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Original Research

The Impact of Assisted Swimming on Front Crawl Performance

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Abstract

Background: In the present study, we aimed to clarify the impact of the Assisted swim (A-swim; towing from propulsion direction) on front crawl performance at maximum and sub-maximum effort levels. **Methods**: Fourteen male collegiate swimmers (age, 21.0 ± 2.0 years; height, 1.73 ± 0.05 m; weight, 67.1 ± 7.1 kg) participated. Participants swam 25-m front crawl at maximal (Max) and submaximal intensity (Submax (80% of the max stroke rate (SR))) with and without an assist (assisted swimming with a towing device and normal swim (N-swim) without the device) for a total of four lengths. In addition to swim velocity (V), SR, and stroke length (SL), one stroke cycle was broken down into four phases—glide, pull, push, and recovery—and analyzed the duration of each phase. **Results**: A significant interaction of level of efforts and presence/absence of towing was confirmed in V, SR, and SL. V and SL showed a significant increase in A-swim compared to N-swim at both Max and Submax. SR was significantly higher in A-swim than in N-swim only at Max. Each phase of stroke showed a significant difference in recovery at Submax and push at Max. **Conclusions**: Despite considering the impact of propulsion from towing, A-swim increased SR, in addition to the V and SL, of swimmers compared with N-swim.

Keywords: swimming; towing; overspeed; stroke rate; stroke length

1. Introduction

Assisted swim (A-swim) refers to pulling a swimmer to assist their propulsion from the direction of travel using a towing device or a rubber tube, and it is considered sprint training in competitive swimming [1–3]. Towing swim with towing power greater than the swimmers' propulsion allows swimmers to reach faster velocities than that achieved by the swimmers themselves [3]. Therefore, it is more familiar training for short-distance swimmers than long-distance swimmers.

Swim velocity (V) is obtained as a product of stroke rate (SR) and stroke length (SL) [4], which is used to analyze swim performances. Generally, SR and SL are in a tradeoff relationship with V (Eqn. 1).

$$V = SR \times SL \tag{1}$$

Therefore, even if SR could be increased, anticipated V improvement cannot be achieved if SL decreases. For example, A-swim reportedly increased V, SL, and SR, and decreased the hand depth [3]. However, when A-swim was incorporated in training for 3 weeks, V did not change while SR increased dramatically and SL decreased dramatically [2]. Although A-swim increased V and SL, propulsive force (mechanical power) exerted by the swimmer to push the water was low [5]. Considering the abovementioned fact, compared to normal swim (N-swim), the training effect of A-swim for a certain period remains unclear; however, A-swim would be expected to increase in swimmers' V, SR, and SL without depending on their propulsive forces to keep up with the towing by the device [3].

As a similar index of swimmers' arm movements, there is a report that broke down arm strokes into several phases and analyzed periodic fluctuations in the velocity of each stroke cycle and the ratio of time required for each phase [6–9]. An attempt to clarify the impact of A-swim on SR and SL by breaking down the stroke movements into phases may lead to a new challenge in swim assessment. Since resistance during underwater propulsion increases in proportion to square ~ cube of V [10,11]. A-swim causes higher resistance on the swimmer's body than N-swim. Therefore, it impacts the swim velocity fluctuations within one stroke cycle, and as a result, a hypothesis holds that the stroke index and duration of each movement in A-swim are different from N-swim. In actual training, A-swim refers to attaching a rubber tube onto a belt around the swimmer's waist where someone pulls the rubber tube from the ground [2,12]. In addition to the rubber tube stretching, the force with which coaches pull the swimmer, and the level of effort by each swimmer vary. In other words, A-swim practiced currently relies on a subjective view of instructors and swimmers in terms of the load and points of focus and it cannot be confirmed that it is an established training method with universal significance. In spite of the considerable degree of evidence on resistance swim similar to this towing swim [13–21], findings on A-swim are rare; thus, detailed reports on the subject are warranted.

Under such a circumstance, in the present study, we aimed to clarify the impact of A-swim on performance at two levels of effort: maximum (Max) and sub-maximum (Submax). We hypothesized that swimming under A-swim conditions can promote a faster V, faster SR, and longer SL at Max and Submax.

