

Relationship between dry-land upper-limb power and underwater stroke power using medicine ball overhead slam as a predictor of swimming speed by upper limbs only

 Yusuke Ikeda  . Department of Health and Sports. Niigata University of Health and Welfare. Niigata, Japan.
 Rio Nara. Department of Health and Sports. Niigata University of Health and Welfare. Niigata, Japan.
Yasuhiro Baba. Department of Health and Sports. Niigata University of Health and Welfare. Niigata, Japan.
Shoichiro Yamashiro. Department of Health and Sports. Niigata University of Health and Welfare. Niigata, Japan.
Tetsuya Hisamitsu. Graduate school of Health and Science. Niigata University of Health and Welfare. Niigata, Japan.
Yoshimitsu Shimoyama. Department of Health and Sports. Niigata University of Health and Welfare. Niigata, Japan.

ABSTRACT

The relationship between power output underwater and on land was investigated by evaluation of underwater power output by the back and upper limbs. Thirteen male competitive swimmers performed the one underwater arm stroke (OUAS) trial, medicine ball overhead slam (MBOS) trial, and lat pull-down test as a predictor of back and upper-limb strength and power underwater and on land. The maximum horizontal velocity of the greater trochanter in OUAS correlated with all vertical velocities of the MB at release in MBOS ($r = 0.544 - 0.777$), with 5 repetition maximums in the lat pull-down test ($r = 0.555 - 0.729$), and with FINA points ($r = 0.783$). In the OUAS trial, increases in horizontal velocity from the start of the OUAS to the maximum horizontal velocity correlated with horizontal velocity at the start of trial, and high-level swimmers accelerated their body in a manner that was dependent on horizontal velocity at the start of the OUAS. These results suggest that underwater power output using only the upper limbs is closely associated with power and strength in dry-land exercise, and that back and upper-limb power and strength are crucial physical elements for competitive swimmers.

Keywords: Performance analysis of sport, Physical conditioning, Resistance training, Sport performance, Lat pull-down, Coaching.

Cite this article as:

Ikeda, Y., Nara, R., Baba, Y., Yamashiro, S., Hisamitsu, T., & Shimoyama, Y. (2022). Relationship between dry-land upper-limb power and underwater stroke power using medicine ball overhead slam as a predictor of swimming speed by upper limbs only. *Scientific Journal of Sport and Performance*, 1(3), 146-161. <https://doi.org/10.55860/ABXA5544>

 **Corresponding author.** Department of Health and Sports. Niigata University of Health and Welfare. Niigata, Japan.

E-mail: ikeda.yusuke.trsc@gmail.com

Submitted for publication June 03, 2022.

Accepted for publication July 01, 2022.

Published August 02, 2022.

[Scientific Journal of Sport and Performance](https://doi.org/10.55860/ABXA5544). ISSN 2794-0586.

©Asociación Española de Análisis del Rendimiento Deportivo. Alicante. Spain.

doi: <https://doi.org/10.55860/ABXA5544>

INTRODUCTION

Sprint performance in competitive swimming is directly affected by physical elements, such as strength, power, endurance, and flexibility. Competitive swimmers exercise daily on land to improve these elements. Resistance training to increase strength and power is a key exercise for sprint swimmers (Muniz-Pardos et al., 2019), and its effects on swimming performance have been demonstrated (Aspenes et al., 2009; Crowley et al., 2017; Weston et al., 2015). Regarding the strength and power of swimmers, previous studies reported strong correlations between upper-limb strength and swimming performance (Morouço et al., 2011; Sharp et al., 1982; Smith et al., 2002; Tanaka et al., 1993; Zamparo et al., 2005). Based on these findings, increases in upper-limb strength need to be prioritized by competitive sprint swimmers. However, swimming coaches and swimmers recognize the demerits of implementing resistance training, namely, increases in body mass and decreases in joint range of motion associated with muscle hypertrophy, which negatively affect swimming performance. Therefore, well-trained swimmers who have already achieved high strength and power levels reduce the proportion of basic resistance training accompanied by increases in body mass and implement high-intensity low-volume resistance training or high-power training specific to swimming movements, including dry-land exercise.

Various training methods have been developed to increase the muscle power of swimmers. Typical methods are resisted swimming using parachutes and hand paddles in water (Cortesi et al., 2019; Gourgoulis et al., 2010; Schnitzler et al., 2011; Telles et al., 2011) and dry-land exercise using a swim bench (Strass, 1988; Tanaka et al., 1993) and medicine ball (MB) (Espada et al., 2016; Sarramian et al., 2015). Regarding the kinematic effects of resisted swimming, Gourgoulis et al. (2010) demonstrated the relevance of sprint-resisted swimming because no alterations were observed in the swimming technique, such as the relative pull length or medial-lateral displacement of the hand. Moreover, specific in-water resistance training interventions were found to have a positive impact on performance (Girolid et al., 2006; Girolid et al., 2007; Ikeda, et al., 2018). Regarding the effects of training on swimming performance, Fone and Tillaar (Fone and van den Tillaar, 2022) suggested that a combined swimming and strength training regimen improved swimming performance more than a swim-only approach to training.

A swim bench is the most commonly used method for dry-land exercise, and its relationship with swimming performance (Sharp et al., 1982), training effects (Tanaka et al., 1993), and kinematic characteristics (Strass, 1988) have been examined. Although the longitudinal training effects of the swim bench for swimming performance currently remain unclear, the importance of movement control and specificity for training exercises in swim-bench training has been emphasized (Crowley et al., 2017). Dry-land exercise using a MB is practiced for core and arm training or testing (Espada et al., 2016; Garrido et al., 2010). Previous studies using a MB investigated the relationship between upper, lower body, and trunk power output and the training effects of throwing movements and suggested its validity and reliability as a total body explosive power test (Ikeda et al., 2007; Ikeda et al., 2009; Kubo et al., 1999; Stockbrugger and Haennel, 2001; Stockbrugger and Haennel, 2003). The greatest advantage of using MB throwing as a dry-land exercise for swimmers is its performance without deceleration in the latter phase of movement, which is beneficial for swimmers. However, limited information is currently available on the relationship between swimming performance and power production during dry-land exercise.

Lat pull-down and pull-up exercises are the most common strength exercises for competitive swimmers. In both exercises, the latissimus dorsi muscle is the agonist muscle (Crate, 1997) and plays an important role during the swimming stroke (Martens et al., 2015). Previous studies investigated the relationship between swimming performance and upper-limb and back strength exercises, such as lat pull-down and pull-up

exercises, and suggested that sprint performance was associated with increases in back and upper-limb strength and power by lat pull-down and pull-up exercises (Garrido et al., 2010; Morouço et al., 2011; Pérez-Olea et al., 2018). These findings may become the rationale for the design of strength training exercises for the back and upper limbs of competitive swimmers. However, swimming performance evaluated in previous studies included swimming factors other than strokes, such as the kick, start, and turn. Therefore, it currently remains unclear how the strength and power of the back and upper limbs during dry-land exercise affect underwater stroke power.

