CHANGES IN STROKE KINEMATICS DURING RESISTED AND ASSISTED FREESTYLE SWIMMING

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Ten subjects swam 50m freestyle trials using; resisted (RS), assisted (AS), and free swimming (FS). Data from 2 underwater cameras were combined to provide a 3-D reconstruction of each trial. During RS, the stroke length (SL), mean 3D resultant hand velocity and average forward velocity (AV) significantly ($p < 0.05$) decreased compared to the FS trial. During RS, the swimmers were unable to generate enough force to prevent the tether from slowing them down. Further, calculations suggest that the average propulsive force acting on the swimmer was not increased during RS. During the AS trial SL, stroke rate and AV increased, while maximum hand depth decreased relative to the FS trial. There appear to be some positive benefits, however the technique changes found during both RS and AS result in these forms of training remaining questionable.

KEY WORDS: resisted, assisted, stroke mechanics, 3D analysis, propulsion, drag.

INTRODUCTION: It has been identified that by applying the principle of specificity of training to swimming, the greatest benefit may be derived from exercises that most closely simulate those motions used in performance (Schleihauf, 1983). Sprint-resisted training (RS) is believed to provide increased resistance for the development of strength while maximising specificity. However, there is a lack of research showing any improvement in performance as a result of RS training, while research examining the effect of RS on stroke mechanics is also limited and generally unfavourable. RS has been shown to alter the stroke length (SL), stroke rate (SR), hand depth, hand velocity and range of movement of the stroke (Maglischo, Maglischo, Sharp, Zier, & Katz, 1984; Payton & Lauder, 1995; Takahashi & Wilson, 1997).

An alternate form of training, assisted swimming (AS) is used for developing speed by allowing an athlete to train above race pace. It has been hypothesised that AS creates a stimulus that allows the athlete to apply a force over a greater distance without adversely affecting their SR, or, to elicit an increase in SR without compromising SL (Maglischo, Maglischo, Zier, Santos, 1985). Despite AS being a popular training modality, there is a lack of research examining its effect on swimming performance and stroke mechanics. Some research has shown it is possible to improve performance (Rowe, Maglischo, & Lytle, 1977), while others in contrast, have demonstrated it elicits a change in stroke mechanics but not performance (Girold, Calmels, Maurin, Milhau, & Chatard, 2003; Maglischo et al., 1985).
There has been a growing concern among coaches and scientists that if the normal stroke mechanics are adversely altered during resisted or assisted swimming, there is a risk of a new less efficient stroke pattern being learned. Any benefit from the principles of specificity of training would therefore be lost and the overall effectiveness of these forms of training would be minimal. It is the aim of this study to try to ascertain what acute effects resisted and assisted swimming have on the mechanics of the freestyle stroke.

METHODS: Ten female junior elite swimmers from the NSW Institute of Sport participated in the study. The subjects were aged 17.0 ± 1.9 years with heights and weights of 1.68 ± 0.06m and 63.2 ± 7.0 kg. Their personal best times for 50m freestyle averaged 28.5 ± 1.4s.

Two underwater video cameras simultaneously filmed a calibrated space located 20m from the start-end of a 50m pool. A ‘Power Reel’ (Total Performance Inc.) was used for both the resisted and assisted trials. It is a motorised reel with a cable that attaches to the swimmer around the waist. During AS, the Power Reel pulled all swimmers at a velocity equivalent to a

28.1s ± 0.8s lap time. During RS, the Power Reel applied an average force of 17.5N ± 2.9N to retard the swimmer. For this condition, therefore, velocities differed between subjects.

All subjects performed a familiarisation session the day before testing where they were given instruction by an Australian national coach. The subjects completed their normal pre-race warm-up before performing one 50m trial under each condition: normal (FS), resisted and assisted freestyle. They were instructed to swim using a normal stroke pattern at 100m freestyle race pace and had approximately 5 minutes rest between each trial.

