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The Comparison of Lower Extremity Malalignment during Hurdle pre-Flight and Traditional Approach at Forward Diving Straight

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ABSTRACT

Background: Approach on the diving springboard provides the initial conditions for the disturbance in the stability of the base of support. The present study is a correlational study conducted to obtain complete and accurate information by examining "the relationship between diving score and dynamic malalignment of Hip, Knee, and Ankle on a 1 m springboard by elite male divers."
Methods: In the present cross-sectional study, the subjects of this study were the 12 top divers of the Iranian League Championship in summer 2016. The passive or reflective markers were attached to the posterior surface of subjects' bodies. The subjects performed Forward Diving Straight (FDS) technique in one of two ways, either the "Hurdle Pre-Flight" or "Hurdle Flight", and the head coach gave them scores. The x and y coordinates of each marker were estimated using KINOVEA software. The relationship among the performance score of "FDS" and dynamic malalignment of Ankle, Knee, and Hip joints in the frontal plane at each step was determined using "Generalized Estimating Equation" (GEE) with the "Identity Function" and the "Normal Distribution".
Results: The Results of GEE modeling showed that there was a significant inverse relationship between FDS score and "L. The mean ankle inversion in the (Hurdle pre-Flight) HPF approach was higher than Traditional (TRD). There was a significant inverse relationship between the FDS score and "L. Hip Add." The results of GEE modeling showed that there was a significant difference between mean scores of TRD-FDS (4.39±0.33) and HPF-FDS (5.67±0.33) approach (P=0.000)
Conclusion: There was a significant inverse relationship between FDS score and "Ankle Eversion/ Eversion, Knee and Hip Abduction/ Adduction" in Swing or Stance Leg.

Introduction

Exercise training is based on the continual repetition of main movements. These repetitions may lead to the imbalances in the musculoskeletal system in terms of changes in strength, flexibility, balance, and coordination of movement, as well as a direct impact on the pattern of bone growth. Such effects may develop the individual risk factors for postural changes [1], which in turn may cause injury. Injuries sustained during diving can either result from catastrophic overloading of joints during a poorly executed dive or, more commonly, from repetitive loading at lower levels of force, such as during a successful dive [2]. There are also special challenges regarding

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the diving and diver approach on the springboard. To perform diving techniques, high power is required for hip, knee, and ankle joint muscle groups. In every sport, some athletes represent true technical excellence. This technical mastery requires a physical structure that supports the sport's biomechanics, the neuromuscular coordination to correctly sequence the movement, the psychological skills to focus effort without unnecessary tension, and the physiology to sustain the movement pattern until the event is completed [3]. In closed skill sports such as swimming, pole vaulting, or sprint kayak, performance depends upon accurately reproducing a movement with minimal variation [4], including diving. According to studies by Pruett 1981and reported by the University of Texas [4], Grace and balance are largely the results of proper body alignment and kinesthetic awareness. Proper poise is required at the initiation of the approach of a dive. Secondly, "the accurate alignment of the body at the end of the board should be maintained via the flexion of knees and push-off with the accompanying extension of the ankles". Finally, a kinesthetic awareness of the body in motion in relation to the center of gravity is key to a graceful execution. Studies at the University of Texas show that the proper display of balance and grace can be severely plagued by inadequate strength in postural and stabilizing muscle and if the musculature is inadequate to control the recoil of the springboard, a diver may not achieve maximal dive height or even more detrimental, loose their balance. There were some evidence of muscular imbalance in divers [5] and postural effects on athletes' performance, as dysfunction is affected by knee varus [6], knee valgus [7], ankle pronation, and supination [8]. Therefore, the importance of the balance of power in muscle groups and postural alignment in the frontal plane is obvious. Every athlete has a movement objective. Whether it is to move faster, jump higher, or even just lift a heavier weight in training, they will try to find a way to meet that objective. If an athlete has a deficit in strength, flexibility, coordination, balance, stability, or perception, they will unconsciously try to find a way to achieve their movement objective even if their method is not biomechanically ideal. This is known as compensating. Compensating will cause deviation from a technical "ideal", and can be dramatically obvious or very subtle. It is an attempt to find a solution to make up for a weakness or control problem. Even high-performance athletes compensate, and it is challenging for the coach to evaluate the root cause of the compensation and formulate a strategy to overcome it. Many athletic performance plateaus are associated with compensatory movement strategies that cannot support further development [9]. The judge score is based on the observation and evaluation of diver's performance on the lateral view or sagittal movement plane, so dive coaches are also looking to improve the performance of their athletes on this movement plane. This is probably why previous studies have sought to improve diver's performance with the approach of exercise physiology and methodology of training [10, 11] and sport biomechanics [12, 13]. Furthermore, in studies with the approach of diving sport injuries, the purpose has been to obtain epidemiology statistics, information about the rate of sport injuries incidence, and types of injuries occurred [14, 15].