Quantitative evaluations of the underwater propulsive force and power of each swimmer will contribute to the development of effective individualized strength training programs based on the identified weaknesses of each swimmer. In competitive swimming studies, there have been many attempts to quantify the forces acting on the body and pushing water (Havriluk, 2005; Hollander et al., 1986; Narita et al., 2017; Narita et al., 2018; Tsunokawa et al., 2019). The findings obtained revealed that wave drag has a negative effect on swimmers as swimming velocity increases (Narita et al., 2017; Tsunokawa et al., 2019; Vennell et al., 2006), and that active drag is proportional to the cube of swimming velocity (Narita et al., 2018). In addition, Narita et al. (Narita et al., 2018) suggested that passive and active drag showed different changes with increases in swimming velocity and this behaviour was associated with the stroke rate. Based on this information, the methods used in these studies are extremely useful for analysing swimming techniques. However, these biomechanical methods may not be practical for assessing underwater power output by the back and upper limbs due to the difficulties associated with measuring propulsive force and active drag during swimming. Therefore, the present study focused on underwater power output in the one underwater arm stroke (OUAS) trial starting from a gliding motion and the strength and power of the back and upper limbs on land in dry-land exercise. A more detailed understanding of the relationship between power output by the back and upper limbs underwater and on land will be useful for developing dry-land exercises that enhance the underwater power output of arm strokes. We hypothesized that an increase in horizontal velocity during OUAS is associated with power output during dry-land exercise using a MB, strength in the lat pull-down exercise, and the competitive level of swimmers. The aim of the present study was to elucidate the relationships among the performance of OUAS, power output in dry-land exercise, and the strength of the upper limbs, and to verify the evaluation of underwater power output by the back and upper limbs in order to confirm the validity of dry-land exercise as a physical training method.

MATERIAL AND METHODS

Participants

Thirteen male Japanese swimmers participated in the present study, including two top-level swimmers (Table 1). FINA points were calculated based on each subject's specialized swimming technique. Subjects regularly raced a short distance of 50-100 m using front crawl and butterfly. They were fully informed of the experimental purpose and procedures of the present study and provided signed informed consent before their participation. All experimental procedures conformed to the Declaration of Helsinki and were approved by the Institutional Review Board at the Niigata University of Health and Welfare (18819-220425).

Procedures

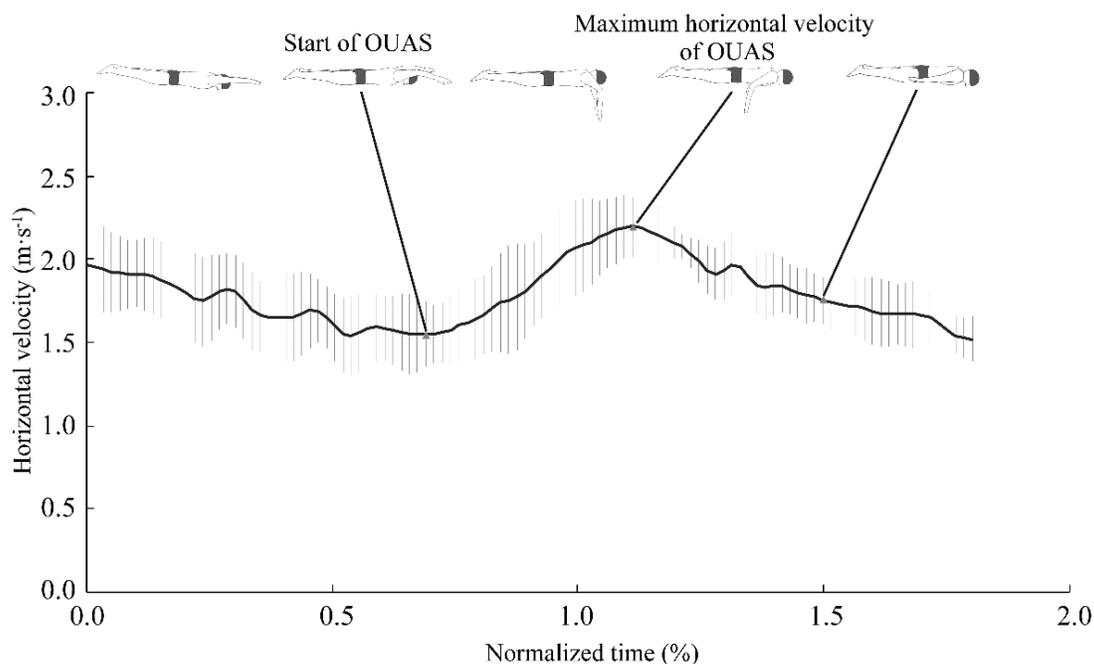
To elucidate the relationships between underwater power output in OUAS and the strength and power of the back and upper limbs in dry-land and lat pull-down exercises, 13 male competitive swimmers voluntarily participated in the present study. One week before the medicine ball overhead slam (MBOS) trial, all subjects performed a familiarization session of MBOS using all MB masses because subjects used a 3-kg MB in MBOS as a daily dry-land exercise. The OUAS and MBOS trials were performed on

separate days to minimize the effects of fatigue associated with each test. Two-dimensional motion data in these sessions were recorded. A strength test using the lat pull-down machine was conducted after the MBOS trial.

Table 1. Physical characteristics and performance in OUAS and MBOS trials.

Variable	Average \pm SD	CV	ICC
Age (yr)	20.31 \pm 2.56	-	-
Height (m)	1.75 \pm 0.04	-	-
Body mass (kg)	71.80 \pm 5.40	-	-
FINA Points	738.40 \pm 83.80	-	-
5 RM in the lat pull-down test (kg)	82.40 \pm 8.53	0.10	-
Maximum horizontal velocity of OUAS ($\text{m}\cdot\text{s}^{-1}$)	2.32 \pm 0.16	0.07	0.867 ***
Horizontal velocity at the start of OUAS ($\text{m}\cdot\text{s}^{-1}$)	1.52 \pm 0.21	0.14	0.655 **
Increase in horizontal velocity in OUAS ($\text{m}\cdot\text{s}^{-1}$)	0.80 \pm 0.13	0.17	0.006
Vertical velocity of the MB at release in 2-kg MBOS ($\text{m}\cdot\text{s}^{-1}$)	12.53 \pm 0.87 ^{a, b, c}	0.07	0.709 **
Vertical velocity of the MB at release in 4-kg MBOS ($\text{m}\cdot\text{s}^{-1}$)	10.55 \pm 0.51 ^{b, c}	0.05	0.858 ***
Vertical velocity of the MB at release in 6-kg MBOS ($\text{m}\cdot\text{s}^{-1}$)	9.31 \pm 0.53	0.06	0.685 **
Vertical velocity of the MB at release in 8-kg MBOS ($\text{m}\cdot\text{s}^{-1}$)	8.96 \pm 0.50	0.06	0.643 **

Note. Values are presented as means \pm SD. ^a, significantly greater than 4 kg, ^b, significantly greater than 6 kg, ^c, significantly greater than 8 kg. OUAS: one underwater arm stroke, MBOS: medicine ball overhead slam CV: coefficient of variance, ICC: intraclass correlation coefficient, RM: repetition maximums. ** $p < .01$, *** $p < .001$.



Note. OUAS: One underwater arm stroke.

Figure 1. Change in average horizontal velocity of the great trochanter from start to finish in the OUAS trial.

The OUAS trial. Underwater maximal power by the back and upper limbs was assessed using the OUAS trial. A light-emitting marker was attached to the greater trochanter (GT) in order to measure horizontal velocity during the OUAS trial. The motion of OUAS was recorded in the sagittal plane using a digital video

camera (GC-LJ20B, SPORTS SENSING Co., Fukuoka, Japan) placed perpendicular to the subject's plane of motion. This camera was positioned beneath the deck approximately 4.5 m from the wall of the pool. The sampling frequency was 120 Hz, and the exposure time was set at 1/500 s. A digitizing system (FrameDIAS V, DKH, Inc., Itabashi-ku, Tokyo, Japan) was used to manually digitize GT. The digitizing rate was 60 Hz. Two horizontal control points in water were used to obtain two-dimensional coordinates underwater. To calculate the coordinate value using two horizontal control points with a level in water and on the ground, the horizontal to vertical ratio of the video image was assessed in advance. We then used this ratio to calculate two-dimensional coordinates (Ikeda, et al., 2018; Ikeda et al., 2021). Coordinate values were filtered digitally using a Butterworth-type fourth-order low-pass filter. The cut-off frequency for the two-dimensional coordinates was 6 Hz (Ikeda et al., 2021). Subjects were allowed to perform non-prescribed warm-up exercises for 30 min in a 25-m indoor swimming pool. They then conducted 2–3 × 10 m OUAS at maximum effort. Following the gliding phase after kicking the wall of the pool (no dive), subjects performed OUAS when they passed the 5-m line in water, which was marked at the bottom of pool. In this test, the start and finish movements of OUAS (Figure 1) were identified by video data (60 Hz), and the horizontal velocity of GT at these points and the maximal horizontal velocity of GT during OUAS were recorded. Increase in the horizontal velocity of GT was calculated by subtracting the start velocity of the OUAS from the maximal velocity of the OUAS. The trial that recorded the maximal velocity was selected for analysis. The range of video recording was 8 m (0–8 m from the wall). Trials were repeated after a 3-min period of rest.

