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ASSESSMENT

Pedometer Accuracy and Metabolic Cost in Elementary School Children While Walking, Skipping, Galloping, and Sliding

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Abstract

Pedometers are commonly used instruments that measure activity in children. While pedometers were designed to measure activity during walking, children often engage in other locomotor movements, such as skipping, galloping, and sliding. This study assessed the accuracy of two pedometers in children performing these movements and quantified the metabolic cost of these movements. Fifty-three children performed these movements on a motorized treadmill for 3 min at 67 m/min and again at 80.5 m/min. Pedometers were most accurate during walking and least accurate during skipping. Pedometers also tended to underestimate step counts during skipping, galloping, and sliding. Skipping, galloping, and sliding elicited greater metabolic cost compared to walking at the same speeds. In the context of teaching a physical education class, pedometer counts across these locomotor patterns could be used as a proxy measure of metabolic cost. Physical educators can use this information when assessing activity in PE classes that incorporate these kinds of locomotor movements.

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The pedometer is a relatively small device that can be worn inconspicuously on the hip and can gauge physical activity levels by registering steps. Technology has increased the functionality of the pedometer by providing the user with estimates of distance walked, calories burned, and time spent in activity. The pedometer has been the focus of much research because of its relatively low cost and ease of use. Researchers have assessed the reliability (Barfield, Rowe, & Michael, 2004; Jago et al., 2006; Schneider, Crouter, Lukajic, & Bassett, 2003) and validity (Bassett et al., 2000; Crouter, Schneider, Karabulut, & Bassett, 2003; Le Masurier & Tudor-Locke, 2003) of pedometers and found them to be useful for assessing physical activity levels in older (Cyarto, Myers, & Tudor-Locke, 2004; King et al., 2005), younger (Cox, Schofield, Greasley, & Kolt, 2006), obese (Swartz, Bassett, Moore, Thompson, & Strath, 2003), and ethnic (Bennett, Wolin, Puleo, & Emmons, 2006) populations.

Fitness levels of children are of great concern, and pedometers have been used for assessing physical activity levels in this population (Beighle, Morgan, Le Masurier, & Pangrazi, 2006; Rowe, Mahar, Raedeke, & Lore, 2004; Rowlands & Eston, 2005; S. Vincent & Pangrazi, 2002). Pedometers are often used in physical education classes and can be incorporated into the curriculum as a way of motivating students to be more active and more aware of their movement experiences (Pangrazi, Beighle, & Sidman, 2003). Physical education teachers can also use the pedometer as an instrument to gauge intensity levels during PE classes. It must be noted, however, that pedometers were designed to count steps during walking. Pedometers are less accurate when the user walks too slowly or too briskly (Beets, Patton, & Edwards, 2005; Crouter et al., 2003; Melanson et al., 2004), and children in PE classes often engage in different types of locomotor movements at different intensities.

The few studies exploring the accuracy of the pedometer during different locomotor movements (Smith & Schroeder, 2008, 2010) suggest that the pedometer is less accurate during skipping, galloping, and sliding than during walking. These studies, however, employed a self-selected pace, and since speed was not tightly controlled, further exploration into this topic is necessary. Additionally, registered step counts during these movements may not accurately reflect activity intensities. As no studies have assessed intensity in locomotor movements such as skipping, galloping, and sliding, it is necessary that this is further quantified for PE teachers when they are designing curriculum.

This study assessed the accuracy of two pedometer models in children walking, skipping, galloping, and sliding at two controlled speeds. It was hypothesized there would be no difference between the actual steps and pedometer steps at a given speed for any of the locomotor movements. This study also quantified metabolic cost during these locomotor movements, and it was hypothesized there would be a significant difference in energy expenditure between the locomotor movements.

Method

The university's institutional review board reviewed and approved this study. Parental consent and child assent was received, and 53 fifth- and sixth-grade children participated in the study (Table 1). Exclusion criteria included inability of children to perform the desired locomotor movements or children wearing shoes other than laced athletic footwear. Each child performed four counterbalanced trials (walking, skipping, galloping, and sliding) at 67.0 $m.min^{-1}$ for 3 min and at 80.5 $m.min^{-1}$ for another 3 min. All data collection was carried out in the gymnasium at the participating elementary school. Prior to data collection, the investigators asked the students to perform the locomotor movements up and down the court to show proficiency of the movements. After students were deemed proficient in adequately performing the skill without extra or missed movements within the skill (i.e., an extra hop in a skip or a missed hop in a skip), height was measured on a Seca 214 portable height rod (Itin Scale Co., Brooklyn, NY) and weight was determined on a balance scale (Detecto, Webb City, MO), both without shoes, after which a Polar HR monitor was fitted around the chest. The investigators then demonstrated the skills on a PROFORM XP 550s motor-driven treadmill (Icon Health and Fitness, Logan, UT), and students practiced on the treadmill, at which time the speed was briefly increased to 67.0 $m.min^{-1}$ and 80.5 $m.min^{-1}$ for familiarization of the protocol. Proficiency evaluation, demonstration, familiarization, and instruction typically lasted approximately 5 to 10 min.