"Video analysis", as one of the assessment methods of dynamic postural malalignment, has limitations. Athletic performance on multiple planes has made it difficult to evaluate them. So most studies about dynamic postural assessment is focused on simulated performance patterns such as "squat" [16, 17] and "jump-landing" [18, 19], and then their results were extended to the athletic performance.

Therefore, a realistic rather than the simulated study of the technique was performed, and we investigated with the participation of elite male divers "the relationship between the score of FDS and dynamic malalignment of ankle and knee".

Methods

In the present cross-sectional study which was conducted to obtain complete and accurate information by examining "the relationship between diving score and dynamic ankle and knee malalignment on a 1 m springboard by elite male divers." The subjects of this study were the 12 top divers of the Iranian League Championship in summer 2016. Ethics Committee of Sport sciences research institute and was approved this study [IR.SSRI.REC.1400.1154]. Prior to the start of the study, all players were aware of the study and signed the informed consent.

They have 20±4 years old, 70±9 kg weight, 172±7 cm height, 23±2 BMI, 13±2 skinfold, 1.5±0.3 endomorphy, 5.5±0.7 Mesomorphy, and 3±1 ectomorphy. After completing the consent sheet, the anthropometric characteristics, static posture, and background of diving sports injuries were assessed. Subjects had no static postural disorder and no injury at the time of the study. Measurements were taken one day in the pool of Tehran Azadi Sport Complex. The information which were needed to participate in the research process was explained to them.

Marker Placement

According to the purpose of the present study, the dynamic posture of hip, knee, and ankle joints were evaluated in the frontal plane during the "Hurdle and take-off" steps (Table 1 and Figures 1, 2). Therefore,

Table 1: Marker name

No.	Marker Name	Location
1	$LTHI_1$	Left Thigh
2	$RTHI_1$	Right Thigh
3	$LTHI_2$	Left Thigh
4	$RTHI_2$	Right Thigh
5	LKNE	Left Knee
6	RKNE	Right Knee
7	LTIB (LSHN)	Left Shin
8	RTIB (RSHN)	Right Shin
9	LANK	Left Ankle
10	RANK	Right Ankle
11	LHEE	Left Heel
12	RHEE	Right Heel

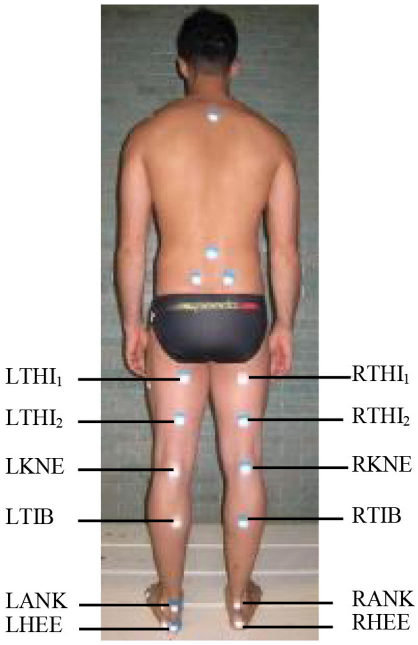


Figure 1: Marker place

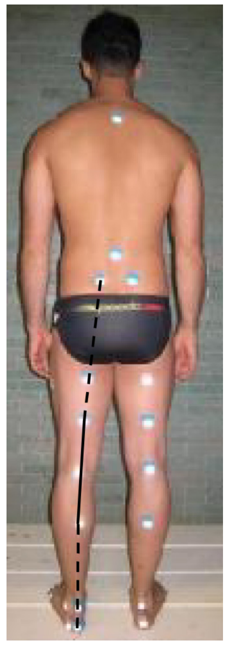


Figure 2: Marker place

passive or reflective markers were attached to the posterior surface of the subjects' bodies.

