THE DECLINE OF SWIMMING PERFORMANCE WITH ADVANCING AGE: A CROSS-SECTIONAL STUDY

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ABSTRACT. Gatta, G., P. Benelli, and M. Ditroilo. The decline of swimming performance with advancing age: A cross-sectional study. J. Strength Cond. Res. 20(4):932-938. 2006.—The aim of this cross-sectional study was to measure the swimming parameters—speed (V), stroke frequency (SF), and stroke length (SL)—in 162 male athletes aged 50-90 (divided into 7 age groups, from A to G) participating in the World Master Championships in the 200-m freestyle event, and to analyze the rates and magnitudes of their age-associated declines. The swimmers were video-recorded by 2 digital cameras during the competitions and the swimming parameters related to every 50-m section (lap) and to the entire race (average) subsequently measured or calculated. Lap V and SF decreased in the second and third quarter (11 and 4% on average) and increased (3% on average) in the fourth quarter of the race, whereas lap SL decreased from the first to the last 50-m section. Average V (m-s⁻¹) decreased from 1.39 ± 0.09 (group A) to 0.84 ± 0.11 (group G); average SL (m) decreased from 2.10 ± 0.20 (group A) to 1.78 ± 0.19 (group G); and average SF (cycles-s⁻¹) decreased from 0.67 ± 0.06 (group A) to 0.47 ± 0.04 (group G). One-way analysis of variance showed significant declines in average V, SL, and SF (p < 0.01) across the 7 groups. The swimming parameters were normalized to the highest values (set equal to 100); thereafter, a linear regression curve was fitted and the regression equations calculated. Decline of SF was about 2.5 times steeper than that of SL. It was highlighted that (a) among the swimming parameters, SL is less affected by the ageing process; (b) SL decreased from group A through group C and thereafter tended to keep steady, whereas the trend for SF was opposite. The results have the potential to give master swimmers and their coaches useful information for training program design.

KEY WORDS. stroke frequency, stroke length, master swimmers, ageing

INTRODUCTION

In cyclical sports, the length of distance covered and the frequency of each cycle represent 2 variables that are widely used in sport technique analysis. These spatial and temporal variables were studied in various sports such as running (e.g., 6), cycling (e.g., 16) and rowing (e.g., 22). Among the components affecting swimming performance, stroke frequency (SF) and stroke length (SL) are widely regarded as kinematics factors of pivotal importance. Usually SF is measured in cycles-s⁻¹ and SL is measured in m-cycle⁻¹; therefore, swimming speed (V), in m-s⁻¹, is equal to:

\[ V = \text{SL} \times \text{SF} \]  

An increase in V is achieved by an improvement of either SL or SF, or both.

At the beginning of the 1970s, the first studies regarding the relationship between SL, SF, and swimming performance were conducted (14). The high interindividual variability of both of these parameters (30), along with the facility that coaches have in measuring and controlling them during the diverse training phases, have attracted the interest of many researchers. Therefore, after the initial observations, many other investigations have been carried out to determine the influence of different variables on the stroke parameters SL and SF. The studies conducted have delved into the influence of gender (11, 26), age (26, 35), different swimming stroke specialties (2, 9, 10, 11, 24, 29), swimming distance (10, 14, 24, 25), performance level (7, 9, 26), type of training (1, 32, 38), and anthropometric characteristics (20, 25, 26). However, in some cases the results have been found to be controversial (17). In summary, it has been demonstrated that (a) high-level swimmers have a longer SL (11, 26); (b) SL is an important index of swimming efficiency (33); (c) SF and SL show a linear relationship until the swimmer reaches a speed corresponding approximately to the anaerobic threshold, beyond which SF increases whereas SL decreases (10, 11, 19, 37); (d) SF has a good positive correlation with arm strength (5) and lactate production but a negative correlation with VO_{max} (20, 36, 39). These findings prove that there is a relationship between the stroke parameters and the energetic and propelling mechanisms of swimming.

Master swimmers, athletes who continue to train and compete well beyond middle age, have been receiving considerable scientific interest. In fact, swimming is often considered the ideal sport for older adults because of a lower risk of injury and because of its cardiovascular and musculoskeletal benefits. The use of master athletes to describe an idealized rate of physiological loss associated with ageing is quite common. However, the available literature on master swimmers focuses especially on age-related changes in swimming performance (13, 31) and metabolism efficiency (28). To the best of our knowledge, the changes in stroke parameters with increasing age have not previously been analyzed. Such an analysis is important in order to understand the cause of the decline in swimming performance with advancing age.

