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Underwater Walking Intensity is Modified by a New and Untested Device that Increased the Lower Limb Surface of Movement

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Abstract

Background: This study aimed to compare exercise intensity through measuring oxygen consumption (VO₂), heart rate (HR), and rating of perceived effort (RPE) during an underwater walking at a standardized gait velocity (step × min⁻¹) when wearing swimsuit (SS) or aquatic pants (AP) that increased the drag force.

Methods: 20 young healthy participants (11 M, 9 F) were recruited; each participant was asked to perform two trials in a random order, one with SS, and the other with AP. Each trial consisted in a 20-minute walk on an underwater non-motorized treadmill at 60, 70, 80, and 90 step × min⁻¹.

Results: The total number of steps during the two trials and the walked distance was the same when wearing SS or AP at all rhythms. VO₂, HR, and RPE were significantly higher with the use of AP at all gait velocities (P < 0.001).

Conclusions: Owing to the larger drag force, AP can be considered as an effective device to increase exercise intensity since the cardiorespiratory response was greater when wearing AP rather than SS.

Keywords: Aquatic Pants, Walking, Drag Force, Oxygen Consumption

1. Background

Exercising in water has become increasingly popular. These activities can be considered as safe and effective training methods to increase cardiorespiratory fitness (1), muscle strength (2), flexibility (3), and body composition (4). However, the main peculiarity of the water environment is represented by the dual-effect of buoyancy and resistance that requires higher levels of energy expenditure, with a relatively little movement or strain on low-joint extremities (5). The water is an equalizing medium; its gravity-minimizing nature reduces compressive joint forces, providing a better exercise environment for people who do not tolerate weight-bearing activities (6, 7). These improvements were demonstrated in people at all ages (8, 9).

During the water-based exercise, the intensity can be increased with different methods. In primis, the simplest way is to increase the executive pace of a movement (10). In the use of devices (i.e. dumbbells) with different buoyancy coefficients, a higher intensity is produced in equal motion (11). Finally, another method to increase the exercise intensity can be obtained by maintaining the same movement pace and buoyancy coefficient, but modifying the dimension and the shape of a device. In that case, a higher drag force can be produced (12). The drag force is the mechanical force generated by the interaction between a solid body and a fluid (liquid or gas) acting oppositely to the relative motion of the body. The increase of the drag force is determined by the density and viscosity of the fluid, by the shape and the area of the body, and by the velocity of the body into the water. In particular, as velocity increases, drag force increases in a quadratic manner. Specifically, drag force can be calculated by the general fluid equation: \( F_d = 0.5 \times p \times A \times v^2 \times C_d \), where \( p \) is the density of water (998.6 kg m⁻³), \( A \) is the projected frontal area (meters squared), \( v^2 \) is the velocity of the subject’s body segments, and \( C_d \) is the drag coefficient (13).

All of these features are important during the water-
based exercise to regulate the intensity, adjust movement velocity and/or the surface of movement (14).

Although different studies have compared cardiorespiratory response to the exercise in water and land environments (15), only a few studies have analysed the same exercise performed on water with or without a device (11, 16).

Due to the increasing application of water-based activities and the lack of comparisons between physiological responses to the use or not use of different apparatus, there is a vital need to obtain a better understanding of the cardiorespiratory responses during exercises performed at different intensities with the use of dragging equipment. Therefore, the aim of this investigation was to observe the potential increase of the drag force wearing a new type of equipment. To verify this, we compared the exercise intensity during an underwater treadmill walking at four different gait velocities wearing a standard swimsuit (SS) or aquatic pants (AP) to increase underwater surface of displacement. We hypothesized that wearing the AP might increase oxygen consumption (VO$_2$), heart rate (HR), and rating of perceived effort (RPE) during the same exercise without any equipment.

2. Methods

Twenty participants (11 M and 9 F) were recruited among University students. The mean age was 24.35 ± 2.8 years, and the mean height and weight were 1.73 ± 0.08 m and 68.35 ± 12.93 kg, respectively, with average normal weight (BMI = 22.70 ± 3.53 kg × m$^{-2}$). The research protocol was performed under supervision of the sport and exercise Medicine division staff of the Department of *** (blind for review) at the University of *** (**). Eligibility criteria included age between 18 and 35 years, body mass index (BMI) between 18.5 and 29.9 kg/m$^2$, and no other health problems and/or any physical limitations that could affect the study results. Information on the purpose and procedures of the study was given to each participant, and written consent was obtained before participation. The study complied with the current laws of *** for research on human participants. The investigation procedure was examined and approved by the *** (blind for review) review board (Ethics Board).

