Research article

RELATIONSHIP BETWEEN THE MTI ACCELEROMETER (ACTIGRAPH) COUNTS AND RUNNING SPEED DURING CONTINUOUS AND INTERMITTENT EXERCISE

Comlavi B. Guinhouya [1,2] **, Hervé Hubert** [1] ✉**, Grégory Dupont** [2] **and Alain Durocher** [1]

[1] Medical Decision Support, Institute of Engineering in Health of Lille, University of Lille 2, France
[2] Laboratory of Human Movement Studies, Faculty of Sport Sciences and Physical Education, University of Lille 2, France

ABSTRACT

This study was designed to investigate the relationship between Actigraph counts and running speed; and to describe differences due to accelerometer position on the body and due to exercise modality. Eleven physical education students (age, 25.1 ± 3.7 years; height, 1.73 ± 0.10 m; body mass, 70.8 ± 10.8 kg) completed two exhaustive exercise tests (continuous and intermittent), with MTI accelerometers mounted both at the hip and ankle. Exercise consisted of running for 3-min at incremental speeds until volitional exhaustion. During both exercise tests, the relationship between the ActiGraph outputs worn at the hip and speed was linear in the range $1.1 - 3.3$ m·s^{-1} ($r^2 = 0.94$ and 0.95, $p < 0.01$ for continuous and intermittent exercise respectively). A coefficient of determination of $r^2 = 0.97$ ($p < 0.01$) was found with ankle wearing from walking, jogging and running at high speeds. There was a body placement effect at all absolute speeds ($p < 0.01$); but no exercise effect on accelerometer counts and no interaction between placement and exercise ($p > 0.05$). The ActiGraph seems to be a reliable tool for estimating a wide range of activity or exercise intensities. An ActiGraph worn at the ankle may be more appropriate to reflect normal human movement.

KEY WORDS: Physical activity, joint kinematics, hip, ankle.

INTRODUCTION

During physical exercise and competition, workload or intensity can be estimated by means of oxygen consumption (VO_2), heart rate (HR), and also subjectively with the rating of perceived exertion (RPE). These measures correlate well to an individual's speed or power output over a wide range of exercise intensities. That is, as speed or power output increase VO_2, HR and RPE increase as well (Åstrand and Rodhal, 1986; Borg, 1990). Thus, the American College of Sports Medicine (ASCM, 2000) usually recommends basing exercise intensity on power output or running speed, and the HR and/or RPE are associated with a target VO_2. Up to now, HR telemetry together with the classical stopwatch has been the most useful tool in training and rehabilitative settings, because of its relative accuracy, reliability, low cost, and ease for later data processing.

Currently, there is a widespread use of the Computer Science and Applications (CSA, model 7164) accelerometer (also called the ActiGraph or MTI accelerometer) in the measurement of physical activity in various conditions. This device is a lightweight single channel motion sensor designed

to detect and record time and varying accelerations. It is used to identify physical activity dimensions – that is, intensity, frequency, and duration – numerous validation studies, both in laboratory and field settings, demonstrated the capability of this tool to measure activity intensities from walking to running (Freedson et al., 1998; Hendelman et al., 2000; Nichols et al., 2000; Swartz et al., 2000; Trost et al., 1998). For practical reasons (e.g. comparison between studies measuring physical activity or its equivalent energy cost), Actigraph is often worn on the hip; but the optimum placement, at least with regard to exercise intensity, remains unknown. Brage et al. (2003b), showed a linear relationship between the ActiGraph outputs and velocity during walking and running but only at moderate speeds (up to 2.5 m·s^{-1}). Above this speed, the ActiGraph seems to be less sensitive to subsequent speed increase. Similar findings were reported in different experimental conditions by other researchers (Freedson et al., 1998; Nichols et al., 2000). Based on some biomechanical differences between walking and running, the authors have attempted to clarify the flattening of the curve of the ActiGraph counts and speed, as speed exceeds 2.2-2.5 m·s^{-1}. In these aforementioned studies, ActiGraphs were always mounted at the hip of participants. During running, it has been reported that oscillations in the vertical plane diminished at higher speeds (Gregor and Kirkendall, 1978), with a tendency to have smaller antero-posterior forces (Williams and Cavanagh, 1987). This finding may be more apparent in the waist when compared with the ankle or the knee. By placing the device on a different anatomical site, it can be hypothesised that the ActiGraph outputs in relation to speed change; thus, providing additional clarification about the main source, which limits its sensitivity at the highest speeds. Since there may be some differences in the joint kinematics during running (Kyrölainen et al., 2001), it was an aim of this study to identify the differences in the ActiGraph output's relation to speed according to the position of the device on the body. Because the ActiGraph measures accelerations/decelerations in the vertical plane, it seems logical to believe that cadence variation in this plane (stride length and frequency) according to activity-type may influence the output. Normal life activities are rarely performed in a continuous way. The bulk of an individual's free-living physical activity (both for children and adults) behaves intermittently, with activity periods of various intensity interspersed with rest (Åstrand and Rodhal, 1986). Since such an activity may account for different biomechanical characteristics as opposed to continuous activity, the common use of only continuous exercise with a view to validating this instrument could be questioned. While continuous exercise resulted in a regular gait pattern (Berthoin et al., 1996), intermittent exercise dealt with continual accelerations, decelerations, stops, turns and starts (Gadoury and Léger, 1986). Furthermore, exploring an intermittent activity might help to obtain additional insight into the functionality of the MTI accelerometer using a larger range of speeds. A second purpose of this study was to compare the relationship between the ActiGraph outputs at the hip and ankle by comparing intermittent versus continuous exercise.