Table 1
Participant Characteristics

Characteristic	Total (*N* = 53) *M* ± *SD*	Boys (*n* = 27) *M* ± *SD*	Girls (*n* = 26) *M* ± *SD*
Age (years)	11.3 ± 0.6	11.4 ± 0.7	11.3 ± 0.5
Height (in.)	57.3 ± 4.3	57.3 ± 5.1	57.3 ± 3.3
Weight (lb)	97.6 ± 25.8	94.6 ± 26.4	100.6 ± 25.2

Students were then fitted with a Velcro Walk4Life pedometer belt (Walk4Life, Plainfield, IL) around the waistline at the hip. An SW-701 Digiwalker (New-Lifestyles, Lee's Summit, MO) was then fitted on the anterior mid-line of the right thigh and another contralaterally on the left. A New-Lifestyles NL-800 pedometer (New-Lifestyles, Lee's Summit, MO) was fitted just laterally to each of the SW-701 pedometers. Pedometers were checked before each session via the shake test. Pedometers were reset and carefully placed in a slotted container, held upright, and shaken in the vertical plane 50 times (S. Vincent & Sidman, 2003). If a pedometer failed to record at least 49 counts or recorded 51 or more counts (±2% error), it was not used.

Twenty-one students also consented to have metabolic data collected. These students were fitted with a Cosmed $K4b^2$ (Cosmed Srl, Italy) portable oxygen analyzer, which was calibrated per manufacturer instructions with 16% O_2 and 3.99% CO_2 before testing.

Before the first trial began, the student was instructed to straddle the treadmill while it was brought up to 67.0 $m \cdot min^{-1}$. The pedometers were reset to 0 and closed, and the student was told to begin when ready. Once the student began, time was kept with the timer on the treadmill and at least two investigators counted the steps. Each step, or belt contact, with the lead foot elicited a count on a hand-tally counter (Lab Safety Supply, Model No. 77270, USA) from the two investigators. While walking and skipping consisted of alternate lead legs, the gallop and slide maintained the right lead throughout the trials. Hand-tally counts were doubled for the skip, gallop, and slide for statistical analysis since the trail leg also contacted the ground. Students were not allowed to hold onto the handrails during the trials other than when sliding, when they could use one hand for balance if needed. At 3 min, the students were instructed to straddle the treadmill and remain still.

At the end of each 3 min, heart rate and a rating of perceived exertion was recorded via the children's OMNI scale (Robertson et al., 2000), and the analyzer was marked for those wearing it. The investigators recorded the pedometer and hand-tally counts, and the student was allowed to get a drink of water and briefly rest, if needed. When the student was ready, the treadmill was brought up to 80.5 $m \cdot min^{-1}$ for the student to complete the second phase of the trial in the same manner. To provide rest between locomotor skills, investigators had students rest while another performed a trial.

Statistical Analyses

All analyses were performed via SPSS 23.0 for Windows (IBM SPSS, Armonk, NY). Since the actual counts (AC) from the hand tally represent the real number of step taken, single measures intraclass correlation coefficients (ICC) from a two-way mixed effects ANOVA along with 95% confidence intervals (95% CI) produced intertester reliability coefficients for determining the degree of objectivity of AC between investigators. Repeated measures ANOVAs determined differences between counts obtained by each pedometer and AC during walking, skipping, galloping, and sliding. Alpha was set at .05 for all tests, and when the main effect was significant, adjustment for multiple comparisons was made via the Bonferroni adjusted form of the least significant difference (LSD). Alpha for these comparisons was set at .01 (.05/5).

Intraclass correlation coefficients were also calculated in the same manner for assessing the reliability between right and left pedometers. An alpha value of > 0.80 denoted statistically significant intramodal reliability. The following guidelines determined the level of agreement of the ICC calculated for each comparison: ≤ 0.79 is low agreement, 0.80 to 0.89 is moderate agreement, and ≥ 0.90 is considered high agreement (W. Vincent, 2005, p. 196). Bland-Altman plots of AC versus the average of the right and left pedometer readings provided an indication of overrepresentation or underrepresentation of steps and agreement between the measures (Bland & Altman, 1986). Scores below 0 indicate an overestimation by the pedometers, and scores above 0 indicate an underestimation of the pedometers. These plots show the variability in pedometer scores while showing the mean error score and the 95% prediction interval. Error scores of 0 indicate that no difference between the actual steps taken and those registered by the pedometer. Percent error was calculated as [(Steps Detected by Pedometer – AC) / AC] × 100.

Repeated measures ANOVAs also determined differences in heart rate (HR), oxygen consumption (VO_2), ventilation (VE), respiratory exchange ratio (RER), and rating of perceived exertion (RPE) between locomotor trials of each speed.