Accordingly, the primary aim of this study was to measure the swimming parameters (V, SF, and SL) of several swimmers of different ages, ranging from 50 to 90 years, and to analyze the rate and magnitude of their age-associated declines. It is hypothesized that the ageing process (a) causes a linear decrease in the swimming parameters and (b) causes similar rates of decline in SF and SL.

METHODS

Experimental Approach to the Problem

A cross-sectional design was used in order to assess how the stroke parameters were affected by ageing. The 200-
m freestyle was judged the best event for the analysis because it is well known that shorter and longer events are characterized respectively by extremely high and low SF (17, 19). For measurement of the stroke parameters, the participants were video-recorded during competition (i.e., world championships), because it was hypothesized that this would be a challenging situation for achieving their best performance. Furthermore, it was assumed that most participants in world championships are highly-trained athletes, thus reducing the limitations of cross-sectional age comparisons in the general population (31).

Subjects
The subjects were 162 male swimmers participating in the 10th Fina World Master Championships, held in Riccione, Italy, in June 2004. They gave their written informed consent for participating in the study, which had been previously approved by the Human Ethics Committee of the University of Urbino, Italy. The swimmers, distributed over an age range of 50–90 years, took part in 200-m freestyle events, and were divided into age groups as presented in Table 1.

Subjects 80 years old and older were gathered in only 1 group, group G, because otherwise more fragmented formations would have been too small. Table 2 shows the swimmers' performance levels, comparing, in each group, the best and worst average V to the world record, which was set equal to 100. In 2 cases, a new world record was set.

Procedures
The competitions were performed in a 50-m indoor swimming pool. Two digital video cameras (Sony DCR-HC1000E; Tokyo, Japan) were set up on both sides at about 10 m over the swimming pool allowing a view of all 8 lanes. The optical axes of the cameras were about 45° to the horizontal plane of the water. Video images were collected at 50 Hz and subsequently analyzed by the same evaluator, thus reducing interevaluator variability. Stroke frequency was measured in cycles-s⁻¹ during 3 strokes performed in the middle of the swimming pool. This measure was collected each 50-m quarter; thus, 4 lap SF values and the average SF value were obtained. In order to assess the intranevaluator variability of this procedure, the SF values for each swimmer were measured 3 times and an analysis of variance (ANOVA) with repeated measures was used. The intraclass correlation coefficient was >0.89. Swimming speed was calculated for each 50-m section (lap V) and over the entire race (average V) from the printed output of the pool’s automatic timing device. For V calculation, the time spent for diving, turning, and gliding was considered without taking into account Chollet’s correction (8). There was in fact evidence of a high interindividual technical variability of these phases in the groups considered. This method will not allow comparisons with data collected from clean swimming by other authors. It is in any case possible to compare the results of the different age groups considered in this study. Lap and average SF were calculated simply by dividing V by SF.

Statistical Analyses
Standard descriptive statistics (mean and SD) were computed, when appropriate, for measured and calculated parameters. Simple ANOVA was used to compare the swimming parameters across the 7 groups considered. Data were analyzed for normality of distribution (kurtosis and skewness were both between -1.9 and 0.1). A Tukey honestly significant difference (HSD) post hoc test was performed when F was declared significant at p < 0.05. Bivariate regression analysis was used for determining the slope with which the swimming parameters decreased with advancing age. The level of confidence was set at p ≤ 0.05. The statistical analyses were carried out on Statistica (version 6.1; StatSoft, Vigonza, Italy).

RESULTS
There was a general pattern of decline in average V, SF, and SL with advancing age, as depicted in Figure 1. For average V, there was a very close cluster around the line of best fit (Figure 1A), whereas for SF (Figure 1B) and SL (Figure 1C) the data were more scattered. Table 3 illustrates respectively lap V, SF, and SL values in each 50-m section of the race. Lap V decreased in the second and third quarter (11 and 4% on average) and increased (3% on average) in the fourth quarter of the race. A similar trend was revealed for lap SF in the 7 groups considered. This was not observable in lap SL, which decreased from the first to the last 50-m section. The percentage declines from first to fourth quarter for groups A, B, C, D, E, F and G were 9.7, 7.7, 12.8, 14.7, 15.2, 14.75, and 13.0%, respectively. The values (mean ± SD) of average V, SF, and SL across the 7 groups are presented respectively in Figures 2, 3, and 4. Average V decreased somewhat linearly from group A to group G. The 1-way ANOVA showed a significant decline (F = 57.46, p < 0.001) across the 7 groups. The post hoc analysis (Tukey HSD test) revealed absence of significant difference only between groups C and D, groups D and E, and groups E and F (p > 0.05). Average SL and SF significantly decreased across the 7 groups (F = 6.62, p = 0.001; F = 25.26, p < 0.001). The post hoc analysis for the average SL parameter showed a significant difference between group A and groups C, D, E, F, and G (p < 0.05 for all

TABLE 1. Number of swimmers included in each of the 7 age groups coded from A to G.

