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Anita Falk Giuliano

DESLOCAMENTO TRIDIMENSIONAL DA MÃO E EFICIÊNCIA PROPULSIVA DA BRAÇADA DO NADO CRAWL EM DIFERENTES INTENSIDADES

Porto Alegre
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Dissertação de Mestrado submetida ao Programa de Pós-Graduação em Ciências do Movimento Humano da Escola de Educação Física, Fisioterapia e Dança da Universidade Federal do Rio Grande do Sul. Orientação: Prof. Dr. Flávio Antônio de Souza Castro (UFRGS)

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“I, I wish you could swim
Like the dolphins, like dolphins can swim”
David Bowie

APRESENTAÇÃO

Esta dissertação de mestrado, cujo objetivo principal é analisar a cinemática segmentar, cinemática de nado e eficiência propulsiva da braçada do nado *crawl*, em diferentes intensidades em homens e mulheres, será apresentada do seguinte modo:

i. Introdução: contextualização sobre o tema e objetivo geral da pesquisa.
ii. Revisão de literatura: aprofundamento teórico sobre os conhecimentos que cercam a temática central de estudo.
iii. Estudos: apresentação de dois estudos, em formato de artigos, que respondem aos problemas de pesquisa delineados na introdução:

    Artigo I: Hand's three-dimensional kinematics in response to different swimming intensities in front crawl stroke (submetido na revista Sports Biomechanics, Qualis A2, fator de impacto: 2.023, https://www.tandfonline.com/toc/rspb20/current).

    Artigo II: Three-dimensional front crawl arm-stroke efficiency and kinematics at different swimming intensities (a ser submetido).
iv. Considerações finais, limitações e perspectivas.

A presente pesquisa foi aprovada pelo Comitê de Ética em Pesquisa da Universidade Federal do Rio Grande do Sul, sob o parecer no 2.672.555 (ANEXO I).

RESUMO

Esta dissertação procurou responder lacunas existentes em relação a cinemática de nado, cinemática segmentar e eficiência propulsiva da braçada do nado *crawl*, em diferentes intensidades em homens e mulheres. Foram desenvolvidos dois estudos, os quais tiveram como objetivos: verificar os efeitos das intensidades de nado sobre a velocidade e o deslocamento tridimensional (3D) das mãos, e sobre variáveis cinemáticas: frequência de braçada (SR), distância percorrida a cada ciclo de braçadas (SL), velocidade média do centro de massa (vCOM) e índice de nado (SI) (estudo I); e comparar e correlacionar a eficiência propulsiva da braçada (ηp), a vCOM e o deslocamento 3D das mãos (estudo II). Vinte nadadores (10 homens e 10 mulheres) de nível regional e nacional nadaram 25 m nado *crawl* em intensidades baixa, moderada e alta. Foi utilizada análise cinemática 3D. Os principais resultados do estudo I foram: da intensidade baixa para alta, a velocidade 3D das mãos aumentou (homens: 1,76 ± 0,12 para 2,67 ± 0,16 m/s; mulheres: 1,63 ± 0,09 para 2,37 ± 0,16 m/s); o deslocamento horizontal das mãos, oposto ao deslocamento do nadador, nas fases propulsivas da braçada reduziu apenas em homens (0,68 ± 0,07 para 0,52 ± 0,10 m) (mulheres: 0,63 ± 0,05 para 0,59 ± 0,09 m); o deslocamento vertical das mãos não foi alterado em resposta a intensidade em ambos os sexos; as mulheres apresentaram um maior deslocamento médio-lateral na intensidade baixa quando comparado as intensidades moderada e alta, os homens não alteraram o deslocamento médio-lateral das mãos entre as três diferentes intensidades de nado; vCOM e SR aumentaram e SL reduziu; SI foi maior na intensidade moderada em ambos os sexos. Os principais resultados do estudo II foram: da intensidade baixa para alta, a ηp reduziu (homens: 34,6 para 33,1%; mulheres 33,3 para 32,1%), vCOM aumentou, e homens apresentaram maior vCOM (1,21 ± 0,09; 1,48 ± 0,05 e 1,77 ± 0,06 m/s) em todas as intensidades quando comparados às mulheres (1,12 ± 0,08, 1,36 ± 0,13 e 1,52 ± 0,10 m/s); correlações significativas foram encontras entre ηp e vCOM (em homens na baixa intensidade e em ambos os sexos na alta intensidade, nessas intensidades, os nadadores que obtiveram maiores vCOM também obtiveram maior ηp) e entre ηp e deslocamento horizontal na alta intensidade (nadadores que apresentaram menor deslocamento horizontal das mãos apresentaram maior ηp). De forma geral, esta dissertação permitiu compreender de forma mais detalhada como alterações na cinemática de nado (SR, SL e

SI) e na cinemática segmentar (velocidade e deslocamento 3D das mãos) podem contribuir para maiores vCOM e ηp, e, portanto, com o desempenho no nado *crawl*.
Palavras-chaves: cinemática; natação; performance; propulsão; velocidade

ABSTRACT

This master thesis investigation sought to understand some gaps regarding swimming kinematics, segmental kinematics and arm-stroke efficiency of front crawl stroke at different swimming intensities in males and females. Two studies were developed, which aimed: to verify the effects of different swimming intensities on three-dimensional (3D) hand speed and hand displacement; and swimming kinematics: stroke rate (SR), stroke length (SL), mean center of mass swimming speed (vCOM) and stroke index (SI) (study I); and to compare and correlate arm-stroke efficiency (ηp), vCOM, and 3D hand displacement (study II). Twenty swimmers (10 male and 10 female) of regional and national level swimmers, performed three bouts of 25 m front crawl at low, moderate, and high intensities. Three-dimensional kinematic analyses were used. From study I the main results were: from low to high intensities, the 3D hand speed increased (males: 1.76 ± 0.12 to 2.67 ± 0.16 m/s; females: 1.63 ± 0.09 to 2.37 ± 0.16 m/s); the horizontal hand displacement (opposite to swimmer displacement, in the propulsive arm phases decreased only in males (males: 0.68 ± 0.07 to 0.52 ± 0.10 m; females: 0.63 ± 0.05 to 0.59 ± 0.09 m); the vertical hand displacement did not change in response to intensity in both genders; females showed higher medio-lateral hand displacement at low intensity when compared to moderate and high, males did not change medio-lateral hand displacement between three different swimming. The vCOM and SR increased; the SL reduced; and the SI was higher in moderate intensity in both genders. The main results from study II were: from low to high intensity, ηp decreased (males: from 34.6 to 33.1%; females: from 33.3 to 32.1%); vCOM increased in response to the intensities and males showed larger vCOM in all intensities when compared to females (males: 1.21 ± 0.09, 1.48 ± 0.05 and 1.77 ± 0.06 m/s; females: 1.12 ± 0.08, 1.36 ± 0.13 and 1.52 ± 0.10 m/s; significant correlations were identified between ηp and vCOM (at low intensity for males and at high intensity for both gender, in those intensities, swimmers who reached greater vCOM also had greater ηp) and between ηp and horizontal hand displacement at high intensity (swimmers with lower hand displacement had higher the ηp). Overall, this master thesis allowed to better understand how swimming kinematics (SR, SL and SI) and segmental kinematic (3D hand speed and 3D hand displacement) can contribute with higher vCOM and ηp, thus, with performance in front crawl stroke.

Keywords: Kinematics; swimming; performance; propulsion; speed

LISTA DE ABREVIAÇÕES, SÍMBOLOS E UNIDADES

%	Percentual
* ou x	Multiplicação
~	Aproximadamente
<	Menor
=	Igual
>	Maior
±	Mais ou menos
≤	Menor ou igual
≥	Maior ou igual
3D	Tridimensional
3DuHand	Velocidade média tridimensional das mãos na fase submersa da braçada
C	Custo energético
cycles/min	Ciclos por minuto
cm	Centimetros
Emax	Potência metabólica máxima
EP	Eficiência Propulsiva
HD	Deslocamento da mão
HHD	Deslocamento horizontal da mão
Hz	Hertz
kg	Quilograma
m	Metros
m/s	Metros por segundo
MLHD	Deslocamento médio-lateral da mão
ηp	Eficiência propulsiva da braçada
SI	Índice de nado
SL	Distância média percorrida pelo corpo por ciclo de braçada
SR	Frequência média de ciclo de braçada
vCOM	velocidade média do centro de massa
VHD	Deslocamento vertical da mão
VN	Velocidade média de nado

m^2/s	Metros ao quadrado por segundo

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SUMÁRIO

1 INTRODUÇÃO

O nado *crawl* é o meio de locomoção aquático mais rápido entre os seres humanos e é, também, o estilo mais difundido entre os nados competitivos (PYNE; SHARP, 2014). O objetivo das provas de natação é completar uma distância definida no menor tempo possível. Desse modo, a velocidade de nado (VN) é o principal indicador de desempenho no esporte. A VN depende da interação das forças propulsivas e resistivas (TOUSSAINT, 2002), ainda, maiores forças propulsivas estão positivamente associadas a maiores VN (MORAIS; FORTE; NEVILL; BARBOSA *et al.*, 2020) e, por este motivo, a propulsão no meio aquático é um fator determinante para o desempenho na natação (TOUSSAINT, 2002).

Há mais de quatro décadas, pesquisadores têm descrito a relação das variáveis cinemáticas de nado com o desempenho na natação (CRAIG; PENDERGAST, 1979; PELAYO; SIDNEY; KHERIF; CHOLLET *et al.*, 1996; SÁNCHEZ; ARELLANO, 2002). Assim como a VN, a frequência média de ciclo de braçada (SR), a distância média percorrida pelo corpo por ciclo de braçada (SL) e o índice de nado (SI) têm sido comumente utilizados por pesquisadores e treinadores para avaliar a técnica do nadador (CAPPAERT; PEASE; TROUP, 1995; SÁNCHEZ; ARELLANO, 2002). Diversos autores (CRAIG; PENDERGAST, 1979; PELAYO; SIDNEY; KHERIF; CHOLLET *et al.*, 1996; SÁNCHEZ; ARELLANO, 2002) sugerem que as variáveis cinemáticas apresentam comportamentos distintos entre nadadores de diferentes níveis técnicos e também variam de acordo com a intensidade de nado e entre os sexos, ainda, pelo fato de serem facilmente ser coletadas, são bastante utilizadas como um meio de estimar o desempenho no esporte.

As mãos desempenham um papel fundamental na contribuição da força propulsiva (SCHLEIHAUF, 1979) e os membros superiores produzem cerca de 90% da propulsão total no nado *crawl* em velocidades máximas (DESCHODT; ARSAC; ROUARD, 1999). A propulsão é o resultado do trabalho mecânico que o nadador despende para superar o arrasto da água e mover-se a frente (ZAMPARO; CORTESI; GATTA, 2020). Já a eficiência propulsiva da braçada (ηp) indica a fração do total de trabalho mecânico útil em relação ao trabalho mecânico total produzido pelo nadador. Dessa forma, a ηp tende a ser maior em nadadores mais habilidosos e pode, portanto, ser utilizada como um indicador técnico (ZAMPARO; CORTESI; GATTA, 2020). Porém, apesar das variáveis cinemáticas de nado, bem como a ηp, quantificarem o resultado da técnica de nado, não fornecem informações mais detalhadas sobre o movimento gerador de força propulsiva (BERGER; DE GROOT; HOLLANDER, 1995).

A compreensão dos movimentos que geram propulsão no meio aquático não é uma tarefa fácil, visto que para realizar a análise da cinemática segmentar, é necessário um sistema de reconstrução tridimensional. Alguns estudos já buscaram ampliar os conhecimentos neste campo, por meio da mensuração da velocidade tridimensional e dos deslocamentos tridimensionais das mãos (FIGUEIREDO; MACHADO; VILAS-BOAS; FERNANDES, 2011; GOURGOULIS; AGGELOUSSIS; VEZOS; ANTONIOU *et al.*, 2008; MCCABE; PSYCHARAKIS; SANDERS, 2011). No entanto, até o presente momento, pouco se sabe sobre os deslocamentos das mãos (HD) nas fases propulsivas da braçada em diferentes intensidades de nado em homens e mulheres e, se maiores ou menores HD nos três planos do movimento podem ter relação com o desempenho.

