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Relationship between performance, dry-land power and kinematics in master swimmers

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The purpose of the study was to analyze the relationships between sprint swimming performance, dry-land power, and kinematics in master swimmers. Twenty-two male master swimmers were separated in two groups based on their chronological age: (i) 30–39 years and; (ii) 40–49 years. Maximum dry-land power was determined through counter movement jump and 3 kg medicine ball throwing (H_{max} and T_{max}, respectively). Kinematic determinants of performance were measured during a maximal bout of 15, 25 and 50 m front crawl (T_{15}, T_{25}, T_{50}). Stroke frequency (SF), stroke length (SL) and stroke index (SI) were calculated as kinematical aspects of the stroke. In the 30-39 group, SI_{25} was correlated to T_{25} ($r = -0.76$, $p < 0.01$, $\eta^2 = 0.96$), the same was observed between SI_{50} and T_{50} ($r = -0.83$, $p < 0.01$, $\eta^2 = 0.96$). Only SI_{50} was significantly correlated to T_{50} ($r = -0.86$, $p < 0.01$, $\eta^2 = 0.97$) in the 40–49 years age cohort. In dry-land power variables, H_{max} and T_{max} were only correlated in the younger master swimmers group ($r = -0.87$, $p < 0.01$, $\eta^2 = 0.97$). There were no significant differences ($p < 0.05$) between younger (30–39 years) and older (40–49 years) swimmers groups in dry-land tests (H_{max} 28.5 ± 5.9 vs. 26.5 ± 3.9 cm and T_{max} 4.2 ± 1.0 vs. 4.2 ± 1.1 m). Our results suggest that swimming performance in younger master swimmers (30–39 years) seem more dependent on kinematic swimming variables than on strength parameters, which were most related to swimming performance in the older master swimmers (40–49 years).

Key words: *master swimmers, kinematic, dry-land power, performance*

1. Introduction

After ending their regular careers, several former swimmers shift to master events, yet continue to devote much time and effort to excel in master competitions. For this reason, master competitions are no longer an extension of recreational sports as in the past.

One consistent fact is that swimming performance declines with age. Masters' peak performance occurs during the late 20's to early 30's, and progressive declines should be expected in further years [6]. Physiological and muscular changes are underlying reasons that can explain such phenomenon. Aging affects muscle mass, muscle fibre type and size, and the efficiency of metabolic pathways [17]. Decreases in maximal oxygen consumption, maximal heart rate, stroke volume, lactate threshold and aerobic enzyme activity should also be expected from adulthood to elderhood [24]. However, such systematic evidence on master swimming is scarce at least about competitive masters that were formerly elite athletes.

Although conflicting reports have emerged regarding the relative energy contribution from aerobic

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and anaerobic metabolism during short sprints, corresponding to the duration of a 50 m swimming race [16], Zamparo et al. [25] indicated that the metabolic power deficit increases the energy cost of swimming and explains performance decreases in master subjects. The stroke mechanic adaptations and a high hydrodynamic resistance verified at slower speed, also make this cohort of swimmers less eficient than younger elite ones [13]. Probably, strength and power losses with age affect the kinematic aspects of the stroke and input novel energetic adaptations. Thus, this urges the need to identify the kinematic and power determinants of performance at different swimmimg speeds, for a better training prescription and to further atenuate substantial performance declines with aging.

Positive links between strength and power and kinematics with performance have been reported for adult swimmers in the past. Girold et al. [9] reported that a combined program of swimming and dry-land strength sets lead to significant gains in sprinting performance. Research conducted with young subjects also found a tendency to enhance sprint swimming performance due to dry-land strength improvements [7]. However, evidences about the possible biomechanical effects from dry-land strength improvements (and thus on performance) in master swimmers are unknown. Therefore, the aim of this study was to compare master swimmers of different age cohorts in both strength and power, and kinematic characteristics. It was hypothesized that with age, sprint performance and power of the swimmer seem to decrease in swimming performance in short duration events.