<table>
<thead>
<tr>
<th>Age group (y)</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>A (50–54)</td>
<td>25</td>
</tr>
<tr>
<td>B (55–59)</td>
<td>41</td>
</tr>
<tr>
<td>C (60–64)</td>
<td>31</td>
</tr>
<tr>
<td>D (65–69)</td>
<td>24</td>
</tr>
<tr>
<td>E (70–74)</td>
<td>17</td>
</tr>
<tr>
<td>F (75–79)</td>
<td>13</td>
</tr>
<tr>
<td>G (≥80)</td>
<td>11</td>
</tr>
<tr>
<td>Total</td>
<td>162</td>
</tr>
</tbody>
</table>

TABLE 2. Slowest and fastest average speed, expressed as percentage of the world record (set equal to 100) in each age group.

<table>
<thead>
<tr>
<th>Age group (y)</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>A (50–54)</td>
<td>75.22–97.47</td>
</tr>
<tr>
<td>B (55–59)</td>
<td>78.50–100.52</td>
</tr>
<tr>
<td>C (60–64)</td>
<td>72.17–95.69</td>
</tr>
<tr>
<td>D (65–69)</td>
<td>71.53–96.66</td>
</tr>
<tr>
<td>E (70–74)</td>
<td>66.76–91.58</td>
</tr>
<tr>
<td>F (75–79)</td>
<td>66.75–95.02</td>
</tr>
<tr>
<td>G (≥80)</td>
<td>49.99–87.35</td>
</tr>
</tbody>
</table>
TABLE 3. Mean (±SD) speed, stroke frequency, and stroke length in each quarter of the race (200-m freestyle) in the 7 groups considered.∗

<table>
<thead>
<tr>
<th></th>
<th>1st q</th>
<th>2nd q</th>
<th>3rd q</th>
<th>4th q</th>
<th>1st q</th>
<th>2nd q</th>
<th>3rd q</th>
<th>4th q</th>
<th>1st q</th>
<th>2nd q</th>
<th>3rd q</th>
<th>4th q</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1.50 ±0.09</td>
<td>1.38 ±0.09</td>
<td>1.34 ±0.10</td>
<td>1.37 ±0.11</td>
<td>0.68 ±0.06</td>
<td>0.65 ±0.06</td>
<td>0.65 ±0.06</td>
<td>0.69 ±0.07</td>
<td>2.21 ±0.23</td>
<td>2.14 ±0.21</td>
<td>2.06 ±0.20</td>
<td>1.99 ±0.20</td>
</tr>
<tr>
<td>B</td>
<td>1.42 ±0.11</td>
<td>1.27 ±0.12</td>
<td>1.23 ±0.13</td>
<td>1.26 ±0.13</td>
<td>0.68 ±0.09</td>
<td>0.62 ±0.07</td>
<td>0.62 ±0.07</td>
<td>0.65 ±0.07</td>
<td>2.12 ±0.24</td>
<td>2.07 ±0.22</td>
<td>1.99 ±0.20</td>
<td>1.96 ±0.21</td>
</tr>
<tr>
<td>C</td>
<td>1.34 ±0.10</td>
<td>1.20 ±0.10</td>
<td>1.15 ±0.11</td>
<td>1.13 ±0.12</td>
<td>0.66 ±0.06</td>
<td>0.63 ±0.06</td>
<td>0.63 ±0.06</td>
<td>0.67 ±0.06</td>
<td>2.04 ±0.24</td>
<td>1.92 ±0.21</td>
<td>1.85 ±0.20</td>
<td>1.78 ±0.20</td>
</tr>
<tr>
<td>D</td>
<td>1.27 ±0.12</td>
<td>1.14 ±0.11</td>
<td>1.09 ±0.11</td>
<td>1.13 ±0.12</td>
<td>0.64 ±0.07</td>
<td>0.61 ±0.06</td>
<td>0.61 ±0.06</td>
<td>0.66 ±0.05</td>
<td>2.02 ±0.24</td>
<td>1.89 ±0.23</td>
<td>1.80 ±0.23</td>
<td>1.72 ±0.22</td>
</tr>
<tr>
<td>E</td>
<td>1.19 ±0.08</td>
<td>1.05 ±0.08</td>
<td>0.98 ±0.08</td>
<td>1.03 ±0.11</td>
<td>0.57 ±0.06</td>
<td>0.55 ±0.05</td>
<td>0.54 ±0.04</td>
<td>0.59 ±0.06</td>
<td>2.09 ±0.20</td>
<td>1.92 ±0.17</td>
<td>1.85 ±0.19</td>
<td>1.77 ±0.20</td>
</tr>
<tr>
<td>F</td>
<td>1.09 ±0.10</td>
<td>0.95 ±0.09</td>
<td>0.90 ±0.09</td>
<td>0.94 ±0.11</td>
<td>0.54 ±0.10</td>
<td>0.52 ±0.07</td>
<td>0.51 ±0.07</td>
<td>0.54 ±0.07</td>
<td>2.05 ±0.23</td>
<td>1.85 ±0.18</td>
<td>1.80 ±0.21</td>
<td>1.75 ±0.19</td>
</tr>
<tr>
<td>G</td>
<td>0.96 ±0.10</td>
<td>0.81 ±0.11</td>
<td>0.78 ±0.11</td>
<td>0.82 ±0.12</td>
<td>0.50 ±0.04</td>
<td>0.45 ±0.04</td>
<td>0.46 ±0.05</td>
<td>0.48 ±0.05</td>
<td>1.95 ±0.25</td>
<td>1.79 ±0.24</td>
<td>1.70 ±0.18</td>
<td>1.69 ±0.17</td>
</tr>
</tbody>
</table>

