Title: Immediate Effects of The Deep Trunk Muscle Training on Lumbar Spine Alignment During Swimming

Running Title: Effective Deep Trunk Muscle Training

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Abstract

Trunk stabilization exercises improve injury prevention and performance, but the effect of deep trunk muscle training for underwater competitive performance and posture has not been clarified. If trunk stability can be obtained immediately after trunk stabilization exercises, such exercises may lead to performance improvements during underwater swimming and improve lumbar lordosis alignment during swim motions. The purpose of this study was to clarify the immediate effects of deep trunk muscle training on lumbar lordosis angle and swimming speed in underwater motion. The trial examined underwater motion before and after two different types and intensities of trunk stabilization exercises (low-intensity and high-intensity). Underwater motion was observed with an underwater high-speed camera placed 7.5 m from the pool wall, while lumbar lordosis angle was measured from the angle formed by markers affixed to the Th12, L3, and S1. During the glide swim, dolphin kick, and flutter kick trials, the maximum lumbar lordosis angle was
calculated. Lumbar lordosis angle and swimming speed were calculated before and after two different intensities of trunk exercise interventions. There were significant differences in lumbar lordosis angle after both exercises during all three underwater motions. The high-intensity intervention elicited a significantly lower lumbar lordosis angle during glide swim, dolphin kick, and flutter kick, while swimming velocity was also improved during glide swim and flutter kick ($P<0.05$). Performing trunk exercise before practice or competition may help improve competition performance by reducing underwater resistance.

Keywords: swimming, lumbar lordosis, deep trunk muscle training, speed improvement
1. Introduction

The deep trunk muscles, such as the transverses abdominis and internal oblique, contribute to the improvement of sports performance (Butcher et al., 2007; Imai et al., 2014; Sato and Mokha, 2009; Sharma et al., 2012) and the prevention of injuries (Durall et al., 2009; Harringe et al., 2007; Hides et al., 2001). Therefore, trunk stabilization exercises aiming to train the deep trunk muscles have been routinely prescribed for athletes in a variety of sports in recent years (Imai et al., 2014; Sharma et al., 2012).

The trunk plays an important role in moving the extremities during swimming motion, and increased trunk stability of the deep trunk muscles can improve performance. Due to their importance for competition, athletes routinely perform trunk stabilization exercises as a part of daily training, as well as to warm up the trunk musculature before a competition. In crawl-type swimming, it has been shown that trunk exercise interventions improve performance (Weston et al., 2015), and our group has previously reported that the trunk exercise interventions improve the 5 m time of entering the water after the start motion (Iizuka et al., 2016). However, the immediate effects of trunk exercises on swimming performance have not been elucidated by using motion analysis, and no research on the optimal type and intensity of exercise has been conducted. In previous studies, basic stabilization training was used as intervention exercise, but practical daily exercises are more intense and different types are being performed. Therefore, the effect of exercise intervention on underwater motion needs to clarify the effects of the previous basic exercise as well as the effect of the high-intensity exercise practiced by the athlete. Moreover, it is important to evaluate the effectiveness of the intervention, by not only evaluating the swimming velocity but by also evaluating the motion analysis of the alignment where the deep trunk muscle directly adheres. We
aimed to clarify the immediate effects of trunk exercise on lumbar lordosis angle and swimming velocity in underwater motion (i.e., glide swim, dolphin kick, flutter kick), as well as the impact of trunk stabilization exercise intensity for swimming athletes.

2. Methods

2.1. Participants

Thirteen swimmers (mean age: 19.3±1.5 years, height: 175.2±5.0 cm, weight: 70.9±4.1 kg, BMI: 23.1±1.2, FINA POINT: 800.7±79.1) were recruited from the swimming team at our university. All swimmers in this study had lengthy swimming careers and participated in national tournaments. The swimmers were all high level athletes. The swimming style of participants was not considered. All participants were provided with and signed written informed consent forms, before participation in the study. Swimmers who had severe respiratory dysfunction (e.g., asthma or pneumonia) or spinal injury were excluded from the study. This study was approved by the Ethics Committee of our university.