Results

Agreement of Steps Between Investigators

There was a mean difference of less than one step count between hand-tally counts of investigators during walking, skipping, galloping, and sliding trials at each speed. There was also high intramodal reliability and level of agreement between the investigators during all movements at each speed (Table 2).

Table 2
Intramodal Reliability Between Hand-Tally Counts During Four Locomotor Movements

Locomotor movement	Intraclass correlation coefficient	95% confidence interval
Walking		
67.0 m·min^{-1}	0.999	0.998 to 0.999
80.5 m·min^{-1}	0.995	0.991 to 0.997
Skipping		
67.0 m·min^{-1}	0.999	0.999 to 1.000
80.5 m·min^{-1}	0.999	0.999 to 1.000
Galloping		
67.0 m·min^{-1}	0.997	0.994 to 0.998
80.5 m·min^{-1}	0.999	0.998 to 0.999
Sliding		
67.0 m·min^{-1}	0.998	0.997 to 0.999
80.5 m·min^{-1}	0.997	0.995 to 0.999

Tests of Pedometer Differences

There was a significant main effect for differences in step counts during walking, $F(4, 49) = 6.9$, $p = .001$; skipping, $F(4, 49) = 23.7$, $p = .001$; galloping, $F(4, 49) = 21.5$, $p = .001$; and sliding, $F(4, 49) = 34.2$, $p = .001$, at 67.0 $m \cdot min^{-1}$. Walking step counts registered by both NL-800s were not significantly different than AC ($p > .01$). For all other locomotor trials, step counts registered by the SW-701 and NL-800 on the right and left side were significantly lower than AC ($p < .01$). Additionally, there were no significant differences in step counts between the right and left SW-701 ($p > .01$) nor the right and left NL-800 ($p > .01$) for any of the locomotor trials. Table 3 shows means and standard deviations for step counts.

There was also a significant main effect for differences in step counts during walking, $F(4, 49) = 4.64$, $p = .003$; skipping, $F(4, 49) = 49.6$, $p = .001$; galloping, $F(4, 49) = 27.1$, $p = .001$; and sliding, $F(4, 49) = 73.6$, $p = .001$, at 80.5 $m \cdot min^{-1}$. Again, the step counts registered by both NL-800s were not significantly different than AC during walking at this speed ($p > .01$). As with the slower speed, step counts registered in all other locomotor trials by the SW-701 and NL-800 on the right and left side were significantly different than AC ($p < .01$) in the faster speed. Furthermore, there were no significant differences in step counts between the right and left SW-701 ($p > .01$) and the right and left NL-800 ($p > .01$) for any of the locomotor trials (Table 3).

Agreement of Steps Between Pedometers

Intramodal reliability and level of agreement was lowest in the SW-701 pedometers during walking at each speed. Low agreement was also noted in the SW-701 during galloping at both speeds and in the SW-701 during sliding during the faster speed. Intramodal reliability was considered moderate and high in both pedometer models during all other locomotor movements (Table 4).

Table 3
Step Counts After Treadmill Walking for 3 Min

Locomotor movement	Actual count	SW-701		NL-800	
		Right	Left	Right	Left
	M ± *SD*	*M* ± *SD*	*M* ± *SD*	*M* ± *SD*	*M* ± *SD*
Walking					
67.0 m·min^{-1}	364.8 ± 31.0	329.4 ± 50.1*	326.1 ± 63.6*	363.6 ± 28.9	361.5 ± 27.6
80.5 m·min^{-1}	389.1 ± 22.0	379.7 ± 25.5*	370.0 ± 49.2*	388.1 ± 21.7	388.2 ± 21.9
Skipping					
67.0 m.min^{-1}	628.6 ± 85.3	495.7 ± 50.1*	491.4 ± 53.9*	459.4 ± 67.4*	460.2 ± 67.1*
80.5 m.min^{-1}	657.3 ± 77.8	473.0 ± 55.3*	470.3 ± 59.3*	429.1 ± 62.2*	431.1 ± 60.2*
Galloping					
67.0 m·min^{-1}	574.5 ± 31.7	501.7 ± 56.6*	501.3 ± 51.4*	441.4 ± 88.2*	446.4 ± 65.7*
80.5 m·min^{-1}	603.1 ± 77.2	512.6 ± 54.4*	508.8 ± 55.6*	445.7 ± 72.5*	444.4 ± 73.8*
Sliding					
67.0 m·min^{-1}	614.1 ± 59.8	506.2 ± 60.6*	502.2 ± 57.9*	454.8 ± 67.5*	448.1 ± 68.9*
80.5 m·min^{-1}	645.0 ± 58.5	471.8 ± 71.5*	468.7 ± 61.5*	418.1 ± 68.9*	412.5 ± 70.8*

*Significantly different from actual counts for given trial and speed.