The MBOS trial. To measure maximal power output by the back and upper limbs, the MBOS trial was performed using 2-, 4-, 6-, and 8-kg MB (Figure 2). Markings were made on the skin directly over the joint centres of the metacarpophalangeal joint, wrist, elbow, shoulder, the elbow, inferior end of the rib, GT, knee, ankle, and hallux using tape. The motion of MBOS was recorded in the sagittal plane for a motion analysis using a digital video camera (GC-LJ20B, SPORTS SENSING Co., Fukuoka, Japan) placed perpendicular to the subject's plane of motion. The sampling frequency was 120 Hz and the exposure time was set at 1/1000 s. The digitizing rate was 120 Hz. In the MBOS analysis, we assumed that the movement of both the arms and legs of subjects during MBOS was symmetrical; therefore, only one side of a subject's upper and lower limbs recorded by the digital video camera was digitized. In the present study, the lengths of two control points for calibration were used to obtain two-dimensional coordinates underwater. To calculate the coordinate value using four horizontal control points with a level on the ground, the horizontal to vertical ratio of the video image was assessed in advance. We then used this ratio to calculate two-dimensional coordinates (Ikeda et al., 2009; Ikeda, et al., 2018). Coordinate values were filtered digitally using a Butterworth-type fourth-order low-pass filter. The cut-off frequency for the two-dimensional coordinates was 6 Hz (Ikeda et al., 2009). After non-prescribed warm-up exercises for 30 min in a laboratory, subjects performed MBOS using the 2-, 4-, 6-, and 8-kg MB at maximum effort. They conducted 2 trials with each MB mass, if the trial failed, an additional trial was conducted. Trials using the same MB were repeated after a 1-min period of rest, and another trial using a different MB was performed after a 3-min period of rest. The trial for analysis was selected based on the vertical velocity of the MB at release. The motion of MBOS was equally divided into two phases: (i) the first half phase between the starting point at which the angular velocity of the shoulder reached 1 radian·s⁻¹ and the middle point (mid-point), which was located between the starting point and release point, and (ii) the second half phase between the mid-point and release point. In the present study, release was defined as the last frame in which subjects were touching the MB. The vertical velocity of the MB as a performance indicator of MBOS was obtained in the next frame of release. In this test, power in the vertical direction for MBOS was calculated as (a) Force = (MB mass × 9.81) + (MB mass × acceleration), (b) Power = force × velocity. Average power was calculated in both the first and second half phases. The angles and angular velocities of the shoulder and elbow were calculated. The centre of mass (CM) was calculated by body segment parameters for Japanese athletes (Ae, 1996).



Note. MBOS: Medicine ball overhead slam.

Figure 2. Movement in the MBOS trial.

Strength testing. The strength of the back and upper-limb muscles was assessed using 5 repetition maximums (RM) in the lat pull-down test. A standard lat pull-down machine (FUNASIS Lat pull-down, BB4322, Senoh, Matsudo, Japan) was used to perform the lat pull-down test. After the MBOS trial, subjects performed a progressive warm-up that consisted of 8 repetitions at 80% of 10 RM and 5 repetitions at approximately 80% of 5 RM. The start load was set at approximately 90-95% of the estimated 5 RM and was increased by 2.5 or 5 kg. Subjects performed 2-3 attempts until 5 RM was achieved. The rest period between attempts was three mins. In the lat pull-down test, each repetition started with the arm fully extended and was completed when the bar was below the chin using the anterior lat pull-down technique (Andersen et al., 2014; Crate, 1997). This test adopted a wide pronated grip (Andersen et al., 2014), which is used in daily resistance training by subjects, and grip width was confirmed by an author who was a certified strength and conditioning specialist. Subjects were instructed to minimize the movement of the hip joint and trunk.

Analysis

Values for each parameter are presented as the mean \pm standard deviation. The coefficient of variance (CV) was calculated by dividing the standard deviation by the mean. To assess relationships between variables, Pearson's product-moment correlations were calculated. The Kruskal-Wallis one-way analysis of variance and Mann-Whitney post-hoc tests were used to examine differences in the MBOS trial at different MB masses. Intraclass correlation coefficients (ICC) were used to examine the relationship between trials in the OUAS and MBOS trials. All statistical procedures were conducted with SPSS Statistics 27, and significance was set at $p < .05$.

RESULTS

Differences between the actual measurement value of the horizontal distance and that of the horizontal distance calculated from digitized coordinates in the calibration on land for MBOS trial and underwater for OUAS were 0.0047 m and 0.0076 m, respectively.

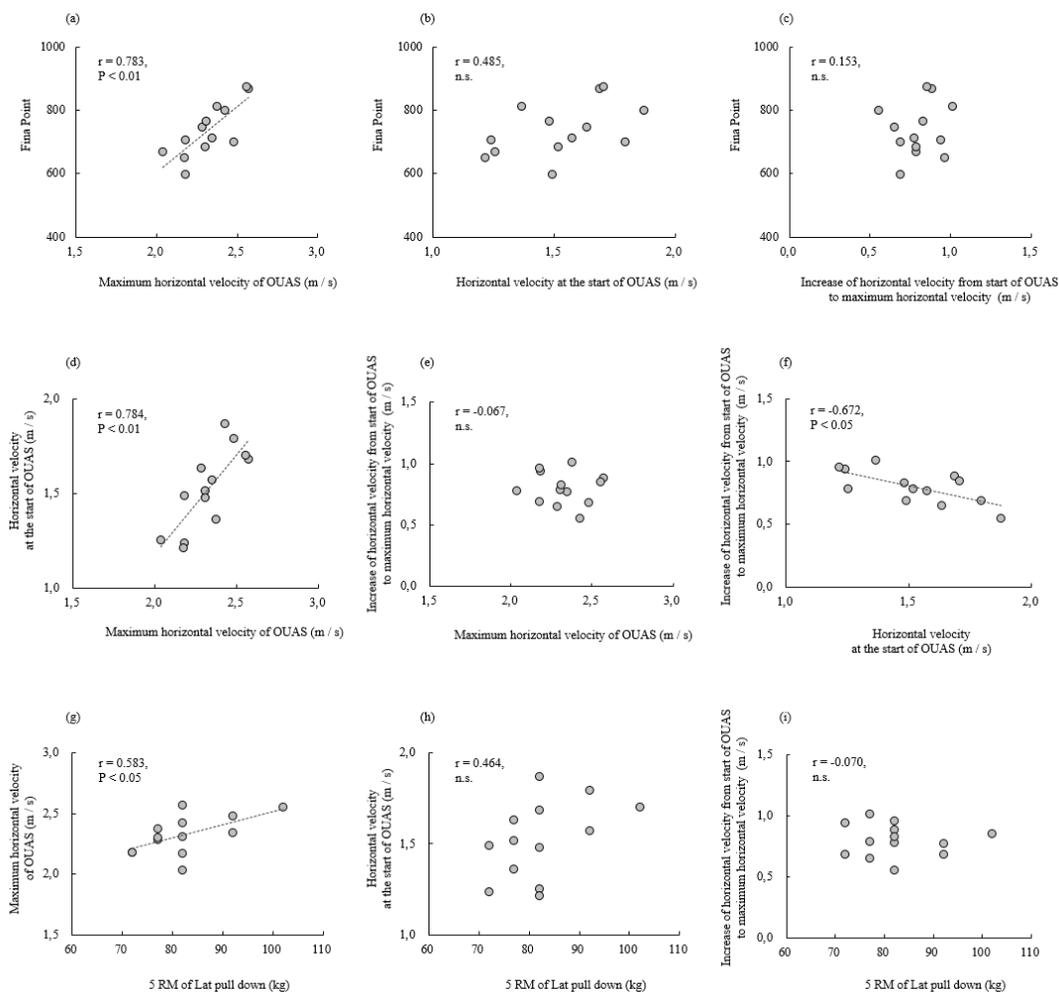
Table 1 shows the physical characteristics of subjects, FINA points, 5 RM in the lat pull-down test, the performance parameters of the OUAS trial, and the vertical velocity of the MB at release. ICC was used to examine the relationship between the best trial and the second trial in the OUAS and MBOS trials. Apart from an increase in horizontal velocity in OUAS, correlations were observed in these ICC. Regarding the CV of performance parameters in the OUAS and MBOS trials, the CV for the maximum horizontal velocity of OUAS