Considerando a falta de informações sobre este tema, foram definidas as seguintes questões:

i) O quanto as mãos dos nadadores se deslocam nos três planos de movimento em diferentes intensidades de nado em homens e mulheres?

ii) Há relação entre o deslocamento das mãos nos três planos de movimento e a eficiência propulsiva?

Dessa forma, para responder as estas perguntas, essa dissertação foi desenvolvida com objetivo geral de: quantificar (i) o deslocamento tridimensional das mãos nas fases propulsivas do nado *crawl* e (ii) as variáveis cinemáticas e a eficiência propulsiva em resposta a diferentes intensidades de nado em homens e mulheres. Por meio de análise cinemática tridimensional, foram desenvolvidos dois estudos, os quais tiveram como objetivos específicos:

- Estudo I: verificar os efeitos das intensidades de nado sobre a velocidade e o deslocamento tridimensional das mãos, e sobre variáveis cinemáticas (SR, SL, vCOM e SI);
- Estudo II: comparar e correlacionar a ηp, a vCOM e o deslocamento 3D das mãos.

2 REVISÃO DE LITERATURA

Neste capítulo, são abordados os seguintes temas: (i) o nado *crawl*; (ii) o deslocamento tridimensional das mãos na fase propulsiva do nado *crawl*; (iii) a cinemática do nado *crawl* e (iv) a eficiência propulsiva da braçada.

2.1 Locomoção no meio aquático e o nado crawl

O desempenho em natação depende do equilíbrio entre as forças propulsivas, geradas pelos membros superiores e inferiores que impulsionam o nadador para frente, e o arrasto, o qual retarda o deslocamento do corpo do nadador (TOUSSAINT, 2002). Para alcançar um melhor desempenho, o nadador deve reduzir o arrasto e aumentar a força propulsiva (TOUSSAINT, 2002). O arrasto é alterado pela área se secção transversa do corpo (área frontal projetada), massa específica do fluido e velocidade de deslocamento do corpo (ZAMPARO; GATTA; PENDERGAST; CAPELLI, 2009). Já a força propulsiva gerada pelos membros superiores pode ser explicada por dois componentes: (1) componente de arrasto, o qual é oposto ao sentido do deslocamento da mão e (2) componente de sustentação, que é perpendicular ao sentido do deslocamento da mão. A soma vetorial dos componentes de arrasto e de sustentação resultam na força propulsiva total (BERGER; HOLLANDER; DE GROOT, 1999). Dessa forma, a força propulsiva pode ser aumentada tanto pela maior produção da força de arrasto, quanto da força de sustentação, porém, a combinação perfeita entre as duas é decisiva para uma propulsão efetiva (GOURGOULIS; BOLI; AGGELOUSSIS; ANTONIOU *et al.*, 2014).

O nado *crawl* é caracterizado pela ação propulsiva cíclica e alternada dos membros superiores e inferiores do nadador em decúbito ventral. De acordo com Silveira; Castro; Figueiredo; Vilas-Boas *et al.* (2017), em média, 12% do total da propulsão no nado *crawl* é gerado pelos membros inferiores, enquanto 88% é resultado da propulsão dos membros superiores em velocidades máximas de nado. Ainda, as mãos e os antebraços são os principais geradores da força propulsiva total (BERGER; DE GROOT; HOLLANDER, 1995) e, dependendo da orientação, da área, da forma, da velocidade e da aceleração das mãos do nadador, maiores ou menores forças propulsivas podem ser aplicadas na água (BERGER; DE GROOT; HOLLANDER, 1995; GOMES; LOSS, 2015).

Segundo chollet; Chalies e Chatard (2000), a braçada completa do nado *crawl* é dividida em quatro fases:

(i) Entrada e apoio da mão na água: fase em que a mão entra na água, à frente do respectivo ombro e desloca-se para frente e para baixo em baixa velocidade, antes de começar o movimento para trás;

(ii) Puxada: fase em que a mão começa a se movimentar para trás, iniciando a propulsão até chegar no plano vertical do ombro;

(iii) Empurrada: fase em que a mão desloca de uma posição abaixo do ombro até a sua saída da água.

(iv) Recuperação: Fase em que a mão sai da água para a próxima entrada.

As fases estão representadas na Figura 1 de cortesi; Giovanardi; Gatta; Mangia *et al.* (2019). É importante salientar que, segundo chollet; Chalies e Chatard (2000), as fases propulsivas da braçada do nado *crawl* são as fases submersas de puxada e empurrada, nas quais a mão se desloca para trás.

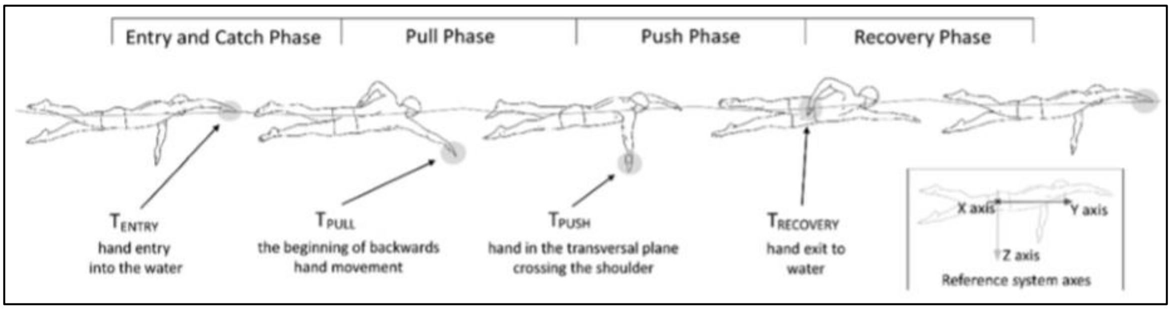

Figura 1. Classificação das fases da braçada do nado crawl proposto por Chollet; Chalies e Chatard (2000), representada por CORTESI; GIOVANARDI; GATTA; MANGIA *et al.* (2019)

Considerando que são nas fases de puxada e empurrada na quais ocorre a aplicação de forças propulsivas pelos membros superiores, compreender de maneira mais ampla os movimentos que geram essas forças no nado *crawl* pode ser determinante para o desempenho no esporte. Para aprofundamento deste tema, serão discutidos, nos próximos capítulos, outros aspectos que interferem no desempenho do nado *crawl*.

2.2 Deslocamento tridimensional das mãos

Por muitos anos, os atletas eram instruídos a empurrar as mãos diretamente para trás dos corpos em uma linha reta. Entretanto, em 1971, Counsilman foi o primeiro a sugerir que as mãos dos nadadores de elite seguem trajetórias submersas que desviam consideravelmente de uma linha reta. Counsilman (1971) verificou que as braçadas submersas durante o nado *crawl* de nadadores de elite seguiam uma trajetória de um “S” alongado ou de um ponto de interrogação invertido, nunca em linha reta. Porém, já há mais de quatro décadas, se reconhece que durante todo o percurso subaquático da braçada do nado *crawl*, as mãos percorrem uma trajetória (Figura 2) que consiste na combinação de movimentos horizontais, verticais e médio-laterais (SCHLEIHAUF, 1979).

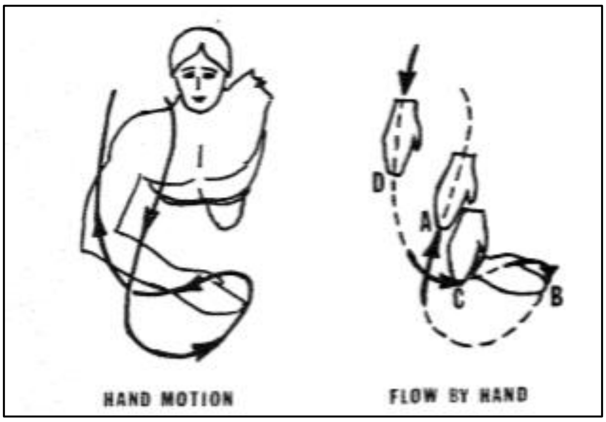

Figura 2. Ilustração da trajetória da mão de Schleihauf (1979)

Os HDs podem ser quantificados por meio de análise cinemática tridimensional. Possivelmente, pelo fato desta metodologia ser bastante complexa, poucos estudos já descreveram os deslocamentos das mãos nos três planos. Gourgoulis; Antoniou; Aggeloussis; Mavridis *et al.* (2010) mensuraram os valores absolutos dos deslocamentos da mão no eixo médio-lateral (amplitude absoluta da posição mais medial até a posição mais lateral da mão; Figura 3a), e horizontal (desde a posição mais para frente que a mão alcança após a entrada na água, até a posição mais para trás dentro da água, oposto ao sentido do deslocamento do nadador; Figura 3b), em mulheres que nadaram 25 m *crawl* na máxima intensidade.

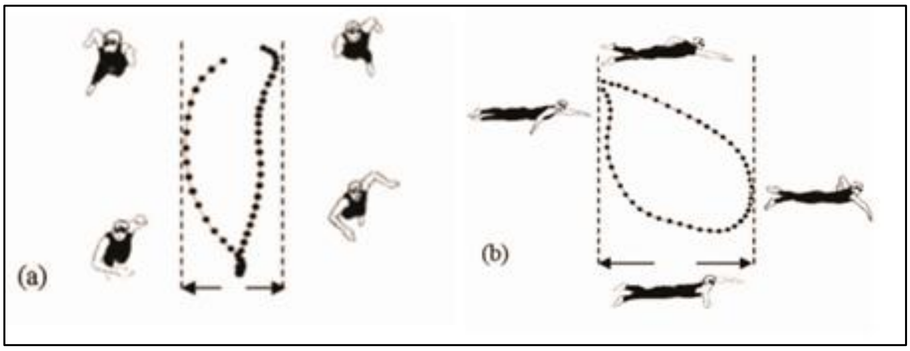

Figura 3. (a) Deslocamento médio lateral da mão direita; (b) Deslocamento horizontal da mão direita. Adaptado de Gourgoulis; Antoniou; Aggeloussis; Mavridis *et al.* (2010).

Como resultado, o HD médio-lateral foi de 0,45 ± 0,13 m e o HD horizontal foi de 0,49 ± 0,07 m. Em outro estudo, Gourgoulis; Aggeloussis; Vezos; Antoniou *et al.* (2008) verificaram o HD médio-lateral e horizontal em mulheres em um ciclo de braçada, durante 25 m *crawl* na máxima intensidade, com palmar pequeno, grande e sem palmares. Em relação aos deslocamentos, o médio-lateral não foi alterado, entretanto, o HD horizontal reduziu com o uso dos palmares. Mccabe; Psycharakis e Sanders (2011) verificaram o HD médio-lateral e vertical absoluto (definido pela posição mais profunda alcançada pela terceira falange distal da mão) em homens durante 25 m *crawl* em máxima intensidade, como resultado, o HD médio-lateral foi de 0,39 ± 0,07 m e o HD vertical de 0,66 ± 0,05 m.

