Effects of Arms-Only Swimming Training on Performance, Movement Economy, and Aerobic Power

Maria Konstantaki, Edward Winter, and Ian Swaine

Context: Forward propulsion in freestyle swimming is predominantly achieved through arm action. Few studies have assessed the effects of arm training on arm power and swimming performance, yet there have not been any investigations on the effects of arms-only swimming training on swimming performance and physiological responses to arm exercise. Purpose: To investigate the changes in arms-only and full-stroke swimming performance, movement economy and aerobic power after an arms-only swimming training program. Methods: Fifteen male county level swimmers were assigned either to an experimental (ES, n = 8) or control group (CS, n = 7). For six weeks ES performed arms-only freestyle swimming exercises for 20% of their weekly training distance three times per week, whereas CS performed their usual swimming training. Before and after the training program, both groups performed a) two time trials, 186 m using arms-only (186\_ARMS) and 372 m using full-stroke (372\_FULL) freestyle swimming, and b) an incremental arm-pulling exercise test. The time to complete the trials was recorded. Peak oxygen uptake (\(V_{\text{O2peak}}\)), peak exercise intensity (\(E_{\text{Ipeak}}\)) submaximal oxygen uptake at 60 W (\(V_{\text{O2-60}}\)) and exercise intensity at ventilatory threshold (\(V_{\text{TW}}\)) were determined from the exercise test. Results: After training, ES had improved in 186\_ARMS (−14.2 ± 3.6\%, \(P = .03\)), \(V_{\text{O2-60}}\) (−22.5 ± 2.3\%, \(P = .04\)), \(E_{\text{Ipeak}}\) (+17.8 ± 4.2\%, \(P = .03\)), and \(V_{\text{TW}}\) (+18.9 ± 2.3\%, \(P = .02\)), but not in \(V_{\text{O2peak}}\) (\(P = .09\)) or in 372\_FULL (\(P = .07\)). None of the measures changed in CS (\(P > .05\)). Conclusion: Arms-only swimming training at 20% of the weekly training distance is an effective method to improve arm conditioning during the preparatory phase of the annual training cycle.

Keywords: conditioning, performance, aerobic power, swimming.

There is very little research on the effects of arms-only swimming training in competitive swimmers. This is surprising since the arm-stroke is known to bring about the majority of the forward propulsion in freestyle swimming.\(^{1,2}\) Competitive swimmers regularly perform arms-only swimming exercises as part of their

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training programs. Of course, in assessing the effects of an arms-only training program, it would be necessary to measure changes in swimming performance, but it might also be useful to assess the effects on arm aerobic power, movement economy, and ventilatory threshold, to aid in explaining any performance changes that occur. Previously, the effects of arms- and legs-only training upon swimming performance and dry-land endurance in club swimmers have been assessed but aerobic power was not measured and the changes in the training group were not compared with changes in a control group. There have been a few other relevant studies that have included comparisons of peak oxygen uptake for swim bench exercise and arms-only swimming, the effects of hand paddle aids on oxygen uptake during arms-only swimming, and the effects of dry-land arm resistance training on arm aerobic power. However, even though these studies have provided insight into the upper body aerobic potential of swimmers, they have not reported swimming performance in conjunction with arm aerobic power following arms-only swimming training.

Movement economy is the ability to sustain greater exercise intensities at a lower metabolic cost and it is an adaptation that occurs in response to endurance training. It has been previously suggested that arm cranking training decreases submaximal oxygen uptake at given intensities thereby improving energy utilization in the trained segments. However, these studies did not use swimming training or swimmers, so direct implications for the training of swimmers are tenuous. Swimming economy has been investigated only in response to reduced swimming training and it was shown that such reduction adversely affects whole-body economy. To this date, changes that occur in arms-only movement economy of swimmers, following arms-only swimming training, have not been reported. Similarly, the ventilatory threshold (VT) has been used as a noninvasive marker of the anaerobic threshold in studies that have attempted to explain metabolic adaptations that occur due to running and cycling training. Training studies that have assessed responses to arm and leg exercise have shown a reduction in the $V_{E}/V_{O_2}$ relationship at given power outputs following arm cranking and leg cycling training. Again, none of these studies used swimmers or arms-only swimming training. It has been shown that a breakpoint in the $V_{E}/V_{O_2}$ relationship can be identified during incremental swimming in a swimming flume, but there have not been any published investigations on the adaptations that occur in the ventilatory threshold for arms-only exercise in swimmers following arms-only swimming training.