2. Materials and methods

Subjects

Twenty-two male master swimmers were separated in two groups based on their chronological age: (i) 30–39 years (11 subjects, 35.7 ± 2.8 years of age, 1.76 ± 0.10 m of height, 72.1 ± 12.7 kg of body mass) and; (ii) 40–49 years (11 subjects, 45.2 ± 2.2 years of age, 1.70 ± 0.09 m of height, 74.7 ± 15.5 kg of body mass).

Volunteered subjects participated on a regular basis in regional and national level competitions. An informed consent with the research purpose and experimental tasks was signed by each subject prior to the participation. All procedures were in accordance with the Declaration of Helsinki in respect to human research. The ethics committee of the hosting institution approved the study design.

Design

The present study analysed the relationship between dry-land power and kinematic determinants of performance in master swimmers. The study included an experimental design comparing two cohort groups. Statistical correlations were implemented to assess the association between selected variables and performance in each cohort group. Accordingly to the characterization survey the swimmers trained 3 sessions per week, participating in regular resistance training units for the past six months, for specific strength endurance abilities of the main muscle groups. All measurements were made during the preparatory period of the winter training cycle to ensure that all swimmers would be in a state of good overall performance. The day before the evaluation, all swimmers performed a low intensity training to avoid fatigue. All measurements were conducted in the swimming pool at the end of the day (between 19 h 00 m and 20 h 30 m) to prevent circadian rhythm disruption.

Dry-land tests

Swimmers were tested in a dry-land environment to assess their upper and lower body strength through power measurements. For lower body power all subjects executed counter movement jumps as described elsewhere [11]. A contact mat (Ergojump Digitime 1000; Digitest, Jyvaskyla, Finland) was used to assess the maximum height (H_{max}, cm) obtained in a full jump. Three repetitions of the exercise were used and separated by a 2-minute time interval. The average H_{max} of three trials was measured to assess lower body power. For the upper body power measure the swimmers completed a 3 kg medicine ball throwing test. Each subject sat on a chair with their back positioned against the chair and held the ball to the front with both hands. They were instructed to throw the medicine ball from the chest forward as far as possible. Torso and hip rotation were not allowed. The maximum throwing distance (T_{max}, m) was measured with a flexible steel tape [11]. Three approved attempts were made with one-minute resting intervals, to ensure that fatigue or learning effects did not influence the performance. Only the best attempt was used for further analysis. Body mass was assessed through a bioelectric impedance analysis method (Tanita BC 420S MA, Japan).

In water tests

All tests were performed in a 25 m indoor swimming pool (28.5 °C of water temperature). After a 600 m low intensity warm-up, each subject completed a 50 m maximal front crawl swimming test (T_{50}) from a push off start in the wall on the surface level (to eliminate the influence of the dive). Performance at 15 and 25 m was determined by two expert researchers with a chronometer (Seiko S140, Japan). Each individual swimming bout was separated by a 10-min period to avoid water turbulence. During each bout, stroke frequency (SF, cycles.min^{-1}) and stroke length (SL, m.cycle^{-1}) were accessed as kinematical indicators based on 6 full movement cycles, from which 3 were identified on the first lap and next 3 on the second lap.

The SF was measured with a crono-frequency meter (Golfinho Sports MC 815, Aveiro, Portugal) from 3 consecutive stroke cycles, in the middle of each lap [2]. The SL was estimated as Craig et al. [3]

$$SL = \frac{v}{SF}$$

where SL is the stroke length (in m.cycle^{-1}), v is the swimming velocity (in m.s^{-1}), and the SF is the stroke frequency (in cycle.min^{-1}). The product of SL to the swimming velocity (v) allowed the assessment of stroke index (SI) considered a valid indicator of swimming efficiency [4].

Statistical analysis

The normality of the distributions was assessed with the Shapiro–Wilk test. Parametric and non-parametric statistics were selected accordingly. Standard statistical methods were used for the calculation of means and standard deviations. Regression analysis was conducted to evaluate how well stroke parameters predicted swimming performance. The Mann Whitney U test was used to compare groups. To assess the level of the practical significance, effect size was computed based on Cohen's d. Ranking Spearman Correlation Coefficients (r_s) were calculated to assess the association between kinematic, power and performance variables. Significance was accepted at the $p < 0.05$ level.