Apesar dos dados apresentados, nenhum dos estudos analisou o HD horizontal, vertical e médio-lateral em uma mesma situação de nado. Considerando que a braçada do nado *crawl* é responsável pela maior parte da propulsão gerada e que a orientação, a área, a forma, a velocidade e a aceleração das mãos do nadador podem gerar maiores ou menores forças propulsivas (BERGER; DE GROOT; HOLLANDER, 1995; GOMES; LOSS, 2015), seria interessante verificar se os deslocamentos das mãos são modificados por diferentes intensidades de nado, entre os sexos e se há relação entre os deslocamentos tridimensionais das mãos e o desempenho

2.3 Cinemática do nado Crawl

Posto que o objetivo do nadador é completar uma dada distância o mais rápido possível, a VN representa a melhor medida de despenho em natação e pode ser obtida pelo o produto entre SR e SL (VN = SR * SL) (CRAIG; PENDERGAST, 1979). Dessa forma, o resultado VN depende do incremento de uma das variáveis (SR ou SL) ou de uma combinação entre as duas. Entretanto, a combinação entre SR e SL pode variar de acordo com a distância da prova, nível técnico do nadador e sexo (CRAIG; PENDERGAST, 1979; SÁNCHEZ; ARELLANO, 2002; SEIFERT; TOUSSAINT; ALBERTY; SCHNITZLER *et al.*, 2010).

Nadadores olímpicos tendem a reduzir a VN e a SR e manter a SL ao passo que a distância da prova aumenta, contrário a isso, quanto mais curta a distância da prova, maior é a VN e a SR (JESUS; COSTA; MARINHO; GARRIDO *et al.*, 2011). Em relação ao nível técnico, nadadores mais habilidosos atingem maiores VN com uma maior SL do que nadadores menos habilidosos (CAPPAERT; PEASE; TROUP, 1995; SEIFERT; TOUSSAINT; ALBERTY; SCHNITZLER *et al.*, 2010). Além da SL estar associada com a habilidade técnica o nadador, maiores SL também estão relacionadas com maiores envergaduras e, por este motivo, considerando que a envergadura dos homens é geralmente maior que a das mulheres, os nadadores atingem maiores SL do que as nadadoras em mesmas distâncias de prova, resultando em maiores VN (JESUS; COSTA; MARINHO; GARRIDO *et al.*, 2011). Pelos motivos apresentados, a combinação entre a SR e SL é considerada um fator determinante para a performance na natação. E, por isso, a SR e a SL são usualmente utilizadas na natação para monitorar a técnica do nadador (CAPPAERT; PEASE; TROUP, 1995; CRAIG; PENDERGAST, 1979; SÁNCHEZ; ARELLANO, 2002).

Outra variável cinemática utilizada para mensurar o desempenho do nadador é o índice de nado (SI), calculado pelo produto entre SL e VN (SI = SL * VN). Segundo Costill; Kovaleski; Porter; Kirwan *et al.* (1985), o SI pode ser utilizado como um indicador de eficiência de nado, pelo fato de que maiores SI resultam da habilidade do nadador de mover-se a frente em uma dada velocidade com o menor número de braçadas. Concordando com esta teoria, Seifert; Toussaint; Alberty; Schnitzler *et al.* (2010) mostraram que nadadores mais habilidosos demonstram maiores SI do que nadadores menos habilidosos, entretanto, em ambos, visto que a SL tende a cair com o aumento da VN, a SI foi menor em intensidades mais altas. Além disso, considerando que a envergadura interfere na SL, mulheres apresentam menores SI quando comparadas a homens em mesmas intensidades de nado (JESUS; COSTA; MARINHO; GARRIDO *et al.*, 2011; SÁNCHEZ; ARELLANO, 2002).

2.4 Eficiência Propulsiva

A máxima VN será alcançada pelo nadador que tiver a maior potência metabólica e o menor custo energético. A potência metabólica máxima (Emax) refere-se ao quanto de energia um indivíduo é capaz de despender por unidade de tempo (deriva das fontes energéticas aeróbias e anaeróbias) e aumenta exponencialmente em função da VN. Já o custo energético (C) pode ser definido como a energia gasta para deslocar uma dada distância em uma determinada VN. Nadadores de elite apresentam menor C e maior Emax do que os nadadores menos experientes e, por esta razão, atingem maiores VN, considerando que: VN = Emax / C (DI PRAMPERO, 1986; ZAMPARO, 2006).

Ainda, o C, na locomoção aquática, depende da eficiência total de nado, da eficiência propulsiva e da resistência hidrodinâmica (ZAMPARO; CORTESI; GATTA, 2020). Por exemplo, um nadador iniciante, que não consegue manter o corpo alinhado com a superfície da água, terá uma maior resistência hidrodinâmica agindo contra o deslocamento do seu corpo do que um nadador mais experiente que reduz a área projetada do corpo alinhando os segmentos horizontalmente na água, portanto, o nadador com pouca experiência vai ter um maior C relacionado ao aumento da resistência hidrodinâmica. Já, entre dois nadadores com a mesma área projetada durante o deslocamento (mesma resistência hidrodinâmica), o nadador que tiver a maior eficiência propulsiva terá o menor C. A eficiência está intimamente ligada com o custo energético e é inversamente proporcional, quanto maior o custo, menor a eficiência (BARBOSA; VILAS-BOAS, 2005).

O conceito de eficiência energética se relaciona com a quantidade de energia despendida para realizar determinada tarefa (BARBOSA; VILAS-BOAS, 2005). Na mesma lógica, a eficiência propulsiva indica a fração do total da energia mecânica despendida na água que resulta no efetivo deslocamento para frente (ZAMPARO; CORTESI; GATTA, 2020). Dessa forma, baseado no modelo teórico da eficiência locomotiva em animais (ALEXANDER, 1983), e em maquinas hidráulicas (FOX; MCDONALD, 1992), Figueiredo; Machado; Vilas-Boas e Fernandes (2011) e Gonjo; Mccabe; Sousa; Ribeiro *et al.* (2018) sugerem que a eficiência propulsiva, ou eficiência propulsiva da braçada (ηp), pode ser estimada pela razão entre a velocidade média do centro de massa (vCOM) e a velocidade média tridimensional das mãos na fase subaquática (3Duhand), como descritos na Equação 1:

$$\eta \boldsymbol{p} = \boldsymbol{vCOM/3DuHand} \quad \textbf{(1)}$$

Nesta equação, o efetivo deslocamento para frente é mensurado pela vCOM e o total da energia mecânica é estimada pela 3DuHand, o resultado, se multiplicado por 100, indica a ηp do nadador em valores percentuais. A 3DuHand e a vCOM podem ser diretamente quantificadas pela análise cinemática tridimensional (FIGUEIREDO; MACHADO; VILAS-BOAS; FERNANDES, 2011; GONJO; MCCABE; SOUSA; RIBEIRO *et al.*, 2018).

A ηp tem uma relação direta com habilidade técnica do nadador, segundo diversos autores, nadadores mais habilidosos apresentam maior ηp do que nadadores menos habilidosos (BARBOSA; LIMA; MEJIAS; COSTA *et al.*, 2009; SEIFERT; TOUSSAINT; ALBERTY; SCHNITZLER *et al.*, 2010; ZAMPARO, 2006). Considerando que a ηp pode ser um indicador de desempenho, é possível, a partir da análise cinemática tridimensional, utilizar o modelo proposto para calcular a ηp e verificar se há relação do deslocamento das mãos nos três planos de movimento nas fases propulsivas do nado crawl com a performance em natação.

3 ESTUDOS

3.1 Estudo 1

Este estudo está formatado nas regras do periódico *Sports Biomechanics*, onde já se encontra submetido.

Hand's three-dimensional kinematics in response to different swimming intensities in front crawl stroke

Brief running head: Hand's three-dimensional kinematics

Abstract: This study aims to verify the effects of different intensities over three-dimensional (3D) hand and swimming kinematics. Ten male and 10 female regional and national level swimmers performed front crawl bouts in low, moderate, and high intensities. A 3D video analysis system (60 Hz) was used to obtain the data. The main results were, from low to high intensities: the 3D hand speed increased (males: 1.76 ± 0.12 to 2.67 ± 0.16; females: 1.63 ± 0.09 to 2.37 ± 0.16 m/s); the horizontal hand displacement in the propulsive arm phases decreased only in males (males: 0.68 ± 0.07 to 0.52 ± 0.10 m; females: 0.63 ± 0.05 to 0.59 ± 0.09 m); the vertical hand displacements did not change with the increased of the intensities and the medio-lateral was larger in low intensity in females when compared to moderate and high intensity, males did not change medio-lateral hand displacement in response to swimming intensity. Mean swimming speed of body center of mass (vCOM) and stroke rate increased from low to high intensities; the stroke length reduced while the intensity increased; and the stroke index was higher in moderate intensity. Lower horizontal, larger medio-lateral and vertical hand displacement in males compared to females, in high intensity, shows kinematic advantages, increasing propulsive forces, and thus resulting in higher vCOM.

Keywords: Biomechanics; performance; three-dimensional analysis; hand displacement; swimming kinematics

Introduction

The knowledge of swimming and segmental kinematics is essential for coaches and athletes to recognize how to improve performance. As the aim of a competitive swimmer is to travel a certain distance in a shorter time, the mean swimming speed of body center of mass (vCOM) is a precise measure for swimming performance analysis. Previous studies (Barbosa et al., 2010; Seifert et al., 2010) have already shown the relevance of working on swimming kinematics improvements such as stroke rate (SR) and stroke length (SL), since the combination of them results in final swimming speed (Craig & Pendergast, 1979), which can be represented by the vCOM. Also, by assessing SL and vCOM it is possible to measure stroke index (SI), which can be used as an estimator of the overall swimming efficiency (Barbosa et al., 2010; McCabe & Sanders, 2012). The swimming kinematics are widely used by researchers, coaches, and athletes, as they are reliable and recognized variables, and are also easy to access.

Considering that swimming movements are performed on three orthogonal planes, three-dimensional (3D) reconstruction system is necessary to access segmental kinematics parameters like 3D hand displacement (HD), 3D hand speed (3DuHand), and vCOM. Through 3D analyses it is possible to understand, specifically, how segments move underwater in order to produce propulsive forces in swimming. Few studies have used 3D reconstruction method to measured 3DuHand and HD (Figueiredo, Zamparo, et al., 2011; Gourgoulis, Boli, Aggeloussis, Toubekis, et al., 2014; McCabe & Sanders, 2012). Nonetheless, there still is lack of knowledge concerning how these variables behave in male and female swimmers in response to different swimming intensities.

Considering arms stroke are the main responsible for producing propulsive forces during front crawl swimming (Silveira et al., 2017) and the most effective propulsive force is delivered by the hands (Toussaint & Beek, 1992), this study aims to verify the effects of three different intensities over hand and swimming kinematics, respectively: (i) the mean 3DuHand and the absolute 3D HD and (ii) vCOM, SR, SL, and SI. It is hypothesised that 3D HD changes with the increment of intensity.

Methods

Participants

Twenty regional and national level swimmers (10 male; age: 21.5± 2.4 years, stature: 1.78 ± 0.05 m, arm span: 1.86 ± 0.07 m, body mass: 72.2 ± 5.6 kg, and experience in competitive swimming: 12.2 ± 5.0 years; and 10 female; age: 23.5 ± 3.7 years, stature: 1.69 ± 0.06 m, arm span: 1.72 ± 0.06 m, body mass: 62.2 ± 6.3 kg, and experience in competitive swimming: 13.5 ± 4.8 years) volunteered for this study. Performance in best individual competition event was transformed in points using the FINA (Fédération Internationale de Natation) points calculator. Best male and female performance were, respectively: 588 ± 68 (539 to 638) and 589 ± 129 (496 to 682) points. No difference was found between the genders ($p = .98$; $d = .009$).

Before data collection, all the procedures were explained, the risks, discomforts and as well as benefits that involved the study. Each swimmer signed a written term of consent. The Local Research Ethics Committee, in accordance with the Declaration of Helsinki, approved this study.

Procedures

Previously to the test, anthropometric measures were obtained, and nineteen anatomical landmarks (≈ 2 cm diameter) were drawn on the skin of each swimmer with a water-resistant black pen for 3D reconstruction (McCabe & Sanders, 2012). To warm-up and get familiar with the 25 m swimming pool where the test took place, all swimmers had fifteen minutes to perform a self-chosen warm-up. According to test procedure, each participant was required to swim three 25 m bouts in front crawl, each one in a different intensity: low, moderate and high, with push start and holding breath in between the 10 m central of the line (where the images were recorded) to avoid any modifications on the kinematics due to dive and breath, respectively. The three intensities were specified as characteristic paces of swimming: low (performed during warm-up), moderate (performed in a 400 m competition), high (performed in a 50 m competition). The order of the intensities was randomized for each subject and they were informed what intensity they were to swim just before their turn. Swimmers had 3 min rest between trials.