Table 4
Intramodal Reliability Between Right and Left Pedometers During Four Locomotor Movements

Locomotor movement	Intraclass correlation coefficient		95% confidence interval	
	SW-701	NL-800	SW-701	NL-800
Walking				
67.0 m·min^{-1}	0.509	0.921	0.276 to 0.685	0.867 to 0.954
80.5 m·min^{-1}	0.557	0.973	0.340 to 0.718	0.976 to 0.992
Skipping				
67.0 m·min^{-1}	0.900	0.994	0.832 to 0.941	0.989 to 0.996
80.5 m·min^{-1}	0.934	0.973	0.888 to 0.961	0.954 to 0.984
Galloping				
67.0 m·min^{-1}	0.790	0.939	0.662 to 0.873	0.897 to 0.964
80.5 m·min^{-1}	0.786	0.927	0.656 to 0.871	0.877 to 0.957
Sliding				
67.0 m·min^{-1}	0.813	0.883	0.693 to 0.889	0.802 to 0.932
80.5 m·min^{-1}	0.716	0.828	0.553 to 0.827	0.715 to 0.898

Bland-Altman Plots

Table 5 displays the mean error scores and the 95% prediction intervals of AC minus the average of the right and left pedometer steps during the five locomotor movements, and Figure 1 illustrates this table with the Bland-Altman plots. The most accurate condition was the NL-800 during walking at 80.5 m·min^{-1}, which had a 95% prediction interval that was within ± 13.8 steps from 0. Skipping at 80.0 m·min^{-1} with the SW-701 was the least accurate condition, with a 95% prediction interval that was within ± 470.7 steps from 0. Table 5 provides the mean error scores and 95% prediction intervals for all conditions, and Figure 1 illustrates the Bland-Altman plots for walking and galloping.

Table 5
Mean Error Scores (Hand Tally – Average of Right and Left Pedometers) in Number of Steps, With Percent Error

Locomotor movement	Intraclass correlation coefficient SW-701 *M* ± *SD* (% error)	Intraclass correlation coefficient NL-800 *M* ± *SD* (% error)	95% confidence interval SW-701	95% confidence interval NL-800
Walking				
67.0 m·min^{-1}	37.1 ± 56.0 (-11.2)	3.88 ± 30.1 (-0.2)	196.2, -107.3	63.7, -57.5
80.5 m·min^{-1}	14.5 ± 28.6 (-3.7)	0.95 ± 6.46 (-0.2)	72.3, -42.9	13.8, -11.9
Skipping				
67.0 m·min^{-1}	135.1 ± 109.0 (-19.7)	168.8±123.9 (-25.0)	353.1, -82.9	416.7, -78.9
80.5 m·min^{-1}	185.7 ± 119.3 (-26.6)	227.3 ± 121.7 (-33.0)	424.4, -53.0	470.7, -17.7
Galloping				
67.0 m·min^{-1}	73.0 ± 72.3 (-11.9)	130.6 ± 100.0 (-21.7)	217.6, -71.5	330.6, -69.3
80.5 m·min^{-1}	92.4 ± 99.5 (-14.0)	158.0 ± 118.0 (-24.8)	291.5, -106.6	394.2, -78.1
Sliding				
67.0 m·min^{-1}	107.3 ± 92.0 (-16.6)	160.0 ± 97.5 (-25.3)	297.6, -77.0	355.0, -34.9
80.5 m·min^{-1}	174.7 ± 103.9 (-26.1)	299.7 ± 94.3 (-35.0)	382.6, -33.1	418.2, 41.1

Tests of Metabolic Differences

Heart rate. There was a significant main effect for HR, $F(7, 45) = 303$, $p = .001$. HR was significantly greater at 80.5 m/min compared to 67 m/min for each locomotor movement ($p < .05$).

For the slower speed, walking HR was significantly lower than HR for all other movements ($p < .05$) and sliding HR was significantly greater than HR for all other movements ($p < .05$). HR during skipping at the slower speed was not significantly different than HR during galloping at the lower speed ($p = 1.0$).