METHODS

Subjects

Eleven students in physical education (9 men and 2 women; aged 25.1 ± 3.7 years) volunteered to participate in this study. Their height and body mass values were 1.73 ± 0.10 m and 70.8 ± 10.8 kg, respectively. They were apparently healthy and moderately fit. Prior to the exercises, they were informed about the procedures and the possible risks of the experiment, and they gave a written informed consent in accordance with the ethical committee for the protection of persons in biomedical research at the University of Lille 2.

Procedures

The subjects were asked to randomly perform two maximal ramp tests (continuous and intermittent) on a tartan track. The exercises were separated by at least 2 days, and the protocol was completed within 2 weeks. Subjects performed these tests at least 3 hours post-absorptive and at the same time of day. During both exercises, the subjects had to walk/run for 3-min at predetermined constant speeds. The first speed was set at 1.1 m·s^{-1} and was increased by 0.56 m.s^{-1} every 3 min until volitional exhaustion. The running pace was dictated by audio signals.

Continuous test

This exercise consisted in running continuously for 3-min at successive speeds ('stages'). Red cones were set at 25-m intervals along the track. Within 2-m of each red cone, a green cone was placed, enabling the identification of the regularity of the paces according to the audio signals. At the highest speeds, if subjects were no longer able to maintain their speed with respect to the red cone, they were asked to stop running - when two consecutive late passages over the green cone were observed. The speed of the last stage enabled maximal speed (MS) to be calculated, according to Kuipers et al. (1985).

Intermittent test

This consisted in running for 10-s over a distance corresponding to a fixed speed (in the range 1.1 to 6.1 m·s⁻¹), alternated by a 10-s passive recovery period. During the recovery periods, subjects were standing still, waiting for the start signal, which was given to nearest the second. At the highest speeds, subjects were allowed to stop running within 3-m after the stop line. After 10-s at rest, they turned around to run in the opposite direction. For example, when running at 3.9 m·s⁻¹, a given subject ran 39.0 m in 10-s. By accounting for the reaction time and the time to stop running, the running phase lasted roughly 12-s. Each stage lasted 3-min, so that a given subject could perform 18 repetitions. The speed of the last entirely completed stage was recorded as the maximal intermittent speed.

MTI accelerometer, ActiGraph, (model 7164)

In both testing procedures, two ActiGraph units (units A and B) were tightly and systematically mounted on both the right-hand side of the hip and at the ankle in the same vertical axis, such that a line could be drawn to join them. The units were always placed in the same location for all participants – that is unit A was always positioned at the right hip, whereas unit B was always positioned at the right side of the ankle. The notch of unit A was steadily pointed upward, when that of unit B was toward the knee. Data was immediately downloaded after each test.

The ActiGraph measures 5.1×3.8×1.5 cm, is lightweight (42 g) and powered by a readily available 2430 coin cell lithium battery. This uniaxial monitor integrates accelerations/ decelerations in the vertical plane via a piezoelectric plate. Acceleration detection ranges from 0.05 to 2.00 g in magnitude and the frequency responses ranges from 0.25 to 2.5 Hz, so that motion outside normal human movement is rejected by a filtered bandpass. The acceleration-deceleration signal is digitized by an analog-to-digital converter and numerically integrated over a user-defined epoch interval. The rate of change of acceleration is sampled 10 times per second and the data sorted into epochs and stored in the internal memory; then the integrator is reset to zero. To begin data collection, the monitor is initialized using a compatible personal computer. A real-time internal clock allows the researcher to begin collecting at the desired time. The output from the ActiGraph is in "counts" per each epoch. "Counts" represent the summed amount and magnitude of acceleration during each epoch. That is, higher numbers represent a combination of higher frequency and intensity of movement. Generally, users adopted a 1-min interval epoch to collect physical activity data over an extended period. However, for the purpose of this study,

ActiGraphs were initialized to capture movement counts within 2-s time intervals. The reasons which motivated the choice of 2-s interval were, firstly for ease when cutting out outputs derived from the intermittent exercise; and secondly to get instantaneous peak counts instead of average counts over a longer period.

