Accelerometry as a Means of Quantifying Training Distance and Speed in Competitive Swimmers.

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The purpose of this study was to examine the potential relationships between accelerometer output (AO) and swim distance (S_{dist}), and AO and swim speed (S_{speed}). Fifty-three competitive swimmers (age: 17.7 ±3.13 yrs.) were fitted with two accelerometers and completed two swim sets to develop prediction equations for swim bout distance (m) and swim bout speed ($m \cdot sec^{-1}$). Significant correlations and regression equations were found for accelerometer output and swim bout distance (Correlation: r = 0.90, R^2= 0.81, p<0.05; Regression: SB_{dist} (m) = (AO · .004) + 18.356, r = 0.98, R^2= 0.96, SEE= 40.4m, p<0.001) and swim bout speed (Correlation: r =080, R^2= 0.64, p<0.05; Regression: SB_{speed} ($m \cdot sec^{-1}$) = (total combined accelerometer counts per second · .001) + .869, R^2= 0.53, SEE= $0.15 m \cdot sec^{-1}$, p<0.001). A sub-sample the swimmers were used to validate and compare actual and predicted swim distance and swim speed (SBD_{act} vs SBD_{pred} and SBS_{act} vs SBS_{pred}) showed significance (r =0.97, R^2 =0.96, p<0.001, and r =0.78, R^2= 0.53, p<0.001 respectively). In conclusion, this study demonstrates that accelerometers have the ability to quantify individual swimming distance and speed with acceptable accuracy and validity.

Key words: Accelerometer, Quantify, Swimming Speed, Swimming Distance

INTRODUCTION

Competitive swim coaches and their respective swimmers are continually challenged to develop and maintain training paradigms over multiple competitive seasons. Successful results from one season to the next are often dependent upon two conditions. The first is that the training sessions elicite an appropriate workload and the second being that the competitive swimmer adheres to these specific workloads. This situation has encouraged many sport scientists to further analyze and quantify competitive training (Hopkins, 1991, Banister and Calvert, 1980, and Mujika et al., 1996). More recently the uses of activity monitors (i.e. accelerometers) have been utilized to analyze arm movement patterns and energy expenditure of competitive swimmers (Ohgi, Y. et al, 2002, and Johnston et al., 2005). The use of accelerometer based activity monitors provide a non-invasive means by which the movement of swimming may be quantified. Therefore, it was the goal of this project to determine whether or not competitive swim training bouts could be quantified after the fact by utilizing available accelerometer technology. More specifically, the purpose of this study is twofold: first, to examine the potential relationships between accelerometer output and swim bout distance, accelerometer output and mean swim bout speed, and second, to compare predicted swim bout distance and swim bout speed (from earlier determined relationships) with that obtained during swims performed during actual observed training sessions.

METHODS

Fifty-three competitive swimmers (33 males and 20 females) were recruited from a local area USA registered swim club to participate in this study. All subjects were registered competitors training with the swim club for one or more years. Their experience levels ranging from beginning level competitive swimmers to US national meet qualifiers. Data collection took place at a 10 lane, 50 m outdoor training facility. Prior to the initiation of the study, the methods and procedures were approved by the University's Human Subject Committee and informed consent was obtained from each subject or their legal guardian.

Swimmers were fitted with two Actical activity monitors (commercially produced Omni-directional accelerometer; Bend, Oregon) worn on their right wrist and right ankle attached via a modified watch strap. All monitors were placed in the same direction for consistency. An arrow labeled on the surface of the device by the manufacture provided a reference axis for orientation. For placement of the ankle monitor, the monitor was place on the posterior portion of the ankle approximately 5.0 cm above the lateral malleolus with the monitor reference arrow pointing forward. The wrist monitor was placed similar to a watch with the monitor reference arrow pointing in the lateral direction when the subjects' arm was extended and the palm was facing downwards. Monitors were programmed to begin recording at an epoch length of 15 seconds initiated at the onset of the swim session.