∗q = quarter, 50-m section of the race.
comparisons), and between group B and groups D, E, F, and G (p < 0.05 for all comparisons). In contrast, average SF stayed at an approximately steady level from group A to group D, but these groups were significantly different from groups E, F, and G (p < 0.05 for all comparisons). Furthermore, group E and group G were significantly different from each other (p < 0.05). The degree of variability in the measured parameters did not change with increasing age. In order to assess the relative decrease of average V, SF, and SL with advancing age, the mean values of the 50–55 age group were set equal to 100 and the other groups' values were calculated as a percentage of the youngest group's values. Furthermore, a linear regression curve was fitted and the regression equations calculated as shown in Figure 5. The decline in SF is about 2.5 times steeper than the decline in SL, as illustrated by the slopes of the regression lines.

**DISCUSSION**

The main purpose of this study was to determine the age-related trend of the swimming parameters V, SL, and SF.
during the 200-m freestyle in male swimmers aged 50–90.

Within the swimming parameters, average V revealed a good inverse linear relationship with age. Average SF and SL, although showing a negative correlation with age, exhibited much higher variability. The high inter-individual differences of SL and SF are well known to be present in swimmers ranging from nonskilled (9, 26) to top-level (11). Therefore, the variability appears to be an intrinsic feature of the stroke parameters, regardless of age, gender, or swimmers' level. However, this represents a restriction when the aim is to estimate population parameters from a sample or for detecting a general trend of the parameters analyzed.

The swimming parameters measured in every 50-m section of the 200-m event exhibited a similar trend in all the age groups considered. As would be expected, V was high at the beginning of the race because the swimmer was still fresh and also because it included the distance attained with the start. In the second and third quarters, a decrease was caused by the arising of local muscular fatigue and by the race distribution strategy. When near the end of the race, the athlete is usually willing to make an extra effort, and this was consistent with the increase in V. An increase in V in the fourth section was attained only with an increase in SF, which counteracted a drop in SL. Swimmers demonstrated a compensatory increase in SF in order to overcome fatigue, and this prevented the slowing down of V. Maintaining or even increasing SL during the race would be too demanding. When fatigue arises, the decrease in SL is attributable to reduced ability to generate the force necessary for forward propulsion, and possibly to increased drag because of body misalignment (12). In fact, SL decreased from the first to the fourth quarter of the race. The decrease in SL throughout the race has also been well documented in young top-level swimmers (11, 24). It is of interest to note that this strategy is generally similar during a period of more than 6 decades. In older swimmers, the reduction in SL could be augmented because of the physiological age-related loss in strength. The percentage decline through the race was lower in younger compared to older groups, thus supporting this hypothesis. It would be of interest to compare the percentage reduction in SL in master and elite swimmers, but to the best of our knowledge these data are not available in the literature.