Data reduction

Mean ActiGraph outputs (counts per epoch) were calculated in the continuous test, for each speed, as an average of the 3-min exercise time. For the intermittent test, the ActiGraph outputs were averaged only over the 9 × 10-s of the running phase (9 × 10-s of recovery apart) during the 3-min exercise time for a given speed. Since the running phases at the highest speeds (from 3.3 m·s⁻¹) lasted 12-s, only the first 10-s data were introduced into the calculation.

Statistical analyses

Data were expressed as means ± standard deviations (mean ± SD). A Kolmogorov-Smirnov test completed by the Lilliefors' method enabled verification for normality. When the variables were not normally distributed, a log-transformation was applied to stabilize the variance, prior to the statistical tests. A series of two-way (exercise, placement and their interaction) analysis of variance (ANOVA) was used to examine the differences in the ActiGraph outputs at the different speeds across the exercise mode, by taking into account placement effects. Furthermore, a one-way ANOVA was used to determine whether the ActiGraph outputs changed across running speeds, in each exercise modality and each placement. If necessary a Tukey post hoc test was applied to locate the differences. Pearson product moment correlation coefficients were used to determine the relation between hip and ankle counts in each exercise modality. Because Brage et al. (2003a) reported significant mean difference (systematic bias) between ActiGraph units, which may translate, in vivo into about 20% difference in walking and 40% difference in running, it was then decided to control for this main effect. Therefore, 20% of the difference between data obtained at the hip and the ankle (during each exercise modality) in walking (1.1 to 1.7 m·s⁻¹), 30% in jogging (2.2 to 3.3 m·s⁻¹), and 40% in running (> 3.3 m·s⁻¹) were used as a controlling factor. The significance level was set at $p < 0.05$.

RESULTS

The ActiGraph outputs during exercises

Table 1 shows the ActiGraph outputs during both exercise modalities (continuous and intermittent)

Table 1. Mean (± SD) Actigraph outputs (counts per epoch) from the continuous and intermittent ramp exercises on each speed.

	Continuous exercise		Intermittent exercise		ANOVA		
	Hip	Ankle	Hip	Ankle	placement	exercise	placement × exercise
1.1 m·s^{-1}	70 (19) n = 11	269 (36)[a] n = 11	65 (16) n = 11	272 (19)[b] n = 11	***, F = 806.8	*ns*, F = 0.02	*ns*, F = 0.39
1.7 m·s^{-1}	169 (33) n = 11	337 (69)[a] n = 11	174 (59) n = 11	340 (83)[b] n = 11	***, F = 62.4	*ns*, F = 0.02	*ns*, F = 0.02
2.2 m·s^{-1}	289 (61)[c] n = 11	358 (146) n = 11	245 (51) n = 11	409 (79)[b] n = 11	***, F = 14.6	*ns*, F = 0.01	*, F = 4.4
2.8 m·s^{-1}	328 (80) n = 11	488 (172)[a] n = 11	295 (37) n = 11	577 (103)[b] n = 11	***, F = 46.8	*ns*, F = 0.7	*ns*, F = 3.6
3.3 m·s^{-1}	363 (63) n = 11	624 (293)[a] n = 11	331 (66) n = 11	749 (182)[b] n = 11	***, F = 52.9	*ns*, F = 0.73	*ns*, F = 3.7
3.9 m·s^{-1}	350 (65) n = 11	781 (256)[a] n = 11	327 (66) n = 11	876 (244)[b] n = 11	***, F = 79.1	*ns*, F = 0.43	*ns*, F = 1.2
4.4 m·s^{-1}	357 (93) n = 9	808 (185)[a] n = 9	320 (70) n = 11	938 (222)[b] n = 11	***, F = 139.8	*ns*, F = 0.13	*ns*, F = 1.73
5 m·s^{-1}	307 (71) n = 5	712 (147)[a] n = 5	326 (75) n = 9	1013 (284)[b] n = 9			
5.6 m·s^{-1}			316 (85) n = 7	1131 (335)[b] n = 7			
6.1 m·s^{-1}			261 n = 1	977 n = 1			

