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SPORTS PERFORMANCE

Does a 4-week training period with hand paddles affect front-crawl swimming performance?

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ABSTRACT
This study investigated the effects of a 4-week training with hand paddles (HPD) on front-crawl swimming performance (SP), clean swimming speed (SPEED), stroke rate (SR), stroke length (SL) and tethered force (TF). Twenty swimmers (10 men and 10 women) were paired according to performance and gender, and were randomly assigned to control (CON, 22.4 ± 2.3 years) or HPD (21.8 ± 1.9 years) groups. During 4 weeks both groups performed the same training, except for a sprint training set (3 times/week, 10 × 10 strokes all-out, 1-min rest) completed with (HPD = 320 cm^2) and without (CON) paddles. Afterwards, both groups performed the same training over a 2-week taper period. SP, SPEED, SR, SL and TF were assessed before (PRE) and after the 4-week period (POST), after the first (T1) and second taper weeks (T2). Swimmers rated their perceived exertion for the sprint training set (RPE_{TS}) and the training session for determining internal training load (ITL). SP, SPEED, SR, SL and TF did not change from PRE to POST, T1 and T2. ITL and RPE_{TS} were not different between groups. Training 4 weeks with HPD does not affect swimming performance, so the use of HPD remains unsupported in such period.

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KEYWORDS
Biomechanics; tethered swimming; strength; sport training

Introduction

The ability to produce propulsive force can influence swimming performance (Toussaint & Truijens, 2005). As upper limbs contribute with up to 85% of propulsive force (Bartolomeu, Costa, & Barbosa, 2018; Toussaint, Hollander, Van den Berg, & Vorontsov, 2000) swimmers dedicate a large part of their training to increase upper limbs' propulsive force (Crowley, Harrison, & Lyons, 2017). Dry-land resistance training has been traditionally used to increase muscle strength, but it is still unclear whether and how much of the strength gain transfers to improvements in swimming performance (Crowley, Harrison, & Lyons, 2018). Conversely, in-water resistance training is suggested to be more sport-specific and effort has been put into better understanding its long-term effects (Crowley et al., 2017).

Different implements have been advocated as specific overload in swimming, such as parachutes, bowls and push-off points. For instance, Gourgoulis, Valkoumas, Boli, Aggeloussis, & Antoniou (2019) showed that 11 weeks of sprint training with parachute were effective to improve swimming performance in different distances (between 3.2% and 7.3%), whereas Mavridis, Kabitsis, Gourgoulis, & Toubekis (2006) observed that the use of a water bowl over 12 weeks resulted in greater competitive performances in 50, 100 and 200 m in the intervention group compared to the control group. These findings support the importance of in-water training with added resistance. Similarly, Toussaint and Vervoorn (1990) reported that 10 weeks of sprint training with push-off points (i.e., adjustable submerged fixed pads along the length of the pool) induced greater positive changes in swimming strength (3.3%), in power (7%) and in performance (time reduction ranged from 1.8% to 3.2% among the tested distances) compared to the control group.

Hand paddles are also suggested as a form to improve propulsive force in swimming by artificially enlarging the hands' area and allowing pushing off against a bigger mass of water (Payton & Lauder, 1995). Therefore, swimmers' hands have to overcome a greater drag in each stroke (Toussaint, Janssen, & Kluft, 1991), without changing trajectory, pitch and sweepback angles (Gourgoulis et al., 2010), which demonstrate the specificity of hand paddles. As a result, some researchers (Barbosa, Castro, Dopsaj, Cunha, & Andries, 2013; Gourgoulis, Aggeloussis, Vezos, Antoniou, & Mavromatis, 2008a) suggested the hand paddles' potential to improve propulsive force, and consequently swimming performance.

Although a large number of studies investigated the hand paddles (Payton & Lauder, 1995; Gourgoulis et al., 2010; Gourgoulis et al., 2008a; Monteil & Rouard, 1994), they focused on the acute changes and their effects after a period of training remain unexplored. Thus, considering the widespread unsupported use of hand paddles during swimming training, the aim of this study was to evaluate the effects of a 4-week in-water resistance training using hand paddles on front-crawl sprint performance, stroke kinematics and propulsive force (tethered force was assumed to represent the propulsive force generated by the swimmers) in trained swimmers. Whereas most of the in-water resistance training studies ranged between 10 and 12 weeks (approximately 3 months), the effect of a 4-week training period may be of great interest in practice as this may represent

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a considerable duration within the current competitive swim seasons.