3. Results

Table 1 presents the swimmer's performance time (15, 25 and 50 m) for both age cohorts. Older swimmers were faster only in T_{15}, however no significant statistical differences ($p > 0.05$) between groups were found for all measured sprinting distances.

Table 1. Mean ± standard deviation values regarding swimming performance in both age-group master swimmers

(n = 11)	30–39 years	40–49 years	P value	Cohen d
T_{15} (s)	10.80 ± 1.55	10.60 ± 1.26	0.755	0.14
T_{25} (s)	18.79 ± 2.82	19.10 ± 2.97	0.805	–0.10
T_{50} (s)	38.22 ± 6.54	38.75 ± 6.90	0.856	–0.07

Table 2 shows the kinematic parameters that were registered during each swimming bout in both age cohorts. No significant differences ($p < 0.05$) were observed between groups in SL and SI. On the other hand, SF in 25 and 50 m was significantly different between groups ($p < 0.01$).

Table 2. Mean ± standard deviation values regarding kinematic variables in the different swimming distances in both age groups

	30–39 years (n = 11)	40–49 years (n = 11)
SF_{25} (cycle.min^{-1})	48.1 ± 6.8	45.5 ± 7.0*^{a}
SF_{50} (cycle.min^{-1})	44.8 ± 7.0	42.2 ± 6.7*^{b}
SL_{25} (m.cycle^{-1})	2.16 ± 0.60	2.17 ± 0.64
SL_{50} (m.cycle^{-1})	1.94 ± 0.50	1.99 ± 0.32
SI_{25} [meter^2.(cycle.s)$^{-1}$]	3.84 ± 1.87	3.67 ± 1.81
SI_{50} [meter^2.(cycle.s)$^{-1}$]	2.82 ± 1.04	2.80 ± 0.80

Legend: * Significantly different between groups ($p < 0.01$). $^{a, b}$ $\eta^2 = 0.98$.

Figure 1 highlights the linear regression of swimming performance and SI in both 25 and 50 m in the 30–39 and 40–49 years age groups. The r-squared of the regresssion analysis of SI and 50 m swimming performance is indicative of a good model in both groups, in contrast to the relationship in the shorter swimming distance (25 m).

Figure 2 displays box plots of performance comparison in counter movement jump and medicine ball throwing in 30–39 and 40–49 years groups to illustrate the spread and differences of samples. There were no statistical significant differences ($p < 0.05$) between younger (30–39 years) and older (40–49 years) swimmers groups in dry-land tests (H_{max} 28.5 ± 5.9 vs. 26.5±3.9 cm and T_{max} 4.2 ± 1.0 vs. 4.2 ± 1.1 m).