Video analysis

To obtain the images for 3D reconstruction and kinematics analyses, the tests were recorded by six stationary and synchronized video cameras (SONY HDR-CX220, Tokyo, Japan) at 60Hz, four were positioned below and two above the water. One complete stroke cycle (the same in the six cameras) was cut from each video (software Sony Vegas Pro 15.0), when the whole swimmer's body was passing through the pre-calibrated space. The calibration volume used was 6.75 m^3 being 4.5 m length (x - axis = horizontal), 1.5 m height (y - axis = vertical) and 1.0 m width (z - axis = medio-lateral) and was positioned half above and half under the water, with x - axis corresponding to swimming direction. Twenty-four specific spots, placed on the calibration volume, and a fixed point, placed on the swimming pool were marked as the frame’s control point as a reference mark (Psycharakis et al., 2005).

The anatomical landmarks and control points were manually digitized using Ariel Performance Analysis System (APAS) software, which incorporates the direct linear transformation (DLT), reconstructing the swimmer’s images into 3D coordinates. The localization of the body center of mass was identified in APAS software, with calculations based on Dempster (1955). The accuracy of the digitalization and calibration procedures were 7.1 mm; 0.8 mm and 5.3 mm, respectively, for the x, y, and z axes. Kinematic data were smoothed with a 4 Hz Butterworth digital filter.

Segmental kinematic analyses

The stroke phases were divided in: (i) entry glide and catch, (ii) pull, (iii) push and (iv) recovery. Considering propulsive phases only pull and push (Chollet et al., 2000). 3DuHand was computed as the sum of the mean’s instantaneous 3D speed of the left and right hand during the underwater phases (Figueiredo, Zamparo, et al., 2011). The absolute HD was measured by the difference between the hand´s position (considering the tip of the 3rd distal phalanx of the left and right finger) and defined in each orthogonal plane as:

- Horizontal (HHD): absolute HD along x - axis, opposite to swimming direction, from the most forward position after entry to the most backward position before exiting the water.

- Vertical (VHD): absolute HD along y - axis, from the uppermost position after entry to the deeper position during underwater phases.
- Medio-lateral (MLHD): absolute HD along z – axis, from the most medial to the most lateral position during the propulsive phases.

Swimming kinematic analyses

The vCOM was calculated by dividing the SL over the time duration (T) of the complete stroke cycle (vCOM = SL/T). SR was defined as the inverse of the stroke cycle duration (time between the first and the third hand entry as a complete stroke cycle) and converted in cycles/min. SL (in m) was defined as center of mass total horizontal displacement in X-axis along one complete stroke cycle. Stroke index (SI in m^2/s) was the product of vCOM and SL (SI= vCOM* SL).

Statistical analyses:

After Shapiro-Wilk test application, mean, standard deviation and mean confidence interval (95%) were calculated. For the segmental kinematic analyses, a three factor ANOVA considering intensity (three), gender (two), and hand sides (two) were applied. For swimming kinematics analyses, two factors (intensity and gender) ANOVA was applied. Mauchly, Levene, and Bonferroni tests were also applied. When interaction was identified, ANOVA was used for repeated measures (intensities) and t test for independent samples (gender). Effect sizes were calculated with eta^2 and Cohen's d. Eta^2 was categorized as: small ($eta^2 \geq 0.01$), medium ($eta^2 \geq 0.06$) or large ($eta^2 \geq 0.14$) (COHEN, 1988). Cohen's d was categorized as: insignificant (between 0 and 0.19), small (between 0.20 and 0.49), average (between 0.50 and 0.79), large (between 0.80 and 1.29) and very large (≥ 1.30) (COHEN, 1988). Statistical analysis were performed on Software SPSS v.20.0 and a significant level of 0.05 was adopted.

Results

As no left- and right-hand effect was found in the segmental analysis, the results show the mean of both sides. 3DuHand increased according to the intensities, for both males and females (F=235.5; $p < 0.001$; $eta^2 = 0.86$). Significant interaction was found between intensities and gender (F=3.198; $p = 0.047$; $eta^2 = 0.082$), however, males and females have statistically increased 3DuHand as intensity increased. Behaviour of 3DuHand is in Figure 1 and the mean limits of confidence were, respectively, for males and females: 1.70 to 1.80 and 1.58 to 1.70 m/s (low intensity); 2.09 to 2.20 and 1.86 to 2.04 m/s (moderate intensity); and 2.58 to 2.78, and 2.28 to 2.47 m/s (high intensity).

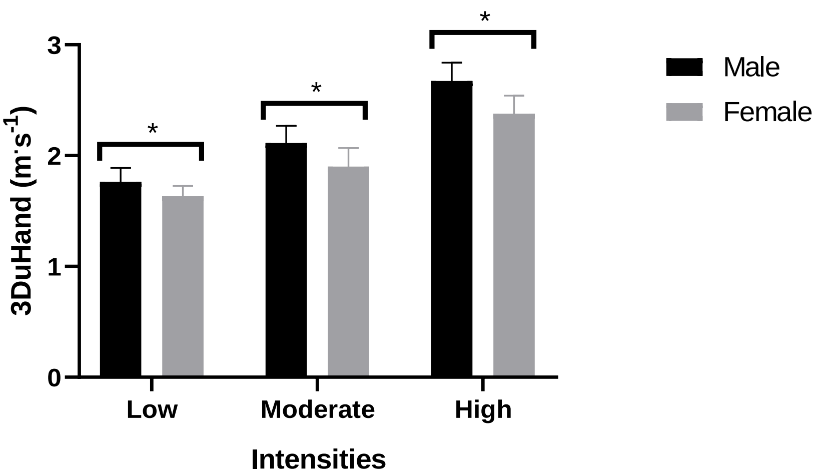

Figure 1 - 3D hand speed (3DuHand) at each intensity for males (n = 10) and females (n = 10); * $p < 0.05$ significantly difference between male and female.

Mean, standard deviation, mean confidence level and statistics results for intensity and gender effects on HD are in Table 1. Regarding the HHD, the values decreased while the intensity increased. It was found higher values for male in moderate intensity and stabilization of the values for female between moderate and high intensity. It was not found any statistic effect of the intensities on VHD, while gender effect was found, with higher values for male when compared with female in moderate and high intensities. Concerning MLHD, no intensity effect was found, but interaction between intensity and gender was found. In this case, male swimmers had not modified their MLHD in response to intensity. However, for female it was found higher MLHD in low intensity when compared to moderate intensity. Furthermore, male showed higher MLHD in high intensity than female.

Table 1. Results of segmental kinematics: horizontal (HHD), vertical (VHD) and medio-lateral (MLHD) hand displacements (HD) in three intensities (low, moderate, and high), in male (n = 10) and female (n = 10) swimmers; F, p-value, and Eta^2 regarding intensity comparison and p value and effect size (ES) regarding gender comparison.

	Intensity effects			Low intensity			Moderate intensity			High intensity		
	F	p	Eta^2	Male	Female	p-value ES	Male	Female	p-value ES	Male	Female	p-value ES
HHD*	12.2	< .001	.24	0.68 ± 0.07	0.64 ± 0.07	.18	0.64 ± 0.06	0.59 ± 0.05	.02	0.55 ± 0.09	0.61 ± 0.1	.06
(m)				0.64 to 0.71	0.61 to 0.68	.57	0.61 to 0.67	0.57 to 0.62	.90	0.50 to 0.59	0.56 to 0.66	.63
VHD	2.12	.12	.05	0.68 ± 0.16	0.63 ± 0.09	.17	0.71 ± 0.08	0.60 ± 0.08	< .001	0.68 ± 0.07	0.58 ± 0.07	< .001
(m)				0.61 to 0.76	0.58 to 0.67	.38	0.67 to 0.75	0.56 to 0.65	1.37	0.64 to 0.72	0.55 to 0.61	1.42
MLHD**	0.92	.40	.02	0.20 ± 0.08	0.20 ± 0.06	.98	0.20 ± 0.08	0.16 ± 0.06	.06	0.22 ± 0.08	0.16 ± 0.05	0.01
(m)				0.16 to 0.24	0.16 to 0.23	< .001	0.17 to 0.24	0.13 to 0.19	.56	0.18 to 0.27	0.13 to 0.19	0.89

*Significant interaction between intensity and gender: $F = 6.71$; $p = 0.02$; $eta^2 = 0.15$; ** Significant interaction between intensity and gender: $F = 3.64$; $p = 0.03$; $eta^2 = 0.08$.

On the split analysis of significant interactions, intensity ($F = 18.1$; $p < 0.001$; $eta^2 = 0.48$) of the male HHD has decreased from low to moderate intensity ($p < 0.001$) and from moderate to high intensity ($p = 0.004$). For females, intensity had no statistical effect over HHD ($eta^2 = 0.10$). Regarding MLHD, no statistical intensity effect was identified for males ($eta^2 = 0.05$), although for females, it was significant ($F = 3.91$; $p = 0.02$; $eta^2 = 0.17$), with higher MLHD at low than in moderate intensity.

Mean, standard deviation, mean confidence level and statistics results for intensity and gender effects for vCOM, SR, SL, and SI are shown in Table 2, for the three intensities, for both male and female. Higher vCOM at every increase of intensity and statistic effect between intensity and gender, with lower values in all intensities, to female, were found. For the SR, it was found higher values, at every increase of intensity and lower values, in high intensity, for female. About SL, it was found lower values at every intensity. Lower values of SL were found in the low and moderate intensities in females in comparison to males. The intensity showed statistic effect on SI, with higher values of SI in moderate intensity in relation to the high intensity. Male swimmers showed higher SI than female swimmers in all three intensities.

Table 2. Results of swimming kinematics: vCOM, SR, SL, and SI in three intensities (low, moderate, and high), in male (n = 10) and female (n = 10) swimmers; F, p-value, and Eta^2 regarding intensity comparison and p value and effect size (ES) regarding gender comparison.

	Intensity effects			Low intensity			Moderate intensity			High intensity		
	F	p-value	Eta^2	Male	Female	p-value (ES)	Male	Female	p-value (ES)	Male	Female	p-value (ES)
vCOM*	219.9	< .001	.92	1.21 ± 0.09	1.12 ± 0.08	.02	1.48 ± 0.05	1.36 ± 0.13	.018	1.77 ± 0.06	1.55 ± 0.10	<.001
(m/s)				1.15 to 1.28	1.06 to 1.18	1.05	1.44 to 1.52	1.27 to 1.45	1.33	1.72 to 1.82	1.45 to 1.59	2.75
SR**	285.8	< .001	.94	28.2 ± 4.6	29.2 ± 4.0	.59	38.0 ± 3.2	40.6 ± 6.0	.24	59.5 ± 5.8	54.6 ± 4.8	.055
(cycles/min)				24.9 -to 31.5	26.4 to 32.1	.23	35.7 to 40.3	36.3 to 44.9	.56	55.4 to 63.7	51.2 to 58.1	.92
SL	96.1	< .001	.95	2.67 ± 0.32	2.33 ± 0.26	.02	2.35 ± 0.18	2.03 ± 0.19	.002	1.79 ± 0.15	1.67 ± 0.20	0.13
(m)				2.43 to 2.90	2.13 to 2.52	1.17	2.22 to 2.48	1.89 to 2.17	.65	1.68 to 1.91	1.52 to 1.81	.68
SI	4.08	.02	.18	3.15 ± 0.61	2.62 ± 0.37	.03	3.49 ± 0.29	2.78 ± 0.38	<.001	3.14 ± 0.30	2.54 ± 0.42	.001
(m^2/s)				2.71 to 3.59	2.35 to 2.89	1.08	3.27 to 3.70	2.50 to 3.05	2.11	2.97 to 3.41	2.23 to 2.84	1.66

*Significant interaction between intensity and gender: F = 6.80; p = 0.003; eta^2 = 0.27; Significant interaction between intensity and gender: F = 5.44; p = 0.009; eta^2 = 0.23.

