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The Relationship Between Horizontal Push-Off and Land-Based Vertical Jump During Tumble Turns in Freestyle Swimming

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Abstract

The aim of this study was to investigate the relationship between the horizontal push-off against the pool wall and the land-based vertical jump performance during the tumble turn in freestyle swimming technique. Twenty-one young male swimmers (age:15.7±1.53 years; height:176.3±7.07 cm; body weight:63.7±7.61 kg) with at least four years of swimming training experience were participated in the study. In this study, the swimmers were tested on land and in the water. To examine the land based vertical jump performance, the countermovement jump, and the drop-jump (25 cm height) tests were performed. In the pool tests, the swimming times at 20 m, 25 m and, 5 m after the tumble turn were recorded. The relationship between land based and in water performance were analyzed using Pearson Correlation Test. A significant relationship was found between the tuck index and the drop jump height ($p<0.05$). A strong positive correlation was found between the tuck index angle, the 25 m swimming time, and the average speed for the last 5 m before the turn ($p<0,05$). As a result, it was investigated that increasing the vertical jump training and the land-based training can also increase the swimming performance. It is recommended that swimming coaches include lower extremity vertical strength training exercises on land in training programs.

Keywords: Acceleration, Tuck Indeks, Countermovement-jump, Drop jump, Plyometric jump

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Serbest Stil Yüzmede Takla Dönüşleri Sırasındaki Yatay İtiş ve Karada Yapılan Dikey Sıçrama Arasındaki İlişkinin İncelenmesi

Özet

Bu çalışmanın amacı, serbest stil yüzme tekniğinde takla dönüşü sırasında havuz duvarına karşı yapılan yatay itiş ile karada yapılan dikey sıçrama performansı arasındaki ilişkiyi araştırmaktır. Çalışmaya en az dört yıllık yüzme antrenman deneyimi olan 21 genç erkek yüzücü (yaş:15.7±1.53 yıl; boy:176.3±7.07 cm; vücut ağırlığı:63.7±7.61 kg) dahil edilmiştir. Bu çalışmada yüzücüler karada ve suda test edilmiştir. Karada dikey sıçrama performansını incelemek için countermovement-jump ve drop-jump (25 cm yükseklik) testleri yapılmıştır. Havuz testlerinde, 20 m, 25 m ve takla dönüşünden sonraki 5 m yüzme süreleri kaydedilmiştir. Karadaki ve sudaki performans arasındaki ilişki Pearson Korelasyon Testi kullanılarak analiz edilmiştir. Tuck indeksi ile drop jump yüksekliği arasında anlamlı bir ilişki bulunmuştur (p<0,05). Tuck indeks açısı, 25 m yüzme süresi ve dönüşten önceki son 5 m'deki ortalama hız arasında güçlü bir pozitif korelasyon bulunmuştur (p<0,05). Sonuç olarak, dikey sıçrama antrenmanının ve kara antrenmanının artırılmasının yüzme performansını da artırabileceği tespit edilmiştir. Yüzme antrenörlerinin antrenman programlarına karada alt ekstremite dikey kuvvet antrenmanı egzersizlerini dahil etmeleri önerilmektedir.

Anahtar Kelimeler: İvmelenme, Tuck indeksi, Countermovement-jump, Drop jump, Plyometric jump

INTRODUCTION

Swimming races are examined under the following four main headings: start, clean swim, turn and finish (23, 25). The push-off or wall contact during the turn phase plays a direct role in determining the speed at which the swimmer leaves the wall (6, 37). The most preferred turning technique in freestyle swimming is the tumble turn. The tumble turn phase consists of five stages: wall approach, tumble, wall contact, wall push-off, and underwater phase (31). The underwater phase divided into two phases: the glide and the underwater propulsion phase (30, 32, 20). According to the results of Lyttle et al's (19) study, there is an effective time saving in turns by using the wall push-off and glide phases. Previous literature has reported that turns account for up to 30-56% of the race and that turn times affect the performance of the race (3, 38).

Well-developed muscles and muscular strength play an important role in the development of swimming performance (7). Maximal explosive muscle strength of the lower extremities is one of the important parameters affecting athletic performance (40). The progression of the swimmer's speed in freestyle is also related to the improvement of the swimmer's strength to push-off during the turns. Therefore, determining the lower extremity strength and preparing the training programs of the athletes in this direction is of great importance in terms of increasing athletic performance (16).