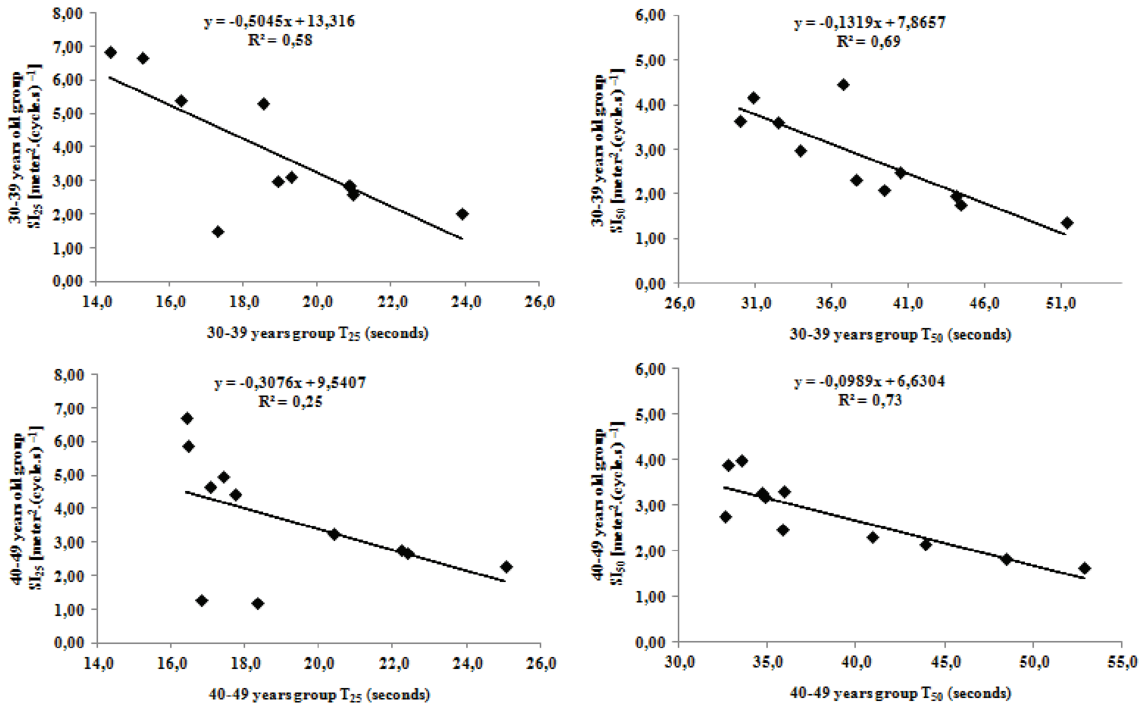

Fig. 1. Linear regression of stroke index at 25 and 50 m and swimming performance at the same swimming distances in 30–39 and 40–49 years group

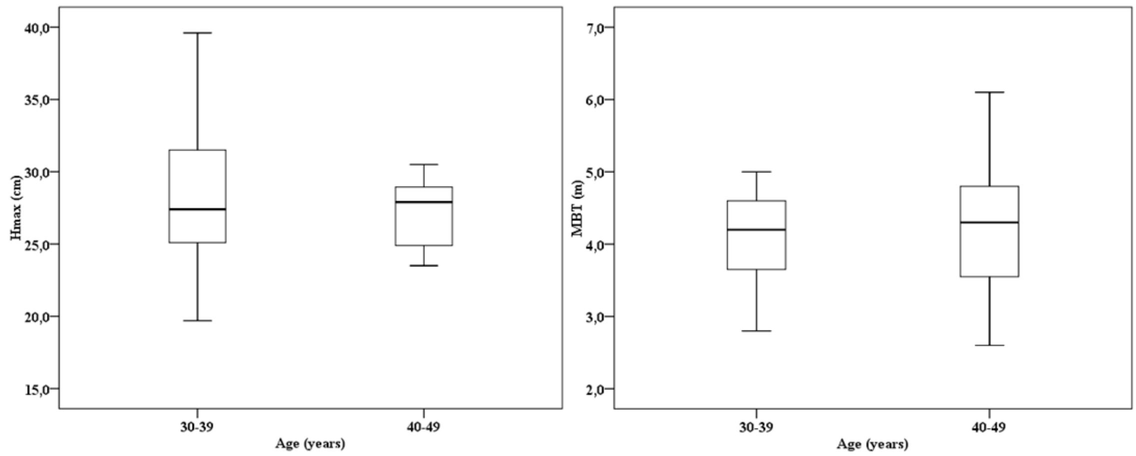

Fig. 2. Performance comparison in counter movement jump and medicine ball throwing in 30–39 and 40–49 years groups

The correlation between performance at diferrent swimming distances and dry-land power variables (H_{max} and T_{max}) is presented in Table 3. There can be observed a tendency related to a decrease in the correlation between H_{max} and the increase in swimming distance covered in the 30–39 years group. On the other hand, in the 40–49 years group, there was observed an increase in the value of correlation between H_{max} and swimming distance covered.