* $p < 0.05$, *** $p < 0.001$, ns= no significant difference.
[a] significant difference between hip and ankle wearing during the continuous exercise.
[b] significant difference between hip and ankle wearing during the intermittent exercise.
[c] significant difference between continuous and intermittent exercises for a hip wearing.
[d] significant difference between continuous and intermittent exercises for an ankle wearing.

and each body placement (hip and ankle). At all absolute speeds, the two-way ANOVA revealed significant body placement effect (p < 0.001). However, except at 2.2 m·s^{-1} (where the Tukey post hoc test showed a significant interaction between exercise and placement, p < 0.05), no other significant combined effect of the exercise modality and placement was observed. In each exercise modality, hip counts were significantly correlated with ankle counts (r = 0.79, p < 0.05 and r = 0.78, p < 0.01, for continuous and intermittent exercise respectively) as shown by Figure 1a and 1b. When controlling for the difference between units, correlation coefficients were greater. Partial correlations between hip outputs and ankle outputs were high and significant (r = 0.95, p < 0.001 for continuous exercise and r = 0.94, p < 0.0001 for intermittent exercise). Pearson correlation coefficient matrix, integrating speed ankle and hip outputs is presented in Table 2.

Table 2. Pearson correlation coefficient matrix, integrating speed ankle and hip outputs.

	Continuous exercise		Intermittent exercise	
	Hip	Ankle	Hip	Ankle
Continuous exercise				
Speed	0.79*	0.94**	0.69*	0.96**
Hip		0.79*	0.98**	
Ankle				0.97**
Intermittent exercise				
Hip				0.78**

* p < 0.05, ** p < 0.01.

Continuous exercise

Figure 2 shows the relationship between ActiGraph output and speed. Accelerometer hip counts increased linearly with speed up to 2.2 – 2.8 m·s^{-1} (r^2 = 0.96, p < 0.05). A significant difference was obtained between 2.2 and 3.3 m·s^{-1} (p < 0.05). Above 3.3 m·s^{-1}, the hip counts increased more

moderately (then the counts levelled-off) and were not significantly different from each other up to the end of the exercise (p > 0.05). The relationship between ActiGraph output and speed remained linear up to 3.3 m·s⁻¹ (r² = 0.94, p < 0.01 in the 1.1 – 3.3 m·s⁻¹ speed range). This relationship weakened from 3.9 m·s⁻¹ (r² = 0.85, p < 0.001 in the 1.1 – 3.9 m.s⁻¹ speed range). Hip counts decreased at the end of the exercise. Ankle counts increased more moderately with speed between 1.1-2.2 m·s⁻¹. No significant difference was found between counts obtained at 1.7 and 2.2 m·s⁻¹ (p > 0.05). From 2.2 m·s⁻¹, the ankle counts increased linearly with speed up to 3.9 m·s⁻¹ (r² = 0.94, p < 0.001 in the speed range of 1.1 – 3.9 m·s⁻¹). Then, no significant difference was obtained between 3.9 and 4.4 m·s⁻¹ (p > 0.05). Nevertheless, a regression analysis showed a coefficient of determination of r² = 0.96 (p < 0.0001) in the speed range of 1.1 – 4.4 m·s⁻¹. Ankle counts decreased significantly between 4.4 and 5.0 m·s⁻¹ (p < 0.05).

When comparing hip and ankle counts during the continuous exercise, a significant difference at every speed was found. Ankle counts were higher than hip counts (0.001 ≤ p ≤ 0.01), except at 2.2 m·s⁻¹ (p = 0.21); likely due to the transition between walking and running.
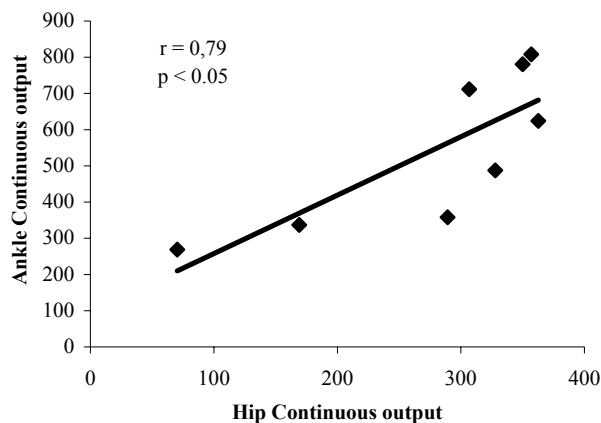
Intermittent exercise