Studies have reported that effective and coordinated work of arm stroking, leg kicking, and trunk movements increase the propulsive force (10, 28). Although it has been demonstrated that swimmers' start and turning abilities increase with the increase in leg extensor muscle strength, it is recommended for swimming coaches to give priority to strength training during their training sessions (12). In order to improve swimming performance with strength training, there must be a well-planned combination between applied swimming training and dryland training (34). Born et al. (3) reported an increase in total turn time, measured from 5 to 10 meters after pushing off the wall, as the race distance increases. This increase in turn time also corresponds to a greater contribution to the overall swim time.

The start and the first 15 m start time influence the finish times of the race (27). Similarly, turns in swimming are important in determining the outcome of the swimming competition; the improvement of the turns has an effect on the shortening of the swimmer's final time (26). It has been reported that improving the turn technique to an excellent level can lead to a reduction of 0.20 s per turn in competitions (21).

Fifty-meter freestyle swimming is based on anaerobic power generation system, which requires a high level of strength and speed (4, 14). The start strategy in swimming competitions is characterized by the athlete moving away from the starting block as quickly as possible and with the greatest possible acceleration. Therefore, the departure from the starting block can be viewed as an explosive event with a motion pattern that requires high power generation for a short period of time (29). In a study, a significant correlation between swimmers' lower extremity strength and output performance indicated (17). Vertical jump performance is associated with grab, swing, track start (1) and kick start (2, 23). The link mechanisms between strength and

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output performance (e.g., power) are naturally multifactorial. Strength or maximum force production is an important component of sprint swimming. West et al. (39) revealed that lower extremity strength, maximum vertical strength, and maximum horizontal strength have an important role in power production at the beginning of swimming. Leg strength is as important in the start technique as it is in turning technique in water.

The vertical jump test is an easy test for both trainers and athletes in terms of applicability. Land exercises are generally aimed at increasing the leg strength of an athlete. The increase in leg strength, especially the strengthening of the knee extensor muscles, positively affects the vertical jump (9, 33). It is thought that the vertical jump and plyometric exercises performed on land will affect the acceleration of the tumble turn in water and the initial acceleration after the turn. Therefore, in this study, the aim is to examine the relationship between horizontal push-off against the wall and land-based vertical jump performance in freestyle tumble turn technique.

METHOD

Research Model

This research is carried out using experimental study design to determine the relationship between tumble turn kinematics and jumping performance.

Characteristics of the subjects

Twenty-one male swimmers (age: 15.7±1.53 years; height: 176.3±7.07 cm; weight: 63.7±7.61 kg; BMI: 20.52±1.49), who have 4 years of training experience and have been performing swimming training for 6 days a week, were participated in the study.

Ethical approval and institutional permission

This study was evaluated with the protocol code of 09.2019.115 from Marmara University Faculty of Medicine, Clinical Research Ethics Committee. Informed consent to the experimental procedure was obtained from the participants before the beginning of the study as required by the Helsinki declaration (1964).

Procedures

Warm-up protocol: Before starting the tests, a warm-up protocol was applied to all swimmers on land and in water. After 10 minutes exercise on land (cross-runs, short sprints, heel and toe walking, squat, etc.), they swam 100 m freestyle in the pool.

Countermovement jump (CMJ): The participants were asked to bend their knees, not exceeding 90 degrees, and jump as high as possible from this position, while the body was in an upright position on the force platform, with their feet bare and shoulder-width apart and hands at their waist. This test was repeated three times, a rest period of 15 seconds was given between the repetitions, and the average of the three repetitions was recorded as the countermovement jump value.

Drop jump (DJ) from a 25 cm height: The participants, ready by standing upright on the 25 cm high springboard, with their feet bare and shoulder-width apart, were asked to land on the force platform in front of them with both feet, jump after falling and land on the force platform again. This test was repeated three times, a rest period of 15 seconds was given between the repetitions, and the average of the three repetitions was recorded as the drop-jump value (from a 25 cm height). Dryland tests of countermovement jump and drop-jump from 25 cm were measured using the Tekscan MatScan® System force platform (Boston, USA).

In order to detect the acceleration during the vertical jump, the accelerometer (Xsens, Technologies B. V. Netherlands) sensor was placed in a waterproof case and fixed to the lumbar region of the participants with the help of an elastic band. Data from Xsens system were recorded at a sample frequency of 100 Hz. After the vertical jump tests were completed, in-water measurements were recorded.