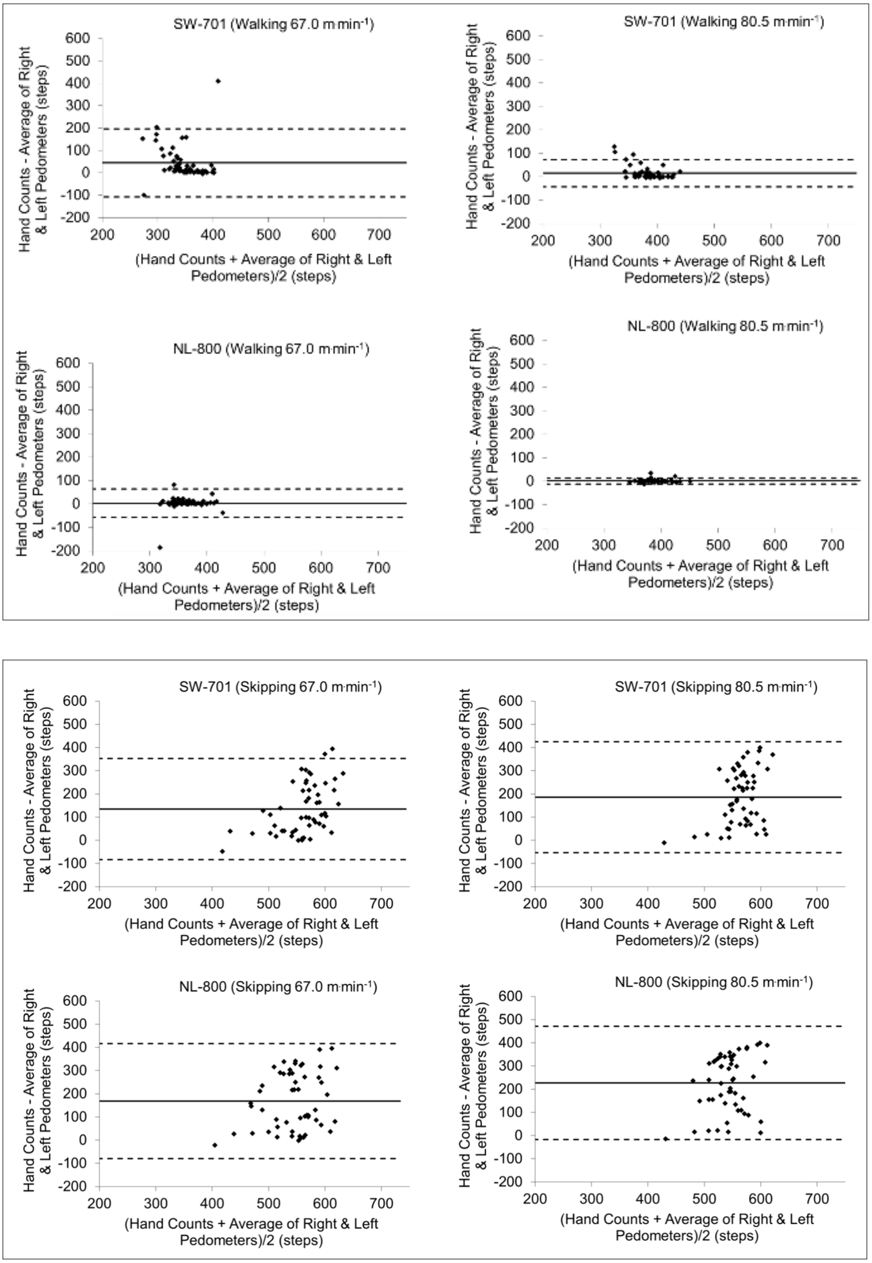

Figure 1. Agreement of pedometer scores of children walking at two speeds on the treadmill. Illustrated are the most accurate (walking) and the least accurate (skipping) of the locomotor skills assessed.

HR during walking at 80.5 m/min was also significantly lower than HR for all other movements ($p < .05$), and HR for sliding was significantly greater than HR for all other movements ($p < .05$). Again, HR during skipping at the faster speed was not significantly different than HR during galloping at the faster speed ($p = .86$). Figure 2 shows these HR responses.

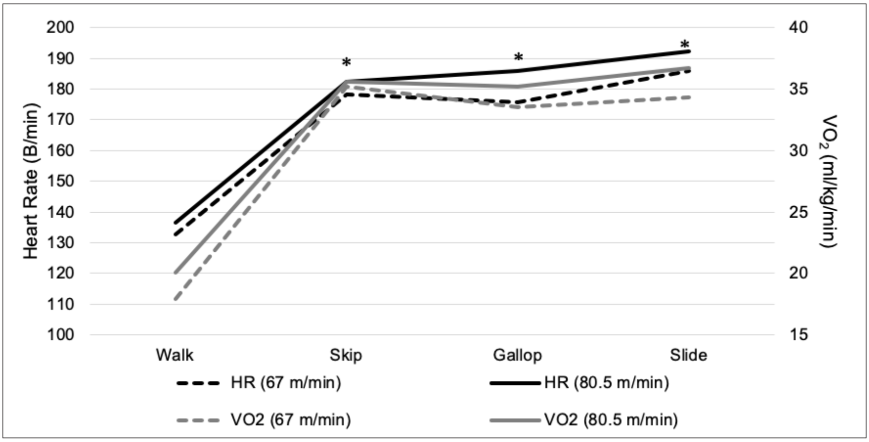

Figure 2. Heart rate and VO_2 responses to different locomotor movements. Heart rate and VO_2 were significantly greater during skipping, galloping, and sliding compared to walking at the same speeds (*$p < .05$).

Oxygen consumption. There was also a significant main effect for VO_2, $F(7, 14) = 103$, $p = .001$. VO_2 was significantly greater at 80.5 m/min compared to 67 m/min for each locomotor movement ($p < .05$) except skipping ($p = .63$).

