**Total energy expenditure in elite open-water swimmers**

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Total energy expenditure in elite open-water swimmers

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Running Head: Total energy expenditure in open water swimming

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Abstract

This study aimed to examine the total energy expenditure (TEE) and physical activity level (PAL) of elite open-water swimmers. Our study group included five world-class competitive open-water swimmers. TEE was measured using the doubly labeled water (DLW) method for 1 week. The TEE was 4549±1185 kcal/day. The PAL was 3.22±0.46. Our results may provide a reference to optimize energy requirement support.

Key words: open water swimming, energy demand, energy requirement, doubly labeled water, nutritional support in sports.
**Introduction**

Open-water (OW) swimming refers to competitive swimming races performed in rivers, lakes, oceans, or water channels, with $\geq 10$-km events being classified as marathon swimming in the latest Fédération Internationale de Natation (FINA) rules (FINA 2017). OW swimming became an official FINA event at the 1991 world championships, with only the 25-km distance on the program, and then included in the 2008 Olympic program, including the 10-km distance. The current World Championship program includes 5-, 10- and 25-km distances and the mixed relay event (Zingg et al. 2014).

The doubly labeled water (DLW) method is the gold standard for estimating total energy expenditure (TEE) in free-living conditions, requiring periodic sampling of urine (Schoeller et al. 1986). Therefore, DLW is suitable for estimating TEE in OW swimming. Estimating an athlete’s TEE during OW training and competition, including an approximation of the physical activity level (PAL), is necessary to develop effective nutritional plans for OW swimmers, as well as to compare energy requirements among different sports (Westerterp 2013).

A previous review reported the maximal aerobic capacity ($V_{O2\text{max}}$) for OW swimmers to be comparable to that of elite marathon runner, professional cyclists, and
middle distance swimmers (Baldassarre et al. 2017). They also reported the physiological
capacity of these athletes to swim at a high percentage of VO$_{2\text{max}}$ (80-90%) for many hours
(Baldassarre et al. 2017), which would require a large TEE and PAL during training. As
such, performance in this event requires sufficient energy intake during training. However,
in the absence of a reference for TEE and PAL range for elite OW swimmers has not yet
been developed. Thus, the aim of our study was to examine the TEE and PAL of
world-class competitive OW swimmers. We hypothesized that these athletes would exert a
large daily TEE to achieve sufficient training to compete over long-distance events.

Methods

Five elite OW swimmers, who represented Japan in 2014-2015, volunteered to participate
in this study (Table 1; 2 men and 3 women; age, 24±4 years). All participants had competed
at elite levels, including the Olympics, World Cup, World Championship, and varsity
levels. All participants were 10-km specialists with experience at the 5-km distance. Two
also have some experience at the 25-km distance. TEE and PAL measurements were
obtained over 1 week of in-season (August-September); with one participant (ID, 904)
having competed in a 3.8-km OW swim during the 1-week training period.
Participants were recruited by word of mouth. Two participants attended an information meeting during which they were informed of the benefits and potential risks of our study and provided their informed consent. The other three participants were mailed a consent form, with explanations about the research provided by telephone, and returned their written informed consent to us by mail. The ethics committee of Fukuoka University approved the consent form and study protocol (approval no. 14-01-02). The participants were not using any medications affecting glucose and lipid metabolism, had no thyroid and heart diseases, and had self-reported weight stability (<5·0% change in body mass over the previous month). The exclusion criteria included pregnancy, lactation, and amenorrhea (absence of three or more consecutive menstrual cycles).

Two participants completed the measurements for body weight, height, DLW dosing, and urine sample collection in our laboratory. Since the other three lived at a distance from our facility, they provided us with their measures of body weight and height and were given the necessary materials for DLW dosing and urine collection, with instructions provided by phone or video conferencing calls. Participants were asked to log their total daily training time and swim distances completed over 1 week in an indoor pool-training period in a provided printing paper. Basal metabolic rate was estimated using the equation from the

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National Institute of Health and Nutrition (BMR\textsubscript{NIHN}) (Ministry of Health, Labour and Welfare 2015). PAL was calculated as TEE divided by the BMR\textsubscript{NIHN} (Sagayama at al. 2017).