2.2. Measurement

Nine self-emitting LED markers (Kirameki, Nobby Tech. Ltd) were attached to anatomical landmarks on the processus spinosus of Th7, Th12, L3, and S1, anterior superior iliac spine, posterior inferior iliac spine, great trochanter, lateral joint space, and lateral malleolus (Figure 1). Marker sticking after palpation was carried out by a skilled physiotherapist. Sagittal alignment of the spine was measured as described by Kobayashi (Kobayashi et al., 2015) (Figure 2). Recording frequency was set at 200 frames per second during underwater motion (i.e., glide swim, dolphin kick, and flutter kick) with a high-speed underwater camera positioned 7.5 m from the pool wall. The
camera was set up to capture the motion of the sagittal view (Figure 3). The underwater motion was observed from the pool wall to 15 m, and subjects swam at full capacity.

2.3. Exercise trial

Research by Iizuka et al. (Iizuka et al., 2016) was our pilot study. In the current study, we followed the exercise intervention method presented in the pilot study. Subjects were allowed an approximate 10-minute warm-up session that included glide swim, dolphin kick, and flutter kick motion, prior to the measurement. The trunk exercise protocol was carried out immediately after initial underwater motions including glide swim, dolphin kick, and flutter kick (pre). After the trunk stabilization exercise protocol, the same underwater motions of glide swim, dolphin kick, and flutter kick were performed (post). After a sufficient rest period (the rest period was about 2 hours and we also checked the subjects for fatigue from the previous trial), a second set of trunk stabilization exercises at a different intensity were evaluated using the same protocol.

Trunk stabilization protocols consisted of three exercises, each of which included content that has been confirmed to enhance activities of the deep trunk muscles, as indicated in our previous study (Okubo et al., 2010). Subjects performed two types of interventions which were conducted at random. Intervention 1 was low-intensity, with participants performing the elbow-knee position for 60 seconds, alternating arm raises in the elbow-knee position for 30 repetitions, and alternating leg raises in the elbow-knee position for 30 repetitions (Figure 4). Intervention 2 was high-intensity, with participants performing an inside bridge for 30 repetitions, elbow-knee with arm raises for 30 repetitions, and elbow-toe with hip extensions on an unstable surface for 30 repetitions. Fifteen seconds of rest was allowed between the exercises (Figure 4). The exercises performed in this study are employed as part of the Japanese national
swimming team routine and are used as a warm-up prior to competition. In addition, these exercise interventions were identical to those used in our previous pilot study (Iizuka et al., 2016).

In addition, in this study, we added the inside bridge of intervention 2 (a) which was not used in previous our research. This exercise is carried out by advanced swimmers in actual training, and it is also used for warming up by Japanese national team swimmers (Figure 5).

2.4. Calculation item

Starting motion was analyzed using three-dimensional motion analysis software (frame DIAS5, DKH Co., Ltd). The lumbar lordosis angle was measured from the angle formed by the markers affixed to the Th12, L3, and S1 sites. The value obtained by subtracting the angle formed by three points from 180° was taken as the lumbar lordosis angle (Figure 2). The maximum lumbar lordosis angle during one kick motion was calculated during the dolphin kick and the flutter kick. The swimming velocity was recorded when the participants were 7.5 m from the pool wall. The smaller lumbar lordosis, the closer posture was to a straight line without lordosis.

2.5. Statistical Analysis

In the statistical analysis, all measurements are shown as means ± standard errors. Two-way factorial analysis of variance (trial × intervention) was used in all measurement items. The Bonferroni procedure was used for the post hoc test. Statistical processing was performed by using SPSS Statistics 25, IBM Japan Inc. P values < 0.05 were considered significant.

3. Results
There were significant differences in lumbar lordosis angle after intervention 1 and intervention 2 during all three underwater motions (i.e., glide swim, dolphin kick, and flutter kick) (Table 1). After the high-intensity intervention 2, the lumbar lordosis angle decreased more significantly than it did after intervention 1 in all three underwater motions (i.e., glide swim, dolphin kick and flutter kick) (Table 1). There were no significant differences in swimming velocity after low-intensity intervention 1 was performed during all three underwater motions. On the other hand, after intervention 2, swimming velocity improved significantly from 1.23 ± 0.36 m/sec to 1.33 ± 0.40 m/sec (p<0.05) in the glide swim, and from 1.61 ± 0.24 m/sec to 1.71 ± 0.27 m/sec in the flutter kick; however, swimming velocity did not improve significantly for the dolphin kick, although a trend was observed (Table 1). In addition, in order to confirm that there was no influence from the previous trial, lumbar lordosis angle and swimming velocity were compared among trials before the trunk stabilization exercises intervention, and there were no significant differences found among the trials (pre-intervention 1 vs. pre-intervention 2).