It is important, in studying arms-only training, to be able to show the extent to which improvements in arms-only function and swimming performance transfer to improvements in whole-body swimming performance. This would be useful to swimmers and swimming coaches, in assessing the value of this type of training. In addition, assessment of arms-only physiological measures in conjunction with assessment of swimming performance might highlight the amount of arms-only swimming training required to bring about performance improvements. The findings from such a study would assist coaches in the design of more effective swimming training programs and might be of use to sports scientists who wish to evaluate the role of specific body segment training within the overall training program. To our knowledge, there have not been any studies that have simultaneously assessed the effects of arm swimming training on arm aerobic power and on
swimming performance. Therefore, the purpose of this study was to investigate changes in swimming performance (arms only and whole stroke) and any accompanying changes in arms-only aerobic power, movement economy and ventilatory threshold, following an arms-only swimming training program.

**Methods**

**Subjects**

With ethics approval by the North Bedfordshire Ethics Committee, fifteen male competitive swimmers (mean ± SD; age: 16.0 ± 3.0 years, stature: 175.0 ± 5.0 cm, body mass: 72.0 ± 8.0 kg) provided written informed consent and participated. The swimmers’ competitive experience ranged from four to eight years and training was performed in a 31-m swimming pool. All participants were county standard swimmers who engaged in training for 1.5 hours at least five times per week. The swimmers’ mean (± SD) personal best performance time in 372-m freestyle before the training study was 321.0 ± 10.0 s. Training distance was recorded for the two months immediately before the study and the mean ± SD was 20,000 ± 2,500 m per week.

**Experimental design**

This study used a randomized controlled design and incorporated an experimental (ES) and a control group (CS). Participants were randomly assigned either to an experimental (n = 8) or control group (n = 7) before the training study commenced. The swimmers’ pretraining times were (mean ± SD) ES: 319.0 ± 11.0 s and CS: 323.2 ± 8.0 s.

**Procedure**

The following section presents the procedure of the training program followed by the procedure and measurements for the time trials, the dry-land arm-pulling test, gas analysis, determination of oxygen uptake, and ventilatory threshold.

**Intervention: Arms-Only Swimming Training Program** The arms-only swimming training program was performed for six weeks at a frequency of three times per week during the preparatory phase of the swimmers’ annual training cycle. ES performed arms-only training on alternate days of the week at the beginning of each assigned training session immediately after the warm-up. On the nontraining days, ES performed their usual training. The amount of arms-only training was monitored for two months before the training study. The average weekly volume of arms-only swimming training comprised 6.0 ± 2% (or 1200 ± 400 m) of the weekly training distance (ie, 20,000 m) and included arms-only swimming exercises for all four strokes (depending on the swimmers’ individual stroke). For the training study, ES were asked to perform arms-only freestyle swimming exercises for 20.0% of their weekly training volume (ie, an increase of 14.0% above the pretraining arms-only weekly training). In terms of training distance, this was equivalent to a 2.25% increase (ie, 2800 m above the pretraining arms-only training). In each arms-only swimming training session, ES performed 1333 m
Arms-Only Swimming Training