**TEE measured using the DLW method**

TEE was measured using the DLW method for 7 days. Details of the DLW methods appear in our previous study (Sagayama at al. 2017). Urine samples were obtained for analysis at 3 h and 4 h on day 0; morning urine on days 1, 2, 4, and 7; samples from the second or third micturition on those days; and one afternoon sample on day 7. Participants recorded the time of urine collection. TEE was calculated using Weir’s formula (Weir 1948), which is based on CO\textsubscript{2} production, and the average food quotient value (0.87± 0.02) for the entire study group (Black, et al., 1986), which was calculated from the food records. The dilution spaces (N\textsubscript{O} and N\textsubscript{d}) were calculated by the plateau method. The dilution spaces, which passed the quality check for analysis, were 1.030±0.006 (range, 1.022–1.038) (Sagayama et al. 2016). The TBW was calculated as the mean of N\textsubscript{d} divided by 1.041 for the dilution space estimated using \textsuperscript{2}H, with N\textsubscript{O} divided by 1.007 used for the dilution space estimated using \textsuperscript{18}O (Racette et al. 1994). The percent body fat was calculated from the TBW using
the stable isotope dilution technique (Wang et al. 1999). Values were expressed as a mean ± standard deviation or individual mean, as appropriate.

Results

Participant characteristics and composition parameters are summarized in Table 1. The TEE and BMR$_{NIHN}$ are reported in Table 2, including the average daily training time and swim distance for each individual. Overall, the calculated TEE was 5614±549 kcal/day for male and 3839±876 kcal/day for female swimmers. The PAL was 3.50±0.25 for male and 3.03±0.50 for female swimmers. The average training time was 267±10 min/day for male and 188±84 min/day for female swimmers.

Discussion

This study was conducted to examine the TEE and PAL of world-class competitive OW swimmers. To our knowledge, this is the first study to have evaluated the TEE and PAL in elite OW swimmers. Our measurements were based on the DLW method, which is appropriate for the measurement of TEE for water sports. As training for OW swimming is normally performed in an indoor pool, we were able to compare our TEE values with
previously published data that have used the DLW technique for competitive swimmers.

Trappe et al. (1997) reported a TEE of 5593±495 kcal/day for elite female swimmers during a summer training camp. Similarly, Jones and Leitch reported a TEE of 3973±868 kcal/day and 2622±476 kcal/day for male and female collegiate swimmers, respectively, who were completing a relatively low training volume (Jones and Leitch 1993). Compared to these previous studies, the average TEE calculated in our study group can be considered close to a high training volume, being above the reported values for moderate-intensity in-season training (Trappe et al. 1997). Moreover, the TEE value and swim distance (17.5±1.0 km/d) reported by Trappe et al. was close to our maximum TEE value (Trappe et al. 1997). Training volume (time) may be a good estimating factor for the calculation of TEE.

The general vigorous effort intensity of crawl swimming (at a speed of ~75 yards/min, or 1.14 m/s) may be calculated from the 10 metabolic equivalents (METs) of training using the compendium of physical activity (Ainsworth et al. 2011). The intensity of swimming strongly depends on the swimming speed (1.0 to 1.6 m/sec) because the energy cost of swimming is speed dependent (Barbosa et al. 2006, Zamparo et al. 2005). The energy expenditure of swimming can be estimated based on values of energy cost since it changes
as a function of swimming speed; however, we could not infer any energy expenditure data because we do not have the average values of swimming speed during the training sessions (only total training time and swim distance), because the training time and distance were included from the competition-simulated speed to warming-up and cooling down speed, and stretching. Otherwise, we could approach from PAL and METs insight in the average intensity during swim. The average PAL for the general Japanese population is 1.75 (Ministry of Health, Labor and Health, 2015). By converting PALs to METs in this study, we estimate that the swimmers performed, on average, 35 METs/day more than the general population. Considering that these athletes would largely perform these 35 METs of exercise during their training session of approximately 220 min, then their training intensity is about 10.5 METs, including 1 MET of resting energy, which is equivalent to performance of vigorous activity over a prolonged duration. It also was close to 10 METs in the compendium of physical activity as the average value in swim activity (Ainthworth, 2011).