The test protocol was carried out in a swimming pool facility with a standardized environment; water temperature was set at approximately 29°C and temperature of air was between 26°C and 30°C (mean 27.28 ± 1.65°C) with 50% humidity, as recommended for a typical water fitness class (17). Before testing, the height and weight were measured respectively to the nearest cm using a stadiometer (Ayrton Corporation, Model St100, Prior Lake, MN) and to the nearest 0.1 kg using an electronic scale (home health care digital scale, model MC-660, C-7300 v1.1). Weight, height, age, and sex were recorded into a computer and a gas analyser. During each session, the participants were outfitted with a breathing mask for expiratory gas collection as well as a heart rate monitor, placed at the level of the xiphoid appendix. Two days before the trial session, the participants were instructed to consume standardized meals (55% carbohydrate, 30% fat, and 15% protein) and to abstain from caffeinated food or beverages 3-hour before the sessions. The protocol consisted of walking on an underwater non-motorized treadmill (Aquatix, IT) with water at the waist level. The pool depth was 1.4 m and the treadmill height was 0.2 m. Body immersion was set before every trial, based on the height of the participant, using 4 adjustable pedestals under the treadmill. The two trials were performed during the same day, one wearing SS and the other wearing AP, in a random order. Before each trial, the participants performed 5 minutes of warm-up and got familiar with the treadmill. After a further 5-minute rest to re-establish the lower heart rate, the participants were instructed to walk following the rhythms dictated by an electronic metronome at 60, 70, 80, and 90 step × min$^{-1}$, each for 5 minutes. The rhythms were derived from an adapted protocol previously adopted by Alberton et al. (10) to reduce the gait cadence because we hypothesized that wearing the AP might increase the exercise intensity (VO$_2$, HR, and RPE); therefore, higher velocities could be excessively difficult to maintain. Furthermore, we added a minute to every stage to facilitate the steady state. No interruptions were provided between stages; there was a rest period of about 45 minutes between the two trials.

The SS consisted of a swim brief for men and two-piece swimsuit for women. These SS were characterized by small surface, close fitting.

AP consisted of long pants, closed with elastic bands at the ankles and at waist, with rubber lines inside the internal surface of the pants front- and back-side. These rubber lines were designed to contrast the textile rolling during the underwater movement, thereby keeping the surface of the pants as wide as possible (Figure 1). In other words, when carrying out the leg movement, pants started to swell in the opposite direction, increasing the total surface. The pulmonary gas exchange (VO$_2$, mL × kg × 1 min$^{-1}$; VCO$_2$, mL × kg × 1 min$^{-1}$) and heart rate (beat × min$^{-1}$) were recorded through a portable gas analyzer (K4b$^2$, Cosmed, IT) and a waterproof heart rate monitor (Polar, FI), respectively. The portable gas analyzer was calibrated before each test, using a known ambient-air and sample gas references, while the turbine flow meter was calibrated with a syringe of 3-liter known volume, following the instruction of the producer. Validity and reliability of the device have been described elsewhere (18). The portable gas ana-
lyzer was placed inside a waterproof box, which was sus-
pended nearby the participant by means of stainless-steel
support to protect the device from splashing water, accord-
ning to a method previously described in similar protocols
(19, 20). All data were recorded during both sessions, with a
telemetry data transmission system from the device to the
computer. RPE was scored using the Borg 6 - 20 scale at 30
seconds before every change of gait velocity; each partic-

   

Figure 1. Aquatic Pants Closed with Elastic Bands at the Ankles and at Waist

Sample size calculation (N) was based on data reported
in a similar protocol by Kanitz et al. (21). The sample size
was calculated with the following equation for each condi-
tion: \( N = \frac{2SD^2(Z_{\alpha/2} + Z_{\beta})^2}{\Delta^2} \). The equation estimated a sam-
ple size of 16.97 that would reflect a result with 80% power.
To ensure an adequate sample size, we oversampled at 20
percent to allow for a 20% dropout rate due to technical problems
or lack of participants interest.

Statistical analyses were carried out using SPSS (version
18.0 for Windows; IBM, Armonk, NY, USA). Results are ex-
pressed as means ± standard deviation or percentage. The
Shapiro-Wilk test demonstrated a normal distribution of
the data. To examine the interaction between the four gait
velocities (60, 70, 80, 90 steps \( \times \) min\(^{-1} \)) and the two condi-
tions (AP vs. SS) for all dependent variables, a 4 \( \times \) 2 within-
within model analysis of variance was applied. Fisher’s
least significant difference post-hoc contrasts with Bonferroni
correction were applied to the different step rhythms. Linear
regressions (\( R^2 \)) were also calculated. Significance
limits were set at the alpha level of \( P = 0.05 \).