The x and y coordinates of each marker were estimated using KINOVEA software. The joint angles in the frontal plane were obtained by the above coordinates and the input formulas in Excel software. The movement angles of ankle and knee at the frontal plane were defined according to Figures 1 and 2, as follows (Table 2):

Diving

There are five elements of a dive in this study that the head coach considered when evaluating a dive which as follows, respectively: Starting position, Approach, Hurdle, Take-off, Forward Diving (Figures 3, 4). The divers performed the task on 1m springboard. Four divers have performed approach TRD (i.e., with one hurdle before take-off), and eight divers with Pre-Flight pattern (PFT) (i.e., with two hurdles before take-off). (Figures 5-7).

Coach Score

Coach Score Criterion was exactly in line with the Criteria for Judging a Dive which approved by the World Swimming, Diving and Waterpolo Federation [21]; In the sport of diving, a judge's award can range from zero (0) to ten (10) points. Awards are given in half-point increments according to the following scale. Therefore, "Excellent" performance (10), "Very good" (8.5-9.5), "Good" (7-8), "Satisfactory" (5-6.5), "Deficient" (2.5-4.5), "Unsatisfactory" (0.5-2), "Completely Failed" (0). Therefore, the coach evaluated and rated the diver's

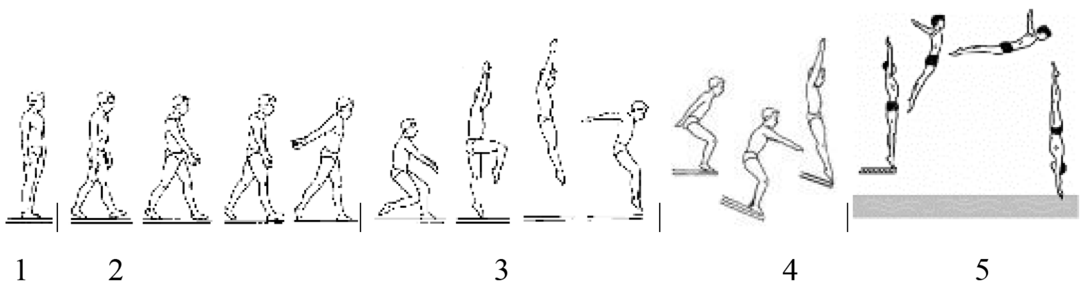


Figure 3: Approach Traditional (TRD) [20]

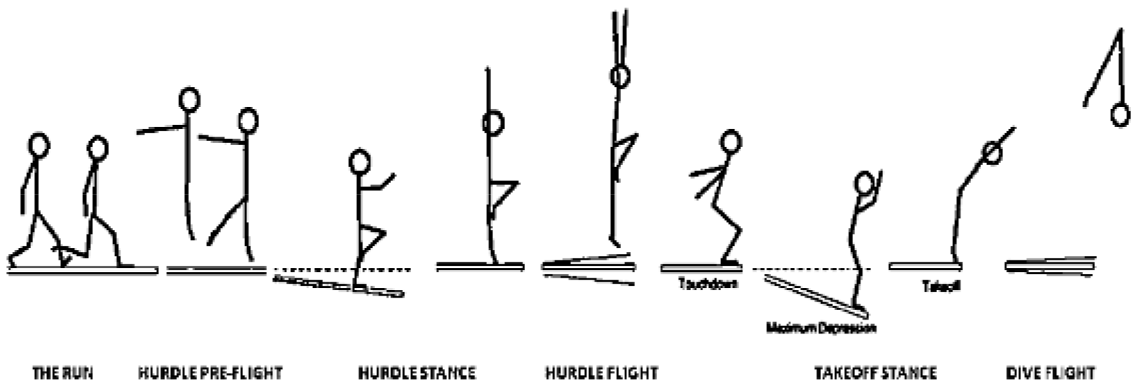


Figure 4: Approach Traditional TRD [20]