4. Discussion

After interventions 1 and 2, the lumbar lordosis angle decreased in all three underwater motions (glide swim, dolphin kick and flutter kick). The elbow-knee and elbow-toe exercises employed in both interventions promote constriction of the transverses abdominis and internal oblique, according to studies examining muscle activity during motion (Okubo et al., 2010). Even in actual muscle activity during underwater motion, it has been reported that alternating trunk muscle activity, and not just lower limb activity, is necessary for an efficient underwater dolphin kick (Kobayashi et al., 2015).
Nakashima also reported that performing the dolphin kick from the trunk stabilizes upper body posture and improves both swimming velocity and propulsion efficiency in computer simulation models (Nakashima, 2009). Furthermore, it has been observed that the activity of the internal oblique during flutter kick increases during the transition from the up-kick to the down-kick (Kaneoka et al., 2015). In the present study, deep trunk muscle activity was promoted by trunk stabilization exercises when the lumbar lordosis was most advanced (i.e., kick switching from hip joint extension-to-flexion direction). Therefore, the lumbar lordosis might have decreased due to the stability of the lumbar spine and pelvis.

In our previous study, we reported that the low-intensity intervention 1 was effective in improving start motion performance (Iizuka et al., 2016). Similarly, in this study, alignment was improved after intervention 1, but no improvement in speed was observed, and intervention 2 showed improvements in both alignment and speed. Based on the above findings, if swimmers are aiming to improve underwater motion performance or body alignment, higher intensity exercise, such as those included in intervention 2, should be recommended. Interventions 1 and 2 differ not only in intensity but also in training content. Intervention 2 includes an inside bridge that facilitates adductor, abdominal, and internal oblique muscle. In order to maintain a more stable underwater posture, cooperative muscle activity of the pelvic rotation bracing and lower limb muscle group is considered important. It would be better to include the inside bridge and elbow-toe with hip extension unstable exercises, which are considered to further activate the muscles involved in pelvic stabilization.

Limitations

No control group was provided in this study; so, the effect of the previous trial cannot
be determined. Without this study an adaptive or synergistic effect of coupling the lower intensity trunk exercises with the higher intensity trunk exercise. However, when comparing the pre-trial effects between intervention 1 and intervention 2, there were no significant differences in both the lumbar lordosis angle and the swimming velocity in any of the underwater motions (i.e., glide swim, dolphin kick, flutter kick). Therefore, we believe that the observed changes in outcome measured in this study are largely caused by the trunk stabilization interventions. In addition, it is unknown whether the muscle activity was actually increased by the exercise interventions and whether there were any changes in muscle activity during underwater motion. Therefore, it is important to consider using muscle activity analysis during underwater motion. The subjects of this study were very high-level swimmers. Therefore, it was possible to contract deep trunk muscles during exercise, and there was a possibility that the intervention effect could be more easily obtained. For low-level athletes, it is possible that the outer muscle is excessively contracted instead of the deep trunk muscle, and the effect obtained by the same exercise content may differ. More research should be done to consider the effect of these interventions on subjects with each level of athleticism.

5. Conclusion

After trunk stabilization exercise, the lumbar lordosis angle during underwater motion decreased. In particular, the use of higher-intensity trunk stabilization and inside bridge exercises decreased the lumbar lordosis angle more, whereas swimming velocity improved during the glide swim and flutter kick.
6. References

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Membership in Learned Societies

Japanese Society of Clinical Sports Medicine
The Japanese Orthopedic Society for Sports Medicine
Japanese Society of Sciences in Swimming and Water Exercise
Japanese Physical Therapy Association
Japan Swimming Federation Medical Committee
Figure 1. Marker Placement
Figure 2. The lumbar lordosis angle

The lumbar lordosis angle was measured from the angle formed by the markers affixed to Th12, L3, and S1. The value obtained by subtracting the angle formed by the three points from 180° was taken as the lumbar lordosis angle.
Figure 3. Camera setting
Figure 4. Contents of Stabilization exercises