3. Results

All participants completed both trials. No adverse ef-
fects or safety concerns were found during the whole ex-
ercise protocol. The mean of the last two minutes of each
stage (from 3rd to 5th minute) of \( VO_2 \) and HR was reported
as the mean ± standard deviation and/or percentage (see
Table 1).

First, taking in exam the gait velocity alone, analysis of
variance indicated statistically significant differences for
all the outcome variables: \( VO_2 \) (\( F = 105.027, P < 0.001 \)), HR
(\( F = 98.435, P < 0.001 \)), RPE (\( F = 250.372, P < 0.001 \)). Finally,
there was a statistically significant difference in the dis-

   

Table 1. Aquatic Pants Closed with Elastic Bands at the Ankles and at Waist

<table>
<thead>
<tr>
<th>Step Rhythm</th>
<th>( VO_2 ) (( \mu L \cdot \text{min}^{-1} \cdot 	ext{kg}^{-1} ))</th>
<th>( HR ) (( 	ext{bpm} ))</th>
<th>RPE (6-20 scale)</th>
</tr>
</thead>
<tbody>
<tr>
<td>60 steps ( \times ) ( \text{min}^{-1} )</td>
<td>15.73% at 60 steps</td>
<td>8.73%, 8.45%, 9.59%, and 7.36% respectively at 60, 70, 80, and 90 steps</td>
<td>6.99% at 80 steps</td>
</tr>
<tr>
<td>70 steps ( \times ) ( \text{min}^{-1} )</td>
<td>10.14% at 60 steps</td>
<td>8.56% at 70 steps</td>
<td>6.99% at 80 steps</td>
</tr>
<tr>
<td>80 steps ( \times ) ( \text{min}^{-1} )</td>
<td>6.99% at 80 steps</td>
<td>12.02% at 90 steps</td>
<td>10.16% at 90 steps</td>
</tr>
<tr>
<td>90 steps ( \times ) ( \text{min}^{-1} )</td>
<td>8.03% at 90 steps</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Post-hoc contrasts showed averagely higher exercise intensity with AP, for all steps. Table 1 reports a higher \( VO_2 \)
value for AP than SS (15.73% at 60 steps \( \times \) \( \text{min}^{-1} \), 12.02% at 70
steps \( \times \) \( \text{min}^{-1} \), 13.07% at 80 steps \( \times \) \( \text{min}^{-1} \), and 8.03% at 90
steps \( \times \) \( \text{min}^{-1} \)). The HR showed similar trend: 8.73%, 8.45%,
9.59%, and 7.36% respectively at 60, 70, 80, and 90 steps \( \times \) \( \text{min}^{-1} \). Moreover, statistically significant higher RPE values
were detected when wearing AP (10.14% at 60 steps \( \times \) \( \text{min}^{-1} \),
8.56% at 70 steps \( \times \) \( \text{min}^{-1} \), 6.99% at 80 steps \( \times \) \( \text{min}^{-1} \),
and 10.16% at 90 steps \( \times \) \( \text{min}^{-1} \)). Levels of significance are re-
ported in Table 1. Finally, complex-modelling ANOVA did
not detect any interaction effect between the four perform-
ing rhythms and the use or not use of AP for all parameters
\( (VO_2, F = 0.940, P = 0.427; HR, F = 0.759, P = 0.521; RPE, F = 0.733, P = 0.073; \text{distance}, F = 0.503, P = 0.789) \). Figure 2
shows relations between \( VO_2 \) and HR for AP and SS condi-
tions. Regression lines were \( y = 2.22814 x + 75.51 (R^2 = 0.3931, P < 0.01) \) and \( y = 2.2262 x + 71.35 (R^2 = 0.4081, P < 0.01) \) re-
spectively for AP and SS. This appears to indicate an over-
all and harmoniously higher exercise intensity when walk-
<table>
<thead>
<tr>
<th>Steps</th>
<th>VO₂ (mL × kg⁻¹ × min⁻¹)</th>
<th>Swimsuit</th>
<th>AP</th>
<th>∆VO₂; P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (60 steps × min⁻¹)</td>
<td>15.04 ± 2.33</td>
<td>17.41 ± 3.57</td>
<td>2.37; P &lt; 0.001</td>
<td></td>
</tr>
<tr>
<td>2 (70 steps × min⁻¹)</td>
<td>18.18 ± 2.06</td>
<td>20.36 ± 4.26</td>
<td>2.18; P &lt; 0.001</td>
<td></td>
</tr>
<tr>
<td>3 (80 steps × min⁻¹)</td>
<td>21.08 ± 4.53</td>
<td>23.84 ± 5.14</td>
<td>2.76; P &lt; 0.001</td>
<td></td>
</tr>
<tr>
<td>4 (90 steps × min⁻¹)</td>
<td>25.39 ± 6.37</td>
<td>27.42 ± 6.07</td>
<td>2.03; P &lt; 0.001</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Steps</th>
<th>HR (beat × min⁻¹)</th>
<th>Swimsuit</th>
<th>AP</th>
<th>∆HR; P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (60 steps × min⁻¹)</td>
<td>99.2 ± 12.44</td>
<td>107.86 ± 12.39</td>
<td>8.66; P &lt; 0.001</td>
<td></td>
</tr>
<tr>
<td>2 (70 steps × min⁻¹)</td>
<td>110.91 ± 13.99</td>
<td>120.29 ± 14.99</td>
<td>9.38; P &lt; 0.001</td>
<td></td>
</tr>
<tr>
<td>3 (80 steps × min⁻¹)</td>
<td>121.02 ± 17.35</td>
<td>132.61 ± 19.47</td>
<td>11.60; P &lt; 0.001</td>
<td></td>
</tr>
<tr>
<td>4 (90 steps × min⁻¹)</td>
<td>134.47 ± 20.81</td>
<td>144.37 ± 22.16</td>
<td>9.90; P &lt; 0.001</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Steps</th>
<th>RPE (Borg 6-20 scale)</th>
<th>Swimsuit</th>
<th>AP</th>
<th>∆RPE; P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (60 steps × min⁻¹)</td>
<td>6.9 ± 1.29</td>
<td>7.6 ± 1.88</td>
<td>0.7; P &lt; 0.001</td>
<td></td>
</tr>
<tr>
<td>2 (70 steps × min⁻¹)</td>
<td>9.35 ± 1.76</td>
<td>10.08 ± 1.95</td>
<td>0.73; P &lt; 0.001</td>
<td></td>
</tr>
<tr>
<td>3 (80 steps × min⁻¹)</td>
<td>11.45 ± 1.43</td>
<td>12.55 ± 1.71</td>
<td>0.80; P &lt; 0.001</td>
<td></td>
</tr>
<tr>
<td>4 (90 steps × min⁻¹)</td>
<td>12.8 ± 1.11</td>
<td>14.1 ± 1.41</td>
<td>1.3; P &lt; 0.001</td>
<td></td>
</tr>
</tbody>
</table>