The study included the assessment of relationships (i.e. correlations), as well as, the development and validation of prediction equations. For the assessment of relationships all subjects (i.e. 53 swimmers) participated in two swim sets using only the freestyle stroke (i.e. front crawl). During the first swim set (Set-A), subjects were given instructions to swim 400, 200, 100, and 50 m swims at a moderate effort. The second swim set (Set-B) included three 50 m swims. In this set swimmers were instructed to complete the first 50 m bout slow, the second at a moderate pace, and the third at maximal effort. A poolside observer recorded actual distance and the corresponding speed for each subject for each swim performed. Swimming speed was determined via a handheld digital stopwatch (Ultrak model 495).

Following data collection Actical activity monitor output (AO) was exported to a Microsoft Excel spreadsheet for each subject and the following Pearson-Product Moment correlations were examined utilizing a single data point from each subject from swim set A and B:

1. AO vs S_{dist}: Total combined (i.e. arm and leg) Actical accelerometer counts and swim bout distance (m).
2. AO vs S_{speed}: Total combined (i.e. arm and leg) Actical accelerometer counts relative to time ($counts \cdot second^{-1}$) and swim bout speed ($m \cdot sec^{-1}$).

For the development phase, linear regression analysis was examined to create descriptive equations for swim bout distance (SB_{dist}) and swim bout speed (SB_{speed}) using the relationships listed above with a randomly selected swim from swim sets A and B respectively (i.e. Data from 40 subjects). The remaining 13 subjects participate in a separate training session in which a randomly selected swim was used for the validation of the descriptive equations thus permitting their use as prediction equations. Mean differences between actual and predicted swim bout distance (SBD_{act} vs SBD_{pred}) and swim bout speed (SBS_{act} vs SBS_{pred}) were determined using paired samples t-tests and agreements between predicted and measured variables were assessed using the Bland-Altman technique. A significance level of $p \leq 0.05$ was set for all statistical tests. All statistical analyses were conducted using statistical software package SPSS 16.0 (Chicago, IL).

RESULTS

Subject characteristics (displayed in table 1.) did not differ between the regression development group or the validation group.

Table 1. Subject Characteristics (mean ± sd)

	Subjects (n=53)	Regression Development Group (n=40)	Validation Group (n=13)
Age (yr)	17.7 ±3.13	17.6 ±2.84	18.1 ±4.01
Height (cm)	173.0 ±9.85	173.6 ±10.20	171.1 ±8.84
Mass (kg)	69.4 ±11.16	70.6 ±10.75	65.75 ±12.10

Pearson correlation coefficients examining the relationship between AO vs S_{dist} (r =0.90, R^2= 0.81, SEE= 59.4m, p<0.05) and AO vs S_{speed} (r =0.80, R^2= 0.64, SEE= 0.13m·sec^{-1}, p<0.05) were both significant. Linear regression analysis for SB_{dist} and SB_{speed} displayed significant results (SB_{dist} (m) = (AO · .004) + 18.356, r = 0.98, R^2= 0.96, SEE= 40.4m, p<0.001, Figure 1, . SB_{speed} (m·sec^{-1}) = (total combined accelerometer counts per second · .001) + .869, R^2= 0.53, SEE= 0.15m·sec^{-1}, p<0.001, Figure 3)

The validation phase for SB_{dist} and SB_{speed} prediction equations diaplyed significant correlations between SBDact vs SBDpred (r =0.97, R^2 = 0.95, p<0.001, Figure 2) and SBS_{act} vs SBS_{pred} (r =0.78 , R^2 =0.61, p<0.001, Figure 4. In addition, a paired samples t-test displayed no significant difference between SBD_{act} vs SBD_{pred} (p= 0.904) or SBS_{act} vs SBS_{pred} (p= 0.727). The Bland-Altman plots resulted in no bias for SBDact vs SBDpred (range limit of 129.5m to 125.1m with a mean of -2.2m) and SBS_{act} vs SBS_{pred} (range of limit of -0.30m·sec^{-1} to 0.33m·sec^{-1} with a mean of 0.02m·sec^{-1}).