Hip accelerometer counts augmented linearly with running speed up to 2.8-3.3 m·s⁻¹. As shown by figure 2, from 3.3 m·s⁻¹ a plateau occurred, and no other significant differences were detected between successive speeds (p > 0.05). Coefficients of determination of r² = 0.95 (p < 0.01) and 0.97 (p < 0.001) were found in the speed ranges of 1.1 – 3.3 m·s⁻¹ and 1.1 – 3.9 m·s⁻¹, respectively. Around the end of exercise, hip counts showed the same decreasing trend observed during the continuous exercise. However, in the ankle, the increase in accelerometer counts wase constantly linear up to 3.9 m·s⁻¹, except from the difference between 1.7 and 2.2 m.s⁻¹ which was not significant (p > 0.05). Above 3.9 m·s⁻¹, ankle counts increased modestly and the differences were not significant. A regression analysis revealed a coefficient of determination of r² = 0.98 (p < 0.0001) in the 1.1 – 5.6 m·s⁻¹ speed range. In the intermittent exercise as in the continuous exercise, hip counts were found to be significantly lower than ankle counts at all speeds (p<0.001 ≤ p ≤ 0.02).

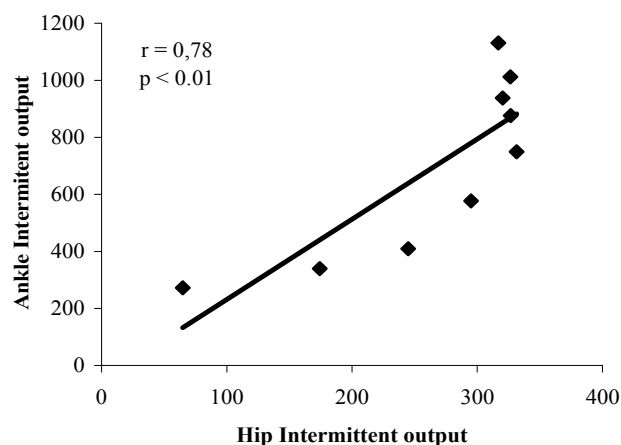### Continuous exercise versus intermittent exercise

As shown in Table 1, there were no significant differences between hip counts in the continuous exercise compared with hip counts during intermittent exercise at each speed (p > 0.05) except

at 2.2 m·s⁻¹ (Hip continuous > Hip intermittent, p < 0.05). Likewise, there were no significant differences when comparing ankle counts in the continuous exercise to the ankle counts during intermittent exercise.

a)

b)

Figure 1. a) Relationship between hip and ankle counts in the continuous exercise (mean data). **b)** Relationship between hip and ankle counts in the intermittent exercise (mean data).

DISCUSSION

This study dealt with the functionality of the MTI accelerometer during a range of exercise intensities. It was designed to investigate the relationship between the ActiGraph counts and running speed; and to describe differences due to accelerometer position on the body and due to the exercise modality. The main finding of this study was that, regardless of the exercise mode, an ActiGraph worn at the ankle may be able to reflect movement from walking, jogging, and running at high speed, in contrast to most of the literature where an ActiGraph worn at the hip does not accurately represent movement when running.
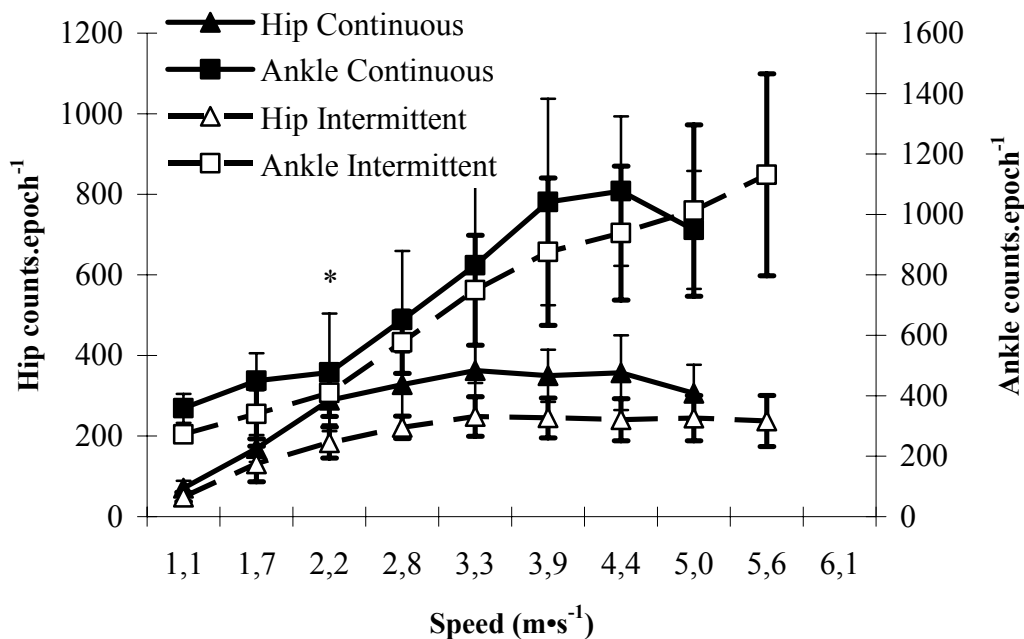
Figure 2. Hip and ankle counts during continuous and intermittent exercise. * denotes a significant combined effect of exercise and placement.