For the in-water tests, the participants were asked to swim freestyle in a 25 m pool at 50 m race pace and maintain this pace until the 10th meter after tumble turn. Participants were asked to use track start technique and starts were performed in accordance with the international competition protocols.

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The 20 m, 25 m, and 5 m (before and after tumble turn) swimming times of the freestyle-swimming participant were determined with a hand chronometer, and the tumble turns were recorded with the GoPro Hero 6 (GoPro®, Inc, , CA). The last 5 m average speed before the turn, 5 m average speed and 25 m average speed after the turn, tuck index (distance between the hip and the pool wall during the turn), and knee joint flexion angle during the turns were recorded and calculated with the recorded time and image data. The acceleration created by the participants in the horizontal plane after the tumble turn was recorded triaxially (x, y, z) with Xsens, which was also used during the vertical jump tests, and calculations were made with the obtained data.

Data analysis

Three-axis data obtained from the Xsens accelerometer placed in the lumbar region of the participants were normalized with the formula $=\sqrt{ax2 + ay2 + az2}$ and calculated as combined acceleration. Evaluations were made based on combined acceleration (18).

Reactive strength index (RSI) from 25-cm drop jump (DJ) data were calculated using the following formulas: (RSI = leap height/ground contact time) and leap height = (0.00980665*(airtime/2)2) /2.

Statistical analysis

The first step was to assess the normality of distribution of the variables using the Shapiro-Wilk test ($p < 0.05$). Data were normally distributed. The relationship between drop-jump contact time, drop-jump hover time, drop-jump height, drop-jump reactive strength index (RSI), countermovement-jump average time, countermovement-jump height, turn acceleration, last 5 m average speed, last 5m average turn speed, and 25 m average speed were evaluated by using the Pearson Correlation test.

FINDINGS

Descriptive statistics of on land and in-water test results were shown on Table 1 and Table 2.

Table 1. On land test results

N=21	Drop Jump	Countermovement Jump
	Mean±SD	**Mean±SD**
Hang time (s)	466.01±90.24	512.38±62.53
Height (cm)	40.71±8.40	32.63±7.83
Knee flexion angle (º)	80.37±8.48	83.43±9.91
Acceleration (m/s²)	3.28±0.89	4.27±2.03
Reactive strength index (m/s)	0.477±0.108	----
Time on ground during landing (s)	530.85±59.82	----

CMJ: Countermovement Jump; DJ: Drop Jump

On land drop jump and countermovement jump test kinematic parameters' mean and standard deviations are shown in the table above (Table 1).

Table 2. In-water test results

N=21	Tumble Turn
	Mean±SD
25 m swimming time (s)	13.16±0.62
Time of the last 5 m before turn (s)	3.419±0.19
Time of the first 5 m after turn (s)	2.404±0.44
25 m average speed (m/s)	1.81±0.40
Average speed of the last 5 m before turn (m/s)	1.46±0.07
Average speed of the first 5 m after turn (m/s)	2.08±0.27
Tuck index (cm)	70.50±11.57
Turn acceleration (m/sn²)	1.88±0.25

In water tumble turn test kinematic parameters' mean and standard deviations are shown in the table above (Table 2).

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Table 3. The relationship between the tumble turn data and, on-land and in-water test results

	N=21	r	p
Turn acceleration (m/s²)	**25 m swimming time (s)**	-.597**	.003
	DJ reactive strength index (m/s)	.445*	.025
	DJ acceleration (m/s²)	.560**	.006
	CMJ height (cm)	.548**	.006
	CMJ knee flexion angle (º)	.543**	.010
	CMJ acceleration (m/s²)	.795**	.000
	Tuck index (cm)	-.781**	.000
	Average speed of the last 5 m before turn (m/s)	.563**	.005

CMJ: Countermovement Jump; DJ: Drop Jump; *: p< 0.01, **: p<0.05

Pearson correlation tests showed that tumble turn acceleration was correlated with 25 m swimming performance and both on land and in water test kinematic parameters (r= 445-781; p<0.05) (Table 3).