2. Materials and Methods

2.1 Participants

Fourteen well-trained male collegiate swimmers voluntarily participated in the present study. Their mean age, height, body mass, and FINA points at long course 50 m freestyle were 21.0 ± 2.0 years, 1.73 ± 0.05 m, 67.1 ± 7.1 kg, and 547.4 ± 83.1, respectively. The following items were set as the inclusion criteria: (i) swimmers who were experienced in sprinting events, and (ii) swimmers without any constriction cases during the last 6 months that could restrict them from performing the required efforts as mentioned in the literature [22].

2.2 Experimental Procedure

The trial was a 25-m front crawl, consisting of A-swim in which swimmers were towed in the propulsion direction using a towing device (Torrent E-Rack Swim Power Trainer; Trilabs Inc., Walnut Creek, CA, USA) installed above the pool wall and N-swim in which swimmers swam without any towing [3,8,14,23] (Fig. 1). Swimmers were instructed to swim at Max and Submax. For Submax, we referred to a previous study [3] and fluctuations in front crawl short-distance race [24] and set SR at 80% of Max. Therefore, all swimmers swam four lengths of 25-m front crawl with a 30-minute break in between. Swimmers swam A-swim after N-swim to smoothen the progress of this experiment; however, the order of level of efforts (setting of SR) was randomized. The swimmers repeated all the trials six times and were instructed to not breathe. Before the experiment, it was confirmed that there was no obvious difference in the rhythm of left-right strokes following a visual observation of the three experienced swimmers (≥10 years history of swimming and ≥4 years history of instruction). To film underwater movements of swimmers as long-distance as possible at 60 Hz, an action camera (GoPro9; GoPro Inc., San Mateo, CA, USA) fixed to a filming pole was used, and an examiner ran along the length of the pool at the speed of swimmers according to the method mentioned in a prior study [25]. Owing to the design of the pool facility, A-swim was filmed from the left side of swimmers while N-swim was filmed from the right side of swimmers to confirm the movement of whole arm stroke [6,26,27].

We connected a non-stretchable nylon cable to a belt on swimmers' abdomen. Swimmers were towed by the towing device at the end of the cable installed at the edge of the pool. During N-swim, swimmers swam as they pulled non-stretchable cables of the device (Fig. 1). The SR of A-swim at Submax was controlled in the range below 80%–90% of N-swim at Max. The SR was measured using a small audible waterproof metronome (Tempo Trainer Pro; FINIS, Inc., Tracy, CA, USA) which swimmers wore under their cap [11].

2.3 Measurements

The towing device was connected to a computer using a USB cable for control. Swim velocity and travel distance was input into the computer at the sampling frequency of 100 Hz using analytical software, Dasylab (Version 13.0, Measurement Computing Corporation, Norton, MA, USA). To analyze V ($m{\cdot}s^{-1}$), we used the travel velocity [28,29] of the belt around the swimmers' waist in the 7.5 m interval between 12.5 and 20 m. The towing load maintained at 24 lbs according to specifications of a previous study [30] for A-swim, and 0 lbs (no load) for N-swim. SR (Hz) was also calculated by counting the number of video frames for two-stroke cycles in the same section. SL (m) was calculated by dividing V by SR.

In the present study, we referred to the coordination index of stroke movements reported by Chollet *et al.* [6] and Seifert *et al.* [9] and divided one stroke cycle of the left arm with the camera into the following four phases; we then calculated the duration of each stroke phase: (1) Glide phase: from the moment the hand enters the water to when the hand starts moving opposite to the direction of travel, (2) Pull phase: from the moment the hand begins to move opposite to the direction of travel to when it reaches right below the shoulder, (3) Push phase: from the moment the hand is right below the shoulder to when it leaves the water near the thigh, and (4) Recovery phase: from the moment the hand leaves the water to when it enters the water. For the duration of each phase, the mean of two-stroke cycles was analyzed.