One complete stroke cycle, from hand entry to hand entry of the same arm, was digitised at 50Hz using Ariel Performance Analysis Software and the following variables analysed:

- Stroke length (SL); difference in horizontal displacement of the hip during one stroke (m).
- Stroke rate (SR); number of strokes per minute (st·min-1).
- Range of movement of the hand (ROM); difference in horizontal displacement of the hand relative to the shoulder during a stroke cycle (m).
- Maximum hand depth (MHD); maximum negative vertical displacement of the hand during the stroke (m).
- Maximum hand velocity (MHV); relative to the hip marker (m·s-1).
- Average resultant hand velocity (3D-HV); the mean 3D resultant hand velocity reached during the stroke (from catch to release), relative to an external marker in the pool (m·s-1).
- Body roll of shoulder and hip angles relative to the horizontal, in the transverse plane (HIP-tilt and SH-tilt) (degrees).
- Elbow angle at mid-stroke (Elb-ang); elbow angle when the wrist and shoulder were in the same transverse plane (degrees).
- Average forward velocity throughout the stroke cycle (AV) (m·s-1).
- Lap time (s); timed over the entire lap.

Statistical significance was assessed using a one way ANOVA with repeated measures (SPSS V10.0) with 3 levels corresponding to FS, RS and AS. All variables were tested for sphericity before analysis and the Greenhouse-Geisser adjustment used where appropriate. The 0.05 alpha level was adopted for all comparisons.

RESULTS:

Table 1 Mean, standard deviation and significance values for all variables.

Variable	***Resisted***	**Free**	***Assisted***	**Significance#**
	mean (± SD)	**mean (± SD)**	**mean (± SD)**	**(p value)**
#SL (m)	*1.65 (± 0.12)	1.88 (± 0.12)	*2.04 (± 0.11)	0.000
#SR ($st \cdot min^{-1}$)	45.3 (± 3.1)	47.3 (± 3.4)	*50.7 (± 3.0)	0.002
ROM (m)	1.03 (± 0.41)	1.04 (± 0.05)	1.01 (± 0.08)	0.585
#MHD (m)	0.44 (± 0.08)	0.45 (± 0.06)	*0.39 (± 0.04)	0.037
MHV ($m \cdot s^{-1}$)	3.33 (± 0.41)	3.38 (± 0.58)	3.71 (± 0.42)	0.185
#3D-HV ($m \cdot s^{-1}$)	*1.94 (± 0.16)	2.04 (± 0.12)	2.11 (± 0.21)	0.030
SH-tilt (deg)	23.7 (± 3.6)	22.2 (± 4.6)	24.3 (± 4.9)	0.485
HIP-tilt (deg)	28.8 (± 7.9)	24.4 (± 9.4)	25.9 (± 6.3)	0.379
Elb-ang (deg)	108.4 (± 0.06)	106.9 (± 9.3)	112.8 (± 12.3)	0.414
#AV ($m \cdot s^{-1}$)	*1.22 (± 0.06)	1.48 (± 0.11)	*1.72 (± 0.04)	0.000
Lap time (s)	38.2 (± 2.1)	31.4 (± 1.4)	28.1 (± 0.8)	N/A

= significant main effect for swimming condition.
* = significant within-subjects contrasts where the condition differs from free swimming.

Mean, standard deviation, and significance ($p < 0.05$) are given for all variables under each condition in Table 1. There were significant differences among SL, SR, MHD, 3D-HV and AV between the conditions. No significant differences were found between conditions for ROM, MHV, SH-tilt, HIP-tilt or Elb-ang.

DISCUSSION: The results of the present study show no change in the ROM, indicating there was no shortening of the arm-stroke during either condition when compared to the FS trial. This suggests a degree of training specificity was maintained in terms of reach during the stroke, from the catch to release.

During AS, subjects significantly increased their SR compared to the FS trial, consistent with the findings of Girold et al. (2003). The increase in SR during AS could initially be considered to be desirable as there was no compromise in the SL. However, there was found to be no increase in either MHV (relative to the body), or 3D-HV (relative to the water). This would tend to suggest that the increased SR was not primarily due to increased hand velocity, but more likely a modified stroke pattern, similar to the results of Maglischo et al. (1985).

There was no significant change found in SR during RS indicating that the subjects were able to maintain specificity of movement speed. This result differs from those of both Takahashi and Wilson (1997) and Maglischo et al. (1984) who both found a decrease in SR during tethered swimming. It is possible, however, that these previous studies utilised a much greater tether resistance, causing swimmers to alter their stroke mechanics.

SL was significantly increased during AS and decreased during RS. There was no difference found in the ROM during either condition indicating that the changes observed in SL were likely to be related to the amount of slip of the hand through the water and not a shortening or lengthening of the arm-stroke. This was an expected finding given the significant differences found in velocity across the trails and is in line with the results of Takahashi and Wilson (1997).