Discussion and Implications

The aim of this study was to verify the effects of three different intensities over hand and swimming kinematics, respectively: (i) the mean 3DuHand and the absolute 3D HD and (ii) vCOM, SR, SL and SI. The main results were: (i) 3DuHand increased from low to high intensity; (ii) HHD decreased with the increase of intensity; (iii) VHD did not change when increasing intensity; and (iv) MLHD did not change with the intensity increase. It was hypothesised that HD would change in response to intensity, although, only HHD had modified. Concerning swimming kinematics, (v) vCOM and SR increased from low to high intensities; (vi) SL reduced while the intensity increased; and (vi) SI was higher in moderate intensity. Gender interaction was found in 3DuHand, VHD, MLHD, vCOM, SR, SL and SI, showing that males and females displayed different kinematic adaptations as the intensity increased.

Regarding the large intensity effect size ($eta^2 = 0.86$) over 3DuHand, it indicates that both male and female, increased hand speed as a strategy to boost their swimming speed. This 3DuHand enhances resulted in vCOM increasing in response to the intensities. These findings are in accordance with other studies (Samson et al., 2015; Seifert et al., 2010): the more swimming intensity augments, the more hand speed increases. The hand speed seems to play an import role to generate propulsive forces to faster thrust the swimmer forward. Despite that, it does not mean that higher 3DuHand will always result in higher vCOM. Seifert et al. (2010) showed that, in same swimming pace, national swimmers had lower hand speed than regional swimmers, suggesting that more skilled swimmers might use higher hand paths and higher propulsive surfaces instead of only increasing hand speed to reach higher vCOM. It shows that vCOM augments is due to a set of mechanical components, as: hand speed, hand displacements, and propulsive surface.

In this current study the sample's skill level was close and gender was compared, different from Seifert et al. (2010). The gender's comparison showed that male reached higher vCOM in all three intensities with higher 3DuHand than female swimmers, demonstrated by a large effect size ($eta^2 = 0.082$). Furthermore, the larger vCOM found in males can also be explained by some differences verified in the absolute HD, SR, SL and SI, discussed in the following paragraphs.

Concerning the HHD, opposite to the swimmer direction, swimmers reduced it when the intensity increased. On the other hand, with split analysis of the significant interactions, males showed smaller HHD in high intensity compared to low and moderate intensity, while females kept the same HHD when incrementing intensity. The reduction of male's HHD might be seen as a positive modification. Gourgoulis, Boli, Aggeloussis, Toubekis, et al. (2014) suggested that shorter HD backwards means that hands are slipping less in the water and are producing larger propulsive drag and lift forces which thrust swimmers forward more effectively. As the magnitude of drag and lift forces depend on the water's density, the hand's surface area, and the magnitude of the resultant velocity. Thus, lift and drag forces are proportional to the square of the hand´s resultant velocity (Schleihauf, 1979). Whilst male swimmers achieved higher 3DuHand (resultant velocity) and also their hand's area is larger than females (Seifert et al., 2011), the magnitude of lift and drag forces would be higher, so, it can possibly explain why males move shorter horizontal HD than females.

Gourgoulis, Aggeloussis, Vezos, Antoniou, et al. (2008) revealed that females, when swimming at maximum intensity, enhanced vCOM (from 1.38 ± 0.07 to 1.42 ±

0.06 m/s) and reduced HHD (from 0.52 ± 0.05 to 0.41 ± 0.03 m) by using large hand paddles. It shows that hand's surface area is intricately connected with larger vCOM and smaller HHD. The female's higher HHD in high intensity, compared to males in this study, could explain one of the kinematics differences of why male reach higher vCOM than female swimmers.

The VHD did not change with the intensity's increase. It must be emphasized that, in this study, the body-roll angle was not verified. According to Castro et al. (2006), body-roll angles decrease as vCOM increases. In this way, shoulders would be closer to the water's surface as swimming speed increases, so to keep the same depth reached by the hand, as swimmers kept in this study, it can be assumed that elbow flexion decreased, and, as Payton et al. (1997) suggested, the downward motion of the hand is higher when elbow flexion is smaller. Despite that, similar founds regarding to VHD in males, was found by McCabe and Sanders (2012). In their study, sprint and distance male swimmers performed 0.66 ± 0.11 and 0.67 ± 0.06 m VHD, respectively, when swimming 400 m front crawl.

A large gender effect size ($eta^2 = 0.054$) was found over the VHD. Males kept higher VHD in moderate and high intensities when compared with females. It was expected to find by gender's anthropometric differences. Males tend to be taller, presenting longer arm span, when compared to females (Ferreira et al., 2015; Seifert et al., 2004), so, it is probably the main reason why males reached deeper VHD than females. Furthermore, the explanation of why male did not perform higher VHD in low intensity, in comparison to females, can be by the larger standard deviation found for this variable in low intensity.

Concerning MLHD, it did not change when intensity increased. Gourgoulis, Boli, Aggeloussis, Toubekis, et al. (2014), showed that female swimmers, at maximum intensity, displayed higher MLHD (0.42 ± 0.08 m), in comparison with results presented. Meanwhile, Gourgoulis, Boli, Aggeloussis, Toubekis, et al. (2014) measured medio-MLHD during entire underwater stroke phases (entry and catch, pull, and push), differently from this study, which measured the MLHD during only propulsive phases (pull and push). As MLHD occurs in catch phase, it is expected to find higher values when whole underwater phase is considered.

The results showed that a small increase (not statistic) in males and a small decrease (not statistic) in females, led to a gender effect in higher intensity: males presented higher MLHD when compared to females. According to Gourgoulis, Boli, Aggeloussis, Antoniou, et al. (2014), propulsive force is resulted from combination of drag and lift forces, depending on the propulsive phase the hand. In this way, the relative contribution of drag and lift forces varies along the propulsive phases. For example, in pull phase, when hands movie primarily backwards (large pitch angles values), drag force is higher when compared to lift force. While in the end of push phase, hands move also in lateral and vertical directions (small pitch angle values), resulting in higher lift force contribution than drag (Gourgoulis, Boli, Aggeloussis, Antoniou, et al., 2014). Thus, higher vertical and MLHD found in males might enhance propulsive force when compared to females,

Considering male's higher vCOM, it is suggested that hand kinematics differences between gender found in this study can play an important role, resulting on higher propulsive force due to drag and lift forces. Thus, higher (1) drag and (2) lift force could have occurred respectively because of:

(1) The increase of 3DuHand.

(2) Lower HHD and higher VHD and MLHD.

The vCOM and SR increased while SL decreased with intensity, as also showed by previous studies (Seifert et al., 2004; Seifert et al., 2010). Males had higher vCOM in all intensities when compared to female (large effect size, $eta^2 = 0.27$). Male's SR was higher than females in high intensity. SR and 3DuHand boost in order to increase vCOM. SL was higher in males than females in low and moderate intensity, but SL difference was not found between males and females in high intensity. Different from what was found, it has been shown that gender did not have effect on SR, while SL was always higher in males when compared to females in same intensities (Ferreira et al., 2015; Seifert et al., 2011; Seifert et al., 2004).

SL is closely related to swimmer's skill level (Seifert et al., 2010) and anthropometric variables (Pelayo et al., 1996). Therefore, it was expected that males had higher SL in all three intensities when compared to female, regarding the anthropometric characteristics. However, it is interesting to underline that females decreased SL 0.30 m from low to moderate intensity and 0.36 m from moderate to high intensity while males decreased SL 0.32 m and 0.56 respectively. It is assumed that this substantial decrease of male's SL from moderate to high intensity was the main factor to have avoided finding different SL of males and females in high intensity. Also, the large decrease on SL from moderate to high intensity, can be seen as a skill gap in males (Seifert et al., 2010) and possibly a reason why they had statistically performed higher SR than female in high intensity, in order to increase vCOM. When the SL's decrease is substantial, coaches and swimmers should work on it, in order to improve performance.

Lastly, a statistic effect of intensity on SI was found (large effect size, eta^2 = 0.18), with higher values in the moderate intensity. Males showed higher SI in all three intensities when compared to females, as found by Sánchez and Arellano (2002). As the SI is a product of vCOM and SL, and males had higher vCOM in all three intensities and higher SL in low and moderate intensity when compared to females, it resulted in higher SI, also showed by Jesus et al. (2011). Thus, both genders had higher SI in moderate intensity as the SL reduced considerably from moderate to high intensity.

Conclusion

The 3DuHand increases due to swimming intensity. As intensity increases, the HHD decreases, and the VHD and MLHD do not change. Specifically, regarding the gender effects in high intensity, males have lower HHD, larger MLHD and VHD, and higher 3DuHand, when compared to females. These differences seem to be kinematic advantages that enhance drag and lift force components, increasing propulsive forces and resulting in higher vCOM in male swimmers.

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3.2 Estudo 2

Este estudo está formatado nas regras do periódico *Sports Biomechanics*.

Three-dimensional front crawl arm-stroke efficiency and kinematics at different swimming intensities

Brief running head: Front crawl arm-stroke efficiency

Abstract: Through three-dimensional (3D) analyses, this study aimed to compare and correlate (i) arm-stroke efficiency (ηp), (ii) mean center of mass swimming speed (vCOM), and (iii) three-dimensional hand displacement (HD) at different swimming intensities. Ten male and 10 female regional and national level swimmers performed three front crawl bouts at low, moderate, and high intensities. The main results revealed: (i) ηp decreased in response to intensity in both genders (males: from 34.6 to 33.1%; females: from 33.3 to 32.1%); (ii) vCOM increased in response to the intensities and males showed larger vCOM in all intensities when compared to females (males: 1.21 ± 0.09, 1.48 ± 0.05 and 1.77 ± 0.06 m/s; females: 1.12 ± 0.08, 1.36 ± 0.13 and 1.52 ± 0.10 m/s); (iii) horizontal HD decreased in response to increase of intensity only in males (males: 0.68 ± 0.07 to 0.52 ± 0.10 m; females: 0.63 ± 0.05 to 0.59 ± 0.09 m), while vertical and medio-lateral HD did not change with the intensity. Significant correlations were identified between ηp and vCOM at low intensity for males and at high intensity for males and females (the higher the ηp, the higher the vCOM) and ηp and horizontal HD at high intensity (the higher the ηp, the lower the horizontal HD).

Keywords: biomechanics, hand displacement, performance, propelling, propulsion

Introduction

In aquatic locomotion, swimmers need to produce mechanical power to overcome hydrodynamic resistance (active drag), regarding water density, and to move forward in the water (Zamparo et al., 2020). According to Toussaint et al. (1989), the ability to swim faster arises from the capacity to increase propulsive force, reduce active drag and keep high propelling efficiency. Propelling efficiency or arm-stroke efficiency (ηp) indicates the fraction of total mechanical power performed in water to produce useful thrust, that moves the swimmer forward (Zamparo et al., 2020). Considering this, ηp can be used to evaluate the effectiveness of stroke technique (Toussaint et al., 1989). Based on the theoretical efficiency in all fluid machines (Fox & McDonald, 1992) applied in rowing animals (Alexander, 1983), Figueiredo, Zamparo, et al. (2011) and Gonjo et al. (2018), through three dimensional (3D) underwater kinematic analyses, have suggested that the ratio of mean center of mass swimming speed (vCOM) and the average 3D underwater hand speed (3DuHand), can be an indirect indicator of the ηp.

