ABSTRACT
Purpose. This study aimed at introducing a method towards determining the dynamical asymmetry of the upper extremities during swimming and to find its relationship with lower-limb movements in children when swimming the breaststroke. Methods. Twenty boys participated in the research, where seven boys were found to perform incorrect lower-limb movements when swimming. Therefore, the subjects were divided into two groups, those who maintained correct lower-limb movements when swimming and those who did not. The subjects swam for short distances using either only their upper limbs or both upper and lower limbs. The water pressure that was exerted on the right and left hand of the subject was recorded for both tests. On the basis of the compiled data, the upper-limb movements' asymmetry index was calculated. Results. Incorrect lower extremity movements when performing the breaststroke resulted in increased upper-limb dynamical asymmetry. Conclusion. The method applied in this study enables one to diagnosis the dynamical asymmetry of upper-limb movements when swimming. Altogether, it was found in the examined group that incorrect lower-limb movements in the breaststroke did not decrease swimming efficiency. However, an increase of the upper extremities' dynamical asymmetry might have decreased the efficiency of the shoulder-girdle muscles' symmetrization. In the case of individuals performing incorrect lower-limb movements in the breaststroke, it is recommended to improve their performance or to swim with the upper limbs only.

Key words: symmetrization, pressure sensors, augmented feedback, therapy

Introduction
The results of research conducted on primary school children are alarming, where the great majority of children are found to display abnormal or incorrect body postures. The number of afflicted children only increases in later school years and can be mainly observed in boys [1, 2]. This occurrence is frequently related to lifestyle diseases, an increased lack of physical activity and incorrect sitting posture [1, 3]. It is also connected with a lack of knowledge about preventive treatments for body posture as well as the effect of pre-pubertal acceleration [4]. Only early prevention, quick diagnosis and suitable corrective treatment may lead to a decrease of this trend. Corrective treatment largely consists of specific exercise, where symmetrical exercises are usually recommended to individuals with scoliotic posture [3], while asymmetrical exercises are used in treating scoliosis [5]. Although many of the suggested exercises are performed in a gym, swimming has been found to enrich such corrective treatments, not only as a form of physical activity, but its increasingly larger role in the prevention and correction of body posture [3, 6]. Water, thanks to its natural properties, such as it having a higher density than air as well as providing buoyancy and increased resistance force (its value increases with velocity squared) provides ideal conditions for such treatment. Contrary to land-based activities, swimming allows a subject’s position to be horizontal, allowing the spine to be unloaded. The main form of propulsion is provided by the upper extremities [7, 8], allowing the spine to be correctly shaped by exercising the muscles of the upper extremities [9]. In this case one very suitable form of swimming is the breaststroke (and its varieties), which can be considered to be a type of symmetrical physical activity [10], and, as such, may be applied in providing treatment for scoliotic body posture. However, one aspect that needs clarification is the frequently observed asymmetrical movements of the lower extremities in the breaststroke [11–13], which may disturb the proper performance of the upper limbs. Such an issue may not even be considered when providing therapeutic treatment, and unfortunately, the recommendation of different types of corrective exercises without detailed knowledge of the disparities that may exist in them can be problematic. This intuitive way of selecting exercises for therapeutic treatment may be even inefficient or harmful. Although there are many methods for monitoring the results of such therapy (such as x-ray, MRI, photogrammetry, etc.), they are unfortunately expensive and most of them are able to provide only long-term diagnoses [14–16]. In addition, their application is usually limited to land-
based activities [17]. Therefore, there is a need to have a tool that is capable of providing objective information on the performance of providing breaststroke swimming as a form of treatment [18]. The research found in this paper aims at introducing a method that can be applied to determining the dynamical asymmetry of the upper extremities during swimming and in finding the relation of these values with the lower limbs movements when performing the breaststroke, especially in regard to children.

**Material and methods**

Twenty 11-year-old boys participated in the study. As primary schools provide swimming lessons for children from the 1st to 3rd grade, it was decided to include only boys who had finished the 3rd grade. Each subject was informed about the experiment and the boys’ parents provided written consent. In addition, approval for the experiment was given by the University’s Senate Committee for the Ethics of Scientific Research. The experiment was conducted at the Research Laboratory on Human Movement in a Natural Environment at the University School of Physical Education of Wroclaw, which received a Certificate of Quality Management System and fulfills the requirements of PN-EN ISO 9001:2001.