In the 30–39 group, SI_{25} was correlated to T_{25} (r = –0.76, $p < 0.01$, $\eta^2 = 0.96$), the same was observed between SI_{50} and T_{50} (r = –0.83, $p < 0.01$, $\eta^2 = 0.96$). Only SI_{50} was significantly correlated to T_{50} (r = –0.86, $p < 0.01$, $\eta^2 = 0.97$) in the 40–49 years age cohort.

Dry-land power variables (H_{max} and T_{max}) were only correlated in the younger master swimmers group (r = –0.87, $p < 0.01$, $\eta^2 = 0.97$) and H_{max} was only correlated to SF_{25} in the 40–49 age master swimmers group (r = –0.61, $p < 0.05$, $\eta^2 = 0.95$). No correlations were observed between T_{max} and kinematics.

Table 3. Correlation matrix between performance (in seconds) in different swimming distances and dry-land power variables

	30–39 years group			40–49 years group		
	T_{15}	T_{25}	T_{50}	T_{15}	T_{25}	T_{50}
H_{max}	–0.86**	–0.83**	–0.75**	–0.68*	–0.80**	–0.81**
T_{max}	–0.78**	–0.71*	–0.64*	–	–0.73*	–0.70*

Legend: * Significant at 0.05 level; ** Significant at 0.01 level.

4. Discussion

This study aimed to analyze the relationships between dry-land power and sprint swimming performance in master swimmers. Our results suggest that swimming performance in younger master swimmers (30–39 years) seems more dependent on kinematic swimming variables than on strength parameters, which were most related to swimming performance in the older master swimmers (40–49 years).

The development in swimming performance over the years can be explained by better training control and evaluation of the swimmers, leading to a more efficient training process [21]. To the best of our knowledge, this study was the first to examine the relationship between kinematic and dry-land power determinants on short distance swimming performance in master subjects. However, contrary to expectations, no significant differences were observed between age cohorts related to swimming performance (T_{15}, T_{25} and T_{50}) and dry-land power performance. This was an unexpected result since muscular performance seems to decrease with age in men [6]. It was reported that decreased muscle mass, type II muscle fiber atrophy and a shift towards a greater expression of the myosin heavy chain I isoform at older age are the major contributors to the age-related decline in anaerobic performance in master athletes [18]. These factors in combination with less motivation for systematic training, led us to the initial hypothesis of a significant reduction in swimming performance with age. This does not in fact turned out.

In Tanaka and Higuchi [23] intervention, peak performance times were observed in swimming athletes between 25 to 40 years old but after this age limit, swimming time increased somewhat linearly until 70 years, whereupon performance time increased exponentially thereafter. Donato et al. [5] conducted a 12-year longitudinal study of high-performance US master swimmers and observed a significant linear 3–8%.decade^{-1} increase in 50 m swimming time for both men and women until 70 years of age. More recently, it was indicated that high-intensity sprint training, combined with hypertrophy resistance training, may potentially slow the decline in anaerobic performance of master athletes into older age [18]. This represents an important suggestion for swimming training prescription with master swimmers mainly because swimming performance is highly dependent on muscular strength and power [8] and previously have demonstrated to be well correlated to upper-body muscular strength and swimming power [1]. Conversely, improvements in arm strength (or at least a minor loss of strength) may result in higher maximum force per stroke and subsequently increase swimming velocity, particularly at short distances [22]. The subjects included in our sample were all experienced in strength training, participating in regular strength sessions. Probably this contributed to the performance maintenance in short swimming distances with age. Indeed, findings from several cross-sectional studies indicated that the declines in muscular power with age are considerably more delayed when compared to cardiovascular endurance [23].

In short distance maximal front crawl tests with an underwater start, any hypothectical differences in the explosive strength of lower limbs between age groups may distinguish cohort groups. Thus, it seems that voluntary muscle function deteriorates less rapidly in the upper limbs (major working muscles during swimming) than in the lower limbs with age [12]. This could be the reason why 40–49 years old swimmers can perform identically or even slightly better ($p > 0.05$) in T_{15} than the younger ones.