was smaller than those for other performance parameters in the OUAS trial, while only slight differences were noted in CV for performance parameters in the MBOS trial. Figure 3 shows the relationships among performance parameters in the OUAS trial, FINA points, and 5 RM in the lat pull-down test. The maximum horizontal velocity of OUAS correlated with FINA points and 5 RM in the lat pull-down test (Figure 3(a)(g)). Regarding the relationships among performance parameters in the OUAS trial, the maximum horizontal velocity of OUAS correlated with horizontal velocity at the start of OUAS (Figure 3(d)), and horizontal velocity at the start of OUAS negatively correlated with an increase in horizontal velocity from the start of OUAS to the maximum horizontal velocity (Figure 3(f)). The maximum horizontal velocity of OUAS and 5 RM in the lat pull-down test correlated with the vertical velocities of the MB in the MBOS trial (Table 2).

Table 2. Correlations between performance in MBOS and OUAS trials and 5 RM in the lat pull-down test.

Variable	Vertical velocity at release in MBOS			
	2 kg	4 kg	6 kg	8 kg
Maximum horizontal velocity of OUAS ($m \cdot s^{-1}$)	0.584 *	0.544	0.777 **	0.684 *
5 RM in the lat pull-down test (kg)	0.590 *	0.729 **	0.672 *	0.555 *

Note. MBOS: medicine ball overhead slam, OUAS: One underwater arm stroke, RM: repetition maximums. *, ** Significant at $p < .05$ and $p < .01$, respectively.



Note. OUAS: One underwater arm stroke.

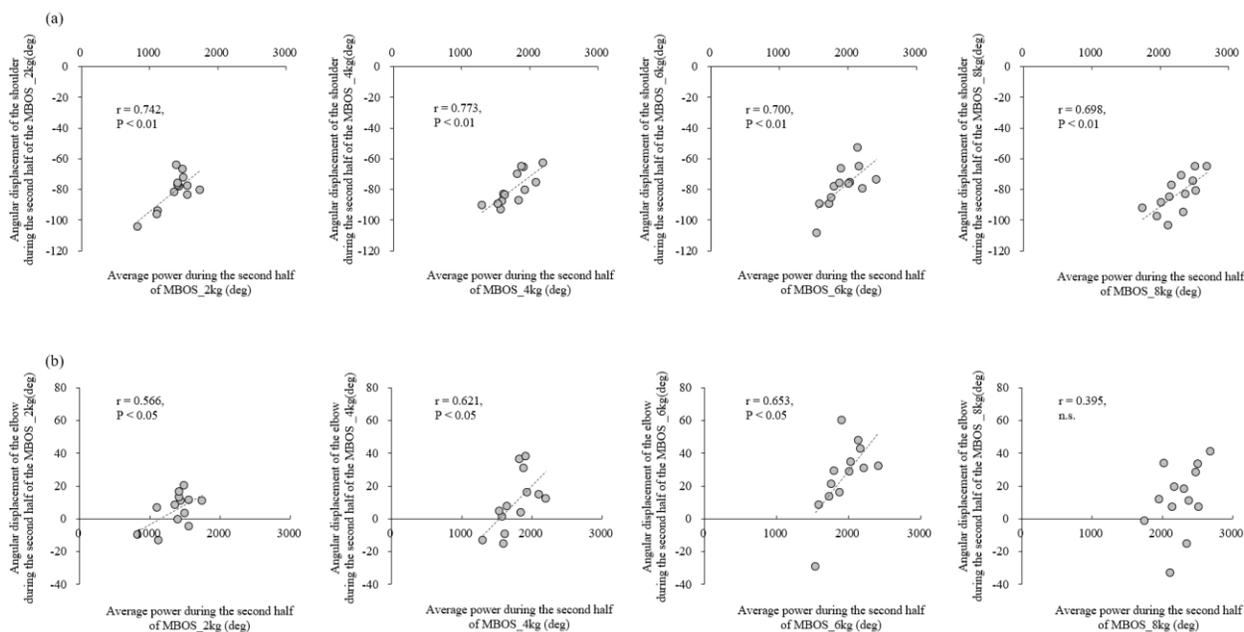
Figure 3. Relationships between OUAS parameters, Fina points, and 5 RM in the lat pull-down test.

Regarding the vertical velocity of the MB at release in the MBOS trial, the Kruskal-Wallis one-way analysis of variance revealed significant differences in the vertical velocities of the MB (Test statistic = 42.324, $p < .001$). Post hoc tests showed that the vertical velocity of the MB in the MBOS trial was significantly greater at 2 kg than at 4, 6, or 8 kg, and significantly greater at 4 kg than at 6 or 8 kg. Furthermore, the vertical velocities of the MB at release did not correlate with those at the mid-point at all MB masses in the MBOS trial (2 kg; $r = 0.016$, n.s., 4 kg; $r = 0.458$, n.s., 6 kg; $r = 0.218$, n.s., 8 kg; $r = 0.267$, n.s.). The Kruskal-Wallis one-way analysis of variance revealed no significant difference in the angle of the shoulder joint at the start of MBOS (Test statistic = 1.025, $p = .795$), at the mid-point of MBOS (Test statistic = 5.277, $p = .153$), or at release in MBOS (Test statistic = 2.777, $p = .427$). Furthermore, the Kruskal-Wallis one-way analysis of variance revealed no significant difference in the angle of the elbow joint at the start of MBOS (Test statistic = 0.158, $p = .984$) or at the mid-point of MBOS (Test statistic = 2.642, $p = .450$). However, the Kruskal-Wallis one-way analysis of variance revealed a significant difference in the angle of the elbow joint at release in MBOS (Test statistic = 18.999, $p < .001$). Post hoc tests showed that the angle of the elbow joint at release in MBOS was significantly greater at 6 kg than at 2, 4, or 8 kg. The Kruskal-Wallis one-way analysis of variance revealed a significant difference in the angular displacement of the shoulder joint during the first half phase of MBOS (Test statistic = 9.320, $p < .05$). Post hoc tests showed that the angular displacement of the shoulder joint during the first half phase of MBOS was significantly smaller at 6 kg ($-45.2 \text{ deg} \pm 7.7$) than at 2 kg ($-35.2 \text{ deg} \pm 9.3$). The Kruskal-Wallis one-way analysis of variance also revealed no significant difference in the angular displacement of the shoulder joint during the second half of MBOS (Test statistic = 1.036, $p = .793$). The Kruskal-Wallis one-way analysis of variance revealed no significant difference in the angular displacement of the elbow joint during the first half phase of MBOS (Test statistic = 2.750, $p = .432$). However, during the second half phase of MBOS, the Kruskal-Wallis one-way analysis of variance revealed a significant difference in the angular displacement of the elbow joint (Test statistic = 9.746, $p < .05$). Post hoc tests showed that the angular displacement of the elbow joint during the second half phase of MBOS was significantly greater at 6 kg ($25.8 \text{ deg} \pm 21.75$) than at 2 kg ($5.6 \text{ deg} \pm 10.10$).