(ie, 4000 m per week) using arms-only freestyle swimming exercises, whereas CS performed the equivalent of this distance using standard training. ES and CS performed the same training volume during the six weeks of training; however, ES performed 14.0% of this distance per week using arms-only training. Therefore, there was no change in the magnitude of directional training due to arms-only training, as arms-only training formed part of the training volume and was not performed in addition to it. The total training volume was the same in ES and CS. The arms-only swimming training included a variety of arms-only freestyle swimming exercises and drills (ie, breathing every 2 to 4–6 strokes, 1 arm only per length, with and without hand paddles and pull buoy). In addition, ES were instructed to focus on their technique, body position in the water and to keep a constant stroke rate per length. Exercises and drills were arranged in sets consisting of moderate to heavy (but not strenuous) swimming designed to elicit heart rate responses between 130 to 170 b·min⁻¹ and included repeated distances of 62 m, 93 m, 124 m, 155 m, and 186 m in a 31-m swimming pool. Rest intervals between the exercises were 15 to 35 s; exercise to rest ratio of 2:1 and up to 1 minute between sets. Some sprint exercise was also performed toward the end of each arms-only training session. To eliminate leg action (kicking) and achieve a streamlined position during the arms-only freestyle swimming training, ES wore an elastic band around their ankles and secured a pull buoy in-between their upper legs (just above the knee joint).

Dry Land Arm-Pulling Exercise Test

All swimmers were habituated to exercising by performing free trials on the arm-pulling ergometer (computer-interfaced microprocessor with a resistance unit and a system of pulleys attached; H. and M. Engineering, Gwent, Wales, U.K.) before testing. Following calibration, maximal pull velocity (MPV) was set constant at 2.66 m·s⁻¹ to allow optimal stroke rate at lower and higher resistance settings.14 Swimmers adopted a prone position on the ergometer and simulated the freestyle arm-pulling action by pulling on the hand paddles with alternating arms. During the exercise test, swimmers breathed via a mouthpiece connected to gas analysis equipment to allow collection of expired gases. Swimmers aged 17 years or over began arm-pulling at 30 W, whereas younger swimmers began arm-pulling at 20 W. The intensity of exercise was dictated by a computer program and was set to increase by 7.5 W·min⁻¹ (slow ramp protocol; H.K. Smith, Univ. of Sunderland, UK). The test ended at volitional exhaustion or when swimmers failed to maintain the intensity of exercise within ± 20 W of the target power output. Peak exercise intensity (EI_peak) was determined at this point.

Gas Analysis

Expired gases were analyzed for their oxygen and carbon dioxide output using on-line gas analysis equipment (COVOX Microlab, Exeter, UK). This equipment comprised paramagnetic oxygen and infrared carbon dioxide analyzers and a pneumotachograph (Servomex Ltd., Sussex, UK). Calibration of the gas analyzers was performed immediately before testing and after every testing session using nitrogen and a gas of known concentration (4.95% CO₂, 15% O₂ + 21.5% O₂; BOC Gases Ltd., Surrey, UK). The reason for using two calibration gases for O₂ was to span the operating range and thus perform calibration above and below the anticipated O₂ values. The expired gases were mixed in a 3-L chamber and sampled at 15-s intervals.
Measurements

Time Trials. All swimmers performed two swimming time trials before and after the six-week training program individually or against each other. The time trials comprised 186 m using arms-only swimming (186_{ARMS}) and 372 m using full-stroke freestyle swimming (372_{FULL}) at maximum effort. Before- and after-training measurements were conducted in the same way and swimmers were instructed to perform in the same way. On both occasions, the time trials were performed two days apart to minimize any effects of residual fatigue. The order of the time trials was randomized to avoid any learning effects. The time trials took place in the beginning of a training session immediately after the warm up. The same warm-up procedure was used for all time trials pre- and posttraining. The swimmers started both time trials by pushing off the pool wall and were allowed to tumble turn. Each swimmer performed the time trial individually. During the tumble turn, swimmers used the butterfly kick in both time trials and on both measurement occasions (before and after raining). The time taken to complete the time trials was measured using a manual chronometer with the same investigator conducting all measurements on both occasions to minimize intrameasurement error. The variation in 186_{ARMS} and 372_{FULL} from repeated testing was 11.0% and 9.0%, respectively.

Oxygen Uptake  During the arm-pulling test, oxygen uptake was recorded every 15 s. Submaximal oxygen uptake was determined at the end of the minute while exercising at 60 W (V_{O2-60}). Peak oxygen uptake (V_{O2peak}) was determined at exhaustion. The variation in V_{O2-60} and V_{O2peak} from repeated testing was 6.0% and 8.0%, respectively.