It has been acknowledged that biomechanical skill in swimming is of great importance for metabolic economy [15] and purposed that when distance diminishes, strength performance increases [14]. It was also previsouly indicated that swimming technique can be improved due to strength training [10]. Sadowski et al. [20] stressed that the ability to perform movements with high speed is represented by muscle power, conversely, an optimal level of strength and power is necessary for successful performance in swimming. Indeed, several studies have reported an association between explosive strength of leg extensor muscles and swimming performance [22]. Others found that strength dry-land training improved swimming performance in young swimmers [7], [8], [20].

However, it seems that contribution of strength parameters to overall swimming bouts performance of 10 s not distinguish older from younger master swimmers. Our results also seem to support previous findings in master swimmers [19], the ability to participate in high-intensity swimming over several decades and suggest that stroke mechanics are determining factors for the overall performance, but only in the younger master group. Indeed, the SI_{50} was significantly correlated to T_{50} ($r = -0.86$, $p < 0.01$) in the 40–49 years cohort.

Nevertheless, some limitations are presented, such as the reduced sample size and the non-specific test as sprint of 50 m. However, this study also has significant merits. Accessing reasonably high level master swimmers on several swimming performance determinants is quite rare. In fact, as far as we know this is the first study that reports the relationships between dry-land strength parameters, kinematics and swimming performance in master swimmers of different age groups. Further research should focus on the effects of aging and gender differences in performance to analyze the peak exercise performances of trained master swimmers with increasing age. Energetics, oximetry, blood lactate and other pertinent data may also be helpful to ensure adequate training throughout the whole master swimming career.

5. Conclusions

Data shows that the front crawl sprint performance in master swimmers is associated with power and kinematical aspects of the stroke. The older master swimmers seem to use a more "powerful stroke" with lower technical quality to swim faster. Contrarily, the younger ones demonstrate a more "technical stroke" to achieve that purpose with good strength values. Coaches should know that those differences may rely on the motor control decrements through the aging process, and should act accordingly.

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References

[1] ASPENES S., KJENDLIE P.L., HOFF J., HELGERUD J., *Combined strength and endurance training in competitive swimmers*, J. Sport Sci. Med., 2009, Vol. 8, 357–365.

[2] CRAIG A., PENDERGAST D., *Relationships of stroke rate, distance per stroke, and velocity in competitive swimming*, Med. Sci. Sports Exerc., 1979, Vol. 11, 278–283.

[3] CRAIG A.B. JR, SKEHAN P.L., PAWELCZYK J.A., BOOMER W.L., *Velocity, stroke rate, and distance per stroke during elite swimming competition*, Med. Sci. Sports Exerc., 1985, Vol. 17(6), 625–634.

[4] COSTILL D., KOVALESKI J., PORTER D., KIRWAN J., FIELDING R., KING D., *Energy expenditure during front crawl swimming: predicting success in middle-distance events*, Int. J. Sports Med., 1985, Vol. 6, 266–270.

[5] DONATO A.J., TENCH K., GLUECK D.H., SEALS D.R., ESKURZA I., TANAKA H., *Declines in physiological functional capacity with age: a longitudinal study in peak swimming performance*, J. Appl. Physiol., 2003, Vol. 94(2), 764–769.

[6] FAIRBROTHER J.T., *Age-related changes in top-ten men's US masters 50-m freestyle swim times as a function of finishing place*, Percpt. Motor Skills, 2007, Vol. 105, 1289–1293.

[7] GARRIDO N., MARINHO D.A., REIS V.M., VAN DEN TILLAAR R., COSTA A.M., SILVA A.J., MARQUES M.C., *Does combined dry land strength and aerobic training inhibit performance of young competitive swimmers?* J. Sports Sci. Med., 2010, Vol. 9(2), 300–310.

[8] GIROLD S., MAURIN D., DUGUE B., CHATARD J.C., MILLET G., *Effects of dry-land vs. resisted- and assisted-sprint exercises on swimming sprint performances*, J. Strength Cond. Res., 2007, Vol. 21, 599–605.