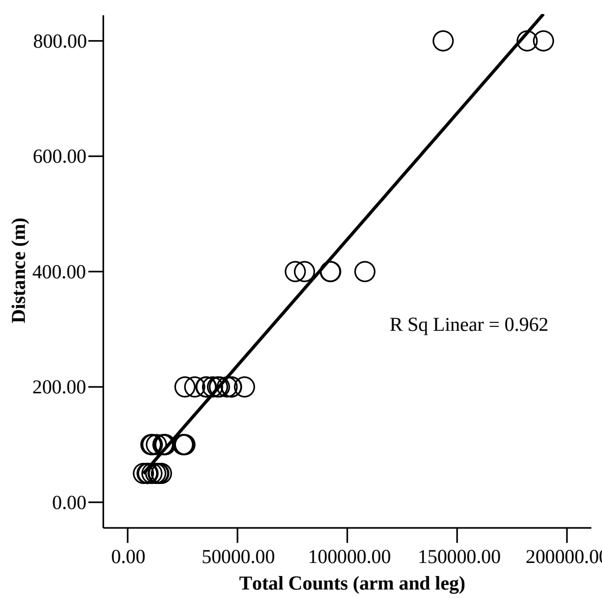

Figure 1. Displays linear regression line for SB_{dist} and AO.

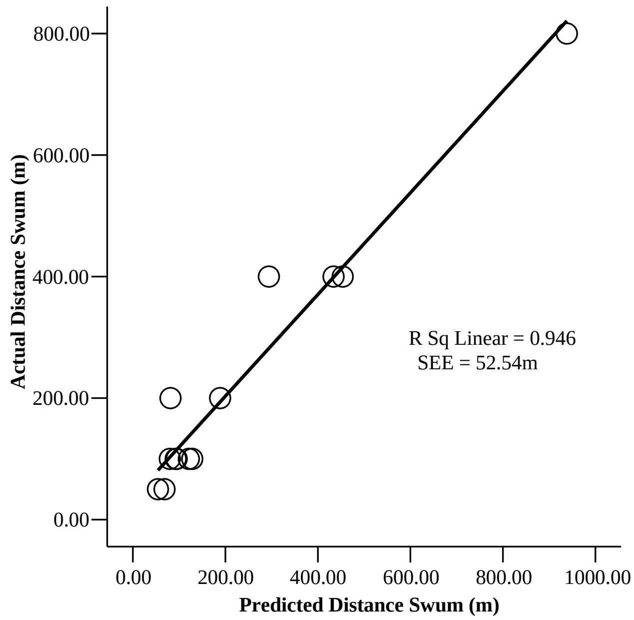

Figure 2. Displays the relationship between SBD_{act} and SBD_{pred}.

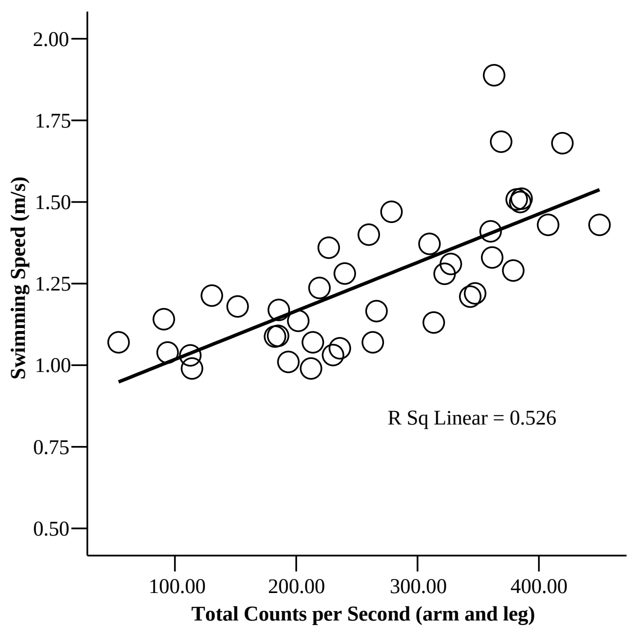

Figure 3. Displays linear regression line for SB_{speed} and AO .