Table 4. The relationship between tuck index and, on-land and in-water test parameters

	N=21	r	p
Tuck Index (cm)	**25 m swimming time (s)**	.589**	0.00
	DJ height (cm)	-.374*	.048
	DJ reactive strength index (m/s)	-.449*	.011
	DJ acceleration (m/sn²)	-.734**	.000
	CMJ height (cm)	-.513**	.009
	CMJ acceleration (m/s²)	-.676**	.000
	Turn acceleration (m/s²)	-.781**	.000
	Average speed of the last 5 m before turn (m/s)	-.425*	.020
	Average speed of the first 5 m after turn (m/s)	.512**	.009

CMJ: Countermovement Jump; DJ: Drop Jump; *: p< 0.01, **: p<0.05

Pearson correlation tests showed that tuck index was correlated with 25 m swimming performance and both on land and in water test kinematic parameters (r= 374-781; p<0.05) (Table 4).

DISCUSSION AND CONCLUSION

This study was conducted to determine the relationship between the horizontal push-off during a tumble turn in the water and land-based vertical jump performance. Jumping is an important performance determinant in swimming. In addition, it is known to be a valid ability identification mark that has the potential to distinguish between elite and non-elite athletes (24). In the present study, the CMJ height, CMJ and DJ acceleration, and DJ reactive strength index increased the turn acceleration and thus positively influenced swimming performance. Also, increasing the average swimming speed in the 5 m before the turn increased the turn acceleration. Furthermore, decrease in the turn acceleration also decreased the tuck index. The increase in DJ height, acceleration, reactive strength index and CMJ height and acceleration decreased the tuck index, indicating that tuck index is decreased in swimmers with greater leg power. Similarly, the fact that the increase in tuck index increased the 25 m swim time suggests that the tuck index should be decreased by increasing leg power to improve performance.

Turn performance in swimming contributed up to 30-56% of the total race time, with the effect on the performance remaining consistent as the race distance increased (3, 38). A similar effect of the turn performance was found in the present study, whereby an increase in turn acceleration resulted in a decrease in the 25 m swimming time. These findings has led researchers to investigate the kinetic and kinematic parameters that affect turning performance. In the literature, it has been reported that the lower extremity strength is an important predictor of turning and swimming performance (13, 15). A study by Jones et al. (13) revealed that elite swimmers demonstrated superior strength and power characteristics and better the swimming turn performance compared to less experienced swimmers. These findings indicated a very large differences which were evident in squat jump peak velocity (elite swimmers: 2.9±0.5 m.s-1, subelite swimmers: 2.3±0.2 m.s-1), suggesting that elite male swimmers with enhanced swimming turn abilities were 30-50% more powerful than subelite males. These results are similar to our findings in which a moderate to high correlation has been found between jump and turning performance (Table 3). However, in this study, the evaluation of lower extremity power with a different jump test (squat jump) and the lack of correlation statistics between power and turn performance do not allow numerical comparison.

In another study by Keiner et al. (15), the relationships between lower extremity strength, jump performance, and swimming performance as well as start and turn performances were examined. They found that 1 RM squat strength (r= -0.54), SJ height (r=-0.65) and CMJ height (r=-0.75) has moderate to high correlation with turn time. In the present study the turn performance also found to have moderate to high correlations with both drop jump and CMJ parameters (Table 3) with a similar CMJ height (Keiner et al. CMJ : 32.93±7.00 cm; our study: 32.63±7.83 cm). The positive correlations that has been found in the present study between turn and jump performances is consistent with the results of the aforementioned study.

In the light of the data obtained in this study, a significant relationship was found between the turn acceleration, the vertical jump height and the drop jump reactive strength index (RSI). Therefore, it is thought that the vertical jump and plyometric exercises performed in land training will affect the acceleration of the turning in the water and the initial acceleration after the turn. Although the number of turns in the short course competitions vary according to the branches, the fact that it is three times more than the long course reveals the importance of the turn acceleration and the high average speed in the first 5 meters after the turn. The swimmers' ability to demonstrate these characteristics suggests that a training program incorporating leg power exercises can be efficient for improving turning performance. Studies by Hermosilla et al. (11) and Jones et al. (13), Sammoud et al. (34), Canas et al. (5) that shows lower extremity strength training improves turning and swimming performance also supports this suggestion. Furthermore, In the study conducted by Yapıcı and Cengiz (40), a relationship was found between 50 meters swimming time and 30 meters sprint time on land (40). It was stated that in order to swim 50 meters fast, one must be also fast on land. The correlation of the test results measured on land and in water in their study is similar to our study in terms of the correlation between power test results on land and in water. Moreover, in addition to enhancing jump performance, the tuck index, which is the angular degree of the lower extremity during the turn, was found to improve both turn performance and 25 m swimming time.