The ActiGraph output relations to speed

Figure 2 indicates that in both exercises, hip output rose linearly with speed in the range of walking (1.1-1.7 m·s⁻¹) to jogging (2.2-3.3 m·s⁻¹). Further significant differences between consecutive speeds were apparent, in the continuous exercise, only with a 1.1 m·s⁻¹ increment, up to 3.3 m·s⁻¹. These findings were similar to those of previous studies (Brage et al., 2003b; Nichols et al., 2000; Sirard et al., 2000). However, in the current study, the levelling off of the ActiGraph output occurred quite later at 3.3 m·s⁻¹. Brage et al. (2003b), with an analogous testing procedure found a levelling off of the ActiGraph output, already at 2.5 m·s⁻¹. Some reasons could explain this discrepancy. Firstly, there is a difference in epoch definition for the two procedures. In the current study, a 2-s epoch was selected to avoid smoothing data, and increase accuracy of the calculation. Since counts obtained over a specific epoch correspond to summarized data over this time period, reducing sampling intervals might provide an additional precision. As reported by Nilsson et al. (2002), there exists an epoch effect when using the MTI accelerometer to assess physical activity in a free-living situation. The authors have reported that outputs obtained over a 5-s epoch were not identical to those drawn by a 60-s epoch. However, when calculating the ActiGraph output during the continuous exercise over 60-s epoch, it appears that the levelling off did not depend on epoch definition, at least in this type of experimental setting. Secondly, the duration of successive stages could account for differences between the two studies. The

running strategy could be somewhat different when running for 3-min instead of 5-min. Thus, averaging data over 5-min may involve some dilution in the final result. Thirdly, it may be an effect of the between-unit errors highlighted by Brage et al. (2003a) in a mechanical setting. One of the particularities of the current study is the similarity of the relation of the ActiGraph output to speed at the hip in both exercises. This result displays a high intra-unit consistency, and suggests that the device provides the same information at the hip, regardless of the type of activity. This assumption is strengthened by the data obtained at the ankle, which showed the same trends. Interestingly, figure 2 shows that ankle counts increased with speed, up to nearly the end of the exercises (a tendency which was not seen at the hip, where the levelling off occurred earlier). The decreasing trend observed toward the end of exercise is probably due to the reduction of the number of subjects involved in running at these higher speeds. The controversial results obtained between the hip and the ankle highlight some important biomechanical explanations to the levelling of the ActiGraph counts. Kyröläinen et al. (2001) found that when running speed increased, the angular velocities of the joint increased to a greater extent in the hip, compared with the ankle and knee joints. As an equilibrium principle, a high angular velocity in a joint may be associated with a low vertical oscillation, and vice versa. Based on this assumption, it can be suggested that when speed increased, low angular velocity in the ankle is

associated with a more important oscillation in the vertical plane. An inverse dynamic process could be observed in the hip joint. This may be a main reason why accelerometer counts were higher in the ankle. However, as these parameters were not evaluated in the current study, further studies are needed to examine this assumption. Data obtained at higher speeds in the ankle joint during both exercises in this study, pointed out the capability of the MTI accelerometer to capture human movements over a wide range of speed. The device could, therefore, discriminate all range of speeds (walking, jogging and running at high velocity) depending upon the body placement. This result is in line with the main effect of biomechanical factors associated with activities (Brage et al., 2003b) and placement, as opposed to the technical limitations of the MTI accelerometer. Thus, it seems obvious that when intensity relations are to be investigated, it may be more appropriate to use an ankle, rather than a hip accelerometer.