Materials and methods

Participants

Twenty swimmers (10 men and 10 women), members of the same squad, participated in this study. They were matched in pairs according to 50-m freestyle performance in the previous season and gender, and were randomly assigned to either control (CON, 22.4 ± 2.3 years; 70.5 ± 10.5 kg; 1.72 ± 0.08 m; hand area: 156 ± 20 cm^2; short-course 50 m freestyle: 31.08 ± 4.73 s) or hand paddles (HPD, = 21.8 ± 1.9 years; 65.5 ± 12.8 kg; 1.70 ± 0.11 m; hand area: 149 ± 25 cm^2; short-course 50 m freestyle: 30.17 ± 4.63 s) groups.

No difference was found between groups' performances in any of the variables at baseline. All participants have regularly competed in swimming for at least 2 years and were training ~10 h/week (in-water + dry-land sessions). The study was approved by an Institutional Ethics Board and the participants were informed of the benefits and risks of the investigation prior to signing an approved informed consent document.

Study design

The design of this randomised controlled trial is in Figure 1. After two introductory weeks (weeks 1 and 2) of low-to-moderate training sessions (same for both groups), the 6-week monitored training period started. During the first 4 weeks (weeks 3–6), both groups performed the same in-water training (5 days per week, i.e., Mon–Fri, 1 training session/day, 10,758 ± 1,172 m/week, distance distribution across low, moderate and high-intensity zones according to the coach's intended prescription: 69 ± 6%, 22 ± 4% and 8 ± 3%, respectively) and an additional experimental sprint training set, which consisted of 10 × 10 strokes (i.e., five complete cycles) at maximal intensity from a push-off start, with 1-min rest. CON performed the experimental set without paddles, whereas HPD used commercially available hand paddles (Stroke Maker, Pro Swim®, surface area (holes were not considered) = 320 cm^2 – 20 cm of length and 19 cm of width, Figure 2), which were fastened to the hand by two adjustable elastic straps around the middle finger and wrist. The hand and the paddle areas were assessed by computerised planimetry (ImageJ v. 1.43, National Institute of Health, Bethesda, USA), which presented high test–retest reliability (ICC = 0.999; CI 95% = 0.996–1.00;

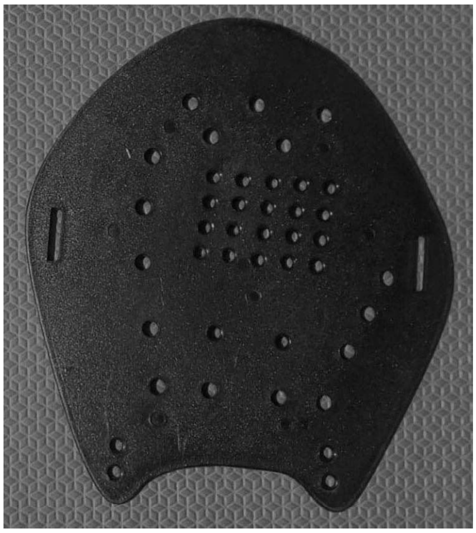

Figure 2. Hand paddles used in this study.

F = 2062.10; $p < 0.0001$; CV = 0.46%; CI 95% = 0.27–0.65%). Wrist was considered as an imaginary line connecting radius and ulnar styloid processes. Swimmers were familiar with the hand paddle size and model. Men and women used the same size. The set was repeated three times a week on non-consecutive days (i.e., Monday, Wednesday and Friday), totalling 12 experimental training sets. We chose to determine sets repetition based on a number of strokes and not on distance as the use of hand paddle increases stroke length (Gourgoulis et al., 2008a; Monteil & Rouard, 1994) and would impact the number of muscle contractions performed. As maximum intensity was required during the experimental sprint training set, possible differences between groups were assumed to be a consequence of the use of hand paddles.