As was mentioned, twenty 11-year-old boys participated in the study. The subjects’ anthropometric features were measured, including age, body mass and body height, finding the examined subjects to be almost nearly homogenous (Tab. 1). During initial water trials, seven of the subjects displayed incorrect (asymmetrical) lower limbs movements when swimming. As such, the twenty boys were then divided into two groups, the first (I) showing correct (symmetrical) lower-limb movements and the second (II) showing incorrect (asymmetrical) lower-limb movements.

The hand’s surface is the most important source of propulsion provided by the upper limbs during swimming [19]. Its trajectory and attack angle determines the propulsion’s force [20]. However, this force is not generated by pressure created by the water on the palm, but by its pressure differential between the palmar and dorsal side of the hand [8, 19]. To measure propulsion two 26 PCB type 5 (Honeywell, USA), connected to a computer, were used. The sensors were placed between the third and fourth finger of both the right and left hand to measure the difference of water pressure exerted on the back and on the palm of each hand. Prior to measurement the pressure sensors were calibrated by signal measurement at depths of 0, 20, 40, 60, 80 and 100 cm. In addition, the pressure sensors were calibrated with normal atmospheric pressure as a reference. The immersion depth of the sensor did not influence the signal level.

The task of the subjects was to swim 15 m in the shortest possible time. The participants each started from a vertical position without pushing off from the wall or swimming pool bottom. The first test was to swim the breaststroke using both the upper and lower limbs (this test was named UL+LL). After a period of rest, the test was repeated. This time, a pull buoy was placed between the lower limbs which immobilized the legs and prevented them from being used as a source of propulsion. The subjects then swam the breaststroke using only their upper limbs (UL). The time to complete the distance and the difference of pressure for the right and left hand were recorded. The signal was sampled at a frequency of 100 Hz. The recorded signals were filtered by a 4th Order Butterworth Filter Stage at a 12 Hz cutoff frequency. The propulsion phases from the 6th to the 10th cycles of both tests were then analyzed. It was assumed that the upper limbs’ propulsion phase started once the difference of pressure is positive for the first upper limb to enter the water, while the end of the phase reflected the last positive value of the measured pressure difference from the second limb (Fig. 1).

![Figure 1. An example of the propulsion phase](image)

| Table 1. The characteristics of the research subjects (means ± standard deviation) |
|-------------------------------|-------------------|-------------------|
| Group                         | I (N = 13)        | II (N = 7)        |
| Age (years)                   | 11.1 ± 0.3        | 10.9 ± 0.2        |
| Body mass (kg)                | 42.7 ± 6.4        | 40.0 ± 7.7        |
| Body height (cm)              | 153.0 ± 4.4       | 149.0 ± 8.2       |
| $t_{15m}$ UL+LL (s)           | 14.2 ± 0.7        | 14.2 ± 1.2        |
| $t_{15m}$ UL (s)              | 19.3 ± 1.8        | 19.0 ± 1.7        |

Group I – correct (symmetrical) lower-limb movement
Group II – incorrect (asymmetrical) lower-limb movement
$t_{15m}$ UL+LL – 15 m swimming time using both upper and lower limbs
$t_{15m}$ UL – 15 m swimming time using only upper limbs
\[ A = \frac{\left| P_R - P_L \right|}{2 \cdot \max(|P_R|,|P_L|)} \cdot 100\% \] (1)

where \( P_R \) and \( P_L \) are the values of the pressure differential for the right and left hand, respectively. The numerator corresponds to the modulus of the partial for the right and left hand, respectively. The denominator represents the modulus of the highest time sample value between \( P_R \) or \( P_L \) multiplied by two. When \( A = 0\% \), the hand movements is symmetrical (\( P_R = P_L \) and \( P_R > 0 \) and \( P_L > 0 \)). Positive asymmetry is assessed when \( 0\% < A < 50\% \) (\( P_R > 0 \) and \( P_L > 0 \) and \( P_R \neq P_L \)). \( A = 50\% \) represents border asymmetry, where one limb has a pressure differential of 0 (\( P_R = 0 \) and \( P_L > 0 \) or \( P_L = 0 \) and \( P_R > 0 \)). For 50% < \( A < 100\% \) there is negative asymmetry (\( P_R > 0 \) and \( P_L < 0 \) or \( P_R < 0 \) and \( P_L > 0 \)). \( A = 100\% \) represents full asymmetry of the hand movements (\( P_R = -P_L \)).