The Kruskal-Wallis one-way analysis of variance revealed a significant difference in the horizontal displacement of the CM in the MBOS (Test statistic = 11.502, $p < .01$). Post hoc tests showed that the horizontal displacement of the CM in MBOS was significantly greater at 8 kg ($0.050 \text{ m} \pm 0.021$) than at 2 kg ($0.022 \text{ m} \pm 0.016$). Other values for the horizontal displacement of the CM were $0.032 \text{ m} \pm 0.015$ at 4 kg and $0.045 \text{ m} \pm 0.020$ at 6 kg.

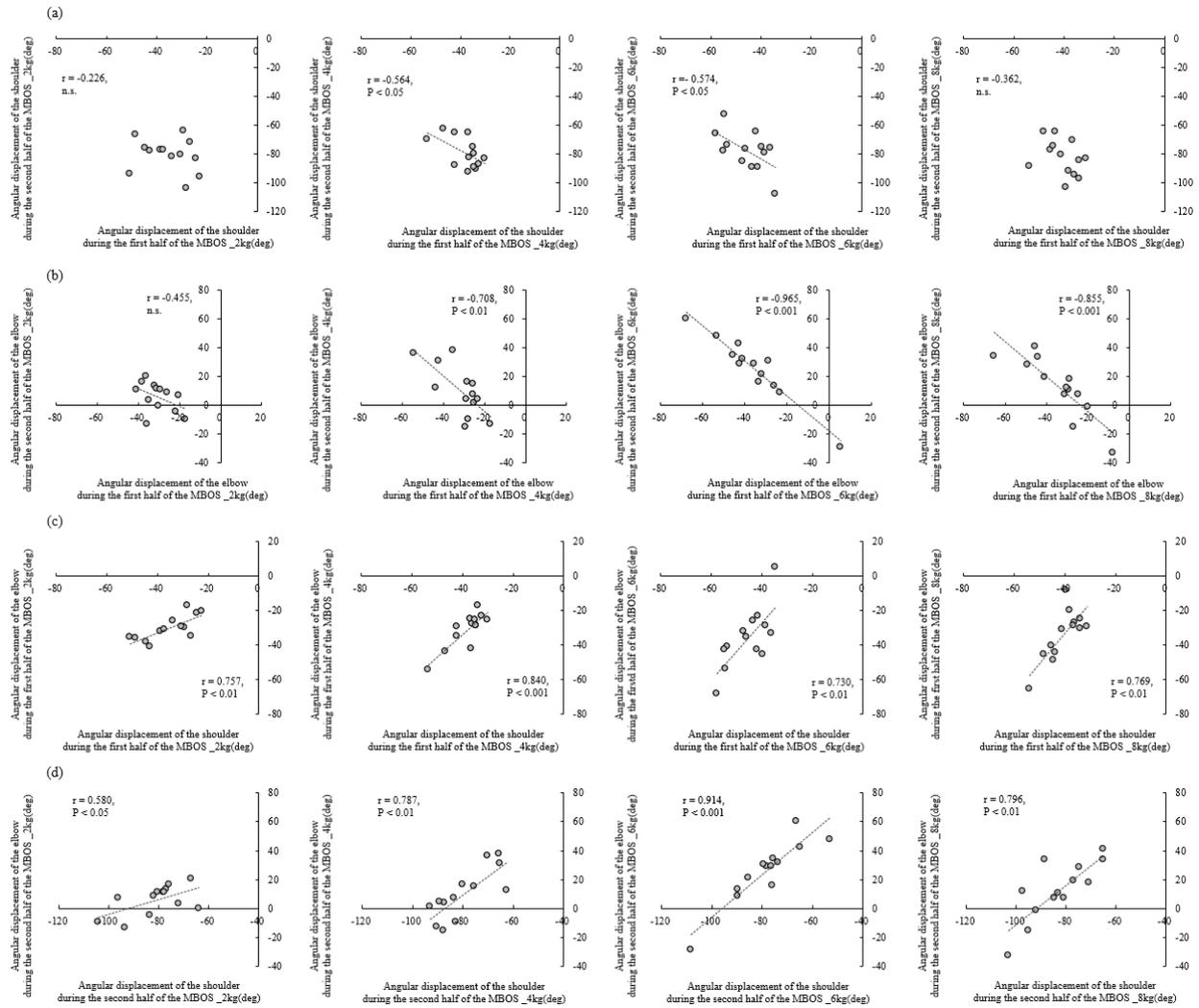
Regarding the relationship between the vertical velocity of the MB at release in MBOS and power exerted on the MB during the first and second half phases, the vertical velocity of the 2-kg MB at release in MBOS did not correlate with average power during the first half phase ($r = -0.081$, n.s.), but correlated with average power during the second half phase ($r = 0.788$, $p < .01$). The vertical velocity of the 4-kg MB at release in MBOS did not correlate with average power during the first half phase ($r = 0.386$, n.s.), but correlated with average power during the second half phase ($r = 0.842$, $p < .01$). The vertical velocity of the 6-kg MB at release in MBOS did not correlate with average power during the first half phase ($r = 0.255$, n.s.), but correlated with average power during the second half phase ($r = 0.842$, $p < .001$). The vertical velocity of the 8-kg MB at release in MBOS did not correlate with average power during the first half phase ($r = 0.159$, n.s.), but correlated with average power during the second half phase ($r = 0.824$, $p < .01$).

Figure 4 shows the relationship between average power and the angular displacement of the shoulder (a) and elbow (b) during the second half phase of MBOS. Correlations were observed between average power and the angular displacement of the shoulder and elbow joints during the second half phase of MBOS, except for the angular displacement of the elbow and average power in the 8-kg MBOS trial. Figure 5 shows the relationships between the kinematic values of the shoulder and elbow joints. Correlations were noted between the angular displacement of the shoulder and elbow joints in the first and second half phases, except for the angular displacement of the shoulder in the 2- and 8-kg MBOS trials (Figure 5 (a)(b)). Regarding the relationship between the angular displacement of the shoulder and elbow joints, the angular displacement of the shoulder correlated with the angular displacement of the elbow during the first and second half phases (Figure 5 (c)(d)). Regarding the relationship between the maximum horizontal velocity of OUAS and the angular displacement of the shoulder and elbow joints in MBOS, the maximum horizontal velocity of OUAS correlated with the total angular displacement of the shoulder in the 2-kg MBOS trial ($r = 0.654, p < .05$), 4-kg MBOS trial ($r = 0.662, p < .05$), and 8-kg MBOS trial ($r = 0.572, p < .05$), but not in the 6-kg MBOS trial ($r = 0.526, p = .065$).