Table 2: Malalignment and Linked Markers

Joint	Malalignment		Linked Markers
	Data (-)	**Data (+)**	
R. Ankle	*Eversion*	*Inversion*	RTIB – RANK – RHEE
L. Ankle	*Inversion*	*Eversion*	LTIB – LANK – LHEE
R. Knee	*Valgus*	*Varus*	RTIB – RKNE – $RTHI_2$
L. Knee	*Varus*	*Valgus*	LTIB – LKNE – $LTHI_2$
R. Hip	*Adduction*	*Abduction*	$RTHI_2$ - $RTHI_1$ – RPSIS
L. Hip	*Abduction*	*Adduction*	$LTHI_2$ - $LTHI_1$ – LPSIS

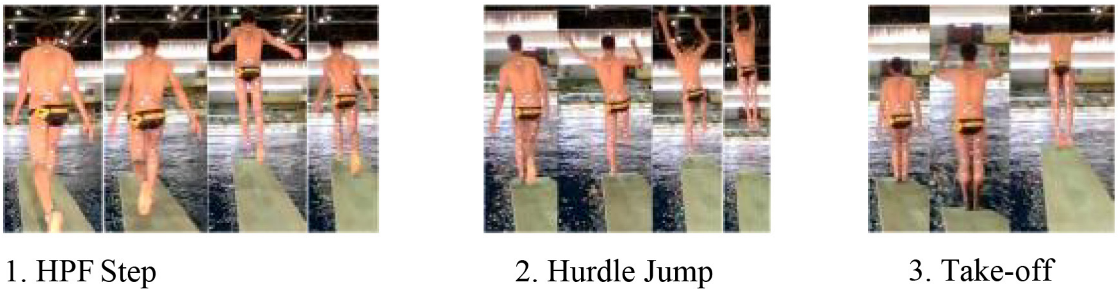


Figure 5: Hurdle pre-flight Approach(HPF) [20]

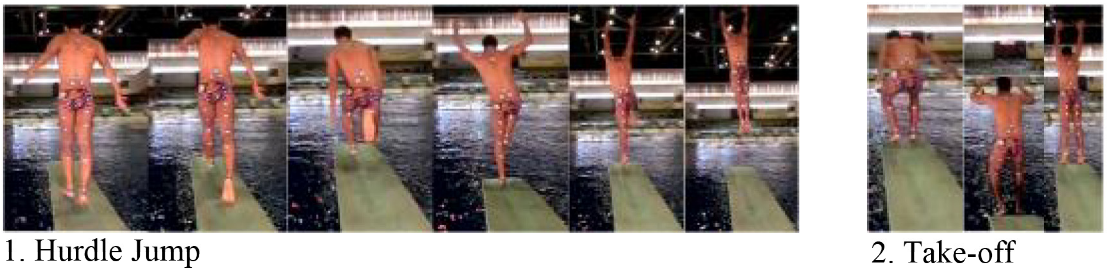


Figure 6: Traditional Hurdle(TH) [20]

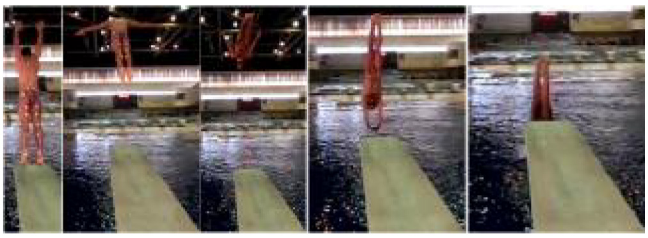


Figure 7: Forward Diving Straight [20]

performance since "Start Position" to "Entry", but video analysis was related to the Start of the hurdle to the end of take-off.