[9] GIROLD S., JALAB C., BERNARD O., CARETTE P., KEMOUN G., DUGUÉ B., *Dry-land strength training vs. electrical stimulation in sprint swimming performance*, J. Strength Cond. Res., 2012, Vol. 26, 497–505.

[10] MAGLISCHO E.W., *Swimming fastest. The essential reference on technique, training, and program design*, Human Kinetics Publishers. Champaign, Illinois, 2003.

[11] MARQUES M.C., VAN DEN TILLAAR R., VESCOVI J., GONZÁLEZ-BADILLO J.J., *Changes in strength and power performance in elite senior female professional volleyball players during the in-season: a case study*, J. Strength Cond. Res., 2008, Vol. 20(3), 563–571.

[12] MCDONAGH M.J.N., WHITE M.J., DAVIES C.T.M., *Different effects of ageing on the mechanical properties of human arm and leg muscles*, Gerontology, 1984, Vol. 30, 49–54.

[13] MEJIAS J.E., BRAGADA J.A., COSTA M.J., REIS V.M., GARRIDO N.D., BARBOSA T.M., *Comparison of performance, energetics, kinematics and efficiency of master versus elite swimmers*, Int. J. Sport Med., 2014, Vol. 15(2), 165–177.

[14] MOROUÇO P., NEIVA H., GONZÁLEZ-BADILLO J., GARRIDO N., MARINHO D., MARQUES M., *Associations between dry land strength and power measurements with swimming performance in elite athletes: a Pilot Study*, J. Hum. Kin., 2011, Vol. 29A, 105–112.

[15] PELAYO P., ALBERTY M., SIDNEY M., POTDEVIN F., DEKERLE J., *Aerobic potential, stroke parameters, and coordination in swimming front-crawl performance*, Int. J. Sports Physiol. Perform., 2007, Vol. 2, 347–359.

[16] PEYREBRUNE M.C., TOUBEKIS A.G., LAKOMY H.K., NEVILL M.E., *Estimating the energy contribution during single and repeated sprint swimming*, Scand. J. Med. Sci. Sports, 2014, Vol. 24(2), 369–376.

[17] REABURN P., DASCOMBE B., *Endurance performance in masters athletes*, Eur. Rev. Aging. Phys. Act., 2008, Vol. 5, 31–42.

[18] REABURN P., DASCOMBE B., *Anaerobic performance in masters athletes*, Eur. Rev. Aging. Phys. Act., 2009, Vol. 6, 39–53.

[19] RUBIN R.T., LIN S., CURTIS A., AUERBACH D., WIN C., *Declines in swimming performance with age: a longitudinal study of Masters swimming champions*, Open Access J. Sports Med., 2013, Vol. 12(4), 63–70.

[20] SADOWSKI J., MASTALERZ A., GROMISZ W., NIŻNIKOWSKI T., *Effectiveness of the power dry-land training programmes in youth swimmers*, J. Hum. Kinet., 2012, Vol. 32, 77–86.

[21] SMITH D., NORRIS S., HOGG M., *Performance evaluation of swimmers*, Sports Med., 2002, Vol. 32, 539–554.

[22] STRZALA M., TYKA A., *Physical endurance, somatic indices and swimming technique parameters as determinants of front crawl swimming speed at short distances in young swimmers*, Med. Sport, 2009, Vol. 13, 99–107.

[23] TANAKA H., HIGUCHI M., *Age, exercise performance, and physiological functional capacities*, Adv. Exerc. Sports Physiol., 1998, Vol. 4, 51–56.

[24] TANAKA H., SEALS D., *Endurance exercise performance in Masters athletes: age-associated changes and underlying physiological mechanisms*, J. Physiol., 2008, Vol. 586, 55–63.

[25] ZAMPARO P., GATTA G., DI PRAMPERO P., *The determinants of performance in master swimmers: an analysis of master world records*, Eur. J. Appl. Physiol., 2012, Vol. 112(10), 3511–3518.