ASSISTED TOWING DOES NOT AFFECT ARM STROKE COORDINATION IN FRONT-CRAWL SWIMMING

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This study clarified changes in arm stroke coordination during assisted swimming. Fourteen male collegiate swimmers swam 25-m front crawls with (A-swim with towing device) and without an assist (N-swim) at a submaximal to maximum (slow, moderate, and fast) effort. Swimming velocity (v), stroke frequency (SF), stroke length (SL), and stroke coordination index (IdC) were then measured. Results revealed that v and SL exhibited a significant interaction, with higher values observed in the A-swim. Furthermore, v significantly increased with effort, whereas SL showed the opposite. No significant interactions were confirmed for SF and IdC, though SF and IdC significantly increased and decreased, respectively, as the effort increased. In conclusion, despite increased v and SL, A-swim does not affect arm stroke coordination during front-crawl swimming.

KEYWORDS: Overspeed, performance, technique, training.

INTRODUCTION: Tethered swimming has been used for competitive swimming training and performance evaluation by artificially adjusting the swimming velocity (Maglischo, 2003). It can be divided into assisted towing swimming (A-swim) and resisted swimming. A-swim increases the swimming velocity (v) by pulling the swimmer toward propulsion. In resisted swimming, the swimmer is pulled in the direction opposite to the direction of propulsion to increase the force on the muscular strength. Focusing on the training effect, unlike resisted swimming, A-swim is rarely reported (Fone et al., 2022). Current studies on A-swim reported that v can be increased, arm stroke frequency (SF) can be increased and the hand depth moving underwater can be changed (Williams et al., 2006). Increasing maximum velocity by 20% reduces arm stroke efficiency (Alcock et al., 2007) and can be an evaluation method for measuring active drag with some limitations (Hazrati et al., 2018). Although this literature focuses on maximal effort, quantifying submaximal kinematics and kinematics could bring new implications for athletes and coaches in terms of utilizing A-swim in training.
The index of coordination (IdC), which is one of the evaluation indexes proposed by Chollett et al. (2000), focuses on the movement of both arms for propulsion by, and it has been the subject of some literature (Seifert et al., 2023). Compared with natural swimming without assisted towing (N-swim), A-swim changes the kinetics and kinematics. Particularly, it has been pointed out that changes in kinematics due to A-swim may be detrimental to performance (Williams et al., 2006); however, the effect of A-swim on the IdC remains unclear. Therefore, this study clarified changes in arm stroke coordination in A-swim at various effort levels by comparing them with N-swim.

METHODS: We included 14 volunteers who were well-trained male collegiate swimmers. Their mean age, height, body mass, and swimming points by the World Aquatics at short-course 50-

m freestyle were 21 ± 2 years, 1.74 ± 0.07 m, 66.3 ± 7.1 kg, and 587 ± 88, respectively. The inclusion criteria were as follows: (i) an experience in sprinting events and (ii) no constraints during the last 6 months that could impede them from performing the required efforts.

The trial was a 25-m front-crawl consisting of A-swim wherein swimmers were towed in the propulsion direction using a towing device (Torren t E-Rack Swim Power Trainer; Trilabs Inc., Walnut Creek, CA, USA). This device was connected to a computer via a USB cable for control and installed above the pool wall. A nonstretchable nylon cable set in the towing device was attached to a belt on the swimmer's waist. The towing device was set to 24 lb (10.9 kg) on the A-swim and 0 lb on the N-swim (Moriyama et al., 2021). Swimmers were instructed to swim at the effort level from submaximal to maximal in both A-swim and N-swim without breathing. At submaximal efforts, we adjusted the SF by using a small audible waterproof metronome (Tempo Trainer Pro; FINIS, Inc., Tracy, CA, USA), which swimmers wore under their caps. Finally, each swimmers' data, which included three trials (slow: 70%–79% of maximum SF, moderate: 80%–89% of maximum SF and fast: maximum effort), were analyzed in both A-swim and N-swim.

