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METHODS OF INTRACYCLE VELOCITY VARIATION ASSESSEMENT IN FRONT CRAWL

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SUMMARY
The aim of this study was to assess the three-dimensional intracycle velocity variation of the body centre of mass (CM) during a 200 m front crawl swimming event to understand the outcomes from different procedures to represent intracycle velocity variation. Ten male swimmers performed 200 m front crawl at maximal intensity. Six video cameras (two aerial and four underwater) were used to record four complete non-breathing cycles, one for each 50 m lap (APASystem was used for processing). The intracycle velocity variation of the CM in three directions (x, y, and z) was computed as the coefficient of variation of the instantaneous velocity, the ratio of the SD (x, y, and z) to the average horizontal v, the difference between the maximal and minimum instantaneous v, and the ratio of the difference between the maximal and minimum instantaneous v values to the average v. Repeated measures one-way ANOVA was used to compare the evolution of the intracycle velocity variation, and between axes of motion. This study evidenced stability in the intracycle velocity variation across the 200 m front crawl race using different methodological approaches, although with differences in-between axes of motion.

INTRODUCTION
The total mechanical work in aquatic locomotion is the sum of the external and internal work [1]. External work is related to the position and velocity changes of the body centre of mass (CM) in the environment, which could be expressed by the intracycle velocity variation of the CM, occurring as propulsive and drag forces change during human swimming [2]. Increases in the intracycle velocity variation leads to higher work to swim at a certain velocity [3,4]. As a consequence, the intracycle velocity variation is considered as an indicator of swimming efficiency [5].
However, the data treatment to quantify intracycle velocity variation may have several approaches; in front crawl, the methods used for its assessment are: (a) the difference between the maximal and minimum instantaneous velocity values (dv) [6,7]; (b) the ratio of the difference between the maximal and minimum instantaneous velocity values to the average velocity value within the stroke cycle (dv/v) [7]; and (c) the coefficient of variation (CV) [8,9,10]. These different mathematical procedures may address different aspects of the v variation within a stroke cycle.

The aim of this study was to assess the three-dimensional intracycle velocity variation of the CM during a 200 m front crawl event, performed at maximal intensity, to understand the outcomes from different procedures to represent intracycle velocity variation in a maximal and fatiguing effort.

METHODS
Ten high level male swimmers volunteered to participate in this study (average (SD)): age 21.6 (2.4) yrs, height 185.2 (6.8) cm, arm span 188.7 (8.4) cm and body mass 76.4 (6.1) kg. All swimmers (mean performance in a 200 m race = 91.6 (2.1)% of the 25 m pool world record) had 11.0 (3.5) yrs experience as competitive swimmers.
After a moderate intensity individual warm-up, totalling 1000 m, swimmers performed a 200 m front crawl simulated race, at maximal intensity, from a push off start (to eliminate the influence of the dive in the analysis of the first stroke cycle). Six synchronised video cameras (Sony® DCR-HC42E) were used to record the event (four under and two above water). Three-dimensional reconstruction of body landmarks digitised (50 Hz) was computed using DLT [11], a calibration frame (3 x 2 x 3 m for the horizontal, vertical and lateral directions; 30 calibration points) and a 6 Hz low pass digital filter. Twenty-one body landmarks, 7th cervical, mandible (mental protuberance), humeral heads, ulnohumeral joints, radiocarpal joints, 3rd dactylions, trochanter major of femurs, tibiofemoral joints, talocrural joints, calcanei and acropodion and the Zatsiorsky anatomical model adapted by de Leva [12] were used. The calibration setup has been described and the accuracy and reliability of the calibration procedures and digitisation have been established by Figueiredo et al. [10]. One complete arm stroke cycle, at mid-pool and without breathing, for each 50 m of the 200 m front crawl was recorded. Test sessions took place in a 25 m indoor pool.

Data analysis
The intracycle velocity variation of the CM in three directions (x, y, z) was computed as follows: (a) the coefficient of variation of the instantaneous velocity-time data (IVV); (b) the ratio of the SD (x, y and z) to the average horizontal v value within the stroke cycle (SD/v); (c) the difference between the maximal and minimum instantaneous v values (dv); and (d) the ratio of the

difference between the maximal and minimum instantaneous v values to the average v value within the stroke cycle (dv/v).
Maximum and minimum v (vmax and vmin, respectively) within the stroke cycle, for x, y and z axes were computed from the instantaneous velocity-time data. The v (x, y and z) was obtained from the intracycle v (x, y and z) data. The relative vmax and vmin (in all the axes) were calculated as a percentage of horizontal v.