Hip and ankle counts comparison across the exercise modalities

This study demonstrated that in each exercise modality, the ActiGraph outputs obtained with an ankle placement were higher than those derived from a hip placement. Most of the reported studies devoted to the validation of this tool, had already highlighted some hip right and left hand-side placement, or right hip and lower back placement differences, in children (Faireweather et al., 1999; Nilsson et al., 2002) and in adults (Nichols et al., 2000). For instance, whereas Nichols et al. (2000) and Nilsson et al. (2002) did not find a significant placement effect, Faireweather et al. (1999) reported a *5%* significant difference between hip right placement and hip left placement on the daily accelerometer counts. These authors have also found a highly significant rank order correlation coefficient ($r = 0.97$, $p < 0.01$), indicating the relative stability of the ActiGraph output with a different placement. The results of the current study, however, appeared to be more modest with reference to this finding. In fact, in both exercise modalities, moderate significant correlation coefficients were found ($r = 0.79$, $p < 0.05$ and $r = 0.78$, $p < 0.01$, for continuous and intermittent exercise respectively) between hip and ankle wearing (see Figure 1a and 1b). These relatively low coefficients can be explained by the fact that, in the current study, two different sites were compared whereas opposite sites were examined by the previous authors. The finding of this study may be in accordance with the extent of the differences in the mechanical load or force that might appear on the different joints (ankle, knee, hip) during walking and running. Analysing joint

kinematics during running events, Kyröläinen et al. (2001) demonstrated that the angular displacements in the ankle during the contact phase reduced with increasing running speed, whereas the hip extended with a larger range. Additionally, these authors reported the same significant increasing trend in the angular velocities obtained at the hip and the ankle in the push-off phase. These differences in mechanical loads might explain the relatively low predictive value of ankle counts by hip counts and vice versa. In both exercises, hip counts explained less than 65% of the total variability of the ankle counts. It can be assumed that the vertical forces acting in the ActiGraph are greater in the ankle joint during walking and running. It seems obvious that the relationship between hip and ankle counts in both exercise procedures is far from linear; an exponential relation could be suspected. Above approximately 160 counts per second (that is 9600 counts per minute), the dynamic range of an ActiGraph worn on the waist is already exceeded, limiting the capability of the instrument to detect any further increase in speed. Conversely, counts obtained at the ankle continued to rise. By using the correction factor for walking and running to account for between-unit errors (Brage et al., 2003a), linear relationships between ankle and hip count were restored in both exercises. This result seems to be proof of the need to adjust for inter-monitor differences in field studies that may not use a multi-point unit-specific calibration. Moreover, it confirms the proportionality between vertical work rate and acceleration detected by the ActiGraph, whatever its placement on the body.

There are a few limitations to the current study. Firstly, an indirect calorimetry measurement has not been measured in parallel, so that an equation could be developed for ankle counts to estimate energy expenditure (as VO_2). This approach may help to develop particular cut-off points for the time spent during activity categories when the ActiGraph is worn on the ankle. A second limitation consists in the lack of measurement of stride length and frequency, over the two exercise modalities. However, such a comparison may not add to the present study, since no exercise effect was found.

CONCLUSIONS

The ActiGraph can be adequately used to assess a wide range of speed depending upon the body placement. The dynamic range of this instrument seems to be quite far from usual human activity, even among highly trained athletes. As expected, a levelling off appears when wearing the device at the hip (above a jogging intensity) – due mostly to

biomechanical factors – whereas ankle wearing provides information even at higher speeds. Further studies are needed to develop particular cut-off points for ankle, based on indirect calorimetry, and / or heart rate measurements. Finally, the use of the ActiGraph for team sports and physical training may be another research direction.

ACKNOWLEDGEMENTS

REFERENCES

American College of Sports Medicine (2000). ACSM's guidelines for exercise testing and prescription. Eds: Franklin, B. A., Whaley, M. H. and Howley, E. T. 6th edition. Baltimore: Lippincott Williams & Wilkins. 145-150.

Åstrand, P.O. and Rodhal, K. (1986) Textbook of Work Physiology. 2nd edition. McGraw-Hill, New York.

Berthoin, S. Baquet, G., Mantéca, F., Lenseil-Corbeil, G. and Gerbeaux, M. (1996) Maximal aerobic speed and running time to exhaustion for children 6 to 17 years old. *Pediatric Exercise Science* **8**, 234-244.

Borg, G. (1990) Psychophysical scaling with applications in physical work and perception of exertion. *Scandinavian Journal of Work in Environment and Health* **16 (Suppl 1),** 55-58.

Brage, S., Wedderkopp, N., Franks, P. W., Andersen, L-B. and Froberg, K. (2003a) Reliabity and validity of the computer science and applications accelerometer in a mechanical setting. *Measurement in Physical Education and Exercise Science* **7(2)**, 101-119.

Brage, S., Wedderkopp, N., Franks, P. W., Andersen, L-B. and Froberg, K. (2003b) Reexamination of validity and reliability of the CSA monitor in walking and running. *Medicine and Science in Sports and Exercise* **35**, 1447-1454.