2.4 Statistical Processing

All values were expressed either as mean ± standard deviation and 95% confidence interval (95% CI). Two-way repeated-measures analysis of variance (ANOVA) (Effort, Max or Submax × Towing situation, A-swim or N-swim) was used to analyze the variations in swimming V, SR, and SL. Additionally, two-way repeated-measures ANOVA (Towing situation × duration of each stroke phase, glide; pull; push; recovery) was used to confirm variance of duration in stroke phase for each level of efforts, i.e., Max and Submax. In cases when the interaction was significant,

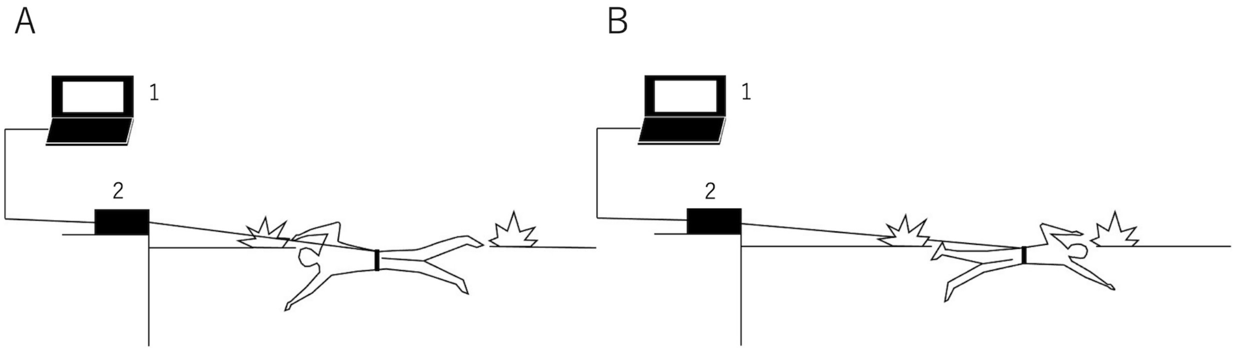

Fig. 1. Apparatus used for the measurements. (A) Assisted swimming (A-swim) in which swimmers were towed in the propulsion direction using a towing device. (B) Free swimming (N-swim) in which the swimmers were not towed (zero load) by a towing device. 1 = Personal Computer, 2 = towing device.

Table 1. Performance variables at Submax and Maximum effort (data are means ± SD).

Variables	Effort	N-swim		A-swim	
		Mean (SD)	95% CI	Mean (SD)	95% CI
V ($m \cdot s^{-1}$)	Submax	1.54 (0.08)	[1.50, 1.59]	2.22 (0.07)	[2.18, 2.26]
	Max	1.64 (0.08)	[1.59, 1.68]	2.26 (0.06)	[2.23, 2.30]
SR (Hz)	Submax	0.84 (0.04)	[0.81, 0.86]	0.84 (0.04)	[0.82, 0.86]
	Max	0.98 (0.05)	[0.95, 1.01]	1.03 (0.07)	[0.99, 1.07]
SL (m)	Submax	1.84 (0.13)	[1.77, 1.92]	2.64 (0.15)	[2.56, 2.73]
	Max	1.69 (0.13)	[1.61, 1.76]	2.20 (0.17)	[2.10, 2.30]

V, swimming velocity; SR, stroke rate; SL, stroke length; Submax, submaximal effort; Max, maximal effort; N-swim, swimming without towing device; A-swim, swimming with towing device; 95% CI, 95% confidence interval.

we performed multiple comparisons with the Bonferroni for each factor. Effect side of interaction and each factor were expressed with bias η^2: $0 < \eta^2 \leq 0.04$ is without effect, $0.04 < \eta^2 \leq 0.25$ is minimum, $0.25 < \eta^2 \leq 0.64$ is moderate, and $0.64 < \eta^2$ is strong [31]. The effect size of Bonferroni Post-hoc test was calculated using Cohen's *d*. Cohen's *d* effect sizes of the magnitude of 0.2, 0.5, and >0.8 corresponded to small, moderate, and large, respectively [32]. The level of statistical significance was set at 5% ($p < 0.05$). We used the IBM SPSS Statistics 27 (IBM Corporation, Armonk, NY, USA) software for statistical analysis.

