Comparative Study of the Response of Kinematical Variables from the Hip and the Center of Mass in Butterfliers

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Abstract
The aim of this study was to compare the intracyclic variation of kinematical variables from the hip and the center of mass (CM) with the purpose to assess if the analysis of kinematical variables of the hip might replace the study of the kinematical variables of the CM. Seven Portuguese male swimmers of national and international level were studied. Each swimmer performed 3 sets of 3x25 meters, at a constant velocity and as close as possible to the maximum, using exclusively frontal inspiration cycles, lateral inspiration cycles and non-inspiratory cycles in each set. Two pairs of cameras were used to create "dual media" images. Another camera was set behind an underwater window in the endwall. One last camera was placed above the water surface. The study comprised the analysis of complete stroke cycles in butterfly using the "Ariel Performance Analysis System" from Ariel Dynamics Inc. Some of the correlations between the maximal vertical amplitude of displacement of the hip and the CM didn't present significant values. All the correlations between the horizontal velocity and horizontal acceleration of the hip and the CM were significant in all breathing models. However, only one swimmer presented in both cases $r \geq 0.95$. So, apparently, the hip does not represent properly the intracyclic variations of the kinematical variables of the CM.
Key words: Butterfly stroke, hip, center of mass, inspiration, intracyclic variation

Introduction
For the study of the velocity and the acceleration of the swimmer it is common to investigate the intracyclic behavior of the center of mass (CM) and the hip. In fact, apparently there is an indiscriminate use of both reference points. For exemple, Korneki and Bober (1978), Hahn and Krung (1992), Togashi and Nomura (1992) and Barbosa et al. (1999) used the hip for the analysis of the velocity and acceleration profiles of the displacement of the swimmer performing butterfly stroke. However, several studies adopted the CM for the analysis of the same kinematical variables in this swimming technique [Sanders et al. (1995), Sanders (1996), Zhu (1996), Vilas-Boas et al. (1997), Alves et al. (1999), Martins-Silva et al. (1999)].
It seems that most authors who used the hip justified their option due to the complexity, time consumption and costs of the methods used to determine the CM kinematics. Obviously, it is easier to locate the position of the hip. Meanwhile, the proximity between the hip and the CM when the subject is in the anatomical position lead to the adoption of this anatomical landmark to replace the study of the CM.
So the question is if the displacement, the velocity and the acceleration of the hip can represent with validity the kinematics of the CM.

Mason et al. (1989) investigated if the analysis of the hip could successfully substitute the study of the CM in breaststroke. Mason et al. (1992) compared the intrastroke velocity and acceleration of the CM and of the hip of elite butterfly swimmers. In both studies, the correlation coefficients were reasonably high. Nevertheless, authors observed discrepancies between the curves of the hip and the CM. And in the study of Mason et al. (1992) the authors didn't distinguish the intracyclic variations according to the breathing technique adopted by the swimmers. In other words, in this investigation Mason et al. (1992) did not indicate if the swimmers used frontal inspiration techniques, lateral inspiration techniques or non-breathing techniques in the stroke cycles analysed.
The aim of this study was to compare the intracyclic variation of kinematical variables from the hip and the CM with the purpose to assess if the analysis of kinematical variables of the hip might replace the study of the kinematical variables of the CM in butterfly, according to the breathing technique.

Methods

Seven male Portuguese swimmers (18.4±1.9 years old; 68.600±6.828 Kg of body mass; 175.8±6.2 cm of height) of national and international level were studied. Each swimmer performed 3 sets of 3x25 meters with a start in the water, at a constant velocity and as close as possible to their maximal speed, using exclusively frontal inspiration cycles, lateral inspiration cycles and non-inspiratory cycles in each set.
Two pairs of video cameras (JVC GR-SX1 SVHS and JVC GR-SXM 25 SVHS) were used for dual media videotape recording in non-coplanar planes. Both pairs of cameras were synchronised in real time and edited on a mixing table (Panasonic Digital Mixer WJ-AVE55 VHS and Panasonic Digital AV Mixer WJ-AVE5) creating one single image of "dual media" as was previously described by Vilas-Boas et al. (1997). One of the two supports was set in one end wall 8.10m away from the trajectory of the swimmer. The second structure was set in one of the lateral walls at a distance of 9.30m from the end wall where the first structure was installed and at 10.20m from the trajectory of the swimmer. Another camera (Panasonic DP 200 SVHS) was set behind an underwater window, placed in the end wall, at a depth of 0.90m. One last camera (Panasonic DP 200 SVHS) was set 4.50m above the water surface. In these two last cases, the optical axis was oriented in the direction of the displacement of the swimmers. Fig. 1 presents the location and the orientation of all cameras used. In all the situations, all cameras or pair of cameras recorded images of the swimmer in non-coplanar planes, each one different from all the other cameras or pair of cameras. Synchronisation of the images was obtained using LEDs placed on the recording field of every camera or pair of cameras, which were turned on regularly and simultaneously to initiate the synchronisation every time the swimmer entered the calibration volume. A 3x3x3 meter cube with 32 calibration points defined the calibration volume.