Abbreviations: AP, Aquatic Pants; RPE, Rating of Perceived Effort.
*P indicates the level of statistical significance.
*Δ (absolute change).

4. Discussion

This investigation aimed to measure the potential increase in exercise intensity wearing a particular type of pants designed to develop the surface of movement during water-based exercise. For this purpose, cardiorespiratory parameters during underwater non-motorized treadmill walking were compared in two conditions, one wearing a traditional SS and the other with AP.

The main result of this study was that HR, VO₂, and RPE outcomes were significantly greater during all the four gait velocities when wearing AP rather than SS. Indirectly, it can be speculated that the conceivable increase of drag force could have determined an overall higher cardiorespiratory response. Apparently, at higher gait velocities, the difference between the two conditions (AP vs. SS) was lower. This flattening effect was more evident observing the tendency in the VO₂ parameter, where there was the highest difference during the lowest gait speed (15.75% of VO₂ at 60 step × min⁻¹) and the smallest variation at the highest gait speed (8.03% of VO₂ at 90 step × min⁻¹). Similarly, HR outcome also showed the same trend: 8.73% at 60 step × min⁻¹ and 7.36% at 90 step × min⁻¹. On the contrary, RPE values did not show any trend, with unexpected higher...
Uncorrected Proof


leagues (1) compared HR, VO
resting metabolic rate. In another study, Pinto and Col-
and without that device showing a post-exercise higher
device. Concretely, they compared the energy expendi-
al. (16) described positive results using a water-dragging
vices developed to increase the drag force. De Souza et
available, only a few investigations described wearable de-
contrast to the larger amount of data about devices to in-
conditions are easily reproducible in a laboratory setting, but

current (26) or adding a water-jet (27); however, these con-
illy modified for instance by walking against an artificial
performance at the same gait ve-
tor to perform the same walking exercise at the same gait ve-
ting to flatten onto the limb and then reducing the to-
total surface of movement; this effect could have determined a
variation in the drag coefficient.