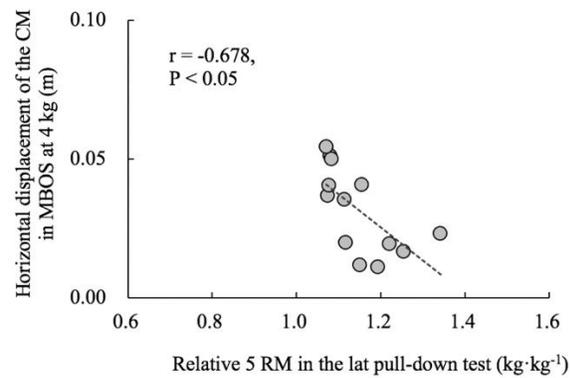
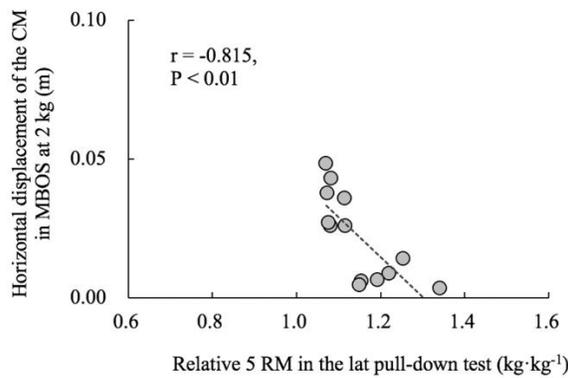
Note. MBOS: Medicine ball overhead slam.

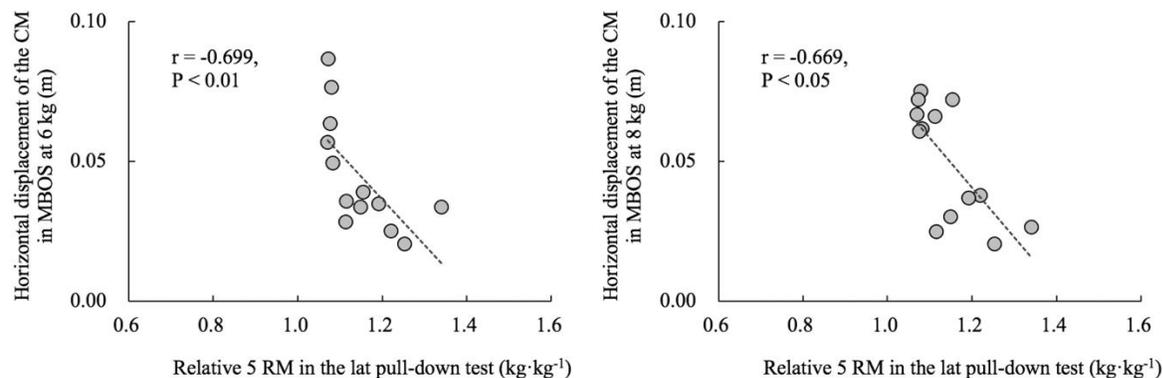
Figure 4. Relationships between average power and angular displacement of the shoulder and elbow during the second half phase of the MBOS trial.



Note. MBOS: Medicine ball overhead slam.

Figure 5. Relationships between the angular displacement of the shoulder and elbow during first and second half phases of the MBOS trial.





Note. CM: Centre of mass, MBOS: medicine ball overhead slam.

Figure 6. Relationship between relative 5 RM in the lat pull-down trial and horizontal displacement of the CM in the MBOS trial.

Figure 6 shows the relationship between relative 5 RM in the lat pull-down test and horizontal displacement of the CM from the start to release in MBOS. Correlations were observed between relative 5 RM in the lat pull-down test and the horizontal displacement of the CM in all MBOS trials.

DISCUSSION

The aims of the present study were to elucidate the relationship between underwater power output by OUAS and strength and power during dry-land exercise and examine a method to assess underwater power output by the upper limbs with the ultimate goal of establishing an approach to evaluate upper-limb power output for competitive swimmers.

The main result of this study was the strong correlation between the maximum horizontal velocity of OUAS, which was used as a predictor of underwater power output by the back and upper limbs, and the performance of dry-land exercise by the upper limbs using a MB. Maximum strength in lat pull-down exercises (Morouço et al., 2011) and power in pull-up exercises (Pérez-Olea et al., 2018) have been shown to correlate with swimming performance. These findings suggest the importance of dry-land exercise by the upper limbs for swimmers, and that the latissimus dorsi muscle, which has the role of adduction, extension, inner rotation, and horizontal extension in the shoulder joint, is closely associated with swimming performance. However, swimming performance evaluated in previous studies included swimming elements other than strokes, such as the kick, start, and turn. To obtain relevant scientific information for the design of effective training programs for dry-land exercise, it is important to elucidate the relationships between each swimming element and strength and power in dry-land exercise. In the present study, high-level swimmers, including elite swimmers, showed faster horizontal velocity during OUAS, and the maximum velocity of OUAS positively correlated with the vertical velocities of the MB at release in MBOS trials (Table 2 and Figure 3). Underwater power output by the back and upper limbs has not yet been evaluated, and the relationships between the performance of OUAS and power and strength in dry-land exercise remain unknown. Therefore, this is the first study to examine power output by the upper limbs in water and on land. The results obtained support the validity of the evaluation approach for underwater power output by the upper limbs and suggest the importance of enhancing power output by the back and upper limbs for competitive swimmers.

Regarding the relationship between the vertical velocities of the MB and the power exerted on the MB in the MBOS trials, the vertical velocities of the MB at the mid-point did not correlate with those at release for any MB mass. Furthermore, the vertical velocities of the MB at release correlated with average power during the second half of MBOS at all MB masses, while no correlations were observed between the vertical velocities of the MB at release and average power during the first half phase. These results suggest that the vertical velocities of the MB at release were determined by average power output during the second half phase regardless of the MB mass.

The small angular displacement of the shoulder and greater angular displacement of the elbow during the second half phase led to greater average power in MBOS (Figure 4). In addition, the total angular displacement of the shoulder from the start point to release, which correlated with the angular displacement of the shoulder during the second half phase, negatively correlated with the maximum horizontal velocities of OUAS. In order to understand the skilled movements of the shoulder and elbow to generate power, Figure 5 shows the relationships among the angular displacement of the shoulder and elbow during the first and second half phases of MBOS. The results obtained showed that the shoulder functioned in concert with the elbow to generate power and suggested that subjects need to extend the shoulder and flex the elbow during the first half phase of MBOS and slightly extend the shoulder and markedly extend the elbow during the second half phase. Furthermore, small extension of the shoulder was associated with great extension of the elbow during the second half phase (Figure 5(d)). In MBOS, which involves the extension and adduction of the shoulder and extension of the elbow, the latissimus dorsi muscle, greater pectoral muscle, and triceps brachii muscle are agonist muscles. Considering these kinematic results and the role of the agonist muscles, it is speculated that the triceps brachii muscle plays a role in power output because the long head of the triceps brachii muscle is a biarticular muscle involved in extension of the shoulder and elbow. Thus, the restriction of the angular displacement of the shoulder for extension by the long head of triceps brachii muscle during the second half phase of MBOS may contribute to the greater extension of the elbow. These kinematic data may be useful for optimizing upper-limb underwater movement to exert propulsive force and instructions on movements during dry-land exercise.

Regarding the different MB masses, the vertical velocities of the MB at release significantly decreased with increasing the MB mass, while no significant differences were observed in the vertical velocity of the MB at release between 6 and 8 kg. Furthermore, the MB mass altered the relationships between the vertical velocities of the MB, the maximum horizontal velocity of OUAS, and 5 RM in the lat pull-down test (Table 2). The highest correlation coefficients were observed at 4 kg (5 RM in the lat pull-down test) and 6 kg (maximum horizontal velocity of OUAS). Regarding the mass of the MB used in resistance training, Ikeda et al. (Ikeda et al., 2007; Ikeda et al., 2009) suggested selecting an appropriate MB mass based on the fitness levels of athletes. The present results suggest that 4-kg or 6-kg MB was a valid mass for our subjects, who achieved high strength levels for 5 RM in the lat pull-down test (range: 72-102 kg). Regarding the kinematic parameters of the shoulder and elbow during MBOS, a significant change was not observed with an increase in the MB mass. The horizontal displacement of the CM during MBOS increased at greater MB masses, which indicated that the CM moved backwards from the start to release in MBOS. Since it is important for swimmers to implement dry-land exercise in consideration of a posture that reduces underwater resistance, the horizontal movement of the body during MBOS needs to be assessed by swimming as well as strength and conditioning coaches.