3. Results

Significant interaction was confirmed in V ($p = 0.001$, $F = 18.887$, $\eta^2 = 0.04$), SR ($p = 0.015$, $F = 7.826$, $\eta^2 = 0.06$), and SL ($p < 0.001$, $F = 36.540$, $\eta^2 = 0.21$) (Table 1). The result of multiple comparisons of each factor showed that for both A-swim and N-swim (Fig. 2), V and SR had significantly higher values at Max than at Submax ($p \leq 0.001$, $d = 0.56$–3.47), whereas SL was significantly lower at Max than at Submax ($p < 0.001$, $d = 1.24$–2.80). Both at Max and Submax, V and SL were significantly higher in A-swim than in N-swim ($p < 0.001$, $d = 3.42$–8.98). However, SR was significantly higher in A-swim than N-swim only at Max ($p = 0.012$, $d = 0.92$), and there was no significant difference at Submax ($p = 0.119$, $d = 0.22$).

Duration of each stroke phase confirmed significant interaction at Submax ($p = 0.019$, $F = 4.103$, $\eta^2 = 0.08$) (Table 2) and Max ($p = 0.045$, $F = 3.555$, $\eta^2 = 0.06$) (Fig. 3). A significant simple main effect was confirmed for the duration of each stroke phase, at Submax, A-swim had significantly higher value than N-swim ($p < 0.001$, $d = 1.03$) only in the recovery phase, but no significant differences observed for the other phases ($p = 0.051$–0.919, $d = 0.03$–0.90). However, at Max, only for the push phase, A-swim had significantly lower value than N-swim ($p = 0.010$, $d = 1.24$), but no significant differences observed for the other phases ($p = 0.073$–0.934, $d = 0.03$–0.61). During the comparison between stroke phases, significant differences were cofirmed between Glide and Pull ($p = 0.001$, $d = 2.33$) and Push ($p < 0.001$, $d = 2.20$), and between Recovery and Pull ($p < 0.001$, $d = 2.49$) and Push ($p < 0.001$, $d = 2.43$) for the A-swim at Submax. These differences were also confirmed between Recovery and Glide ($p = 0.016$, $d = 1.29$), Pull ($p = 0.011$, $d = 1.73$) and Push ($p = 0.002$, $d = 2.04$) for the A-swim at Max. However, no significant differences were observed during N-swim in any of the stroke phases both at Submax ($p = 0.052$–1.000, $d = 0.19$–1.33) and Max ($p = 0.219$–1.000, $d = 0.15$–0.87).