Dry-land training was part of athletes' training routines. It was accomplished from week 1 to 6 (the same for both groups) and consisted of four weekly sessions. Two sessions/week focused on developing muscle strength and power (~60 min, interspaced by 72 h) and two sessions/week of core strengthening (~60 min, interspaced by 72 h).

A 2-week taper period was conducted in the weeks 7 and 8, when the dry-land training was ceased, and the in-water training volume was progressively reduced (Week 7 = 7,300 m and Week 8 = 6,250 m) while intensity was maintained. Throughout the entire study, the same sport scientist was responsible for coaching and controlling the training loads of all participants. He also monitored swimmers' performance throughout the experimental sprint training set to ensure maximal intensity.

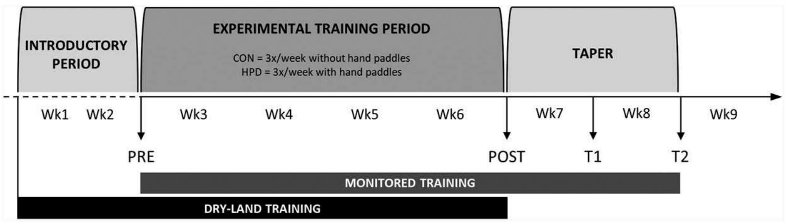

Figure 1. Experimental design. PRE, POST, T1 and T2 correspond to testing moments. Light grey indicates that both groups performed the same training.

Tests took place at the beginning of weeks 3 (PRE), 7 (POST), 8 (T1) and 9 (T2) (Figure 1).

Swimming tests

All the tests were performed in a 25-m outdoor pool (water temperature: 27.5 ± 0.5°C), using the front-crawl stroke, in the first 2 days of the week (Monday and Tuesday) and at the same time of the day (±1 h). After a standardised warm-up (~15 min), the tethered force and the 50-m freestyle performance were assessed in the first and second testing sessions, respectively.

Swimming performance and kinematics

Swimming performance was assessed on four occasions (Figure 1). Each swimmer individually (to avoid pacing effect) performed one 50-m maximal front-crawl swim from a push-off start. Trials were manually timed by three experienced operators (ICC = 1.00, IC 95% = 0.99–1.00, F = 11,804.021, $p < 0.0001$, CV = 0.2%; CI 95% = 0.1–0.2%) using digital chronometers. The average time was retained for analysis.

Clean swimming speed, stroke rate and stroke length were measured in both 25-m splits in the central 10 metres of the pool (i.e., the first and the last 7.5 m of each 25-m split were discarded) and the average value of each variable was retained for analysis. Gold-standard references were positioned on both sides of the pool at the distances of 7.5 and 17.5 m and two cameras (HDR-PJ270 and HDR-CX240, Sony®, acquisition frequency: 60 Hz), mounted perpendicular to the pool at the marks, and synchronised by a visual signal recorded all the procedures. Digital lines were superimposed onto the videos on Kinovea (v.0.8.24, Paris, France) and the instants in which the swimmers' head crossed the lines were identified. Clean swimming speed was calculated by dividing the distance (i.e., 10 m) by the time spent between the marks. Stroke rate, expressed in cycles per minute, was quantified by analysing the time of the first three complete cycles performed after the initial 7.5 m computed by video analysis. Stroke length, expressed in metres, was obtained by the ratio between swimming speed and stroke rate, converted to cycles per second.

Tethered force

A fully tethered swimming system (CEFISE, Nova Odessa, Brazil, maximum load cell traction/compression capacity: 1000 N, acquisition frequency: 200 Hz) evaluated the tethered force on four occasions (Figure 1). The test consisted of two 10-s maximal front-crawl swims (arms and legs) with breath held, self-selected stroke rate with 4 min of rest. The beginning (after approximately eight strokes of moderate swimming) and the end of the test were signalled by a whistle. To avoid inertial effects, 1 s was given between the whistle and the start of data acquisition. All testing procedures complied with a previous investigation (Barbosa, Barroso, & Andries, 2016).

Individual force–time curves were smoothed using a fourth-order Butterworth low pass digital filter with a cut-off frequency of 8 Hz. The tethered force was represented by the average of all force values obtained in 10 s, which presented high reliability (ICC = 0.997; CI 95% = 0.993–0.999; F = 698.789; $p < 0.0001$; CV = 1.8%; CI 95% = 1.3–2.3%). Only the highest average force was retained for analysis.