Unfortunately, no information about the swimmers' awareness of the race distribution strategy used is available in this study. This could not be done in the present study because the research had to be conducted in a field laboratory at the side of the swimming pool, where carrying out this kind of survey with athletes involved in a world championship competition would be difficult. Further multidisciplinary investigations seem necessary to address this issue and to explore the effect of a different chosen strategy on final performance.

Average V (both individual and mean values), calculated during the 200-m freestyle, decreased linearly with advancing age. This is in contrast with the findings of Donato et al. (13) who found a markedly accelerated rate of decline in swimming performance after about 70 years of age. However, they analyzed the 50-m and 1,500-m freestyle events and collected the results of the top 10 swimmers in their age group during a 12-year period. This is quite different from what was done in this study. The overall magnitude of the reduction from group A to group G is 0.55 m·s⁻¹ (about 40%) and supports the previous findings of Rahe and Arthur (27), who reported a decline of 1% per year, although they referred to swimmers aged 27.5–57.5.

From the analysis of the curves depicted in Figures 2–4, the decline in V appears to be attributable mainly to SL until about the age of 65 and to SF thereafter. Interpretations of these facts must be made carefully because of the small sample size of groups F and G and the variance of the SF and SL data. SL is thought to be dependent essentially on force production capacity, specifically (a) forward propulsion (15, 17), (b) the swimmer's technical ability to minimize active drag (1), and (c) level of upper body strength (5). It is well known that, at least in young elite swimmers, the lower limbs contribute little to propulsion compared to the upper limbs (4, 34), and it is generally recognized that age-dependent loss in strength is more pronounced in the lower than in the upper limbs (18). However, Bemben et al. (3) showed that, in contrast with previous findings, in healthy men ranging in age from 20 to 74, the greatest decline in force production with increasing age occurred for the forearm extensors. Furthermore, the highest decline in maximal force production, maximal rate of force production, and maximal impulse occurred at an early age. It is tempting to speculate that the reduction in V is attributable mainly to a decrease in force production capacity until 65 years of age and to a weakening in metabolic efficiency thereafter. Indeed, SF has been associated more with energy production mechanisms (20, 36, 39). However, because force and anaerobic energy production mechanisms are somewhat related to each other (20, 21), the explanation is uncertain at present.

Considering equation 1, a progressive decline in V with advancing age could entail a decrease in both SL and SF. However, the relative magnitude of reduction of the stroke parameters is peculiar. Based on the results presented, it could be argued that, in general, the ageing process affects SF more than SL. It can be hypothesized that once technical abilities are improved to one’s best, they are maintained during the years and are only partially affected by the ageing process. On the other hand, it is interesting to note that in young swimmers, increase in V is dependent essentially on technique and therefore on improvement in SL (23, 29). Moreover, in nonskilled swimmers, SL is the most important factor affecting performance and the effectiveness of force propulsion (26). Findings from these studies and from the present study suggest that SL is the first stroke parameter swimmers need to improve, and its decline during the ageing process is considerably more delayed than that of SF.

In conclusion, it can be said that, supporting the first hypothesis, a physiological decrease in V with advancing age was observed. On the other hand, opposing the second hypothesis, a steeper decline in SF compared to SL in men 50–90 years of age was demonstrated. Furthermore, an original perspective of the stroke parameters trend during the race sections and the entire race was presented, although stroke parameters’ evolution during the ageing process must be confirmed.

**Practical Applications**

The following implications can be drawn from this study:

(a) Based upon the results of the present study, coaches
should make an attempt to pay more attention to SL when a swimmer is training at intensities from maximal lactate steady state to maximal oxygen uptake, whereas during anaerobic training the focus should be on SF. (b) The rate of decline in SF with advancing age is higher than the rate of decline in SL; hence, a partial redressing of the training programs could be taken into consideration, with special regard to the definition of the stroke parameters during the training sessions. (c) A different race distribution model could be tested in order to evaluate the effect on final performance and fatigue. (d) The number of master athletes who train for improving their performance has been growing in recent years. Therefore, the results presented in this study have the potential to give master swimmers and their coaches useful information for training program design.

REFERENCES


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