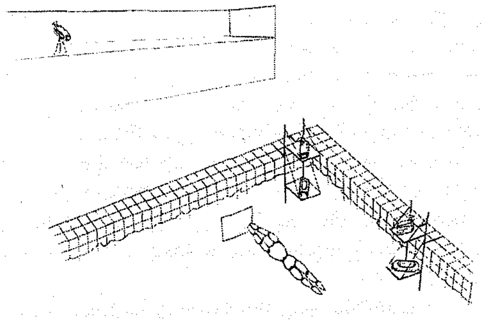

Fig. 1: The location and the orientation of all cameras used.

The study comprised the analysis of complete stroke cycles in butterfly using the "Ariel Performance Analysis System" from Ariel Dynamics Inc. and a VCR (Panasonic AG 7355) at a frequency of 50 Hz. Zatsiorsky's model adapted by [de Leva (1996)] with 22 anatomical points of reference was adopted. The 3D reconstruction of the digitised images was performed using the "Direct Linear Transformation" procedure [Abdel-Aziz and Karara (1971)]. It used a filter with a cut-off frequency of 5Hz, as suggested by [Winter (1990)] for the analysis of the velocity and the acceleration of the CM and the hip.
Analysed pairs of parameters were: (i) the intracycle variation of the vertical amplitude of displacement of the hip and the CM; (ii) the intracycle variation of the horizontal velocity of the hip and the CM and; (iii) the intracycle variation of the horizontal acceleration of the hip and the CM.
In order to investigate the level of association between the intracycle variations of the hip and the CM variables, the Pearson Correlation Coefficient was used for the paired values on each curve ($p<0.05$). However, according to Mason et al. (1992), the hip only represents with validity the CM if $r \geq 0.95$. Therefore, the validity of the hip variables was accepted when $r \geq 0.95$.

Results

Table 1 presents the Pearson Correlation Coefficients between the intracycle variation of the vertical amplitude of the hip and the CM. Not all swimmers presented significant correlations in the breathing techniques analysed. In fact, in some cases the correlations were negative, but without statistical significance. In any case, the reference value sugested by Mason et al. (1992) wasn't achieved. Therefore, the mean values of the correlations found in the three breathing techniques studied were very low.

Table 1: Pearson Correlation Coefficients (r) between the intracycle variation of the vertical amplitude of the hip and the center of mass using frontal inspiration cycles (Frt.), lateral inspiration cycles (Lat.) and non-inspiratory cycles (Non-insp.).

	Frt. (r)	Lat. (r)	Non-insp. (r)
Swimmer A	0.275	0.549 *	0.252 *
Swimmer B	0.173	- 0.023	- 0.117
Swimmer C	0.028	0.219	- 0.225
Swimmer D	0.292 *	0.822 *	0.304 *
Swimmer E	0.660 *	0.449 *	0.353 *
Swimmer F	0.638 *	0.660 *	0.307 *
Swimmer G	0.678 *	0.507 *	0.061
Mean ± sd	0.392 ± 0.264	0.455 ± 0.281	0.146 ± 0.250

* $p<0.05$

Table 2 presents the Pearson Correlation Coefficients computed between the intracycle variations of the horizontal velocity of the hip and the CM. All correlations between the intracycle variations of the horizontal velocity of the hip and the CM were significant using frontal inspiration cycles, lateral inspiration cycles and non-inspiratory cycles. However, only swimmer F ($r=0.970$, $p<0.0001$) presented, for frontal inspiration cycles, higher values than those proposed as reference by Mason et al. (1992). In the other two breathing techniques this swimmer presented significant correlation but did not reach the reference value. Apparently there was a big variation among the correlation coefficients between swimmers. For exemple, the lowest value was observed in swimmer E using non-inspipatory cycles ($r=0.342$, $p=0.0016$).

Table 2: Pearson Correlation Coefficients (r) between the intracycle variation of the horizontal velocity of the hip and the center of mass using frontal inspiration cycles (Frt.), lateral inspiration cycles (Lat.) and non-inspiratory cycles (Non-insp.).