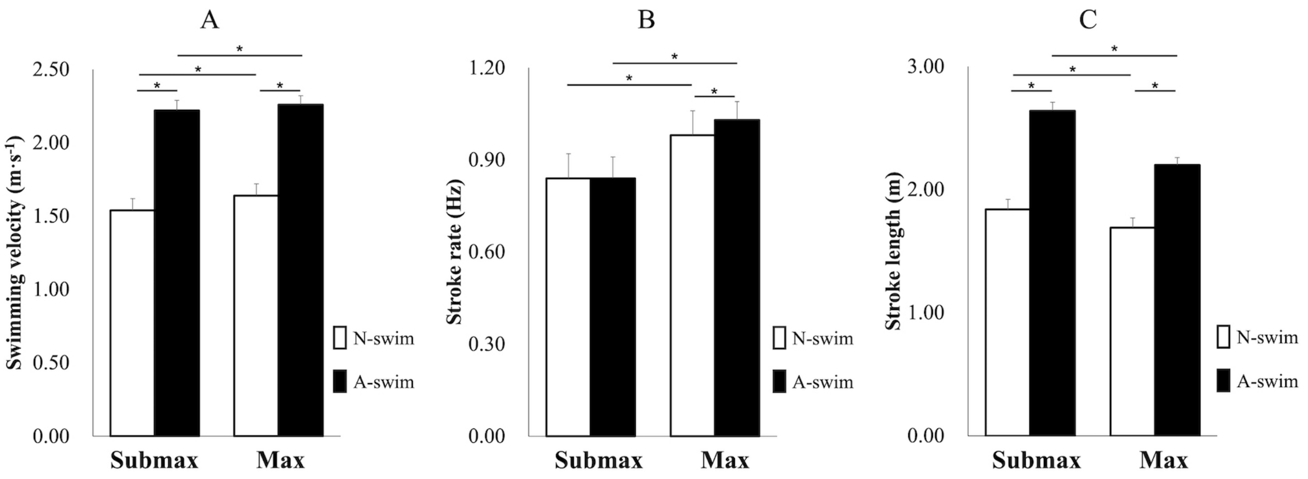

Fig. 2. Swimming velocity (m·s^{-1}). (A) stroke rate (Hz). (B) and stroke length (m). (C) in Submax and Max. Data are presented as mean ± SD. *, $p < 0.05$.

Table 2. The duration of each stroke phase at Submax and Max (data are means ± SD).

Stroke phase	Effort	N-swim		A-swim	
		Mean (SD)	95% CI	Mean (SD)	95% CI
Glide	Submax	0.37 (0.09)	[0.32, 0.42]	0.37 (0.07)	[0.33, 0.41]
	Max	0.24 (0.06)	[0.21, 0.27]	0.24 (0.05)	[0.21, 0.27]
Pull	Submax	0.27 (0.06)	[0.23, 0.30]	0.24 (0.04)	[0.21, 0.26]
	Max	0.25 (0.03)	[0.21, 0.27]	0.23 (0.04)	[0.21, 0.26]
Push	Submax	0.28 (0.03)	[0.26, 0.30]	0.25 (0.02)	[0.24, 0.27]
	Max	0.27 (0.02)	[0.26, 0.29]	0.23 (0.03)	[0.21, 0.25]
Recovery	Submax	0.29 (0.04)	[0.27, 0.32]	0.34 (0.04)	[0.31, 0.36]
	Max	0.27 (0.03)	[0.28, 0.30]	0.29 (0.02)	[0.28, 0.30]

Glide, glide phase; Pull, pull phase; Push, push phase; Recovery, recovery phase; Submax, submaximal effort; Max, maximal effort; N-swim, swimming without towing device; A-swim, swimming with towing device; 95% CI, 95% confidence interval.

4. Discussion

In the present study, we aimed to clarify the impact of A-swim at Max and Submax effort levels on performance. The main finding of this study was that the higher values were confirmed in V, SR, and SL in A-swim compared to those of N-swim at both of Max and Submax. These results supported previous studies in the literature [3,5] and verified our hypotheses.

On the body of swimmers moving forward in the water, in addition to their thrust for propulsion [26,27], there exists resistance that increased in proportion to square to the cube of the propulsion velocity [10,11]. To illustrate, among the total resistance on the body, the thrust required to propel forward becomes propulsion [26,27,33]. Conversely, in A-swim, swimmers constantly swim with thrust. Therefore, in order to increase V, propulsion more than towing must be created by the limbs. In the present study, swimmers had significantly higher V at Max than Submax for both N-swim without the towing device and A-swim with the towing device. In conclusion, it is evident that the towing force of 24 lbs is a load that male competitive swimmers with a FINA POINT of approximately 500 who participated in this study can adjust their V in voluntary.

The arm movements in front crawl can be classified into three patterns based on the coordination of both arms [6]; however, in all patterns, the velocity of the front crawl was not constant, wherein acceleration and deceleration repeat dependent on the movements of strokes [26,27]. Focusing on the changes brought about by the level of efforts with/without towing revealed the presence of a significant interaction between V, SR, and SL. In addition, even if SR is controlled, V and SL were drastically higher when towed. This result indicated that with towing, even in phases with no acceleration and those in which the swimmer might decelerate, constant towing from the front results in a difference in acceleration within one stroke cycle between A-swim and N-swim. In other words, in A-swim, the towing cable can move the swimmers forward constantly, regardless of swimmers' arm-stroke position, even in the recovery phase when no propulsion is generated against the water.