The v and travel distance were inputted into the computer at 100 Hz using the analytical software Dasylab (Version 13.0, Measurement Computing Corporation, Norton, MA, USA). To analyze v (m/s), we used the travel velocity of the belt around the swimmers' waist (Moriyama et al., 2021) in the 7.5-m interval between 12.5 and 20 m. Swimmers' underwater movements were recorded at 60 Hz using two action cameras (GoPro9; GoPro Inc., San Mateo, CA, USA) placed on both sides of the swimmer and both cameras were synchronized by transferring LED lights. SF (Hz) was also calculated by counting the number of video frames for one stroke cycle in the same section. To calculate SL (m), we divided v by SF. Furthermore, using two cameras that recorded underwater strokes of the left and right arms, we accurately quantified the lag time from the start of propulsion of one arm to the end of propulsion of the other arm and then calculated the IdC (%). To calculate IdC, we first classified the arm stroke movement into four phases according to the movements of each arm, calculated the time when the propulsive movement disappeared in each arm, and then divided it by the required time taken for two strokes (1 stroke cycle) (Chollet et al., 2000).

All values are expressed as mean ± standard deviation and 95% confidence interval. The variations in v, SF, SL, and IdC were analyzed using two-way repeated-measures ANOVA (effort, slow, moderate or max × towing, A-swim or N-swim). If the interaction was significant, we conducted multiple comparisons using Bonferroni for each factor. The effect side of the interaction and each factor were expressed with bias η_p^2. The effect size of the Bonferroni post hoc test was calculated using Cohen's *d*. The level of statistical significance was set at 5% ($p < 0.05$). All statistical data were analyzed using the IBM SPSS Statistics 27 (IBM Corporation, Armonk, NY, USA) software.

RESULTS: The velocity(/power)-time series fluctuations during intra-cyclic arm stroke were seen in both A-swim and N-swim at maximal and submaximal effort. A significant interaction was observed for v (F = 22.095, p < 0.001, η_p^2 = 0.630) and SL (F = 104.574, p < 0.001, η_p^2 = 0.889); however SF (F = 2.755, p = 0.082, η_p^2 = 0.175) and IdC did not (F = 0.244, p = 0.785, η_p^2 = 0.018) show significant interactions (Table 1). Multiple comparisons of each factor showed that with an increasing effort for both A-swim and N-swim, v was significantly higher (p < 0.003, d = 0.5–2.1), whereas SL was significantly lower (p < 0.001, d = 0.9–2.6). At each effort, v and SL were significantly higher in A-swim than in N-swim (p < 0.001, d = 2.4–8.3). Regarding SF and IdC, a significant main effect of effort was confirmed, and the value increased with increased effort in SF (F = 444.270, p < 0.001, η_p^2 = 0.972) and in IdC (F = 180.272, p < 0.001, η_p^2 = 0.933). However, no main effect of towing situations was observed for either SF (F = 0.661, p < 0.431, η_p^2 = 0.048) or IdC (F = 3.950, p < 0.068, η_p^2 = 0.233). Figure 1 shows populations in the towing situations (A- or N-swim) where the SF and IdC were higher. The effect size between towing situations was d = 0.4–0.6 for IdC and d = 0.1–0.2 for SF.

Table 1: Performance variables at different effort levels (data are expressed as mean ± standard deviation (SD))