Peak Exercise Intensity  Peak exercise intensity (EI_{peak}) was determined at the end of the arm-pulling test. The test ended at volitional exhaustion or when swimmers failed to maintain the intensity of exercise within ± 20 W of the target power output.

Ventilatory Threshold  The method used for determination of ventilatory threshold was based on that suggested by Fukuba et al\textsuperscript{15} and was taken to be the point at which there was a sudden systematic increase in the ventilatory equivalent for O\textsubscript{2}. The values for V_{E}/V_{O2} were plotted against exercise intensity (W). Two straight lines were fitted on the V_{E}/V_{O2} data (one before and one after the VT breakpoint) indicating a “V-slope.” The intersection of the lines was taken as the exact point of VT and the exercise intensity that coincided with the VT was interpolated. The variation in VT\textsubscript{W} from repeated testing was 8.0%.

Statistical Analysis

Following an exploratory analysis of data for normality, a two-way analysis of variance (ANOVA; variable \times condition) was used to assess the differences in 186-m arms only (186_{ARMS}), 372-m full stroke (372_{FULL}), oxygen uptake at 60 W (V_{O2-60}), aerobic power (V_{O2peak}), peak exercise intensity (EI_{peak}), and exercise intensity at ventilatory threshold (VT\textsubscript{W}) in ES and CS at baseline. Two-way ANOVA (variable \times time) was employed to assess the differences in 186_{ARMS},
372_{FULL}, V_{O2-60}, V_{O2peak}, E_{peak}, \text{ and } V_{T\gamma} \text{ in ES and CS before and after the six-week arms-only swimming training program. Significance levels were set at } P < .05. \text{ Paired samples } t \text{ tests using the Bonferroni adjustment were used to locate significant differences. Values are reported as mean } \pm \text{ standard deviation (SD). Statistical analyses were performed using SPSS 13.0 statistical software.}

**Results**

**Time-Trial Performance**

Before training, there were no significant differences \((P = .09)\) in the mean \(\pm\) SD values for 186_{ARMS} \text{ in ES } (187.0 \pm 10.0 \text{ s}) \text{ and CS } (183.0 \pm 8.0 \text{ s}) \text{ and for } 372_{FULL} \text{ (} P = .07)\text{ in ES } (319.0 \pm 11.0 \text{ s}) \text{ and CS } (323.2 \pm 8.0 \text{ s}). \text{ After training, there were substantial changes for } 186_{ARMS} \text{ in ES } (-14.02 \pm 3.6\% \text{, } P = .03) \text{ and no changes in CS } (1.6 \pm 0.5\% \text{, } P = .08) \text{ as shown in Figure 1. There were no substantial changes for } 372_{FULL} \text{ in either ES } (P = .07) \text{ or CS } (P = .07) \text{ as shown in Table 1.}

**Submaximal Oxygen Uptake**

Before training, there were no significant differences \((P = .06)\) in the mean \(\pm\) SD values for oxygen uptake at 60 W \((V_{O2-60})\text{ in ES } (1.57 \pm 0.22 \text{ L\cdotmin}^{-1}) \text{ and CS} \text{.

**Figure 1** — Times for 186_{ARMS} (s) in arm-trained (experimental) and control group before and after training. Values are mean \(\pm\) SD. *Significant at } P < .05.
Table 1  Mean ± SD Values for 372-m Whole Stroke ($372_{\text{FULL}}$; s), Peak Oxygen Uptake ($V_{O2\text{peak}}$; L·min$^{-1}$), Oxygen Uptake at 60 W ($V_{O2\text{-60}}$; L·min$^{-1}$), Peak Exercise Intensity ($E_{\text{Ipeak}}$; W), and Exercise Intensity at Ventilatory Threshold ($V_{T\text{W}}$; W) in ES (Arm-Trained Swimmers) and in CS (Control Swimmers) Before and After Training. *Significant at $P < .05$