The strength of the back and upper limbs measured by the lat pull-down test correlated with the performance of OUAS and MBOS. In addition, relative 5 RM in the lat pull-down test correlated with the horizontal displacement of the CM in MBOS (Figure 6). These results suggest that the basic strength of the back and

upper limbs was associated with power output underwater and on land, and that swimmers with high relative strength in the lat pull-down test maintained their body position during the MBOS movement. Since body position has an impact on swimming performance, swimming as well as strength and conditioning coaches need to consider the effects of the strength of the back and upper limbs on underwater posture and body position, and also focus on a swimmer's posture during dry-land exercise. The positive relationships between strength and power in lat pull-down and pull-up exercises and swimming performance demonstrates the importance of the strength of the back and upper limbs for competitive swimmers (Garrido et al., 2010; Morouço et al., 2011; Pérez-Olea et al., 2018). Pérez-Olea et al. (Pérez-Olea et al., 2018) suggested that sprint swimmers need to enhance maximum strength, not muscular endurance, in pull-up exercises. Based on previous findings, increases in the strength of the back and upper limbs using different muscular contraction types and training postures in various training exercises will improve sprint swimming performance. Furthermore, it may be important for swimming and strength coaches to adopt a concept that connects basic strength and power in typical resistance exercise and specific strength and power in dry-land exercise to enhance underwater power output.

One of the main results in the present study was the negative correlation between horizontal velocity at the start of OUAS and the increase in horizontal velocity from the start of OUAS to the maximum horizontal velocity (Figure 3 (f)). We hypothesized that high-level swimmers may acquire great horizontal velocity of the OUAS by greatly increasing the horizontal velocity from start of the OUAS to the maximum horizontal velocity. However, the results obtained showed that the increase in horizontal velocity was influenced by horizontal velocity at the start of OUAS, and high-level swimmers accelerated the body in a manner that was dependent on horizontal velocity at the start of OUAS. Regarding the relationship between swimming velocity and drag, Narita et al. (Narita et al., 2018) suggested that the effects of active drag increased at higher swimming velocities and highlighted the importance of underwater power output at a high velocity. Although OUAS has not yet been examined as a predictor of underwater power output, the results of the present study, including the relationship between the maximum velocity of OUAS and FINA points, demonstrate the validity of the method to evaluate underwater power output, and suggest that OUAS, which alters velocity at the start of OUAS, is effective underwater power training for the back and upper limbs.

There were several limitations that need to be addressed. A motion analysis of OUAS was not conducted and differences were noted in velocity of the start of OUAS. Therefore, the impact of kinematic characteristics during OUAS and horizontal velocity at the start of OUAS on performance are unknown. An experiment that uses a common horizontal velocity at the start of OUAS may provide useful information for dry-land exercise. Future studies are needed to examine the movement of OUAS at different horizontal velocities at the start of OUAS.

CONCLUSIONS

The present study showed that the performance of OUAS has potential as a predictor of underwater power output for competitive swimmers, and that this underwater power output is associated with strength and power measured by the lat pull-down test and in the MBOS trial. Furthermore, the results of the present study suggest a relationship between performance and the kinematic characteristics of the upper limbs in the MBOS trial. The results obtained also indicate the importance of increasing basic strength by typical resistance training and specific power by dry-land exercise focused on swimming techniques. In the design of training exercises for competitive athletes, the validity and objectivity of each exercise are essential for an exercise to be adopted in programs. Therefore, these results will be useful for swimming as well as strength and conditioning coaches.

AUTHOR CONTRIBUTIONS

The idea for this study and the study design were proposed by Ikeda. Ikeda analysed the data and drafted the manuscript. Nara, Baba, Yamashiro, and Hisamitsu performed measurements. Shimoyama critically reviewed the manuscript.

SUPPORTING AGENCIES

This work was supported by JSPS KAKENHI Grant Number 20K11430.

DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

ACKNOWLEDGMENTS

We would like to thank the members of the Niigata University of Health and Welfare swimming team for their help with data collection.

REFERENCES

- Ae, M. (1996). The inertia parameters of the body for Japanese children and athletes. *Jpn J Sports Sci* 15(3): 155-162. (in Japanese).
- Andersen, V., Fimland, M.S., Wiik, E., Skoglund, A., & Saeterbakken, A.H. (2014). Effects of grip width on muscle strength and activation in the lat pull-down. *J Strength Cond Res* 28(4): 1135-1142. <https://doi.org/10.1097/JSC.000000000000232>
- Aspenes, S., Kjendlie, P.L., Hoff, J., & Helgerud, J. (2009). Combined strength and endurance training in competitive swimmers. *J Sports Sci Med* 8(3): 357-365.
- Cortesi, M., Di Michele, R., & Gatta, G. (2019). Effects of intracyclic velocity variations on the drag exerted by different swimming parachutes. *J Strength Cond Res* 33(2): 531-537. <https://doi.org/10.1519/JSC.0000000000002010>
- Crate, T. (1997). Analysis of the lat pulldown. *Strength Cond* 19: 26-29. [https://doi.org/10.1519/1073-6840\(1997\)019<0026:aotlp>2.3.co;2](https://doi.org/10.1519/1073-6840(1997)019<0026:aotlp>2.3.co;2)
- Crowley, E., Harrison, A.J., & Lyons, M. (2017). The Impact of resistance training on swimming performance: a systematic review. *Sports Med* 47(11): 2285-2307. <https://doi.org/10.1007/s40279-017-0730-2>
- Espada, M.C., Costa, M.J., Costa, A.M., Silva, A.J., Barbosa, T.M., & Pereira, A.F. (2016). Relationship between performance, dry-land power and kinematics in master swimmers. *Acta Bioeng Biomech* 18(2): 145-151. <https://doi.org/10.5277/ABB-00223-2014-02>
- Fone, L., & van den Tillaar, R. (2022). Effect of different types of strength training on swimming performance in competitive swimmers: a systematic review. *Sports Med Open* 8(1): 1-26. <https://doi.org/10.1186/s40798-022-00410-5>
- Garrido, N., Marinho, D.A., Reis, V.M., van den Tillaar, R., Costa, A.M., Silva, A.J., & Marques, M.C. (2010). Does combined dry land strength and aerobic training inhibit performance of young competitive swimmers? *J Sports Sci Med* 9(2): 300-310.
- Garrido, N., Marinho, D.A., Barbosa, T.M., Costa, A.M., Silva, A.J., Pérez-Turpin, J.A., Marques, M.C. (2010). Relationships between dry land strength, power variables and short sprint performance in young