We then examined the changes in the duration of each stroke phase from the point of towing. Narita *et al.* [11] reported that when swimmers' SR was controlled using a

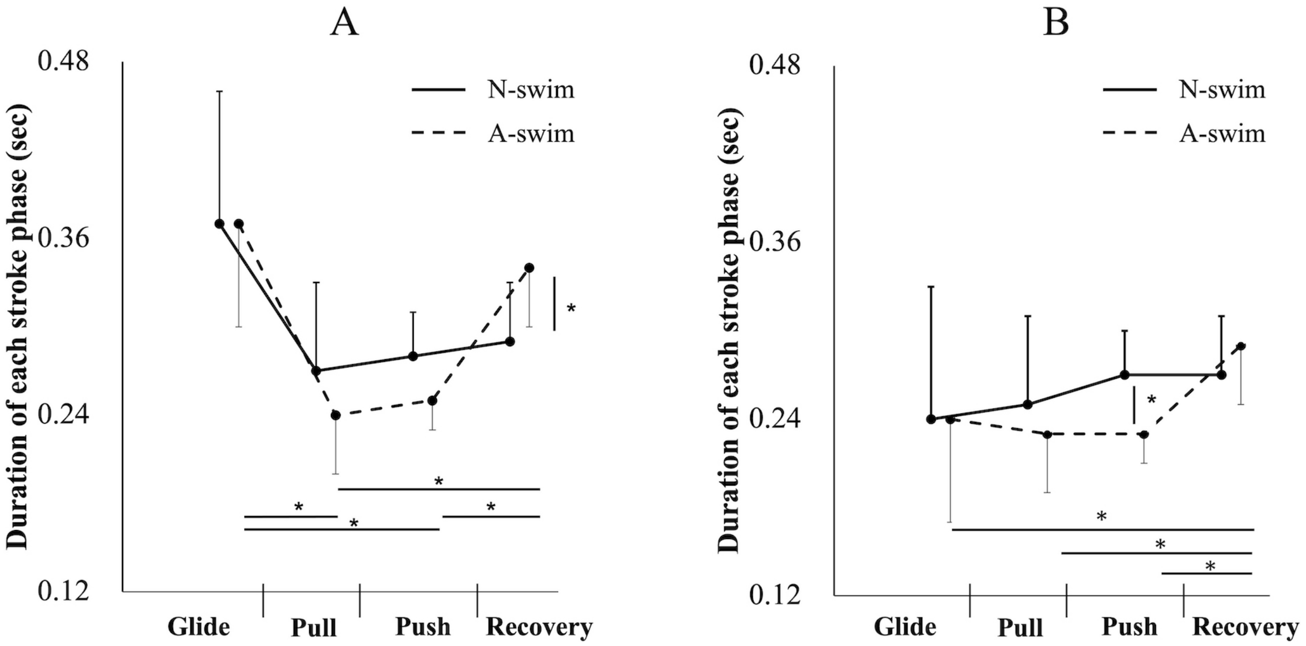

Fig. 3. Duration of each stroke phase (s). (A) Submax and Max effort during N-swim (solid line) and A-swim (dotted line). (B) Data are means ± SD.

small audible waterproof metronome, swim itself became different from N-swim in some cases. In other words, as observed in the present study, in A-swim at Submax, as swimmers synchronized their arm movements to the metronome used to recreate the SR of N-swim, it might have impacted the difference in the duration of the recovery phase.

In terms of A-swim at Max, Williams *et al.* [3] reported that the position of stroke was shallower than that of N-swim, increasing SR. In the present study, although we cannot discuss changes in the stroke arm positions, the results supported those reported by a previous study [3]. High SR in A-swim might be explained by the difference in duration of the recovery phase at Submax and time difference in the push phase at Max. For example, by adjusting the coordination of arm strokes and kicking, the point at which the arm leaves the water might move closer to the head. However, even when comparing SL at Max between A- and N-swim, SL is considerably longer under towing. Therefore, details of the movement difference by SL cannot be determined. Prior studies [1,34,35] that examined the arm angles of competitive swimmers from the side reported that swimmers moved their hands, forearms, and upper arms perpendicular to the floor to push the water and gain thrust. Therefore, the swimmers gained an increased area of the forward project in the direction of propulsion. In other words, in A-swim, by being towed from the propulsion direction, water collides with the surface of the arm in the propulsion direction, possibly promoting the acceleration of the push phase. If this inference is correct, when synchronizing the stroke with the metronome rhythm, adjustments were being made in the recovery phase. To verify this inference properly, a difference of both arms in N-swim and A-swim should be confirmed, and pressure difference in both sides of hands should be quantified using a pressure sensor [26,27,36,37]. In any case, A-swim contributes to increasing swimmers' SR as well as SL and V.