There was no significant change found in elbow angle or body roll between the different conditions. The results showed a significant decrease in the MHD during AS with no significant change found in the RS condition. This finding suggests that during AS, as there was no change in the elbow angle or body roll, yet the MHD was shallower, the upper arm may have been more horizontally abducted than during the FS trial (Payton & Lauder, 1995). This finding could account for part of the increase in SR and confirm why there was no change observed in the ROM. The shallower stroke could contribute to the increase in SR as the total distance travelled by the hand underwater could be less and therefore the hand would spend less time underwater. Along with these changes there was also an increase in the SL which may indicate that the subjects had been pulled along by the Power Reel, rather than increasing their propulsive forces to keep up with the reel.

There was no significant change in MHV during AS or RS. This could initially be considered a positive result, as it has been proposed that the benefit derived from training is specific to the speed of movement and any decrease in speed relative to the body would therefore reduce positive transfer effects (Schleihauf, 1983). However, one of the aims of assisted swimming is to increase hand speed, through an increase in SR (Maglischo et al., 1985). It appears that while there was an increase in SR during AS, there was no significant increase found in MHV. It is possible that due to the decrease in MHD, the total distance travelled by the hand underwater was less, which could partly account for the increase in SR without a subsequent increase in MHV. It would then appear that AS does not achieve some of its aims, as it appears to modify stroke mechanics in order to achieve its objectives.

The forces applied by the hand against the water are usually considered to be proportional to the square of hand velocity (Toussaint & Beek, 1992). There was a significant decrease in 3D-HV in RS which could indicate a possible decrease in propulsive force produced by the hand. This would suggest that there may have been no overload provided to the arms during RS, which would compromise the inherent purpose of this form of training.

During constant velocity swimming, the average propulsive force applied by the swimmer is equal to the resistance force which must be overcome. This can be related to swimming velocity according to Equation 1 (Toussaint & Beek, 1992), where F_D is the active drag force in Newtons, v is the velocity of the swimmer in $m \cdot s^{-1}$, and A is a proportionality constant specific to each individual;

$$F_D = A \cdot v^2 \quad (1)$$

Using Equation 1, the resulting F_D can be approximated for both FS and RS (the force from the Power Reel during AS was unknown, making it impossible to calculate F_P during AS). Using a value of "A" for elite female swimmers of 24 (Toussaint & Beek, 1992), the values of "v" obtained in this study for FS and RS ($1.48 m \cdot s^{-1}$ and $1.22 m \cdot s^{-1}$ respectively, see Table 1), and the force provided by the Power Reel "F_{PR}" (17.5N) during the RS trial, the resulting values for F_P during the FS and RS conditions can be calculated:

$$\text{FS:} \quad F_P = F_D = 52.6N \quad (2)$$

$$\text{RS:} \quad F_P = F_D + F_{PR} = 35.7N + 17.5N = 53.2N \quad (3)$$

Although only an estimation, this result indicates that the decrease in velocity of the swimmers during RS is such that there is very little added total force for the swimmer to overcome. Reduced 3D-HV during RS could suggest that there was more propulsive force being provided from elsewhere, possibly from the kick, or that there was a shift in the proportion of lift and drag dominated propulsion. These findings question the assumption that RS increases the amount of force applied by swimmers and that it can therefore be considered as a form of resistance training. It should be noted, however, that there were no hydrodynamic forces calculated in this study and any comments on the differences in propulsive forces produced by the hand, arm or kick are therefore speculative.

CONCLUSION: Swimming velocity during RS was reduced by an amount that implied there was no compensatory increase in force production by the swimmers. While most measures of technique remained constant, the reduction in SL implied that swimmers were unable to prevent the hand slipping back further during each stroke. This finding was supported by a reduction in 3D-HV, suggesting a decrease in force production by the arms. If this is the case, then the efficacy of this form of training must be questioned as it appears to fail the fundamental objective of RS training – to provide an increased load to work against.

The findings of this study show that AS can elicit positive changes in both SR and SL that are in line with the principles of training specificity. Subjects, however, also decreased MHD, resulting in their mechanics not being completely maintained. Therefore this form of training remains questionable, although it is thought that under the proper instruction from a coach, it could be beneficial to swimmers.

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