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<th>Arm trained</th>
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<td></td>
<td>Before training</td>
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<tr>
<td>372$_{\text{FULL}}$</td>
<td>319.0 ± 11.0</td>
<td>315.0 ± 16.0</td>
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<td>$V_{O2\text{peak}}$</td>
<td>2.36 ± 0.30</td>
<td>2.33 ± 0.30</td>
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<tr>
<td>$V_{O2\text{-60}}$</td>
<td>1.57 ± 0.22</td>
<td>1.28 ± 0.13*</td>
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<tr>
<td>$E_{\text{Ipeak}}$</td>
<td>121.0 ± 10.0</td>
<td>148.2 ± 8.0*</td>
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<tr>
<td>$V_{T\text{W}}$</td>
<td>58.0 ± 13.0</td>
<td>69.0 ± 6.0*</td>
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(1.62 ± 0.37 L·min$^{-1}$). After training, there were substantial changes in ES (−22.50 ± 2.3%, $P = .04$), but no significant changes in CS (1.02 ± 0.8%, $P = 0.09$). These results are shown in Table 1.

**Peak Oxygen Uptake**

Before training, there were no significant differences ($P = .06$) in the mean ± SD values for peak oxygen uptake ($V_{O2\text{peak}}$) in ES (2.36 ± 0.30 L·min$^{-1}$) and CS (2.43 ± 0.22 L·min$^{-1}$). After training, there were no substantial changes for $V_{O2\text{peak}}$ in either ES ($P = .09$) or CS ($P = .07$). These results are shown in Table 1.

**Peak Exercise Intensity**

Before training, there were no significant differences ($P = .08$) in the mean ± SD values for peak exercise intensity ($E_{\text{Ipeak}}$) in ES (121.0 ± 10.0 W) and CS 123.0 ± 12.0 W). After training, $E_{\text{Ipeak}}$ increased significantly in ES (+17.80 ± 4.2%; $P = .03$), but did not change substantially in CS (0.97 ± 0.23%, $P = 0.06$). These results are shown in Table 1.

**Exercise Intensity at Ventilatory Threshold**

Before training, there were no significant differences ($P = .08$) in the mean ± SD values for exercise intensity at ventilatory threshold ($V_{T\text{W}}$) in ES (58.0 ± 13.0 W) and CS (54.0 ± 11.0 W). After training, $V_{T\text{W}}$ increased significantly in ES (+18.96 ± 2.3%, $P = .02$), but did not change substantially in CS (0.93 ± 0.20%, $P = .07$). These results are shown in Table 1.

**Discussion**

The main purpose of this study was to investigate whether arms-only swimming training is associated with a change in whole stroke swimming performance. The secondary purpose was to assess whether any changes in swimming performance...
could be explained by concomitant changes in arms-only aerobic power, movement economy, and ventilatory threshold. The findings showed that arms-only swimming performance improved notably (Figure 1), and was accompanied by changes in arms-only peak exercise intensity, ventilatory threshold, and movement economy, but these improvements did not transfer to whole stroke swimming (Table 1). These findings are in agreement with those of previous studies that have used combined dry land and “in-water” resistance training programs such as arm cranking\textsuperscript{16} and different types of tapering\textsuperscript{17}.

One of the most plausible explanations for the present findings (and those of previous similar studies) relates to the importance of coordination of the arms and legs in freestyle swimming. It might be the case that metabolic or performance improvements in arms or legs separately are not easily assimilated into the whole stroke, because of the knock-on effects upon arm and leg coordination. Indeed, it has been shown that the addition of the leg-kick to arms-only freestyle swimming modifies the underwater trajectory of the wrist\textsuperscript{18}. It has also been proposed that the external torque associated with changes in body roll cycle imposes additional demands on the arms and legs to generate sufficient amount of fluid forces in nonpropulsive directions\textsuperscript{19}. Subsequently, the quantification of arm and leg coordination in swimming has received much research attention. Recently, indices of coordination have been reported for freestyle\textsuperscript{20}, backstroke\textsuperscript{21}, breaststroke\textsuperscript{22}, and butterfly swimming\textsuperscript{23}. It has been shown that arm and leg coordination is an advanced skill which depends upon swimming speed, type of kick used (two-beat or six-beat), and also swimming proficiency. Therefore, it might be that, in the current study, subjects were either not given adequate opportunity to assimilate their improved arms-only performance into altered arm and leg coordination, or perhaps that they did not have the ability to do so. Perhaps, specific whole stroke coordination skill training is needed alongside or subsequent to arms- or legs-only swimming training, before improvements in whole stroke performance can be seen.