For the slower speed, walking VO_2 was significantly lower than VO_2 for all other movements ($p < .05$). There were no significant differences in VO_2 between galloping, skipping, and sliding movements at 60 m/min ($p > .05$).

VO_2 while walking at 80.5 m/min was significantly lower than VO_2 for all other movements at 80.5 m/min ($p < .05$), and VO_2 during sliding was significantly greater than VO_2 during all other movements ($p < .05$) except skipping ($p = .37$). There was also no significant difference in VO_2 between skipping and galloping ($p = .74$) at this faster speed. Figure 2 shows the VO_2 responses.

Ventilation. There was a significant main effect for VE, $F(7, 14) = 41.7$, $p = .001$. VE was significantly greater at 80.5 m/min compared to 67 m/min for sliding only ($p < .001$). There were no significant differences in VE between speeds for any of the other movements ($p > .05$).

VE during movement at 67 m/min was significantly lower during walking compared to all other movements ($p < .05$); however, there was no significant difference in VE between skipping, galloping, and sliding at this speed ($p > .05$).

At the faster speed, VE during walking was still significantly lower than VE during all other movements ($p < .05$) and similar to the VE at the slower speed. There was no significant difference in VE between skipping, galloping, and sliding at 80.5 m/min ($p > .05$). Figure 3 shows the ventilatory responses during the locomotor movements.

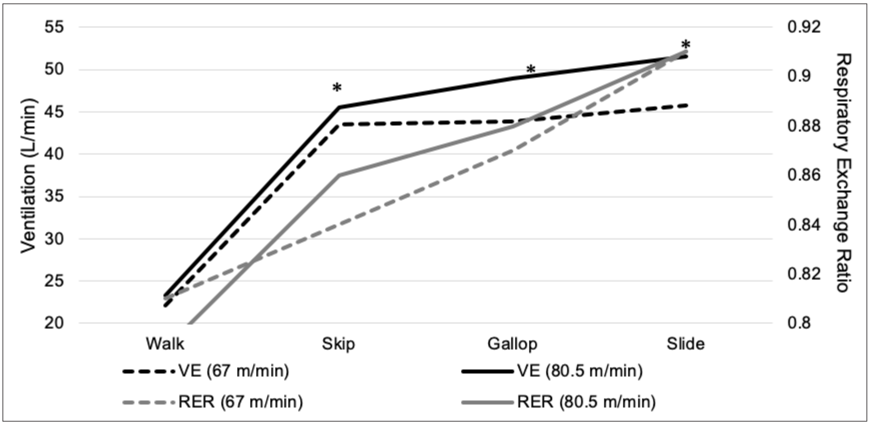

Figure 3. Ventilation and respiratory exchange ratio responses to different locomotor movements. Ventilation and respiratory exchange ratio were significantly greater during skipping, galloping, and sliding compared to walking at the same speeds (*$p < .05$).

Respiratory exchange ratio. While a significant main effect was found for RER, $F(7, 14) = 10.9$, $p = .001$, no differences existed between the speeds for any of the skills ($p > .05$).

The only significant difference in RER at 67 m/min existed between walking and sliding ($p = .001$). RER was not significantly different between any of the other movements at this speed ($p > .05$).

Walking at 80.5 m/min elicited a significantly lower RER compared to all other movements ($p < .05$), and there was no significant difference in RER between any of the other movements at this speed ($p > .05$). Figure 3 also shows RER responses.

Rating of perceived exertion. Finally, a main effect for RPE was also evident among the different skills and speeds, $F(7, 45) = 28.0$, $p = .001$. The faster speed was perceived as significantly harder than the slower speed for all movements ($p < .05$) except walking ($p = 1.0$).

For 67 m/min, walking was perceived as significantly easier compared to all other movements ($p < .05$) and skipping was perceived to be significantly easier than sliding at this speed ($p = .001$). All other movements were not perceived to be significantly different at 67 m/min.

Walking at 80.5 m/min was also perceived as significantly easier compared to all other movements at 80.5 m/min ($p < .05$). Skipping was also perceived significantly easier than galloping ($p = .038$) and sliding ($p = .001$), and there was no significant difference in perceived effort between galloping and sliding at this speed ($p > .05$). Figure 4 shows RPE responses.