Internal training load and perceived exertion of the training set

The intensity was determined by the session ratings of perceived exertion (sRPE) method (Foster et al., 2001) 30 min after the end of the session by asking the participant "How was your training session today?". Participants had to choose a descriptor and a number from 0 to 10, which could also be provided in decimals. They were familiar with the CR-10 Borg RPE scale (Foster et al., 2001) as this was part of their training routine. Internal training load (ITL) was calculated by multiplying the sRPE score by the duration of the training session in minutes.

Additionally, we considered that an eventual hand paddle effect could not be noticed in the session RPE due to the influence of the other parts of the training session. Therefore, RPE (RPE_{TS}) was also obtained immediately after the experimental set by asking the participant "How was your training set?".

Statistical analysis

Data were presented as means and standard deviation. Normality and homogeneity were verified using Shapiro-Wilk and Levene tests, respectively. Mixed models, with time and groups as fixed factors and participants as a random factor, were used to compare changes in swimming performance, clean swimming speed, stroke rate, stroke length, tethered force, per cent changes (compared to PRE) in these variables, ITL and RPE_{TS}. When a significant F-value was found, Tukey post hoc was used for multiple comparison purposes. The effect size was calculated through partial eta squared (η_p^2) and interpreted the following thresholds: >0.01–0.09: small; >0.09–0.25: medium; and large >0.25. Significance was set at $p < 0.05$.

Results

Participants from both groups attended all training sessions during the entire training period. Descriptive statistics of swimming performance, clean swimming speed, stroke rate, stroke length and tethered force for CON and HPD are available in Table 1. Per cent changes of these variables are detailed in Figure 3. None of the variables changed ($p > 0.05$) throughout the monitored period. Similarly, no differences were found between per cent changes of the groups.

The ITL dynamics for both groups are shown in Figure 4. No differences were found between the weekly average ITLs of CON and HPD in both experimental and taper periods (CON = 1508 ± 208 AU vs. HPD = 1528 ± 232 AU, p = 0.97, and CON = 762 ± 197 AU vs. HPD = 784 ± 178 AU, p = 0.98, respectively).

All the RPE_{TS} are shown in Figure 5. There was no difference between groups throughout the whole experimental period (CON = 5.4 ± 0.7 vs. HPD = 5.6 ± 1.1, p = 0.22).

Table 1. Descriptive statistics of swimming performance, clean swimming speed, stroke rate, stroke length and tethered force in all moments for control (CON) and hand paddles (HPD) groups.

	PRE	POST	T1	T2	Group effect			Time effect			Interaction		
					F	P	η_p^2	F	P	η_p^2	F	P	η_p^2
Swimming performance (s)													
CON	32.03 ± 4.27	31.93 ± 4.30	31.89 ± 4.43	31.96 ± 3.72	0.09	0.77	0.0044	0.13	0.94	0.0001	0.22	0.88	0.0003
HPD	31.28 ± 4.78	31.28 ± 4.86	31.48 ± 4.86	31.50 ± 4.58									
Clean swimming speed (m . s^{-1})													
CON	1.46 ± 0.18	1.46 ± 0.17	1.47 ± 0.18	1.45 ± 0.16	0.14	0.72	0.0071	0.27	0.85	0.0004	0.95	0.42	0.0007
HPD	1.50 ± 0.21	1.50 ± 0.21	1.48 ± 0.22	1.48 ± 0.20									
Stroke rate (c . min^{-1})													
CON	53.8 ± 3.7	54.9 ± 4.5	55.5 ± 4.9	56.5 ± 3.4	0.01	0.92	0.0005	0.81	0.49	0.0122	0.83	0.48	0.0123
HPD	54.8 ± 5.8	55.2 ± 4.3	55.2 ± 5.0	54.8 ± 4.9									
Stroke length (m)													
CON	1.62 ± 0.13	1.60 ± 0.14	1.59 ± 0.10	1.55 ± 0.10	0.42	0.53	0.0190	1.47	0.23	0.0142	1.63	0.19	0.0082
HPD	1.64 ± 0.14	1.63 ± 0.19	1.61 ± 0.17	1.63 ± 0.18									
Tethered force (N)													
CON	90 ± 31	92 ± 25	92 ± 26	91 ± 23	0.52	0.48	0.0279	1.32	0.28	0.0010	0.04	0.99	0.0001
HPD	81 ± 32	83 ± 33	82 ± 32	81 ± 32									