The mean asymmetry coefficient for each subject was then determined and the results were checked by seeing if the requirements of using a parametric test were fulfilled. The Shapiro-Wilk test was applied to determine the normality of the variables' distribution. The homogeneity of variations was verified by using the Levene test. The influence of the lower limbs on upper-limb movement symmetry was verified by an analysis of variations with repetitions and Fischer's post-hoc test. The level of statistical significance was set as \( p < 0.05 \).

Results

When only the upper limbs propelled the body, the participants of both groups obtained the same dynamical asymmetry values (Fig. 2). However, the results from both groups were significantly different once the lower limbs were used as a second source of propulsion. The usage of the lower limbs of group I, using the correct movements, did not result in upper-limb movement asymmetry, while the incorrect lower-limb movements of group II reflected an increase in upper-limb movement asymmetry. ANOVA results revealed that the greatest influence on the dynamical asymmetry of the upper limbs could be influenced by two factors: the amount of propulsion and the type of movements performed by the lower extremities. The usage of the lower limbs of group I, showing symmetrical lower-limb movements. It may seem that asymmetrical lower-limb movements, considered as incorrect, should lower the performance capacity of the subjects. However, the time required to swim the 15 m distance for both groups was identical when both the upper and lower extremities were used as a source of propulsion. Hence, such a statement cannot be made.

Nonetheless, it was observed that incorrect lower-limb movements negatively influenced upper-limb movements due to an increase in dynamical asymmetry. It should be noted that lower limb movement asymmetry when swimming the breaststroke is largely understood as incorrect through the rules of International Swimming Federation (FINA, Fédération Internationale de Natation) [22]. There were several attempts to explain the origin of how this asymmetry came about [11–13]. The results obtained indicate that the correctness of the lower extremities' movements in the breaststroke should also be perceived through its coordination with the upper extremities' movements. This is because the human body is a biokinematic chain of linked components which mutually interact [23]. Errors, specifically asymmetric movements, created by the lower extremities may negatively influence the performance of the upper extremities. Their influence on the muscle system's development may be different and depend on the degree of congruity within such a pattern. The results obtained in this study question the usage of the breaststroke with asymmetric movements of the lower extremities as a measure to symmetrize the muscles of the shoulder girdle. Unequally shaped shoulder girdle muscles disturb spine mechanics and have a poor effect on their statics [24]. An incorrect, long-lasting load of this kind may cause maladaptation and structural changes in the spine area [25]. From a mechanical view-
point, providing a balanced load is a necessary aspect in the case of providing corrective treatment to the spine. Therefore, a careless application of competitive swimming strokes for body posture correction may create disadvantageous effects [26–28]. Some recommendations that consider modifying the usage of competitive swimming strokes for therapy can be found in literature [3, 29]. However, none of them are supported by any objective forms of data. For example, such attempts were made by Iwanowski and Fecica [26], but the limited amount of collected data was caused by a lack of tools which could be applied in water [17]. The conditions of a water environment make it difficult, even impossible, to properly adjust diagnostic methods that are used on land. Therefore, it is important to build a valid, user-friendly and low-cost assessment tool that is adequate in diagnosing the effectiveness of swimming therapy. It is hoped that the presented method in this study meets these requirements. Moreover, this method is not harmful to the tested subjects and can be applied at each stage of therapy. In addition, the obtained results facilitate archiving and enable one to make comparisons with the recorded data. The data on the performance of the limbs’ movements give the ability to quantitatively assess as well as conduct modifications of treatment, allowing for an individual approach to a subject. Such augmented feedback increases performance [30] and the motivation of participants [31]. Moreover, faster feedback yields improvement and reduces the duration of therapy [32]. However, upon completing treatment for postural defects, other, more sophisticated methods (X-ray, photogrammetry, etc.) should be used to assess the final results. In addition, one limitation of the presented method is the focus on causes of movement, e.g., the forces. Hence, in order to obtain a more complete account of the movements, future studies should include video recording.

Conclusion

1. The applied method allows for diagnosis of dynamical asymmetry present in upper limbs movements during swimming.
2. Incorrect lower limb movements in the breaststroke did not decrease sports efficiency of the examined group. However, an increase of the upper extremities’ dynamical asymmetry might have decreased the efficiency of the shoulder girdle muscles’ symmetrization.
3. In the case of incorrect lower limb movements present in the breaststroke, it is recommended to improve their performance or to swim using the upper limbs only.

References


Paper received by the Editors: January 21, 2010
Paper accepted for publication: May 26, 2011

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