Statistical analysis
Average (SD) computations for descriptive analysis were obtained for all variables selected (normal distribution of the data was verified with Shapiro–Wilk's test). A one-way repeated measures ANOVA was used to compare the studied parameters throughout the 200 m and between axes of motion. When a significant F-value was achieved, Bonferroni post-hoc procedure was performed to locate the pairwise differences between the means. All statistical analysis was performed using STATA 10.1 (StataCorp, USA) and the level of statistical significance was set at $p \leq 0.05$.

RESULTS AND DISCUSSION
Swimmers' intracycle velocity variation was found to be stable in the course of the 200 m front crawl race for the three axes of motion, independent of the calculation method used to assess it IVV (x: $F_{(3,27)}=1.6$, $p=0.21$; y: $F_{(3,27)}=0.82$, $p=0.49$; z: $F_{(3,27)}=2.18$, $p=0.12$) dv (x: $F_{(3,27)}=0.33$, $p=0.80$; y: $F_{(3,27)}=0.19$, $p=0.90$; z: $F_{(3,27)}=0.89$, $p=0.46$), IVV/v (x: $F_{(3,27)}=1.6$, $p=0.21$; y: $F_{(3,27)}=1.34$, $p=0.28$; z: $F_{(3,27)}=0.41$, $p=0.41$) and dv/v (x: $F_{(3,27)}=0.36$, $p=0.78$; y: $F_{(3,27)}=1.43$, $p=0.26$; z: $F_{(3,27)}=1.89$, $p=0.15$). This stability is in accordance with Psycharakis et al. [7]. However, differences were found between the axes, depending on the method of calculation (Figure 1).

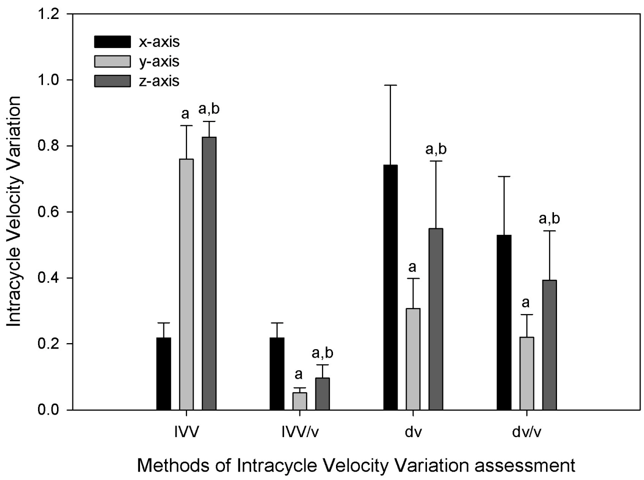

Figure 1: Average intracycle velocity variation (SD) using several methods for the intracycle velocity variation assessment along the three axes of motion. [a,b] Different from x and y axis, respectively. $p \leq 0.05$

A higher absolute magnitude in the lateral and vertical IVV compared to the swimming direction was found, as also reported before [11]. However, when comparing with the method used in the mentioned work (dv), results were changed, dvx higher than dvy and dvz. In the relative values of IVV (IVV/v), because in y and z axes the average v were very low, implied a great IVV y and z (since it was calculated using the coefficient of variation).
Complementarily, dvx and dvx/v values were greater than the ones reported previously [7], which could be due to the fact that average v was lower. Psycharakis et al. [7] reported higher values for the z compared to the y axis; however, the present study showed slightly lower values of y axis and slightly higher values in z axis, which could be due to changes in swimming technique.
Each IVV calculation method has its advantages and disadvantages. The methods that include two (maximum and minimum) instantaneous v points do not evidence the whole intracycle v pattern. The use of the coefficient of variation is the only approach sensitive to the mean swimming velocity and to the dispersion of the instantaneous velocity throughout the stroke cycle, and not to a single or couple of instantaneous moments. Therefore, mathematically, this is the more accurate method to the quantification of intracycle velocity variation [5]. Still, when comparing the magnitudes (e.g. between axes) it should be taken into account the differences caused by a larger or smaller mean in the values obtained and the mathematical strategies that can be used to normalize it to allow a real comparison.

CONCLUSIONS
This study evidenced stability in the intracycle velocity variation across the 200 m front crawl race, using different methodological approaches. Also, different calculation methods present different conclusions when comparing the three axes of motion.

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