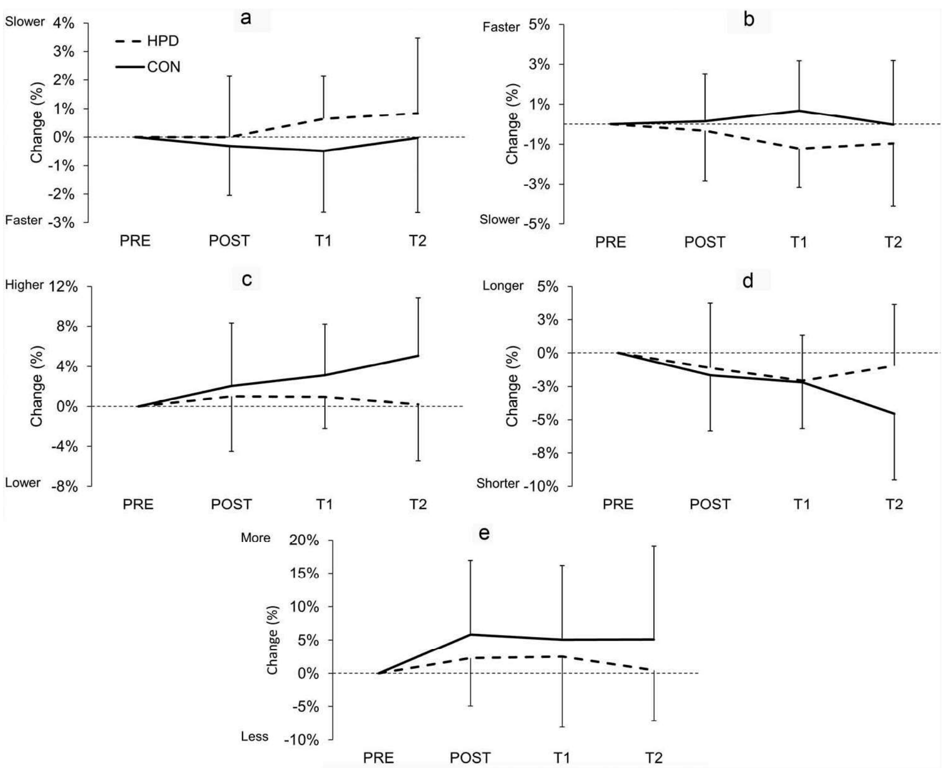

Figure 3. Per cent changes from PRE of performance (A), clean swimming speed (B), stroke rate (C), stroke length (D) and tethered force (E).

Discussion

In the present study, we investigated the effects of a 4-week specific in-water resistance training using hand paddles on front-crawl sprint performance, stroke kinematics and propulsive force in trained swimmers. Even though hand paddles acutely increase swimmers' propulsive force (Barbosa et al., 2013; Gourgoulis et al., 2008a, 2008b) while maintaining movement specificity (Gourgoulis et al., 2008a; Monteil & Rouard, 1994), our data demonstrated that this implement failed to induce changes in swimming performance, clean swimming speed, stroke rate, stroke length and tethered force after a 4-week intervention period. This result is not in accordance with earlier in-water resistance training results (Girold, Calmels, Maurin, Milhau, & Chatard, 2006; Gourgoulis et al., 2019; Mavridis et al., 2006; Toussaint & Vervoorn, 1990).