Variables	Effort	N-swim		A-swim	
		Mean (SD)	95% CI	Mean (SD)	95% CI
v ($m \cdot s^{-1}$)	Slow	1.48 (0.11)	[1.42, 1.55]	2.18 (0.08)	[2.14, 2.22]
	Moderate	1.56 (0.10)	[1.50, 1.62]	2.22 (0.07)	[2.17, 2.26]
	Fast	1.68 (0.08)	[1.63, 1.72]	2.27 (0.06)	[2.23, 2.30]
SF (Hz)	Slow	0.72 (0.08)	[0.68, 0.77]	0.73 (0.09)	[0.68, 0.78]
	Moderate	0.83 (0.09)	[0.78, 0.88]	0.85 (0.10)	[0.79, 0.90]
	Fast	0.98 (0.11)	[0.92, 1.04]	1.00 (0.13)	[0.93, 1.07]
SL (m)	Slow	2.06 (0.19)	[1.95, 2.17]	3.03 (0.29)	[2.86, 3.19]
	Moderate	1.90 (0.16)	[1.81, 2.00]	2.64 (0.28)	[2.48, 2.80]
	Fast	1.73 (0.18)	[1.62, 1.83]	2.30 (0.28)	[2.15, 2.46]
IdC (%)	Slow	−13.00 (5.20)	[−16.00, −10.00]	−16.55 (6.15)	[−20.10, −13.00]
	Moderate	−9.68 (5.78)	[−13.01, −6.34]	−12.35 (6.11)	[−15.88, −8.82]
	Fast	−4.18 (5.30)	[−7.24, −1.12]	−6.61 (6.86)	[−10.57, −2.65]

v, Swimming velocity; SF, Stroke frequency; SL, Stroke length, IdC, Index of arm coordination; N-swim, Natural swimming without towing; A-swim, Assisted towing swimming; 95% CI, 95% confidence interval

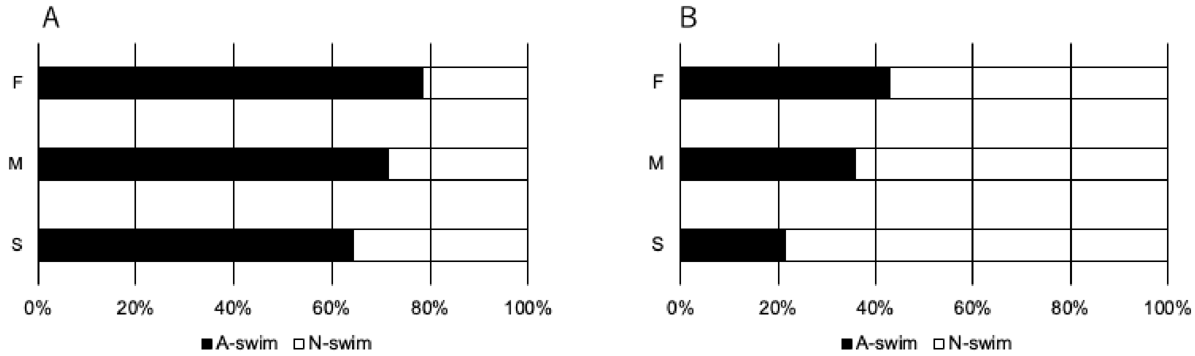

Figure 1: Ratio of number of participants who obtained higher values in each maximum effort (F), moderate (M), and slow (S) by towing situations (N-swim, Natural swimming without towing; A-swim, Assisted towing swimming) (A) represents SF and (B) represents IdC.

DISCUSSION: This study clarified changes in arm stroke coordination during assisted swimming. The main findings were as follows. First, a significant interaction between A-swim and N-swim was observed in v and SL. Additionally, increased v and decreased SL were noted with effort levels in both A-swim and N-swim. Second, although SF and IdC showed no significant interaction, the main effect of effort level was observed, and the value in SF increased and value in IdC decreased as the effort level increased.

v, which is the product of SF and SL, is used to analyze swim performances. In each swimmer, even when v is changed relative to the maximum effort, v and SF decrease, while SL increases (Seifert 2023, Moriyama 2021). This study observed changes like those in the literature in both A-swim and N-swim, suggesting that the towing force set in this study allowed swimmers to adjust their v as in N-swim. However, we need to consider that changes in these indicators demonstrated a significant interaction. Consistent with the findings of a previous study (Moriyama et al., 2021), v and SL were significantly higher in the A-swim than in the N-swim. We used the SF of maximal A-swim and N-swim as the standard, which may have led to changes in relative values and the interaction becoming significant. Conversely, no significant interaction was observed for changes in SF, indicating that the level of effort remained consistent across the two towing situations.