4.1 Practical Implications to Improving Swimming Performance

Since SL of A-swim is longer than that of N-swim, its effectiveness as a training to improve swimmers' technique has been indicated [5,12]. In contrast, the present result showed that A-swim significantly increases SR of swimmers compared to N-swim. Futhermore, Girold *et al.* [2] reported that 3 weeks of A-swim training increased SR and strength at a high velocity. Therefore, A-swim could also be an effective training method to improve the rotation of arms. However, even if SR is increased with A-swim, SL might decrease [12]. Additionally, it has been reported that A-swim may change the stroke pattern [3,12], slow down the hand speed, and/or cannot maintain the kinetics of the hand movement [3]. Thus, A-swim may be masking the decrease in propulsive force. Actually, in semi-tethered swimming, there are concerns that the coordination of strokes (coordination pattern) may be changed [23] and that the propulsive force exerted by the swimmer may be decreased [3,22]. Regardless, when swimmers and coaches are implementing A-swim, it is imperative to focus on changes in stroke movements in addition to SR and SL.

As an assessment method of physical strength elements (powers that impact V), the tethered resisted swim is a major knowledge; however, A-swim might be considered a new evaluation method in addition to being a training method. Meaning comparing the difference in acceleration and deceleration of stroke movements using towing can clearly show the propulsion phase and deceleration phase of swimmers. In the future, a more detailed analysis of kinetics which especially include measuring the thrust of arm stroke [27] and kinematics of stroke movements in A-swim is anticipated. Confirming the towing force setting may also be useful. Depending on the swimmers' performance level, it could exceed the velocity of towing.

4.2 Practical Implications to Promoting Health

Swimmers can achieve a faster V in A-swim compared with N-swim. For recreational swimmers who swim mainly out of interest or for health maintenance, they can train for longer distances in a fixed time through faster swimming and improved skills efficiency with A-swim. In other words, A-swim can serve as a useful training for both competitive and recreational (health conscious) swimmers. As training for health maintenance is different from performance, the use of A-swim to keep training at maximal velocity with lower energy cost, compared with N-swim, can help to reduce the physiological effort relation to recovering strategies and to avoid overtraining. This will also allow better control over training intensities.

Sex difference, given that V is a product of SR and SL, it is likely that the benefits derived from A-swim in females will be similar to males.

5. Conclusions

We conclude that A-swim with a load of 24 lbs increases SR in addition to the V and SL of swimmers compared with N-swim, even considering the impact of propulsion by towing. Furthermore, from the changes in the duration of the push phase, impact on stroke movements was indicated. There is a possibility, however, A-swim negatively change kinetics and kinematics. Therefore, for coaches and swimmers, understanding the characteristics of A-swim and carefully pay attention to changes in swimming performance due to it could be needed if introducing A-swim into training.

Author Contributions

SIM, YW and KM conceptualized and designed the study. SIM, KM, and YT performed the research. SIM wrote the manuscript. SIM and KM analyzed the data. YT, YW, JEM, PF, HPN, and DAM reviewed and edited the manuscript. All authors read and approved the final manuscript.

Ethics Approval and Consent to Participate

All swimmers signed the informed consent from prior to participating in the study. This study was approved by the Institutional Ethics Committee of Tokyo Gakugei University, Japan (approval number 494). All human research procedures were in accordance with the ethical standards of the committee responsible for human experimentation (institutional and national), and with the Helsinki Declaration of 1975 as revised in 2013.

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Conflict of Interest

The authors declare no conflict of interest. PF, HPN, and DAM are serving as one of the Guest editors of this journal. DAM is are serving as one of the Editorial Board members. We declare that PF, HPN, and DAM had no involvement in the peer review of this article and has no access to information regarding its peer review. Full responsibility for the editorial process for this article was delegated to AT.

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