	Frt. (r)	**Lat. (r)**	**Non-insp. (r)**
Swimmer A	0.518 *	0.882 *	0.846 *
Swimmer B	0.713 *	0.638 *	0.534 *
Swimmer C	0.563 *	0.711 *	0.437 *
Swimmer D	0.928 *	0.599 *	0.592 *
Swimmer E	0.471 *	0.918 *	0.342 *
Swimmer F	0.970 *	0.764 *	0.537 *
Swimmer G	0.498 *	0.648 *	0.635 *
Mean ± sd	0.666 ± 0.208	0.737 ± 0.124	0.560 ± 0.159

* p<0.05

Table 3 presents the Pearson Correlation Coefficients between the intracycle variations of the horizontal acceleration of the hip and the CM. As in the case of the velocity, the correlations between the intracycle variations of the horizontal acceleration of the hip and the CM presented significant values in all swimmers and in all the analysed situations. Once more swimmer F, using frontal inspiration cycles, obtained higher values (r=0.951, p<0.0001) than the reference proposed by Mason et al. (1992). The lowest correlation was observed for swimmer E (r=0.303, p=0.0161) using non-inspiratory cycles.

Table 3: Pearson Correlation Coefficients (r) between the intracycle variation of the horizontal acceleration of the hip and the center of mass using frontal inspiration cycles (Frt.), lateral inspiration cycles (Lat.) and non-inspiratory cycles (Non-insp.).

	Frt. (r)	**Lat. (r)**	**Non-insp. (r)**
Swimmer A	0.548 *	0.809 *	0.816 *
Swimmer B	0.734 *	0.699 *	0.460 *
Swimmer C	0.461 *	0.729 *	0.491 *
Swimmer D	0.923 *	0.576 *	0.626 *
Swimmer E	0.566 *	0.862 *	0.303 *
Swimmer F	0.951 *	0.739 *	0.897 *
Swimmer G	0.431 *	0.524 *	0.369 *
Mean ± sd	0.669 ± 0.213	0.705 ± 0.120	0.567 ± 0.223

p<0.05

Fig. 2 presents the intracyclic variations of the horizontal velocity of the hip and the CM of one of the swimmers studied. It is possible to see that the intracyclic behaviour of both variables is different. The velocity of the hip presented a higher intracyclic variation of the velocity than the CM, especially in the change from the insweep to the upsweep. One other difference verified is that there seems to exist a temporal difference between the occurrence of the velocity peaks of the two most propulsive phases. In other words, these events apparently occur first in the CM and some time later in the hip.

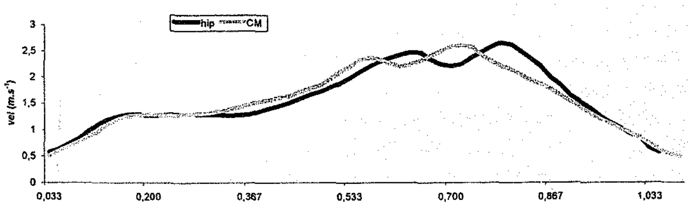

Fig. 2: Intracyclic variations of the horizontal velocity (vel.) of the hip and the center of mass (CM) of a studied swimmer.

Discussion

According to Mason et al. (1992), in this kind of study the statistical procedures, specially the inferential ones, have some limitations. To assess if the hip represents with validity the CM it is necessary to collect a high number of observations. In other words, it is necessary to determine the correlation between the paired values of the hip and the CM frame by frame in one single stroke cycle. With these methodologies it is easy to have 70, 80 or even 90 frames per cycle in some cases, with common 50Hz or 60 Hz sampling frequencies. Therefore, the probablility to obtain significant correlations with low associated variances between both variables is quite high. However, in a case like this, the hip might not present a similar behaviour as a function of time when compared to the CM. So, Mason et al. (1992) suggested a reference value. These authors only assume that the hip represents the CM with validity if $r \geq 0.95$.

Not all the correlations found in this study between the vertical amplitude of displacement of the hip and the CM presented significant values. And in any case the reference value suggested by Mason et al. (1992) was achieved. In fact, in some cases the correlations were negative, the fact they did not present statistical significance. This probably traduces some tendency variations the fact of the slope of the trajectory of the hip and the CM. This means that when the CM or the hip are in a rising trajectory, the hip or the CM tend to describe a descendent trajectory.

Analysing the intracyclic variations of the horizontal velocity and the horizontal acceleration the results are similar. In both cases only swimmer F overcame the reference value and always used the frontal inspiration technique. On the other hand, the lowest value was always observed in the swimmer E adopting non-inspiratory cycles. It seems that the results were not consistent for all swimmers. In other words, the shift of the CM relative to the hip presents variations according to the swimmer analysed [Mason et al. (1989, 1992)]. There are swimmers that present high correlations in some breathing techniques, such as swimmer F and others with low correlations, as for example swimmer E. It is known that the selection of a more waving or a more flat style in the simultaneous techniques should be done according to the kinanthropometric characteristics of the swimmers [Zhu (1996)]. So, the swimmers studied in this investigation presented different results according to the breathing techniques adopted due to their individual characteristics being more appropriate to one technique instead of another.