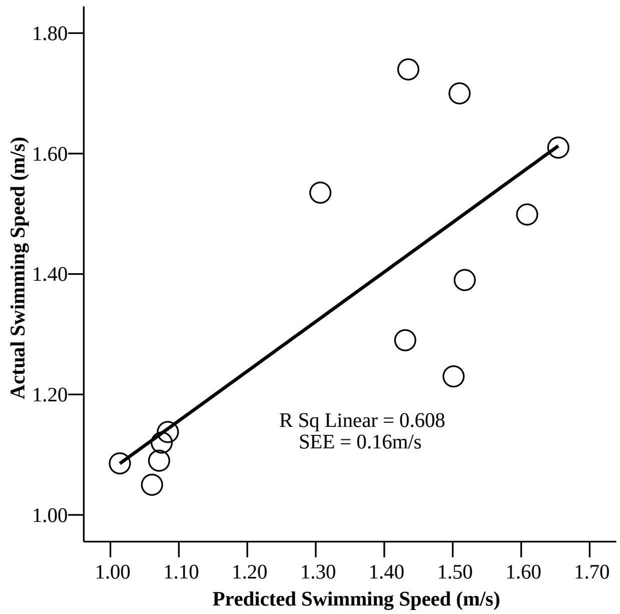

Figure 4. Displays the relationship between SBS_{act} and SBS_{pred}.

DISCUSSION

The present study shows that activity monitors have the ability to quantify the swimming distance and speed of competitive swimmers after completing a competitive training session. Thus, activity monitors provide a useful tool with which the experimenter (or coach) could track the adherence of an athlete to a pre-set training session. It is important to note that accelerometer technology remains a new tool with regard to the quantification competitive swim training; therefore, very limited literature has documented the use of accelerometers to assess the training distance and speed of competitive swimmers after they have completed their swim session.

Previous studies have included the use of accelerometers to examine swimmers (competitive and recreational) and suggest that accelerometers may also have the ability to estimate swimming energy expenditure (Johnston, J. and Stager, J., 2005), examine swim stroke phases (Ichikawa et al., 1999), and detect fluctuations in performance due to fatigue during a training session (Ohgi, et al., 2002). In addition to the present data, other recent studies have similarly examined competitive swim training and report encouraging data supporting the further use of accelerometers. For example, preliminary experiments conducted by the Counsilman Center for the Science of Swimming using the Actical activity monitor displayed data that are in support of the relationships between swim bout distance, swimming speed, and accelerometer output reported in the present study (Wright et al., 2007, and Hinman et al., 2008). The current study more thoroughly explored the validity of predicting swim bout distance and swimming speed from accelerometer output. Furthermore, the data from Wright et al. (2007) suggest that when a swimmer is instructed to swim fast, there is a larger contribution from kicking that is evident from the subsequent greater leg accelerometer output. This appears to indicate that in addition to swim speed and swim distance a swimmer's relative effort from day to day or set to set, might be reflected in the comparative outputs of the appropriately placed accelerometers.

Although, the findings from the current study support the use of accelerometers as a non-invasive means to monitor a swimmer's adherence to and effort in a competitive swim training session, the application of a single regression equation to predict swimming distance and speed for different types of swimming and or swimmers of different skill levels is limited. It is recommended, albeit more time consuming, to create individual regression equations (e.g. for distance and speed) for each swimmer. This may provide stronger algorithms. In addition the use of an accelerometer with a shorter epoch length would also be ideal. This would produce a greater detailed set of data from which an experimenter or coach may examine training sessions.

In conclusion, this study displayed a significant relationship between swim bout distance, swimming speed, and accelerometer output (i.e. Actical activity monitor). The study also showed that accelerometers have the ability to accurately measure swim bout distance and mean swim bout speed. Future suggestions include the use of accelerometers during actual competition, as well as, the development of computer software that will allow for the immediate display and interpretation of accelerometer output upon the completion of a training session.

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