One of the key findings in this study was that arms-only swimming training at 20.0\% of the weekly training distance performed three times per week for six weeks improved muscle endurance in the trained segments. Similar adaptations in local muscle endurance of the trained segments have been observed previously following arm cranking\textsuperscript{24} and triathlon training\textsuperscript{25}. Tanaka and Swensen\textsuperscript{26} suggested that endurance training induces distinct muscular adaptations that are concerned with a decrease in the activity of the glycolytic and oxidative enzymes, increase of intramuscular substrate stores, and capillary, as well as mitochondrial, density. Even though we did not perform measurements of intramuscular enzymes or substrates in this study, the muscular adaptations that occurred in ES after arms-only training were reflected by the increased peak exercise intensity achieved in the arm-pulling exercise test. In addition, the posttraining $\text{E}_{\text{peak}}$ values are comparable to those previously stated by Swaine\textsuperscript{27} (148.0 ± 8.0 versus 149.6 ± 25.0 W, respectively) for arm-pulling exercise.

After training, marked reductions were noted in submaximal oxygen uptake at 60 W ($\text{V}_2\textsubscript{O2-60}$) and in exercise intensity at ventilatory threshold ($\text{V}_\text{T}_W$) in ES during the arm-pulling test. It has been postulated that following training there is an increased capability in the trained segments to perform exercise at a lower metabolic cost and that the ventilatory threshold is achieved at higher exercise intensities following running training\textsuperscript{28}. The findings in this study indicate that
arm movement economy in the arms of ES improved following arms-only swimming training. Previously, movement economy has been shown to improve in response to cycling and running training. However, there have not been any swimming studies that have assessed the changes in arm movement economy and in arm ventilatory threshold following arms-only swimming training with which to compare our data. Nevertheless, there is evidence from a previous study that assessed leg-kicking economy following a leg-kicking swimming training program, that showed similar improvements in leg movement economy (−20.4 ± 3.0%) and in exercise intensity at ventilatory threshold (+28.0 ± 5.0%) after training.

Peak oxygen uptake during arm-pulling exercise did not increase following arms-only swimming training in ES despite the notable increase in peak exercise intensity. Gregg et al reported that it is possible improvements in endurance performance take place without a concomitant change in aerobic power. In addition, it has been previously suggested that performance in middle-distance freestyle swimming depends largely upon aerobic power. In this study, it was shown that middle-distance swimming performance did not improve following arms-only swimming training, which could be due to lack of improvement in aerobic power. Studies that have demonstrated significant increases in VO2peak following cycling and swimming training used untrained subjects and recreational or collegiate swimmers and thus, the increases in peak oxygen uptake after-training could be attributed to the experimental group’s initial state of training. In this study, we used county standard swimmers who might have reached a “ceiling” in their aerobic potential due to competitive swimming training and therefore might have required a higher training stimulus for noticeable improvements in aerobic power to take place.

### Conclusion and Practical Applications

The findings of this study demonstrate that six weeks of arms-only training at 20.0% of the weekly training distance improves arms-only swimming performance and enhances movement economy and muscular endurance in the trained segments. However, this type of training did not bring about improvements in whole body middle-distance swimming performance or in arm aerobic power. One explanation for these findings is that adequate time and training needs to be given to assimilation of the improvements in arms-only performance into whole stroke arm and leg co-ordination. Such findings could be of use to swimming coaches whose aim is to use an effective training program to improve upper body conditioning in their swimmers. These findings could also be useful to sport physiologists who wish to investigate the separate contribution of the arms to whole body performance in swimmers. Further research needs to be undertaken to identify how best to allow assimilation of the arms-only improvements into whole stroke coordination, so as to bring about improvements in swimming performance.

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References