The force-time profile during maximal A-swim has been confirmed to have force fluctuations within each arm stroke (Formosa et al., 2011). Therefore, we evaluated changes in the

velocity(/power)-time profile during assisted towing with constant force at maximal and submaximal efforts, supporting previous literature. IdC dependent on the relationships between both arm coordination, increased with v, supporting a previous study (Seifert 2023), however, the difference between A-swim and N-swim was insignificant. Therefore, for A-swims, even if hand depth changes compared to N swims (Williams et al., 2006), it does not seem to affect IdC at maximal and submaximal efforts.
Contrary to a previous study conducted under the same towing force (Moriyama et al., 2021), SF of A-swim at maximum effort compared to N-swim did not increase significantly, and effect size was lower (d = 0.1) compared with previous study (d = 0.9). However, it may not be possible to deny SF improvement during maximum effort with A-swim as a higher SF was observed in A-swim for some swimmers. A similar trend was observed in individual data of IdC, with some swimmers having higher values in A-swim. The A-swim may result in fluid dynamics effects different from N-swim where swimmers are exposed to velocity which is not self-achievable (Moriyama et al., 2021). Future research is expected to include expanding sample size, analyzing hand thrust considering the left-right arms difference (Formosa, et al., 2011) and incorporating computational fluid dynamics (Marinho et al., 2011).

CONCLUSION: A-swim exposes swimmers to unusual speeds and drags. Assisted towing, which allows SF to be adjusted along with v, does not impair IdC. Athletes and coaches should pay close attention to the interrelationship between expected effects and changes in performance due to A-swim.

REFERENCES

Alcock A., & Mason B. (2007). Biomechanical Analysis of Active Drag in Swimming, *Proceedings of the XXV ISBS Symposium*, Ouro Preto, Brazil, 212-215.

Chollet D, Chalies S, Chatard JC. (2000). A new index of coordination for the crawl: description and usefulness. *Int J Sports Med*. 21(1), 54-59. https://doi:10.1055/s-2000-8855

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), 19. https://doi.org/10.1186/s40798-022-00410-5

Formosa D.P., Mason B., Burkett B. (2011). The force-time profile of elite front crawl swimmers. *J Sports Sci.* 29(8), 811-819. doi:10.1080/02640414.2011.561867

Hazrati, P., Sinclair, P. J., Spratford, W., Ferdinands, R. E., & Mason, B. R. (2018). Contribution of uncertainty in estimation of active drag using assisted towing method in front crawl swimming. *J Sports Sci.*, 36(1), 7-13. https://doi.org/10.1080/02640414.2016.1276295

Maglischo E.W. (2003) *Swimming fastest*. Human Kinetics: Champaign, IL, USA.

Marinho D.A., Silva A.J., Reis V.M., et al. (2011). Three-dimensional CFD analysis of the hand and forearm in swimming. *J Appl Biomech*. 27(1), 74-80. https://doi:10.1123/jab.27.1.74

Moriyama, S-I, Watanabe, Y., Masuda, K., Toyoda, Y., Morais, J. E., Forte, P., Neiva, H. P., Marinho. D.A. (2022). The Impact of Assisted Swimming on Front Crawl Performance. *J.Mens Health*. 18(7), 151. https://doi.org/10.31083/j.jomh1807151

Seifert, L., & Carmigniani, R. (2023). Coordination and stroking parameters in the four swimming techniques: a narrative review. *Sports biomech*, 22(12), 1617-1633. https://doi.org/10.1080/14763141.2021.1959945

Williams BK, Sinclair PJ, Galloway M. (2006). Changes in stroke kinematics during resisted and assisted freestyle swimming. *Proceedings of the XXIV ISBS Symposium*, Salzburg-Austria

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