Previous studies investigated different implements (elastic tube, bowl, parachute and push-off points), training frequencies (3 to 4 times per week), sets (1 to 3 sets per session) and durations (from 3 to 12 weeks). They all reported that the improvements in competitive performances were greater in the intervention groups than in the control groups (Girold et al., 2006; Gourgoulis et al., 2019; Mavridis et al., 2006; Toussaint & Vervoorn, 1990), and this may be of great practical relevance. While some source of errors can be raised (e.g., biological maturity, unmatched number of participants in the

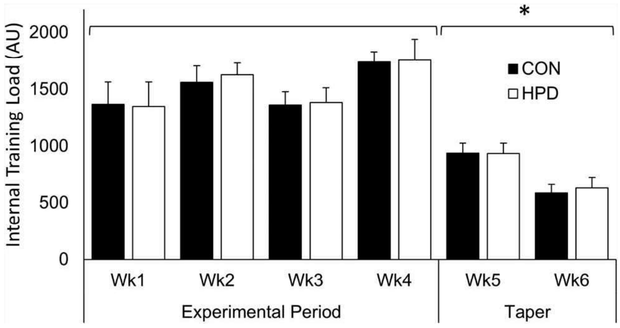

Figure 4. Dynamics of internal training load over the study period for control (CON) and hand paddles (HPD) groups. * $p < 0.05$ from the average internal training load of the experimental period.

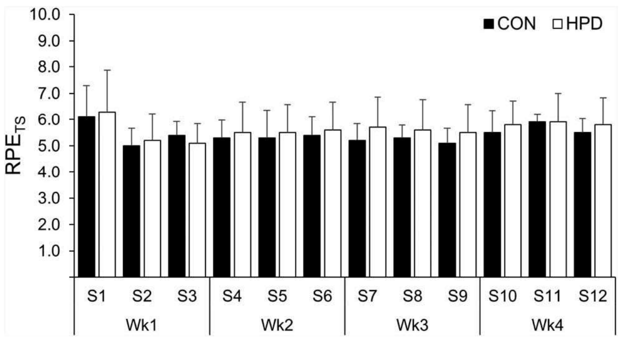

Figure 5. Ratings of perceived exertion of the experimental training set (RPE$_{TS}$) over the study period for control (CON) and hand paddles (HPD) groups.

groups, and adherence to the training programme), their results indicate that the in-water resistance training can be effective to improve swimming performance.

Although the 4-week period could be firstly argued as a short time to verify resistance training effects, Loturco et al. (2019) investigated the effects of 4 weeks of power training in elite young soccer players and reported likely improvements across different tests (speed, change of direction and vertical jump). In addition, Kobal et al. (2017) reported that after 4 and 8 weeks of different resistance training protocols, elite young soccer players improved maximal strength, speed and vertical jump height, and the largest improvements were observed in the first half of the training period. Also, Girold et al. (2006) have noticed positive responses in swimmers with elastic tubes (resisted swimming) in an even briefer period (i.e., 3 weeks), so this hypothesis was dismissed. Then, the difference between earlier results and those of the present study may rely on both the intensity provided the implement and the training set volume.

Different from hand paddles, the elastic tube linearly increases resistance as extended (Girold et al., 2006) until swimmer's propulsive force is no longer sufficient to overcome elastic resistance, and swimming speed approaches zero (similar to the fully tethered swimming). Under this condition, it is assumed that swimmers can produce the greatest amount of force in water and are induced to improve their ability to coordinate arms and legs propulsive forces altogether as otherwise they would be pulled backwards by the elastic tube. With bowls and parachutes, swimmers try to pull harder against the water due to the implements' added resistance (Gourgoulis et al., 2010), which increases impulse applied per stroke (Schnitzler, Braziel, Button, Seifert, & Chollet, 2011). Considering that these implements successfully changed swimming performance over time (Girold et al., 2006; Gourgoulis et al., 2019; Mavridis et al., 2006), while hand paddles did not, it is conceivable that training with hand paddles provides lower intensity than elastic tubes and parachutes do.

The idea that hand paddles may not increase training intensity is supported by Tsunokawa, Tsuno, Mankyu, Takagi, & Ogita (2018), who verified that these implements cause an increase in propulsive forces without changing the resultant pressure. This indicates that the enlarged area provided by the paddle supplements the lower pressure differences caused by a reduced hand speed and, therefore, the greater swimming speed and stroke length noticed during paddles swimming should be attributed to a greater efficiency, not to an increased muscle power generated by the upper limbs. Authors then suggested that hand paddles could lead to a reduction in the training load in some cases (Tsunokawa et al., 2018). Interestingly, our results showed that both internal training load and RPE$_{TS}$ were not different between HPD and CON. In other words, the use of paddles did not impose any increase on athletes' relative physiological stress and, hence, there was no additional stimulus for a differentiated training-induced adaptation (Impellizzeri, Rampinini, & Marcora, 2005).

