syndrome (Luke, Roizen et al. 1994, Allison, Gomez et al. 1995). Other studies found higher walking energy expenditure in people with Down syndrome (Agiovlasitis, McCubbin et al. 2009) and people with intellectual disability (including Down syndrome) (Lante, Reece et al. 2010). However, no differences were found in resting energy expenditure (Fernhall, Figueroa et al. 2005) or during walking (Mendonca, Pereira et al. 2009) between people with and without Down syndrome in other studies. Conflicting results in previous research may be due to different participant characteristics such as age. Based on this past research, we cannot assume people with Down syndrome are a homogeneous group in terms of energy expenditure, therefore our results are specific for young people (aged 16 to 24 years) with Down syndrome.

There are a number of limitations that need to be addressed. We only assessed overground walking at two submaximal intensities which meant that there were few light and vigorous activities recorded. The uneven number of bouts in each activity category (sedentary, light, moderate and vigorous) may have impacted the specificity and sensitivity of our results. Face mask fit and air leakage may be a problem for people with Down syndrome due to small nose and flatter facial features; however, a small sized face mask was chosen and checked for air leaks prior to testing. Lastly, the sample size was relatively small. Despite this, the sample size was sufficient to detect significant differences and correlations. In addition, our results cannot be extended to children younger than 16 years of age or adults older than 24 years.

Future directions

Future research should expand the evidence-base of the psychometric properties of activity monitors such as SenseWear and RT3 in larger samples and across a broader range of physical activities. In addition, the causes of discrepancies in energy expenditure estimation could be explored, particularly in relation to movement patterns of people with Down syndrome. The RT3 activity count thresholds for physical activity intensity for people with Down syndrome presented in this study are preliminary and it is recommended that their accuracy be assessed in a larger population of youth with Down syndrome and in other age groups.

Conclusion

Both the SenseWear armband and RT3 tri-axial accelerometers overestimated energy expenditure during walking tasks in young people with Down syndrome. This implies that energy expenditure estimates from both monitors should not be used for people with Down syndrome in research on achieving physical activity guidelines and longitudinal health studies evaluating physical activity levels as both would overestimate time spent in moderate to vigorous physical activity. SenseWear and RT3 monitors may have applications in estimating indicators of daily physical activity, by measuring steps, and in the case of the RT3, by accurately assessing counts so that time spent performing moderate and vigorous intensity physical activity can be estimated in young people with Down syndrome.

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Suppliers

a. BodyMedia Inc., Pittsburgh, PA
b. Stayhealthy Inc., Monrovia, CA
c. CareFusion, Yorba Linda, CA

Figure legend

Figure 1a. Bland-Altman plot for agreement between SenseWear and OxyCon (METs) with a line at 0 – no difference. Note: Δ = rest, ○ = self-selected walking pace, □ = fast walking pace.

Figure 1b. Bland-Altman plot for agreement between RT3 and OxyCon (METs) with a line at 0 – no difference. Note: Δ = rest, ○ = self-selected walking pace, □ = fast walking pace.

Figure 1c. Bland-Altman plot for agreement between SenseWear and observer (steps) with a line at 0 – no difference. Note: ○ = self-selected walking pace, □ = fast walking pace.

Table 1. Testing protocol (in order of performance)

Activity	**Duration (minutes)**
Sitting	3
Standing	2
Sitting	3
Walk 1: comfortable pace, familiarisation	6
Sitting	3
Lying down	10
Standing	2
Sitting	3
Walk 2: self-selected pace*	6 – 10
Sitting*	10
Walk 3: fast pace*	6 – 10
Running	≥ 1

NB: * data extracted for analysis from these activities

Table 2. Participant characteristics

Characteristic	
Age, mean (SD)	20 (2)
Adolescent (10 to <18 years)	2
Young adult	8
Height (cm), mean (SD)	157.2 (8.9)
Weight (kg), mean (SD)	67.7 (13.1)
Gender (Male: Female)	5:5
Body Mass Index, mean (SD)	27.4 (4.9)
Normal range (18.5 to 24.9)	4
Overweight (25 to 29.9)	2
Obese (≥30)	4
Type of Down Syndrome	
Trisomy 21	10
Level of intellectual disability	
Mild	5
Moderate	5

Table 3. Validity of SenseWear and RT3 (n=10, data from test 2)

Activity	**Mean (SD)**		**Mean difference (95%CI)**		**Correlation**		**Bland-Altman**
			SenseWear energy expenditure (n=10)				
	SenseWear METs	OxyCon METs	SenseWear - OxyCon	p	Pearson's r	r^2	Limits of agreement
Rest	1.1 (0.1)	1.1 (0.1)	-0.03 (-0.09 to 0.04)	0.35	0.72	.52	-0.2 to 0.2 METs
Walking pace							
Self-selected	5.0 (0.6)	3.5 (1.2)	1.5 (0.8 to 2.3)	0.001	0.58	.34	-0.5 to 3.6 METs
Fast	5.7 (0.6)	4.6 (1.2)	1.1 (0.8 to 1.9)	0.015	0.35	.12	-1.2 to 3.4 METs
			RT3 energy expenditure (n=10)				
	RT3 METs*	OxyCon METs	RT3 - OxyCon	p	Pearson's r	r^2	Limits of agreement
Rest	1.1 (.1)	1.1 (0.1)	-0.1 (-.12 to .01)	.07	.72	.52	-0.2 to 0.1 METs
Walking pace							
Self-selected	4.7 (.9)	3.5 (1.2)	1.2 (.7 to 1.8)	<.001	.82	.67	-.2 to 2.7 METs
Fast	6.2 (0.9)	4.6 (1.2)	1.6 (.8 to 2.4)	<.001	.52	.27	-0.5 to 3.8 METs
			SenseWear steps (n=10)				
	SenseWear Steps	Observed Steps	SenseWear - Observed	p	Pearson's r	r^2	Limits of agreement
Walking pace							
Self-selected	884 (214)	903 (220)	-18 (-51 to 15)	0.24	0.98	.96	-110 to 74 steps
Fast	1096 (116)	1165 (159)	-69 (-120 to -18)	0.014	0.91	.83	-212 to 74 steps