Faireweather, S.C., Reilly, J.J., Grant, S., Whittaker, A. and Paton, J.Y. (1999) Using the computer science and applications (CSA) activity monitor in preschool children. *Pediatric Exercise Science* **11**, 413-420.

Freedson, P., Melanson, E. and Sirard, J. (1998) Calibration of the computer science and applications, Inc. accelerometer. *Medicine and Science in Sports and Exercise* **30**, 777-781.

Gadoury, C. and Léger, L. (1986) Validity of the 20-m shuttle run test and Canadian standarized test of fitness to predict aerobic capacity of adult.

Sciences et Techniques des Activités Physiques et Sportives **7**, 57-68.

Gregor, R. J. and Kirkendall, D. (1978) Performance efficiency of world class female marathon runners. In: *Biomechanics VI-B.* Eds: Amussen, E. and Jörgensen, K. Baltimore: University Park Press. 40-45.

Hendelman, D., Miller, K., Bagget, C., Debold, E. and Freedson, P. (2000) Validity of accelerometry for the assessement of moderate intensity physical activity in the field. *Medicine and Science in Sports and Exercise* **32**, S442-S449.

Kuipers, H., Verstappen, F.T., Keizer, H.A., Geurten, P. and van Kranenburg, G. (1985) Variability of aerobic performance in the laboratory and its physiologic correlates. *International Journal of Sports Medicine* **6(4)**, 197-201.

Kyröläinen, H., Belli, A. and Komi, P.V. (2001) Biomechanical factors affecting running economy. *Medicine and Science in Sports and Exercise* **33**, 1330-1337.

Nichols, J.F., Morgan, C.G., Chabot, L.E., Sallis, J.F. and Calfas, K.J. (2000) Assessment of physical activity with the computer science and applications, Inc., accelerometer: Laboratory versus field validation. *Research Quarterly for Exercise and Sport* **71**, 36-43.

Nilsson, A., Ekelund, U., Yngve, A. and Sjöström, M. (2002) Assessing physical activity among children with accelerometers using different time sampling intervals and placements. *Pediatric Exercise Science* **14**, 75-84.

Sirard, J.R., Melanson, E.L., Li, L. and Freedson, P.S. (2000) Field evaluation of the computer science and applications, Inc. physical activity monitor. *Medicine and Science in Sports and Exercise* **32**, 695-700.

Swartz, A.M., Strath, S.J., Bassett, D.R. Jr, O'Brien, W.L., King, G.A. and Ainsworth, B.E., (2000) Estimation of energy expenditure using CSA accelerometer at hip and wrist sites. *Medicine and Science in Sports and Exercise* **32**, S450-S456.

Trost, S.G., Ward, D.S., Moorehead, S.M., Watson, P.D., Riner, W. and Burke, J.M.R. (1998) Validity of the computer science and applications (CSA) activity monitor in children. *Medicine and Science in Sports and Exercise* **30**, 629-633.

Williams, K.R. and Cavanagh, P.R. (1987) Relationship between distance running mechanics, running economy, and performance. *Journal of Applied Physiology* **63**, 1236-1245.

AUTHORS BIOGRAPHY

Comlavi B. GUINHOUYA
Employment
Research Assistant, Institute of Health Engineering of Lille, University of Lille 2,
Degree
PhD candidate
Research interest
Exercise Physiology, Health Promotion and Disease in Children, Evaluation of Medical Practices
E-mail: comlavi.guinhouya@etu.univ-lille2.fr

Hervé HUBERT
Employment
Associate Prof., Institute of Health Engineering of Lille, University of Lille 2
Degree
PhD
Research interest
Health Economics, Evaluation of Medical Practices
E-mail: herve.hubert@univ-lille2.fr

Grégory DUPONT
Employment
Associate Prof., Research and Training Unit in Sport and Physical activity Sciences of Liévin, University of Artois
Degree
PhD
Research interest
Exercise Physiology, Intermittent Exercises, High Level Footballer's Physical Training
E-mail: greg_dupont@yahoo.com

Alain DUROCHER
Employment
Prof., Director of the Institute of Health Engineering of Lille, University of Lille 2,
Degrees
MD, PhD
Research interest
Evaluation of Medical Practices, Medical Reanimation
E-mail: alain.durocher@univ-lille2.fr

KEY POINTS

- Actigraph counts are not influenced by the type of activity.
- The levelling off of Actigraph output depends mainly on its location on the body, and does not reflect a lack of sensivity at higher speeds.
- The ActiGraph can be an alternative tool to estimate activity intensity in various conditions.

✉ **Hervé Hubert, PhD**
EA 3614, Modelling Complex Systems, Medical Decision Support , Institute of Engineering in Health of Lille, University of Lille 2, France