- competitive swimmers. *Journal of Human Sport and Exercise* 5(2): 240-249. <https://doi.org/10.4100/jhse.2010.52.12>
- Girolid, S., Calmels, P., Maurin, D., Milhau, N., & Chatard, J.C. (2006). Assisted and resisted sprint training in swimming. *J Strength Cond Res* 20(3): 547-554. <https://doi.org/10.1519/R-16754.1>
- Girolid, S., Maurin, D., Dugué, B., Chatard, J.C., & Millet, G. (2007). Effects of dry-land vs. resisted- and assisted-sprint exercises on swimming sprint performances. *J Strength Cond Res* 21(2): 599-605. <https://doi.org/10.1519/R-19695.1>
- Gourgoulis, V., Antoniou, P., Aggeloussis, N., Mavridis, G., Kasimatis, P., Vezos, N., Boli, A., & Mavromatis, G. (2010). Kinematic characteristics of the stroke and orientation of the hand during front crawl resisted swimming. *J Sports Sci* 28(11): 1165-1173. <https://doi.org/10.1080/02640414.2010.507251>
- Gourgoulis, V., Valkoumas, I., Boli, A., Aggeloussis, N., & Antoniou, P. (2019). Effect of an 11-week in-water training program with increased resistance on the swimming performance and the basic kinematic characteristics of the front crawl stroke. *J Strength Cond Res* 33(1): 95-103. <https://doi.org/10.1519/JSC.0000000000001879>
- Havrilik, R. (2005). Performance level differences in swimming: a meta-analysis of passive drag force. *Res Q Exerc Sport* 76(2): 112-118. <https://doi.org/10.1080/02701367.2005.10599273>
- Hollander, A.P., De Groot, G., van Ingen Schenau, G.J., Toussaint, H.M., De Best, H., Peeters, W., Meulemans, A., & Schreurs, A.W. (1986). Measurement of active drag during crawl arm stroke swimming. *J Sports Sci* 4(1): 21-30. <https://doi.org/10.1080/02640418608732094>
- Ikeda, Y., Kijima, K., Kawabata, K., Fuchimoto, T., & Ito, A. (2007). Relationship between side medicine-ball throw performance and physical ability for male and female athletes. *Eur J Appl Physiol* 99(1): 47-55. <https://doi.org/10.1007/s00421-006-0316-4>
- Ikeda, Y., Miyatsuji, K., Kawabata, K., Fuchimoto, T., & Ito, A. (2009). Analysis of trunk muscle activity in the side medicine-ball throw. *J Strength Cond Res* 23(8): 2231-2240. <https://doi.org/10.1519/JSC.0b013e3181b8676f>
- Ikeda, Y., Sasaki, Y., & Hamano, R. (2018). Factors Influencing spike jump height in female college volleyball players. *J Strength Cond Res* 32(1): 267-273. <https://doi.org/10.1519/JSC.0000000000002191>
- Ikeda, Y., Ichikawa, H., Shimojo, H., Nara, R., Baba, Y., & Shimoyama, Y. (2021). Relationship between dolphin kick movement in humans and velocity during undulatory underwater swimming. *J Sports Sci* 39(13): 1497-1503. <https://doi.org/10.1080/02640414.2021.1881313>
- Kubo, Y., Ae, M., & Fujii, N. (1999). The effect of technical training on mechanical energy flows in medicine-ball backward throwing. *Jpn J Biomech Sports Exerc* 3(3):170-178. (in Japanese).
- Martens, J., Figueiredo, P., & Daly, D. (2015). Electromyography in the four competitive swimming strokes: a systematic review. *J Electromyogr Kinesiol* 25(2): 273-291. <https://doi.org/10.1016/j.jelekin.2014.12.003>
- Morouço, P., Neiva, H., González-Badillo, J.J., Garrido, N., Marinho, D.A., & Marques, M.C. (2011). Associations between dry land strength and power measurements with swimming performance in elite athletes: a pilot study. *J Hum Kinet* 29A: 105-112. <https://doi.org/10.2478/v10078-011-0065-2>
- Muniz-Pardos, B., Gomez-Bruton, A., Matute-Llorente, A., Gonzalez-Aguero, A., Gomez-Cabello, A., Gonzalo-Skok, O., Casajus, J.A., & Vicente-Rodriguez, G. (2019). Swim-specific resistance training: A systematic review. *J Strength Cond Res* 33(10): 2875-2881. <https://doi.org/10.1519/JSC.0000000000003256>
- Narita, K., Nakashima, M., & Takagi, H. (2017). Developing a methodology for estimating the drag in front-crawl swimming at various velocities. *J Biomech* 54: 123-128. <https://doi.org/10.1016/j.jbiomech.2017.01.037>

- Narita, K., Nakashima, M., Sengoku, Y., Homma, M., Tsubakimoto, S., & Takagi, H. (2018). A comparison between active drag in front-crawl and passive drag on the body with a streamlined position at various velocities. *Japan J Phys Educ Hlth Sport Sci* 63: 505-515. <https://doi.org/10.5432/jjpehss.17051>
- Pérez-Olea, J.I., Valenzuela, P.L., Aponte, C., & Izquierdo, M. (2018). Relationship between dryland strength and swimming performance: pull-up mechanics as a predictor of swimming speed. *J Strength Cond Res* 32(6): 1637-1642. <https://doi.org/10.1519/JSC.0000000000002037>
- Sarramian, V.G., Turner, A.N., & Greenhalgh, A.K. (2015). Effect of postactivation potentiation on fifty-meter freestyle in national swimmers. *J Strength Cond Res* 29(4): 1003-1009. <https://doi.org/10.1519/JSC.0000000000000708>
- Schnitzler, C., Brazier, T., Button, C., Seifert, L., & Chollet, D. (2011). Effect of velocity and added resistance on selected coordination and force parameters in front crawl. *J Strength Cond Res* 25(10): 2681-2690. <https://doi.org/10.1519/JSC.0b013e318207ef5e>
- Sharp, R.L., Troup, J.P., & Costill, D.L. (1982). Relationship between power and sprint freestyle swimming. *Med Sci Sports Exerc* 14(1): 53-56. <https://doi.org/10.1249/00005768-198201000-00010>
- Smith, D.J., Norris, S.R., & Hogg, J.M. (2002). Performance evaluation of swimmers: scientific tools. *Sports Med* 32(9): 539-554. <https://doi.org/10.2165/00007256-200232090-00001>
- Strass, D. (1998). Effects of maximal strength training on sprint performance of competitive swimmers. In: *Swimming science V*. Champaign, IL: Human Kinetics Books. pp. 149-156.
- Stockbrugger, B.A. & Haennel, R.G. (2001). Validity and reliability of a medicine ball explosive power test. *J Strength Cond Res* 15(4): 431-438. [https://doi.org/10.1519/1533-4287\(2001\)015<0431:varoam>2.0.co;2](https://doi.org/10.1519/1533-4287(2001)015<0431:varoam>2.0.co;2)
- Stockbrugger, B.A. & Haennel, R.G. (2003). Contributing factors to performance of a medicine ball explosive power test: a comparison between jump and nonjump athletes. *J Strength Cond Res* 17(4): 768-774. [https://doi.org/10.1519/1533-4287\(2003\)017<0768:cftpoa>2.0.co;2](https://doi.org/10.1519/1533-4287(2003)017<0768:cftpoa>2.0.co;2)
- Tanaka, H., Costill, D.L., Thomas, R., Fink, W.J., & Widrick, J.J. (1993). Dry-land resistance training for competitive swimming. *Med Sci Sports Exerc* 25(8): 952-959. <https://doi.org/10.1249/00005768-199308000-00011>
- Telles, T., Barbosa, A.C., Campos, M.H., & Junior, O.A. (2011). Effect of hand paddles and parachute on the index of coordination of competitive crawl-strokers. *J Sports Sci* 29(4): 431-438. <https://doi.org/10.1080/02640414.2010.523086>
- Tsunokawa, T., Mankyu, H., Takagi, H., & Ogita, F. (2019). The effect of using paddles on hand propulsive forces and Froude efficiency in arm-stroke-only front-crawl swimming at various velocities. *Hum Mov Sci* 64: 378-388. <https://doi.org/10.1016/j.humov.2019.03.007>
- Vennell, R., Pease, D., & Wilson, B. (2006). Wave drag on human swimmers. *J Biomech* 39(4): 664-671. <https://doi.org/10.1016/j.jbiomech.2005.01.023>
- Weston, M., Hibbs, A.E., Thompson, K.G., & Spears, I.R. (2015). Isolated core training improves sprint performance in national-level junior swimmers. *Int J Sports Physiol Perform* 10(2): 204-210. <https://doi.org/10.1123/ijsp.2013-0488>
- Zamparo, P., Pendergast, D.R., Mollendorf, J., Termin, A., & Minetti, A.E. (2005). An energy balance of front crawl. *Eur J Appl Physiol* 94(1-2): 134-144. <https://doi.org/10.1007/s00421-004-1281-4>