Puel et al. (31) reported that when the phases of the turn technique in freestyle swimming were evaluated, the important factors were found to be wall approach, tumble, wall contact, push-off, and glide. They reported that the performance of the turn increases when a higher horizontal force is created during the push-off phase of the tumble turn (31). In the light of the findings of the present study, the significant relationship between the turn acceleration, tuck index and the drop jump and CMJ performance, and the average speed of the first 5 m after the turn is in parallel with their data. Furthermore, Nichol et al. (26) found that the average speed of approaching the wall, especially 5 m before the wall, has strong positive correlation (r=0.854) with male swimmers' freestyle total turn time (26). We also found that turn acceleration has moderate correlation with the average speed of the last 5 m before turn (r=0.563). Born et al. (3) also reported that in freestyle tumble turns, the last 5m times approaching the wall were correlated with faster swimming velocities, based on the results obtained from the 2019 European Short Course Swimming Championships. These results show that faster male swimmer are able to perform better turn and swimming performance. Additionally, they also stated that the 5m gliding time after the wall push-off is correlated with turn and swim performance. In our study, the average speed of the first 5 m after the turn was not found to be correlated with turn acceleration. In addition, the time for the last 5 m before the turn found to be 2.29-2.93 seconds (3, 25) which is lower than our results. It has been found that gliding phase after push-off is mainly determined by the horizontal force applied to the wall (26, 35) and the elite swimmers showed higher on-wall force production than sub-elite swimmers (13). As the swimmers in the aforementioned studies has higher level of swimming experience (i.e., European championship competitors, Olympics, or World Championships), this may have caused the results to be different.

In the light of the data obtained in this study, a significant relationship was found between the turn acceleration, the vertical jump height and the calculated jump strength index (RSI). Therefore, it is thought that the vertical jump and plyometric exercises performed in land training will affect the acceleration of the turning in the water and the initial acceleration after the turn. Although the number of turns in the short course competitions vary according to the branches, the fact that it is three times more than the long course reveals the importance of the turn acceleration and the high average speed in the first 5 meters after the turn.

Weimar et al. (38) reported a speed of 1.90 m/s in water during a study that includes countermovement-style horizontal push movements both in and out of the water. It is thought that this propulsion speed from the wall is lower than the first 5 m speed after the turn in this study due to the arrival speed to the wall.

During turn execution, feet depth and tuck index are critical kinematic parameters that influence turn quality. Therefore, it is essential to analyze the effect of these variables on the characteristics of the turn (36). In the present study, it has been found that there is a negative correlation between the tuck index and the turn acceleration during tumble turn. In the study by David et al. (8) no significant relationship was found between the tuck index and the 5m time after the tumble turn, which is inconsistent with the results of the present study. In this study, we have found that swimmers who tucks from a longer distance from the wall achieve faster average speed of the first 5 m after turn (Table 4). Longer wall distance during tuck, which means less range of knee joint angle, reduces the time to extent lower limbs and swimmers turn further away from the wall, thus have to cover a shorter distance (8). But, the longer the tuck index increased 25 m swim time. This can be due to the fact that there is also gliding and stroking phases during 25 m swim which may affect the swim time. Whereas Skyriene et al. (36) reported a positive correlation between tuck index and swim time 7.5 m before the turn, which is in parallel showing that faster swimmers get closer to the wall before the tuck. Studies in the literature that consider the optimal Tuck Index to be around 0.7 (36). But, the tuck index in the present study is the distance of the hip from the wall, and it is not normalized to leg length as the aforementioned studies. Therefore, no numerical comparison could be conducted.

CONCLUSIONS

It is found that there is a direct correlation between the vertical jump values obtained in this study and the horizontal push-off values during the tumble turn. Therefore, it is thought that improving the vertical jump performance will increase the horizontal propulsion performance in water. Vertical jumps that are made during on-land exercises will have a positive effect on horizontal push-off during in-water rotation or turn. It is recommended for swimming coaches to incorporate lower extremity vertical strength exercises to be performed on land into their athletes' daily training programs.

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