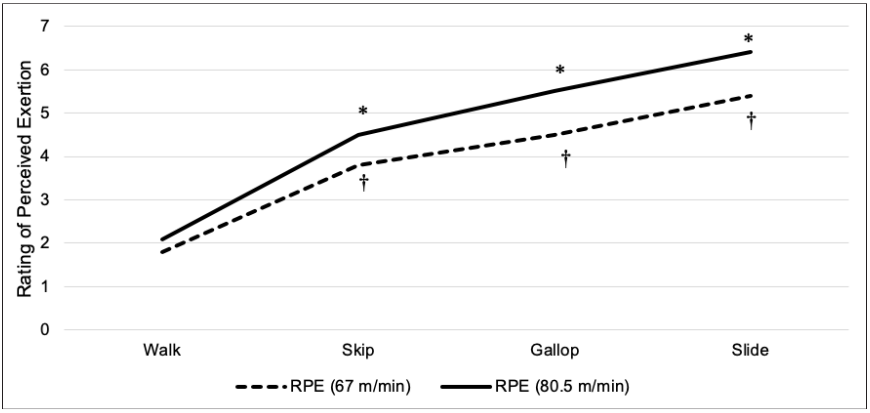

Figure 4. Rating of perceived exertion for different locomotor movements. Perceived exertion was rated significantly higher in all other movements compared to walking (*$p < .05$). While there was no significant difference in perceived exertion between speeds during walking, ratings were significantly higher between speeds for all other movements ($^{\dagger}p < .05$).

Percent Change With Increasing Speed

An increase in speed elicited an increase in steps, HR, VO_2, VE, RER, and RPE within each locomotor movement. Figure 5 shows how an increase in speed during galloping and sliding, compared to the other movements, resulted in the greatest increases in metabolic and perceptual demand, although this is not reflected in increases in step counts.

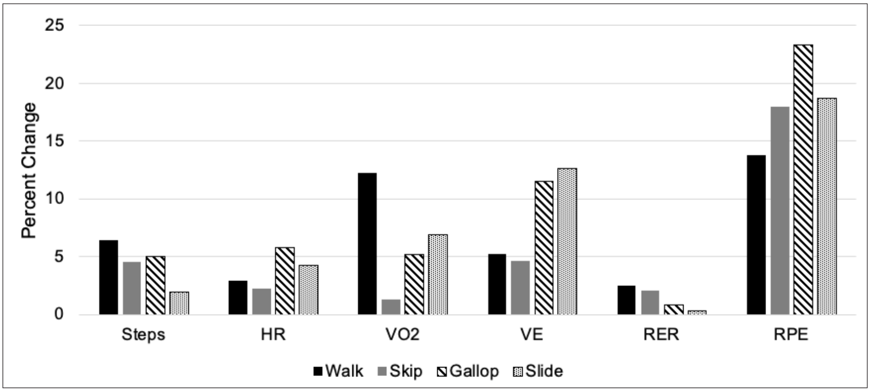

Figure 5. Percent change from 60 m/min to 80.5 m/min for each locomotor movement.

Discussion

This study explored the accuracy of pedometers during various locomotor movements at two speeds. The SW-700 and the NL-800, a spring-levered and piezoelectric pedometer, respectively, were chosen for this study because of the vast literature examining their accuracy in a variety of populations and circumstances. The SW-701 has been determined to be one of the better performing pedometers on the market (Crouter et al., 2003; Schneider et al., 2003) and the NL-800 is more sensitive to tilts or slower walking speeds (Melanson et al., 2004). Because significant differences were found between actual counts and pedometer counts for all locomotor skills at all speeds except with the NL-800 during walking at either speed, the null hypothesis for this study was not retained.

The NL-800 also had the lowest error scores for walking at either speed, thus deeming it the more accurate of the two pedometers during walking, and this is in agreement with previous literature (Crouter, Schneider, & Bassett, 2005). The SW-700 has also been explored for accuracy in the literature and found to be less so for walking at slower speeds (Beets et al., 2005) compared to faster (Karabulut, Crouter, & Bassett, 2005) or self-paced walking

(Schneider et al., 2003). The difference in accuracy in this study is in some agreement with the stated studies, with greater mean error (11.2%) at the slower speed compared to the faster speed (3.7%). The findings of accuracy between the SW-700 and NL-800 for walking were expected, as it has been suggested that piezoelectric devices are more accurate than spring-levered devices during walking (Nakae, Oshima, & Ishii, 2008.). One case during walking at the slower speed with the SW-701 could be considered an outlier, as could three cases at the faster speeds (Figure 1), thus steps on these devices may not have registered properly due to tilt (Duncan, Schofield, Duncan, & Hinckson, 2007) or another circumstance such as gait.

In locomotor movements other than walking, both pedometers underestimated step counts at each speed. Some suggest an acceptable error of no more than 3% in controlled conditions (Hatano, 1993) and 10% in free-living conditions (Schneider, Crouter, & Bassett, 2004), both of which were surpassed in every non-walking locomotor movement at each speed. This may be explained by the force generated with each step during the stride of the locomotor movements and the sensitivity of the pedometer to register a step. For example, the skip, which includes a step and a hop for each stride, may generate a force great enough to be registered by the pedometer for either the step or hop, but not always both. The same can be said for the gallop and the slide, which involve a lead leg and a trail leg. For each of the non-walking movements, the SW-701 had less error than the NL-800. The SW-701 was designed to register a count with a vertical force of 0.35Gs (Tudor-Locke, Ainsworth, Thompson, & Matthews, 2002), so it may be that one of the steps during the strides of the non-walking movements was less than that.