The time for completion of the 10-km OW swim is about 2 hours, which is comparable to that of a marathon run. The PAL value of 3.22 for the elite OW swimmers in our group was higher than the previously reported PAL of 1.99 for elite distance runners completing a
marathon in <3 h (Schulz et al. 1992). Perhaps, the major difference in PAL between
swimming and running depends on the difference between the energy cost of swimming
(1.0-1.6 m/sec) and that of running (1.0 kcal/ weight kg /km) (Barbosa et al. 2006, Margaria
R et al. 1963). Moreover, the energy expenditure value could have different propelling
efficiency and body drag, which strongly influence the energy cost even if at the same
swim speed, compared with running cost (Toussaint and Beek 1992). Moreover, the higher
training energy level for elite OW swimmers compared to distance runners likely reflects
differences in the competitive environment, with OW swimming performed in water
temperature of 25-28°C (FINA regulations), with waves and wind.

One of the participants in our study group (ID, 904) completed a 3.8-km OW swim race
(ocean swim at the average swim speed of 1.45 m/s from the calculation of total time and
the distance: first-prize winner) on day 5 of the training week, with one other participant
(ID, 903) competing in the same distance on day 8 (one day after the end of the
experimental week; ocean swim the average swim speed of 1.40 m/s from the calculation of
total time and the distance: second-prize winner). These intensities were close to the
intensity reported by Zamparo et al. (2005) of 1.34 m/s for gold medal elite swimmers
during a 2-km in-pool trial. The speed may be faster by the course and the current in ocean,
but it is inferred that our subjects were at the top level. Therefore, their in-competition results may reflect a great PAL and TEE in daily training.

This study has some limitations. First, isotope dosing and urine collection were performed by 3 of 5 subjects. However, we provided instructions by phone or video conferencing calls; consequently, the dilution spaces passed the quality check for analysis. Thus, we determined that they finished their sample collection without problem. Second, we could not analyze the time spent on individual activities because any other records than the training could be an additional burden to the top athlete; thus, we reduce the strain of measurement. Third, the number of subjects is low because it is difficult to recruit top athletes for world class valuable data. Further study needs more TEE data from top athletes for energy requirements of OW swimmers.

To the best of our knowledge, this is the first study to have used the DLW method to determine the TEE and PAL for elite competitive OW swimmers. The TEE was 5614±549 kcal/day for male and 3839±876 kcal/day for female swimmers. The PAL was 3.50±0.25 for male and 3.03±0.50 for female swimmers. These values can be used as a baseline to estimate the TEE and PAL over 1 week for elite competitive OW swimmers in-season.
Acknowledgements

We wish to thank the volunteers who participated in this study and the coaches. This investigation was supported by the Fukuoka University Institute for Physical Activity. Data analysis was supported by a research grant to HS from the JSPS (16J11877).

Conflict of interest statement

The authors state that there are no personal conflicts of interest.
References


of elite female runners measured by respiratory chamber and doubly labeled water. J Appl Physiol. 72:23–28. PMID: 1537719


Table 1. Characteristics of the study group

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<tr>
<th>ID</th>
<th>Gender</th>
<th>Height (cm)</th>
<th>Weight (kg)</th>
<th>TBW (kg)</th>
<th>Fat (%)</th>
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BMI, body mass index; TBW, total body water.
Table 2 Energy expenditure

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<tr>
<th>ID</th>
<th>TEE (kcal/day)</th>
<th>BMR&lt;sub&gt;NIHN&lt;/sub&gt; (kcal/day)</th>
<th>PAL</th>
<th>Training time (min/day)</th>
<th>Swim distance (m/day)</th>
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BMR<sub>NIHN</sub>, estimated basal metabolic rate; PAL, physical activity level; TEE, total energy expenditure.