It is known that swimmers can increase propulsive forces by boosting 3DuHand or enlarging propulsive surfaces area (for instance, using hand paddles), or a combination of both (Tsunokawa et al., 2019). Also, the increment of propulsive forces might result in greater ηp (Gourgoulis, Aggeloussis, Vezos, Kasimatis, et al., 2008). Although it is still not clear if the way that swimmers move their hands, specifically hand displacement (HD) in horizontal, vertical, and medio-lateral plans, can result in greater propulsive forces and ηp. Thus, if the swimmers modify their HDs to increase vCOM. Therefore, through 3D motion capture analyses, this study aims to compare and correlate (i) ηp, (ii) vCOM, and (iii) 3D HD at different intensities in male and female swimmers. It is hypothesized that the increment on swimming intensities implies changes on ηp, vCOM, and HDs in male and female swimmers, thus it is expected to find significant and positive correlations between the variables.

Methods

Participants

Twenty regional and national level swimmers (10 male; age: 21.5± 2.4 years, stature: 1.78 ± 0.05 m, arm span: 1.86 ± 0.07 m, body mass: 72.2 ± 5.6 kg, hand area: 1.48 ± 0.07 m2, and experience in competitive swimming: 12.2 ± 5.0 years; and 10 female; age: 23.5 ± 3.7 years, stature: 1.69 ± 0.06 m, arm span: 1.72 ± 0.06 m, body mass: 62.2 ± 6.3 kg, hand area: 1.33 ± 0.07 m2, and experience in competitive swimming: 13.5 ± 4.8 years) volunteered for this study. Hand area was estimated by the Equation 1, proposed by Du Bois e Du Bois (1916) for the total body area with an application of a constant for hand area proposed by Amirsheybani et al. (2001) as follows:

$$H_A = \left((0.007184 * BM^{0.425}) * (ST^{0.725}) * 0.78\right) \quad (1)$$

Where HA is hand area, BM is body mass and ST is stature. Each swimmer's best individual performance in a competition event was transformed in points using the FINA (Fédération Internationale de Natation) points calculator. Best male and female performance were, respectively: 588 ± 68 (539 to 638) and 589 ± 129 (496 to 682) points, with no difference being found between the genders (p = .98; d = .009). All the procedures, risks, discomforts, and benefits that involved the study were explained before data collection. Each swimmer signed a written term of consent. The Local Research Ethics Committee, in accordance with the Declaration of Helsinki, approved this study.

Procedures

Previously to the test, anthropometric measures were obtained, and nineteen anatomical landmarks (≈ 2 cm diameter) were drawn on each swimmer's skin with a water-resistant black pen for 3D reconstruction. They were: the vertex of the head (above swim cap), right and left of the: tip of the 3rd distal phalanx of the finger, wrist axis, elbow axis, shoulder axis, hip axis, knee axis, ankle axis, 5th metatarsophalangeal joint, and the tip of 1st phalanx (McCabe & Sanders, 2012). To warm-up and get familiar with the 25 m swimming pool where the test took place, all swimmers had fifteen minutes to perform a self-chosen warm-up, taking into account the range of speeds and short distance they would swim during the test.

According to test procedure, each participant was required to swim three bouts of 25 m front crawl at low, moderate, and high intensities, with push start and holding breath in between the 10 m central of the line (where the images were recorded) to avoid any modifications on the kinematics due to dive and breath, respectively. The three intensities were specified as characteristic paces of swimming: low (performed during warm-up), moderate (performed in a 400 m freestyle event), high (performed in a 50 m freestyle event). The order of the intensities was randomized for each subject and they were informed what intensity they were to swim just before their turn. Swimmers had 3 min rest between trials.

Video analysis

To obtain the images for 3D reconstruction and kinematics analyses, the tests were recorded by six stationary and synchronized video cameras (SONY HDR-CX220, Tokyo, Japan) at 60 Hz. Four were positioned below and two above the water. One complete stroke cycle (the same in the six cameras) was cut from each video (software Sony Vegas Pro 15.0), when the whole swimmer's body was passing through the pre-calibrated space. The calibration volume used was 6.75 m^3 being 4.5 m length (x - axis = horizontal), 1.5 m height (y - axis = vertical) and 1.0 m width (z - axis = medio-lateral) and was positioned half above and half under the water, with x - axis corresponding to swimming direction. Twenty-four specific spots, placed on the calibration volume, and a fixed point, placed on the swimming pool were marked as the frame's control point as a reference mark (Psycharakis et al., 2005).

The anatomical landmarks and the control points were manually digitized using Ariel Performance Analysis System (APAS) software, which incorporates the direct linear transformation (DLT), reconstructing the swimmer's images into 3D coordinates. The localization of the body center of mass (COM) was identified in APAS software, with calculations based on Dempster (1955). The accuracy of the digitalization and calibration procedures were 7.1 mm; 0.8 mm and 5.3 mm, respectively, for the x, y, and z axes. Kinematic data were smoothed with a 4 Hz Butterworth digital filter.

Arm-stroke efficiency

Arm-stroke efficiency (ηp) was quantified through the equation suggested by Figueiredo, Zamparo, et al. (2011), based on the theoretical efficiency in all fluid machines (Fox & McDonald, 1992) applied in rowing animals (Alexander, 1983), as follows:

$$\eta p = vCOM/3DuHand \quad (2)$$

Where vCOM is the mean swimming speed of the center of mass and 3DuHand is the 3D underwater hand speed. The vCOM was estimated by dividing the horizontal displacement of center of mass in one stroke cycle over its total duration. The 3DuHand was computed as the sum of the mean's instantaneous 3D speed of the left and right hand during the underwater phases.

Hand displacement (HD)

The absolute HD was measured by the difference between the hand´s coordinates of the tip of the 3rd distal phalanx of the left and right finger, during the underwater stroke phases: (i) entry glide and catch, (ii) pull, (iii) push, being propulsive phases only pull and push (Chollet et al., 2000). The HDs were defined in each orthogonal plane as:

- Horizontal (HHD): absolute HD along x - axis, opposite to swimming direction, from the most forward position after entry to the most backward position before exiting the water.
- Vertical (VHD): absolute HD along y - axis, from the uppermost position after entry to the deeper position during underwater phases.
- Medio-lateral (MLHD): absolute HD along z – axis, from the most medial to the most lateral position during the propulsive phases (pull and push).

Statistical analyses

After Shapiro-Wilk test application, mean, standard deviation and mean confidence interval (95%) were calculated. A three factor ANOVA considering intensity (three), gender (two), and hand sides (two) were applied. Mauchly, Levene, and Bonferroni tests were also applied. When interaction was identified, ANOVA was used for repeated measures (intensities) and t test for independent samples (gender). Effect sizes were calculated with eta^2 and Cohen's d. Eta^2 was categorized as: small (≥ 0.01), medium ($\geq$

0.06) or large (≥ 0.14) (COHEN, 1988). Cohen's d was categorized as: insignificant (between 0 and 0.19), small (between 0.20 and 0.49), average (between 0.50 and 0.79), large (between 0.80 and 1.29) and very large (≥ 1.30) (COHEN, 1988). Pearson correlation coefficients were applied between (i) ηp and (ii) vCOM; and (i) ηp and (iii) HDs at each intensity, by gender and for all swimmers grouped. Statistical analysis was performed on Software SPSS v.20.0 and a significant level of 0.05 was adopted.

Results

As expected, males had larger hand area than females with very large effect size ($p < 0.001$, ES = 2.14). Figure 1A shows the behavior of ηp at the three intensities for female and male swimmers. A reduction occurred in ηp at high intensity compared to low and moderate intensities ($F = 4.09$; $p = 0.0025$; $eta^2 = 0.18$). No interaction between gender and intensity was identified ($p > 0.05$). At low, moderate and high intensities, the ηp was, respectively for female and male (mean and 95% confidence interval limits): 33.3 (31.5 – 35.0)% and 34.6 (33.1 – 36.1)%; 34.3 (32.9 – 35.6)% and 34.9 (32.9 – 36.9)%; and 32.1 (29.8 – 34.5)% and 33.1 (31.2 – 35.0)%. Figure 1B shows the behavior of vCOM at the three intensities for female and male. As expected, vCOM was increased in response to the intensities ($F = 219.9$; $p < 0.001$; $eta^2 = 0.92$), with statistical interaction between intensity and gender ($F = 6.80$; $p = 0.003$; $eta^2 = 0.27$), and with lower values ($p < 0.05$), in all intensities, for females. At low, moderate and high intensities, the vCOM was, respectively for female and male (mean and 95% confidence interval limits): 1.12 (1.06 – 1.18) m/s and 1.21 (1.15 – 1.28) m/s; 1.36 (1.27 – 1.45) m/s and 1.48 (1.44 – 1.52) m/s; and 1.52 (1.44 – 1.59) m/s and 1.77 (1.72 – 1.82) m/s.

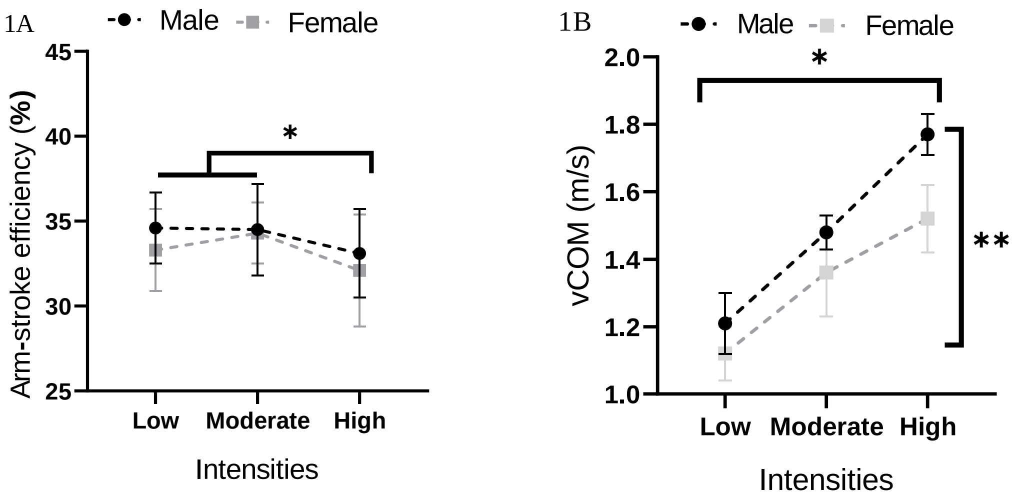

Figure 1A. Arm stroke efficiency (%) in male (n = 10) and female (n = 10) at the three intensities.*Arm stroke efficiency was lower at high intensity ($p < 0.05$) than at low and moderate intensities. Figure 1B. Center of mass swimming speed (vCOM – m/s) male (n = 10) and female (n = 10) at the three intensities.* vCOM has statistically increased from low, to high intensity ($p < 0.05$). ** Males had higher vCOM than females at the three intensities.

The HD and 3DuHand are in Table 1. There was no right or left side effect on HD, so these results are mean of right and left. For the HHD, there was a statistical intensity effect ($F = 12.1$; $p < 0.001$; $eta^2 = 0.25$), with gender interaction. In this case, males had decreased the HHD in response to intensity ($F = 18.1$; $p < 0.001$; $eta^2= 0.66$), but not the females. There was no intensity effect on VHD ($eta^2 = 0.05$) and MLHD ($eta^2 = 0.02$). Nonetheless gender effect was found in VHD, with greater values in males when compared with females at moderate ($p = 0.003$; $eta^2 = 1.64$) and high intensities ($p = 0.004$; $eta^2 = 1.53$), and on MLHD, male swimmers displayed greater values than females at high intensity ($p = 0.03$; $eta^2 = 2.66$). The 3DuHand increased according to the intensities, for both males and females ($F = 235.5$; $p < 0.001$; $eta^2 = 0.86$). Significant interaction was found between intensities and gender ($F = 3.198$; $p = 0.047$; $eta^2 = 0.08$): the males presented higher values than the females. However, both have statistically increased 3DuHand as intensity increased. Specific gender comparisons are on Table 1. The only significant correlations were among ηp with vCOM and with HHD (Table 2). It can be observed that (i) the higher the ηp, the higher the vCOM at low intensity for males, and at high intensity for males, females and both genders grouped; (ii) as higher the ηp, lower the HHD, at high intensity, for males and both genders grouped. No significant correlation was found at moderate intensity.