Therefore, the hip does not seem to represent with validity the intracyclic behaviour of kinematical variables of the CM in butterfly. In spite of the normally close anatomical proximity of the CM compared to the hip, when the subject lies in the anatomical position, the intersegmentar actions performed during the stroking action will change the position of the CM constantly. In the simultaneous techniques, specially in the waving ones, the body movement will promote a higher change in the position of the CM due to higher intersegmentar variations [Mason et al. (1992)].

It is the phenomena described above that might explain that the velocity of the hip presents a higher intracyclic variation than the velocity of the CM and the temporal difference between the two curves, as it was previously described by Mason et al. (1989, 1992). Consequently, the movement parameters of the hip should not be used without caution for the technique evaluation, by the researcher or the coach, due to a shift in phase of the hip from true movement pattern of the entire body [Mason et al. (1989)].

In conclusion, apparently, the hip does not properly represent the intracyclic variations of the kinematical variables (displacement, velocity and acceleration) of the CM in butterfly.

References

Abdel-Aziz Y., Karara H. (1971). Direct linear transformation: from comparatur coordinates to object coordinates in close range photogrammetry. Proceedings ASPUS Symposium on close range photogrammetry. pp. 1-18. Church Falls.

Alves F., Cunha P., Gomes-Pereira J. (1999). Kinematic changes with inspiratory actions in butterfly swimming. In: K. Keskinen, P. Komi, P. Hollander (eds.). Biomechanics and Medicine in Swimming VIII. pp. 9-14. Gummerus Printing House. Jyväskylä.

Barbosa T., Sousa F., Vilas-Boas J.P. (1999). Kinematical modifications induced by the introduction of the lateral inspiration in Butterfly stroke. In: K. Keskinen, P. Komi, P. Hollander (eds.). Biomechanics and Medicine in Swimming VIII. pp. 15-20. Gummerus Printing House. Jyväskylä.

De Leva P. (1996). Adjustments to Zatsiorsky-Seluyanov's segment inertia parameters. J. Biomechanics. 29(9): 1223-1230.

Hahn A., Krug T. (1992). Application of knowledge gained from the coordination of partial movements in Breaststroke and Butterfly swimming for the development of technical training. In: D. MacLaren, T. Reilly, A. Lees (eds.). Biomechanics and Medicine in Swimming VI. pp. 167-172. E and FN Spon. London.

Kornecki S., Bober T. (1978). Extreme velocities of a swimming cycle as a technique criterion. In: B. Eriksson, B. Furberg (eds.). Swimming Medicine IV. pp. 402-407. University Park Press. Baltimore, Maryland.

Martins-Silva A., Alves F., Gomes-Pereira J. (1999). Determinant factors in a 200 m butterfly swim as related to the fluctuation in horizontal velocity of the body centre of gravity. In: K. Keskinen, P. Komi, P. Hollander (eds.). Biomechanics and Medicine in Swimming VIII. pp. 21-24. Gummerus Printing House. Jyvaskyla.

Mason B., Patton S., Newton A. (1989). Propulsion in Breaststroke swimming. In: W. Morisson (ed.). Proceedings of the VII International Symposium of the Society of Biomechanics in Sports. pp. 257-267. Melbourne.

Mason B., Tong Z., Richards R. (1992). Propulsion in the Butterfly stroke. In: D. MacLaren, T. Reilly, A. Lees (eds.). Biomechanics and Medicine in Swimming VI, pp. 81-86. E and FN SPON, London.

Sanders R., Cappert J., Devlin R. (1995). Wave characteristics of Butterfly Swimming. J. Biomechanics. 28 (1). pp. 9-16.

Sanders R. (1996). Some aspects of butterfly technique of New Zeland Pan Pacific squad swimmers. In: J.P. Troup, A.P. Hollander, D. Strasse, S.W. Trappe, J.M. Cappaert, T.A. Trappe (eds.). Biomechanics and Medicine in Swimming VII. pp. 23-28. E and FN Spon. London.

Togashi T., Nomura T. (1992) A biochemical analysis of the swimmer using the butterfly stroke. In: D. MacLaren, T. Reilly and A. Lees (eds.). Biomechanics and Medicine in Swimming VI. pp. 87-91. E and FN Spon. London.

Vilas-Boas J.P., Cunha P., Figueiras T., Ferreira M., Duarte J. (1997) Movement analysis in simultaneous swimming techniques. In K. Daniel, U. Huffmann and J. Klauck (Eds.). Cologne Swimming Symposium, pp. 95-103. Sport Fahnemann. Verlag, Bocknem.

Winter D. (1990). Biomechanic and motor control of human movement. John Wiley and sons. Chichester.

Zhu J. (1996). Trunk rotations, body waving and kineanthropometric characteristics in the symmetrical swimming strokes. PhD Thesis. Catholic University of Leuven. Not Published.