To the authors' knowledge, no studies have examined the forces generated during these types of movements. One may also presume that since the NL-800 is thought to be more accurate, error in these movements would be less, which is contrary to these findings. It could be that one of the steps in the stride did not generate a force great enough to have a significant contribution in propelling the body forward. It is obvious that movement in these skills requires both legs to move the body, but that the contribution of one leg is much less than that of the other.

This study also explored differences in pedometer readings on the right and left side. While level of agreement was found to be low in the right and left SW-701 during walking and galloping at each speed and during sliding at the faster speed, significance between these step counts were not statistically different. Since manufacturer guidelines suggest placing the pedometers on the right side, one would be encouraged to do so. Should this not be feasible during a physical education class, placing the device on the left side is still a viable option and would produce similar results.

This study also quantified the metabolic cost of performing these locomotor movements, and since significant differences were evident, the alternate hypothesis was retained. Walking elicited the lowest energy expenditure of all the locomotor skills at either speed, whereas sliding produced the greatest. Skipping, galloping, and sliding clearly generated greater metabolic cost compared to walking and thus can be considered movements that require greater effort. The magnitude of these changes is pronounced, for example, as indicated by a 32–40% increase in HR during skipping, galloping, and sliding at either speed compared to walking. Supporting these findings are student's perception of exertion, where skipping, galloping, and sliding were rated much higher than walking.

Physiologically and perceptually, it is clear that an increase in speed causes an increase in energy expenditure and rating of effort for all movements. It is also clear that an increase in speed elicits an increase in actual step counts, and while this was the case for step counts registered on the pedometer during walking, it was not for the other movements. In almost all cases, step counts registered by both pedometers was lower at the faster speeds during skipping, galloping, and sliding, with error being the highest at this faster speed. This may be attributed to the students performing movements on the treadmill, as they had only performed them overground prior to this study. Some studies have shown changes in kinematics from overground to treadmill walking (Alton, Baldey, Caplan, & Morrissey, 1998), while others suggest changes are minimal (Riley, Paolini, Della Croce, Paylo, & Kerrigan, 2007). Since no studies have examined gait during skipping, galloping, or sliding, it may be that performing these movements on a moving belt at a constant speed can result in inconsistent patterns, thus increasing error in the pedometers.

Step counts during these locomotor movements are higher than those during walking at either speed, thus suggesting the higher counts relate to greater metabolic demand. In other words, while the pedometers showed substantial error in accurately measuring step counts during skipping, galloping, and sliding, counts registered during these movements were higher than those for walking, reflecting the greater energy cost of the activity. The physical educator should consider this when incorporating these kinds of movements into the lesson. If using pedometers in a lesson during which these types of locomotor movements occur, the physical educator can expect a greater metabolic demand and higher step counts, thus reflecting more intense activity.

Conclusion

Pedometers have been available for many years and continue to be a viable tool for measuring physical activity in children during nonstructured (Fukushima et al., 2016; Hazell et al., 2016; Stearns et al., 2016; Vandenbroucke, Seghers, Verschueren, Wijtzes, & Baeyens, 2016) and structured (Burns, Brusseau, & Hannon, 2015; Fu, Brusseau, Hannon, & Burns, 2017; Jones, Brusseau, Kulinna, & van der Mars, 2016) periods. Tudor-Locke et al. (2006) noted, evaluation of pedometers under controlled conditions alone is not sufficient for accuracy to be determined. Comparison to other measures of activity (actual counts as well as accelerometer counts), the environment tested (overground and treadmill movement), and other factors should be considered. Results of this study suggest the NL-800 reflects greater accuracy during walking and that the SW-701 has less error during all other locomotor skills for each speed. Since physical education classes involve a variety of movements other than walking, the SW-701 seems to be a better choice should a teacher be inclined to use pedometers. These pedometers are acceptable for tracking steps during walking, and while accuracy is in question during skipping, galloping, and sliding, the increases in step counts during these movements reflect the greater metabolic demand. Physical education teachers can now be aware that changes in locomotor movements, specifically skipping, galloping, and sliding, will result in increases in energy expenditure and that these increases can be substantial. If asking students to perform locomotor skills other than walking, physical educators must be aware of the duration and intensity they are prescribing so as to administer the activity appropriately. Students enjoy the novelty of performing various locomotor movements, and since energy expenditure is increased, it can also benefit the cardiovascular system.

Pedometers are an economical tool that can be used for tracking physical activity and motivating the user to be active. This study is the first to show evidence that changing locomotor movements in children results in changing metabolic cost, and this is also reflected by increases in step counts on the pedometer. A limitation of these findings, however, is that the movements were conducted at the same absolute speed on a treadmill. Future studies should explore the accuracy of the pedometers and metabolic cost of these locomotor movements during overground traversing since these skills are not normally performed on a treadmill. While skipping, galloping, and sliding are common locomotor movements performed by children, other movements commonly instructed in physical education classes, such as crab walking, bear walking, and even tumbling, can also be explored.

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