Table 1. Horizontal (HHD), vertical (VHD), medio-lateral HD (MLHD) and 3D underwater hand speed (3DuHand) at the three intensities (low, moderate, and high), in male (n = 10) and female (n = 10) swimmers; p- value and effect size (ES) regarding gender comparison.

	Low intensity			Moderate intensity			High intensity		
	Male	Female	*P*-value (ES)	Male	Female	*P*-value (ES)	Male	Female	*P*-value (ES)
HHD* (m)	0.68 ± 0.05 0.63 to 0.72	0.64 ± 0.05 0.60 to 0.68	0.20 0.80	0.64 ± 0.05 0.60 to 0.68	0.59 ± 0.05 0.55 to 0.63	0.08 1.0	0.55 ± 0.06 0.50 to 0.60	0.61 ± 0.09 0.54 to 0.68	0.10 0.78
VHD** (m)	0.68 ± 0.12 0.60 to 0.77	0.63 ± 0.09 0.56 to 0.69	0.24 0.47	0.71 ± 0.05 0.67 to 0.76	0.60 ± 0.08 0.54 to 0.67	0.003 1.64	0.68 ± 0.06 0.63 to 0.73	0.58 ± 0.07 0.53 to 0.63	0.004 1.53
MLHD** (m)	0.20 ± 0.07 0.15 to 0.25	0.20 ±0.08 0.16 to 0.23	0.98 < 0.001	0.20 ± 0.05 0.17 to 0.24	0.16 ± 0.05 0.12 to 0.20	0.07 0.80	0.22 ± 0.03 0.14 to 0.18	0.14 ± 0.03 0.14 to 0.18	0.029 2.66
3DuHand* m/s	1.75 ± 0.09 1.69 to 1.82	1.64 ± 0.11 1.56 to 1.72	0.022 1.09	2.13 ± 0.14 2.03 to 2.24	1.95 ± 0.16 1.83 to 2.07	0.016 1.19	2.68 ± 0.15 2.57 to 2.79	2.37 ± 0.19 2.24 to 2.51	0.001 1.81

HHD: horizontal HD; VHD: vertical HD; MLHD: medio-lateral HD; 3DuHand: 3D underwater hand speed. * intensity vs gender statistical interaction. ** gender statistical effect.

Table 2. Correlations between ηp and vCOM and HHD; in male (n = 10) and female (n = 10) and both genders grouped (n = 20).

	Low intensity	High intensity	
	vCOM ($m \cdot s^{-1}$)	vCOM ($m \cdot s^{-1}$)	HHD (m)
ηp (%)	Male: r = 0.70; p = 0.023	Male: r = 0.84; p = 0.002 Female: r = 0.62; p = 0.05 Grouped: r = 0.51; p = 0.02	Male: r = -0.71; p = 0.002 Grouped: r = -0.61; p 0.002

Discussion

The purpose of this study was to compare and to correlate (i) ηp, (ii) vCOM, and (iii) HD at different intensities in male and female swimmers. Briefly, the main results revealed: (i) ηp was lower at high intensity than at low and moderate intensities in both genders; (ii) vCOM increased in response to the intensities, and males showed higher vCOM in all intensities when compared to females; (iii) HHD decreased in response to the intensity increase only in males, while VHD and MLHD did not vary with the intensity. Significant correlations were identified between ηp and vCOM at low intensity for males and at high intensity for males and females (as higher the ηp, higher the vCOM) and ηp and HHD at high intensity (as higher the ηp, lower the HHD).

Considering that ηp is defined as the rate of useful mechanical work in relation to the overall mechanical work produced by the swimmer (Zamparo, 2020), the range of ηp found in three intensities in male and females swimmers, between 29.8 to 36.9%, shows that less than 40% of the propulsive force produced by the body muscles was used effectively to thrust the swimmer forward. Gonjo et al. (2018) found ηp from 38 to 42% (vCOM: 1.08 ± 0.06 m/s) and Figueiredo, Zamparo, et al. (2011) verified ηp from 34 to 47% (vCOM: 1.36 ± 0.06 to 1.56 ± 0.08 m/s), both at front crawl in male swimmers. These results indicated that less than 50% of the mechanical power was utilized for effective propulsion.

In the present study swimmers decreased their ηp according to the intensity, showing lower np at higher intensity. Previous researches (Seifert et al., 2010; Zamparo et al., 2005) have shown that, in order to increase velocity, SR enhances (leading augments in 3DuHand), but SL decreases. According to Zamparo (2006), ηp is closely related with SL, whereas these two parameters are connected to the ability to exert effective strokes in water. In this way, considering that vCOM = SR*SL, and SL decreases (showing that the effectiveness of one stroke cycle is reduced) and SR increases to supply the loss of SL and produce more propulsion by boosting 3DuHand at higher intensities (thrusting swimmer's body faster by increasing mechanical power), it is reasonable to find lower ηp at higher paces.

Furthermore, SL, vCOM, 3DuHand, and ηp depend on the swimmer's skill level (Seifert et al., 2010). Seifert et al. (2010) showed that national swimmers can reach higher vCOM and ηp by keeping same SR, but greater SL and lower 3DuHand than regional swimmers at similar intensities. It shows that swimmers with higher technical level are able to swim faster by optimizing the amount of mechanical power spent into useful mechanical work (Zamparo et al., 2020). It is interesting to highlight that higher vCOM was reached than the vCOM showed by Figueiredo, Zamparo, et al. (2011) and Gonjo et al. (2018). Taking this into consideration, the reason to finding lower values of ηp when compared to them, could be explained by the higher vCOM swam at high intensity or by the sample´s swimming skills level.

Despite the fact that anthropometric measures can influence ηp (Zamparo, 2006), no interaction between gender and intensity was identified on ηp. In accordance with this result, a simplified model to calculate ηp proposed by Zamparo (2006) also showed no differences in ηp in male and female swimmers (same age group). According to Zamparo et al. (2020), when comparing the same technical skills in females and males, females could display lower mechanical power output, however, they have similar ability to transform it into useful mechanical work. Thus, as ηp is a good indicator of technical skills and, in the present study, performance level was similar in both genders, it is consistent to have found close ηp between genders.

Nevertheless, it is important to notice that the same intensity did not result same pace between swimmers. The vCOM increased in response to intensity in both genders. However, males reached greater vCOM in all three intensities when compared to females. These results are in accordance with previous studies (Sánchez & Arellano, 2002; Seifert et al., 2004), which show that at same distance competitions, males attain higher vCOM. The fact that males can swim faster, did not interfere on ηp. At same intensities, males have greater values of underwater 3D hand speed and thereby achieve higher vCOM than females, if they keep the same proportion of the amount of energy expend (measured by the 3D hand speed), to the useful work (measured by vCOM), it will result in similar ηp (as ηp = vCOM/3Duhand).

The HHD decreased in males in response to intensity, but not in females. Gourgoulis, Aggeloussis, Vezos, Antoniou, et al. (2008) showed mean HHD in females at maximum intensity front crawl of 0.52 ± 0.05 m. Comparing values found in this research, at high intensity, with Gourgoulis, Aggeloussis, Vezos, Antoniou, et al. (2008), males get closer (0.55 ± 0.06 m) to their results, but females had larger horizontal HD (0.61 ± 0.09 m).

Intensity did not affect VHD. In accordance with this result, similar VHD was found in short and long distance male swimmers specialists, at 25 m maximum intensity: 0.66 ± 0.05 and 0.66 ± 0.06 m (McCabe et al., 2011) and 400 m maximum intensity: 0.66 ± 0.11 and 0.67 ± 0.06 m (McCabe & Sanders, 2012). It demonstrated that the maximum hand depth reached is not modified by the distinct paces or even if the swimmer is specialist in short or long distances. However, differences were found between genders. Males kept greater VHD at moderate and high intensities when compared to females. It was expected, in respect to anthropometric differences, due to males' tendency of being taller, presenting longer arm span than females (Ferreira et al., 2015; Seifert et al., 2004).

The MLHD did not change when intensity increased. Despite other studies (McCabe et al., 2011; McCabe & Sanders, 2012) indicated greater medio-lateral HD than this paper, possibly by different methodology used (all underwater water stroke phases were considered by them, while here it was measured only in push and pull phases). They also showed very close values between different intensities. At sprint pace were found 0.39 ± 0.07 m (McCabe et al., 2011) and at distance pace were found 0.39 ± 0.11 m (McCabe & Sanders, 2012). The results suggest that MLHD remains the same regardless of the swimming intensity. Gender effect was found in MLHD at high intensity. A small increase (not statistic) in males and a small decrease (not statistic) in females, led to a statistic interaction between intensity and genders: males displayed greater MLHD when compared to females. Even though, three different studies verified MLHD in female swimmers at 25 m front crawl maximum intensity, indicating: 0.37 ± 0.15 m, 0.42 ± 0.08 m and 0.45 ± 0.13 m (Gourgoulis, Aggeloussis, Vezos, Antoniou, et al., 2008; Gourgoulis et al., 2010; Gourgoulis, Boli, Aggeloussis, Toubekis, et al., 2014). Despite the values being closer to the ones found in male swimmers by McCabe et al. (2011) and McCabe and Sanders (2012), it seems to not have a clear behavior regarding to MLHD at maximum intensity between male and female swimmers.

Regarding the significant correlation found among ηp with vCOM, swimmers with higher ηp reached higher vCOM (specifically at low intensity for males, and at high intensity for males, females and both genders grouped). In accordance with Seifert et al. (2010), it shows clearly, that better swimmers have greater ηp and, through this reason, they can reach higher vCOM. Thus, performing a high ηp is a crucial factor that can determine swimming performance (Toussaint et al., 1989).

The significant correlation found between ηp and horizontal HD at high intensity for both genders grouped and for males, revealed that when the horizontal HD is smaller, ηp is larger. Gourgoulis, Aggeloussis, Vezos, Kasimatis, et al. (2008) verified that swimmers when using large hand paddles, had larger ηp than without hand paddles or with small hand paddles. Furthermore, in a complementary research, Gourgoulis, Aggeloussis, Vezos, Antoniou, et al. (2008) verified that when swimmers increased the size of hand paddles (at 25 m maximum intensity), the HHD decreased significantly, respectively: 0.52 ± 0.05 m, without paddles, 0.46 ± 0.04 m with small paddles and 0.41 ± 0.03 m with large paddles. It indicated that greater ηp and smaller HHD were result of greater propulsive area.

Considering that the magnitude of propulsive forces (drag and lift) depend on the water's density, the hand's surface area and the magnitude of the resultant velocity, the only way that a swimmer can increase propulsive force is using equipment which enlarge the propulsive surfaces area, as hand paddles, showed by Gourgoulis, Aggeloussis, Vezos, Antoniou, et al. (2008) and Gourgoulis, Aggeloussis, Vezos, Kasimatis, et al. (2008) or through boosting resultant hand's velocity, or a combination of both (Tsunokawa et al., 2019). The correlation between ηp and HHD was only at high intensity, probably because of the increment in propulsive forces through greater 3DuHand at high intensity than in low and moderate intensity. Whereas 3DuHand increases, lift and drag forces enhance, therefore, the hand faces larger forces (greater mass of water) to overcome, making the hand move shorter distances.

Thus, considering that lift and drag forces are proportional to hand area and the square of the relative velocity of the hand, the fact that males have greater hand area and had reached higher 3DuHand at high intensity than females, may affect the magnitude of propulsive forces. It can, possibly, explain why it was not found significant correlation between ηp and HHD at high intensity in females. Bearing that in mind, when applying a higher propulsive force by the hand on the water, the response of the water on the hand increases. In this way, higher 3DuHand, in respect to a projected hand area, would face greater resistance to overcome. Thus, shifting a shorter distance backwards (opposite to swimming direction), thrusting the body forward more efficiently.