NB: SD=standard deviation; CI=confidence interval; MET=metabolic equivalent; *RT3 calories were converted to METs using the equation METs = Calories per minute x 200 / [3.5 x Weight (kg)] (AHA 1995).

Table 4. Inter-monitor reliability of the SenseWear monitor using Intraclass Correlation Coefficients (2,1) (ICC) and 95% confidence intervals (CIs) (n=8 complete sets of data)

Activity	**Energy Expenditure (METs), Mean (SD)**		**Correlation between left and right SenseWear METs**	**Steps, Mean (SD)**		**Correlation between left and right SenseWear steps**
	Left SenseWear	Right SenseWear	ICC (95% CI)	Left SenseWear	Right SenseWear	ICC (95%CI)
Rest	1.1 (.1)	1.1 (.1)	.86 (.32 to .97)			
Walking at own pace	5.2 (1)	5.4 (1)	.97 (.88 to 1)	830 (138)	774 (182)	.88 (.39 to .98)
Walking at fast pace	5.7 (.7)	5.8 (.9)	.88 (.4 to .98)	1058 (128)	994 (267)	-.32 (-5.58 to .74)

NB: MET=metabolic equivalent; SD=standard deviation; ICC=intraclass correlation coefficient. CI=confidence interval

Table 5. Re-test reliability of the SenseWear and RT3 monitors using Intraclass Correlation Coefficients (2,1) (ICC) and 95% confidence intervals (CIs)

Activity	**Mean (SD)**		**Correlation between day 1 and day 2**
SenseWear energy expenditure (n=10)			
	Day 1 METs	Day 2 METs	ICC (95%CI)
Rest	1.1 (0.1)	1.1 (0.1)	.81 (.22 to .95)
Self-selected pace walking	5.2 (1.0)	5.0 (0.6)	.80 (.19 to .95)
Fast pace walking	5.7 (0.7)	5.7 (0.6)	.72 (-.11 to .93)
RT3 energy expenditure (n=9)			
	Day 1 METs	Day 2 METs	ICC (95%CI)
Rest	1.1 (.1)	1.1 (.1)	0.9 (.56 to .98)
Self-selected pace walking	4.5 (.9)	4.6 (.7)	.61 (-.75 to .91)
Fast pace walking	5.8 (.7)	6 (.7)	.46 (-1.4 to .88)
Criterion measure: OxyCon Mobile (n=9)			
	Day 1 METs	Day 2 METs	ICC (95%CI)
Rest	1.1 (0.1)	1.1 (0.1)	.58 (-.88 to .90)
Self-selected pace walking	3.4 (1.0)	3.5 (1.2)	.97 (.87 to .99)
Fast pace walking	4.3 (1.2)	4.6 (1.2)	.9 (.56 to .98)
SenseWear steps (n=10)			
	Day 1 steps	Day 2 steps	ICC (95%CI)
Self-selected pace walking	869 (220)	884 (214)	.96 (.83 to .99)
Fast pace walking	1074 (121)	1096 (116)	.90 (.59 to .98)
Criterion measure: observed steps (n=10)			
	Day 1 steps	Day 2 steps	ICC (95%CI)
Self-selected pace walking	916 (229)	903 (220)	.99 (.95 to 1)
Fast pace walking	1166 (169)	1165 (159)	.91 (.65 to .98)
Observed speed, m/s (n=10)			
	Day 1 speed	Day 2 speed	ICC (95%CI)
Self-selected pace walking	1.1 (0.2)	1.1 (0.2)	.87 (.46 to .97)
Fast pace walking	1.4 (0.2)	1.4 (0.2)	.92 (.69 to .98)

NB: SD=standard deviation; ICC=intraclass correlation coefficient; CI=confidence interval; MET=metabolic equivalent, m/s=speed in meters per second

Table 6. Sensitivity and specificity of previously published cut points and the current studies newly developed cut points for physical activity level.

	Author	**Population**	**Cut point (counts/minute)**	**Sensitivity (%)**	**Specificity (%)**
Light physical activity	Vanhelst (2010)	TD children 10-16years, n=40	>41	100	89
(>2 to <3 METs)	Ryan (2014)	Children with CP, n=18	>51.9	100	94
	Current paper	Young adults with DS, n=10	>52	100	94
Moderate physical	Vanhelst (2010)	TD children 10-16years, n=40	>950	100	60
activity	Ryan (2014)	Children with CP, n=18	>689.3	100	56
(3 to 6 METs)	Rowlands (2004)	TD young men, n=19	>984	100	56
	Current paper	Young adults with DS, n=10	>1389	100	81
Vigorous physical	Vanhelst (2010)	TD children 10-16years, n=40	>3410	0	100
activity (>6METs)	Rowlands (2004)	TD young men, n=19	>2341	100	83
	Current paper	Young adults with DS, n=10	>2448	100	88

NB: TD=typically developing, CP=cerebral palsy, DS=Down syndrome