Literature reported a variable relationship between HR
and VO, depending on the type of aquatic exercise (22), inten-
sity (23), water depth (19), and temperature (20). Similar
to Shono et al. investigations (24, 25), our analysis re-
vealed a linear relationship between HR and VO in both
conditions. Despite coefficients of determination that
were moderate for the AP and the SS (R² ≈ 0.4), regression
lines were comparable with equivalent slopes (2.28 for AP
and 2.26 for SS, Figure 2). Interestingly, the AP HR : VO
to was higher compared to that of SS indicating that simi-
lar VO levels corresponded a larger HR response in AP con-
dition. This could support the hypothesis that during AP
condition, a higher cardiorespiratory intensity is needed
to perform the same walking exercise at the same gait ve-

From a practical perspective, the drag force can be eas-
ily modified for instance by walking against an artificial
current (26) or adding a water-jet (27); however, these con-
ditions are easily reproducible in a laboratory setting, but
with a concrete difficult application in the field. In con-
trast to the larger amount of data about devices to in-
crease the buoyancy (28) that are also largely commercially
available, only a few investigations described wearable de-
vices developed to increase the drag force. De Souza et
(16) described positive results using a water-dragging
device. Concretely, they compared the energy expendi-
ture during a session of strength training performed with
and without that device showing a post-exercise higher
resting metabolic rate. In another study, Pinto and Col-
leagues (1) compared HR, VO, and electromyographic sig-
nals during exercise with a water-dragging force equipment,
water-floating equipment, and without any equipment.
The HR and VO showed significantly higher values dur-
ing the aquatic workout with both devices compared to
the same performance without equipment. More inter-
estingly, a greater electromyographic response was seen
using the drag force device than with the water-floating
equipment, which in turn suggested a greater resistance to
the movement in that condition.

This investigation presents several limitations. The
main limit is probably due to that the AP has three sizes.
We selected the appropriate size following the waist cir-
cumference as a standard criterion. This entailed that a
non-uniform drag force was probably produced. Another

critical point consisted in the positioning of the under-
water non-motorized treadmill. The treadmill was placed
near the poolside; then, waves generated by the lower
limbs might have affected the surface movement of the AP.
Finally, temperature and humidity variations could have
slightly affected the reading of the respiratory volumes
by the gas analyzer. Nonetheless, these variations should
be considered as minimal and acceptable variations since
punctual calibration of the gas analyzer was performed be-
fore all trials.

To summarize, the AP seemed to be an effective tool to
increase exercise intensity during underwater walking. It
was concretely difficult to make strict comparisons among
our results and the other aforementioned results mainly
due to that devices were basically different; second the
types of exercise were not standardized (as the our) and
finally some investigations focused on the elderly or other
populations which were not similar to our sample. Fur-
thermore, the effectiveness of AP to increase the intensity
in other types of exercise rather than underwater walking
has not been proven. Future protocols should take into
consideration investigating other types of population, es-
pecially people who need to exercise with low movement
velocity, in particular for knee and / or hip osteoarthritis,
where aquatic protocols are strongly recommended (29).
Another interesting point concerns the capacity of the un-
derwater waves to create unbalanced conditions (4). The
use of AP could further stress this phenomenon due to the
larger surface; this may produce an increase in static and
dynamic balance capacities. One non-secondary aspect of
the use of AP concerns the possibility to hidden the own
body from the other views during workout sessions. This
should be taken into account when discussing about mo-
tivation to exercise (30) and explaining reasons for early
dropouts, since the AP could help hide their own body, es-
pecially for those people who do not feel comfortable with
their own body image.

In conclusion, the AP could be considered as an effec-
tive device to increase exercise intensity. The results of
the present study indicated that AP was able to increase VO,
HR, and RPE during an underwater walking in comparison
with traditional swimsuit. The increase of drag force could
have determined an overall higher cardiorespiratory re-
response during the underwater walking. Nevertheless,
the difference of cardio-metabolic parameters when wearing
swimsuit or AP was not the same in each gait velocity. Fi-
ally, AP may be an effective device to increase exercise in-
tensity and improve cardio-metabolic and physical fitness.

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any institution or private entity.

References