Conclusion

The ηp, vCOM, and HHD changed in response to intensity while VHD and MLHD did not change when the intensity increased. Differences between gender were found in vCOM, HHD, VHD, and MLHD. The ηp decreased at high intensity, while vCOM increased in response to the intensities. Males showed larger vCOM in all intensities and shorter horizontal HHD at high intensity when compared to females. Lastly, the higher the ηp, the higher the vCOM at low intensity for males, and at high intensity for males, females and both genders grouped; and (ii) the higher the ηp, the lower the HHD, at high intensity, for males and both genders grouped. Swimmers should try to reduce horizontal HHD through increasing propulsive forces in order to increase ηp, thus reaching higher vCOM specially at maximum swimming intensity.

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Disclosure statement

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3 CONSIDERAÇÕES FINAIS

A partir da realização dos estudos, pode-se ampliar e unificar conhecimentos já descritos na literatura em relação aos deslocamentos das mãos nos três planos de movimento e a relação às variáveis cinemáticas e eficiência propulsiva da braçada do nado *crawl* em resposta a diferentes intensidades de nado em homens e mulheres. De maneira geral, a partir dos dois artigos produzidos nessa dissertação de mestrado, pode-se concluir que:

1- As mãos (direita e esquerda) dos nadadores apresentam o deslocamento tridimensional de forma similar, ou seja, não houve diferença em relação aos deslocamentos entre a mão direita e esquerda de um mesmo sujeito;
2- Homens e mulheres apresentam diferenças em relação aos deslocamentos das mãos nos eixos horizontal, vertical e médio-lateral.
3- O deslocamento horizontal e médio-lateral são alterados em resposta a intensidade de nado. Os homens reduzem o deslocamento horizontal, e aumentam o deslocamento médio-lateral da mão em resposta a intensidade de nado, enquanto as mulheres apresentam maior deslocamento médio-lateral da mão na intensidade baixa em relação à moderada e alta intensidade.
4- A 3DuHand, vCOM e SR aumentam, enquanto a SL reduz com a intensidade de nado e o SI tende a ser maior em intensidades moderadas em ambos os sexos. Homens alcançam maiores 3DuHand, vCOM,e SI do em todas as intensidades, maior SR apenas na intensidade alta e maior SL nas intensidades baixa e moderada em comparação com as mulheres;
5- A ηp reduz na alta intensidade de nado e não se diferencia entre os sexos. Nadadores de ambos os sexos apresentam maior ηp nas intensidades baixa e moderada em comparação à intensidade alta;
6- A ηp tem relação com o desempenho. Na alta intensidade, nadadores com maior ηp tende a alcançar maiores vCOM;
7- O deslocamento horizontal tem relação com a ηp na alta intensidade. Nadadores de ambos os sexos que apresentam menor deslocamento horizontal da mão demonstraram maior ηp na alta intensidade.

4 LIMITAÇÕES

Podem ser apontadas como limitações do presente estudo:

O deslocamento tridimensional das mãos no nado *crawl* foi quantificado de maneira absoluta nas máximas amplitudes de cada eixo, porém a partir desses dados não é possível descrever a trajetória das mãos como retilínea ou sinuosa ou, ainda, em relação às trocas de direção e de sentido que as mãos realizam durante as fases propulsivas.

O deslocamento médio-lateral foi quantificado apenas nas fases descritas como propulsivas por CHOLLET; CHALIES e CHATARD (2000), entretanto, a 3Duhand também utilizada para o cálculo de ηp é mensurada durante todas as fases submersas da braçada. Então, possivelmente, o deslocamento médio-lateral devesse, também, ser mensurado na fase de entrada e agarre da mão na água.

Pelo fato do cálculo de ηp não considerar a contribuição dos movimentos propulsivos dos membros inferiores para a vCOM, este método utilizado pode superestimar a eficiência dos membros superiores.

5 PERSPECTIVAS

A partir das conclusões e limitações apresentadas, sugere-se que o menor deslocamento horizontal das mãos pode ser um fator determinante para um melhor desempenho em altas intensidades no nado *crawl* em homens e mulheres. Porém, outros estudos seriam pertinentes para verificar se este menor deslocamento horizontal das mãos também apresenta correlações com outras variáveis cinemáticas, especialmente aquelas capazes de mensurar a técnica do nadador, como SL e SI.

Ainda, a mensuração dos deslocamentos verticais e médio-laterais das mãos de forma absoluta, não permite compreender de forma mais aprofundada como esses deslocamentos contribuem para a propulsão gerada. Considerando que a orientação das mãos e as trocas de direção exercem um papel importante neste contexto, sugere-se que novos estudos sejam realizados, contemplando a trajetória percorrida total, para a melhor compreensão de como, nadadores mais eficientes, movem as mãos na água durante as fases subaquática do nado *crawl*.

Por fim, o cálculo utilizado para estimar a eficiência propulsiva da braçada, representa um bom instrumento para avaliar a técnica do nadador. Entretanto, à medida que há propulsão de membros inferiores, acredita-se que este cálculo devesse ser repensado por novos estudos, considerando a velocidade dos pés, pois a propulsão dos membros inferiores contribui na velocidade média do centro de massa do nadador.

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ANEXO 1

UFRGS - PRÓ-REITORIA DE PESQUISA DA UNIVERSIDADE FEDERAL DO RIO GRANDE DO

PARECER CONSUBSTANCIADO DO CEP

DADOS DO PROJETO DE PESQUISA

Título da Pesquisa: Energética, Eficiência Propulsiva e Coordenação na Natação
Pesquisador: Flávio Antônio de Souza Castro
Área Temática:
Versão: 2
CAAE: 82225718.5.0000.5347
Instituição Proponente: Universidade Federal do Rio Grande do Sul
Patrocinador Principal: Financiamento Próprio

DADOS DO PARECER

Número do Parecer: 2.672.555

Apresentação do Projeto:
Trata-se de projeto de pesquisa apresentado por professor da ESEFID, vinculado a uma tese de doutorado do Programa de Pós-Graduação em Ciência do Movimento Humano que retoma para nova avaliação deste CEP, após solicitação de adequação.

Objetivo da Pesquisa:
Objetivo geral

analisar parâmetros energéticos, eficiência de nado e modelos coordenativos nos quatro estilos da natação em diferentes velocidades.

Os objetivos especificos são subdivididos de acordo com os cinco estudos que serão apresentados ao longo deste projeto.

Três estudos iniciais de revisão sistemática:
Estudo 1: Parâmetros energéticos na natação: uma revisão sistemática Objetivo: revisar sistematicamente as evidências dos estudos que avaliaram parâmetros energéticos nos quatro

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estilos e em diferentes distâncias e velocidades.

Estudo 2: Eficiência propulsiva na natação: uma revisão sistemática
Objetivo: revisar sistematicamente os estudos em natação que determinaram a eficiência propulsiva em diferentes distâncias e velocidades.

Estudo 3: Parâmetros coordenativos na natação: uma revisão sistemática
Objetivo: revisar sistematicamente as evidências nos resultados de coordenação em diferentes distância e velocidades na natação.

Dois estudos no modelo ex-post-facto:
Estudo 4: Energética, eficiência e coordenação em 400 m nado crawl
Objetivo: analisar as relações entre parâmetros energéticos, eficiência propulsiva e índice de coordenação ao longo do T400.
Estudo 5: Eficiência propulsiva, coordenação e trajetória das mãos nos quatros estilos de nado em diferentes velocidades
Objetivos: (I) determinar a p em todos os estilos e em diferentes velocidades; (II) determinar os IdCs (nados alternados) e TTGs (nados simultâneos) e (III) verificar as influências da trajetória das mãos e dos pés na p.

Avaliação dos Riscos e Benefícios:
Os riscos e benefícios estão adequadamente apresentados.

Comentários e Considerações sobre a Pesquisa:
Trata-se de um projeto de tese de doutorado que busca, como objetivo geral, analisar parâmetros energéticos, eficiência de nado e modelos coordenativos nos quatro estilos da natação em diferentes velocidades. Serão realizadas três revisões sistemáticas e dois estudos do tipo ex-post-facto, para responder três problemas de pesquisa: (I) quais as evidências e heterogeneidades encontradas nos estudos que avaliaram os parâmetros energéticos, de eficiência e coordenação na natação em nadadores competitivos? (II) qual o comportamento dos parâmetros energéticos, eficiência propulsiva e coordenação dos 400 m nado crawl em máxima intensidade? (III) qual o comportamento da eficiência propulsiva e da coordenação em diferentes velocidades nos quatros estilos da natação competitiva (borboleta, crawl, costas e peito)? Para responder o problema (I) os métodos de revisão sistemática serão aplicados. Para o problema (II) serão utilizados métodos de ergoespirometria durante o nado, lactacidemia e cinemetria tridimensional. Para responder o

problema (III), métodos de cinemetria tridimensional serão utilizados.

Nos estudos do tipo ex-post-facto participarão 20 nadadores competitivos (número estimado a partir de cálculo amostral), com idade acima de 18 anos. Os atletas serão avaliados em relação às características antropométricas, aos vários estilos de natação em distâncias de 25m, desempenho em 400 metros nado crawl com snorkel (tubo respiratório), consumo máximo de oxigênio, percepção subjetiva ao esforço, concentração de lactato. As avaliações ocorrerão em duas sessões distintas.

O projeto sem dúvida alguma é meritório, onde os resultados poderão contribuir para o maior conhecimento e compreensão das variáveis investigadas, podendo fornecer informações tanto ao treinador quanto aos atletas.

Havia sido solicitado esclarecimentos com relação a forma de contato com os nadadores. Os autores atenderam a solicitação, informando que o contato não será direto, mas sim por redes sociais, anexando inclusive o cartaz que será utilizado.

Considerações sobre os Termos de apresentação obrigatória:
Folha de rosto, adequada.
Orçamento, adequado
Cronograma, adequado.
Projeto completo, adequado
Termo de consentimento, adequado.
Material de divulgação/convite, adequado
Autorização de instituições participantes, presente.

Conclusões ou Pendências e Lista de Inadequações:
Atendidas as solicitações, o projeto encontra-se em condições de ser aprovado.

Considerações Finais a critério do CEP:
Aprovado.

Este parecer foi elaborado baseado nos documentos abaixo relacionados:

Tipo Documento	Arquivo	Postagem	Autor	Situação
Informações Básicas do Projeto	PB_INFORMAÇÕES_BÁSICAS_DO_PROJETO_1060521.pdf	21/04/2018 09:24:33		Aceito
Outros	Resposta_parecer.pdf	21/04/2018 09:24:12	Flávio Antônio de Souza Castro	Aceito
Outros	cartazricardo.pdf	21/04/2018 09:23:07	Flávio Antônio de Souza Castro	Aceito
Projeto Detalhado / Brochura Investigador	completo2.pdf	21/04/2018 09:22:43	Flávio Antônio de Souza Castro	Aceito
Folha de Rosto	Folha_de_Rosto_assinada.pdf	18/01/2018 18:10:08	Flávio Antônio de Souza Castro	Aceito
Parecer Anterior	parecer_aprovacao_compesq.pdf	04/01/2018 17:04:38	Flávio Antônio de Souza Castro	Aceito
Declaração de Instituição e Infraestrutura	anuencia_institucional.pdf	04/01/2018 17:04:09	Flávio Antônio de Souza Castro	Aceito
TCLE / Termos de Assentimento / Justificativa de Ausência	TCLE.pdf	04/01/2018 17:03:51	Flávio Antônio de Souza Castro	Aceito

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Plataforma Brasil

Continuação do Parecer: 2.672.555

Situação do Parecer:
Aprovado

Necessita Apreciação da CONEP:
Não

PORTO ALEGRE, 24 de Maio de 2018

Assinado por:
MARIA DA GRAÇA CORSO DA MOTTA
(Coordenador)

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