The comparison among investigations indicates that the training set volume may affect the in-water strength training outcomes and should be a factor to be considered. The study that investigated the training with elastic tubes (Girold et al., 2006) used 6 all-out 30-s front-crawl sprints three times a week, which corresponds to ~900 m weekly (assuming 30 s as 50 m), whereas the training sets with push-off points were estimated to be around 1,300 m/week. Investigations involving parachute and bowl employed lower weekly volumes ranging from 600 to 780 m (Gourgoulis et al., 2019; Mavridis et al., 2006), but these implements reduce speed and augment the effort duration. All these volumes are higher than that used herein (~450 m/week) and may explain the lack of change observed in the present study. In other words, the larger number of muscle contractions performed in the studies with higher volumes and longer intervention periods may provide more opportunities to the swimmers to practice the skill, to trigger neural adaptations, and eventually to increase muscle strength. Although this hypothesis seems reasonable from the in-water strength training perspective, the dry-land resistance training literature indicates that strength gains are not affected by training volume (Bottaro, Veloso, Wagner, & Gentil, 2011; Radaelli et al., 2015). Further studies should be conducted to examine the effects of greater volumes of training with paddles.

Concerning kinematics, previous cross-sectional researches demonstrated that the per cent increase of the stroke length tends to be slightly greater than per cent decrease of the stroke rate in paddle swimming, which then causes an increase of swimming speed (Barbosa et al., 2013; Gourgoulis et al., 2008a). We acknowledge that the magnitude of these effects may vary according to the paddle size, but the effects are generally the same. In a 4-week perspective though, stroke rate and stroke length are not affected by hand paddles. Assuming that the increase of tethered force may contribute to increase stroke length (i.e., by the increase of the external mechanical power), and the former did not change over the training period, no change in the later was expected.

Tethered force did not change after the experimental or taper periods. As sport-specific actions are employed during the tethered swim test, eventual increases of the propulsive force occasioned by the training with hand paddles may not be detected immediately after the end of the experimental period, but rather in the subsequent weeks due to coordination adjustments. Bobbert & Van Soest (1994) suggested that training programmes should allow athletes to practice the specific task with improved muscle strength, so they can adapt their motor control and take benefit from higher levels of strength. However, even after 2 weeks of reduced training load (taper) without the implement, no changes were observed in tethered force and swimming performance, indicating that hand paddles do not affect these variables after 4 weeks of intervention.

The in-water strength training should be designed to improve propulsive force and, consequently, swimming performance. Our results failed to show any positive effect of hand paddles on these variables after 4 weeks of training. Therefore, there are no evidences to recommend swimming coaches to use hand paddles during sprint-training sets with the aim of improving 50-m freestyle performance, kinematic parameters and tethered force within such period.

These results represent the effects of the use of hand paddles alone and should not be extrapolated when hand paddles are combined to other implements (such as parachutes or elastic tubes), in which a different condition is found, and the effects may differ. In addition, hand paddles were investigated within the 4-week period limits and, although there is one study that has noticed positive responses in a briefer period with a different implement (Girold et al., 2006), it is still unknown whether longer periods of training with paddles would elicit greater accumulated effects and, eventually, positive changes in swimming performance. Further studies should be conducted to examine the effects of longer periods of training with paddles. On the other hand, it should also be considered that periods longer than 4 weeks may represent a considerable amount of time within a swimming competitive season.

Finally, some limitations may be raised: (1) our results relate to the specific distance and duration of our assessments, limiting the generalisation of our findings to middle- and long-distance swimming performances, (2) participants were moderately trained swimmers, and responses might differ in both highly trained and less trained athletes, and (3) the use of a single size of hand paddles cause the swimmers to have the same propulsive hand surface, which may affect swimmers differently.

Conclusion

Hand paddles do not have any effect on swimming speed, stroke rate, stroke length and tethered force after 4 weeks of training, so their use remains unsupported for improving swimming sprint performance in such period.

Disclosure statement

No potential conflict of interest was reported by the authors.

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