Stabilization exercises intervention 1; (a) Elbow-Knee (60 s), (b) Elbow-Knee with Arm raise (30 repetitions), (c) Elbow-Knee with Leg raise (30 repetitions). Stabilization exercises intervention 2; (a) Inside bridge (30 repetitions), (b) Elbow-Knee with Leg raise (30 repetitions), (c) Elbow-toe with Hip extension unstable exercise (30 repetitions).
Figure 5. Actual warm up exercise performed before the swimming race in the FINA World Championships in 2015
Table 1. Lumbar lordosis angle and swimming velocity before and after training intervention

|                     | Glide Swim | Dolphin Kick | Flutter Kick |
|---------------------|------------|--------------|--------------|
|                     | Intervention 1 | Intervention 2 | Intervention 1 | Intervention 2 |
| Lumbar lordosis angle |            |              |              |
| pre(deg)            | 17.6±10.4  | 16.5±10.2    | 33.4±16.9    | 32.2±16.8    |
| post(deg)           | 15.3±10.1* | 8.8±9.5**++  | 28.0±17.2*   | 21.1±18.0**++|
| Swimming velocity   |            |              |              |
| pre(m/sec)          | 1.27±0.38  | 1.23±0.36    | 1.80±0.20    | 1.77±0.23    |
| post(m/sec)         | 1.28±0.38  | 1.33±0.40**+ | 1.81±0.20    | 1.85±0.22    |

*p<0.05 (vs pre), **p<0.01 (vs pre), ***p<0.05 (vs intervention 1), ****p<0.01 (vs intervention 1)

| Source                       | F value | P value | effect size | ANOVA 2 way (Bonferroni) |
|------------------------------|---------|---------|-------------|--------------------------|
| Lumbar lordosis angle        |         |         |             |                          |
| glide swim                   |         |         |             |                          |
| Pre and Post                 | 19.9    | 0.01    | ** 0.62     | Pre > Post               |
| Contents of intervention     | 13.7    | 0.03    | ** 0.53     | Intervention 1 > Intervention 2 |
| Pre and Post×Intervention    | 10.7    | 0.007   | ** 0.47     |                          |
| dolphin kick                 |         |         |             |                          |
| Pre and Post                 | 14.8    | 0.002   | ** 0.55     | Pre > Post               |
| Contents of intervention     | 6.8     | 0.023   | ** 0.36     | Intervention 1 > Intervention 2 |
| Pre and Post×Intervention    | 9.2     | 0.011   | ** 0.43     |                          |
| flutter kick                 |         |         |             |                          |
| Pre and Post                 | 16.3    | 0.002   | ** 0.58     | Pre > Post               |
| Contents of intervention     | 0.7     | 0.41    | * 0.06      | Intervention 1 > Intervention 2 |
| Pre and Post×Intervention    | 15.1    | 0.002   | ** 0.56     |                          |
| Swimming velocity            |         |         |             |                          |
| glide swim                   |         |         |             |                          |
| Pre and Post                 | 19.9    | 0.01    | ** 0.62     | Pre > Post               |
| Contents of intervention     | 13.7    | 0.03    | ** 0.53     | Intervention 1 > Intervention 2 |
| Pre and Post×Intervention    | 10.7    | 0.007   | ** 0.47     |                          |
| dolphin kick                 |         |         |             |                          |
| Pre and Post                 | 2.2     | 0.17    | 0.15        |                          |
| Contents of intervention     | 0.6     | 0.8     | 0.01        |                          |
| Pre and Post×Intervention    | 2.4     | 0.15    | 0.17        |                          |
| flutter kick                 |         |         |             |                          |
| Pre and Post                 | 5.8     | 0.03    | * 0.38      | Pre > Post               |
| Contents of intervention     | 0.4     | 0.54    | 0.03        |                          |
| Pre and Post×Intervention    | 1.8     | 0.21    | 0.13        |                          |
In both intervention 1 and intervention 2, lumbar lordosis angle decreased post-intervention compared to pre-intervention. After the high-intensity intervention 2, the lumbar lordosis angle was more significantly decreased than in intervention 1 in all three underwater motions (pre vs post).

In intervention 2, swimming velocity improved significantly from 1.23 ± 0.36 m/sec to 1.33 ± 0.40 m/sec in the glide swim, and from 1.61 ± 0.2 m/sec to 1.71 ± 0.27 m/sec in the flutter kick (pre vs post). In the glide swim, after high-intensity intervention 2, lumbar lordosis angle was more significantly decreased than after intervention 2.

There were no significant differences between the pre-trials (pre-intervention 1 vs. pre-intervention 2).