Kinematic Data Collection

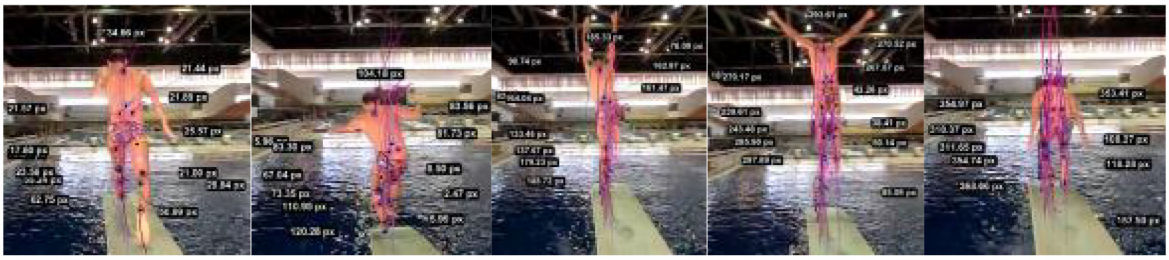
Casio Exilim EX-ZR200 camera was used to record kinematic data, and images were captured in 2D at 120 frames per second. The camera was placed at the beginning of the longitudinal direction of springboard to record the technique on the frontal plane. The camera was placed in the posterior view, parallel to the sacrum area, so that diver's body was seen during the technique performance. The distance between camera and diver was adjusted so that to keep the subject's image at optimum size with minimal perspective. Reflective markers were used to track the organs by the camera.

Kinematic Data Processing

The recorded videos were examined by KINOVEA software which has already been verified and validated [22, 23]. The operator showed the exact location of markers to the software by following each marker in each frame of the image. Then, image calibration was performed. At this point, certain longitudinal values were introduced to the software to calculate the x and y coordinates of all image markers using trigonometric identities. Then, the longitudinal and transverse coordinates of all followed markers by the software were determined, and data were extracted from the software. Like all motion analysis software, the first output of this software is a set of data based on the x and y of each marker over time which is based on the time taken in the technique and the number of markers, these data are very large. All extracted information were imported into Excel software, and then the x and y coordinates of all markers were saved based on time. According to the angles considered in this study, trigonometric formulas were written, and all angles were extracted. (Figure 8, 9.)

Statistics

Data were summarized and reported for qualitative variables with frequency and percentage and quantitative variables with the mean (standard deviation). Furthermore, the normality of the quantitative variables



1 2 3 4 5

Figure 8: Determination of movement angles of lower extremity joints during "Hurdle" step

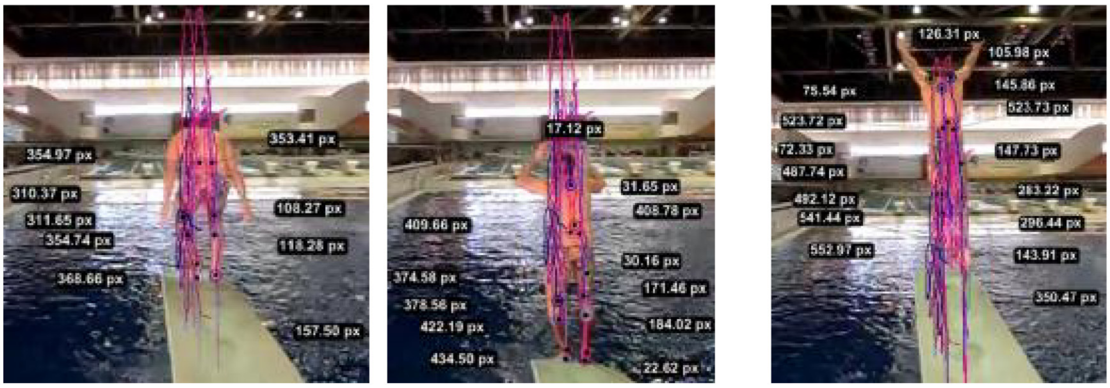


Figure 9: Determination of movement angles of lower extremity joints during "Take-off" step

used in the analysis was evaluated using descriptive indices such as "Skewness" and "Kurtosis". The relationship between the performance score of "FDS" and dynamic malalignment of Ankle, Knee and Hip joints in the frontal plane at each step was determined using GEE with the "Identity Function" and the "Normal Distribution". The dynamic malalignment of knee and ankle joints in the frontal plane at various repetitions and steps was compared using GEE with "Logit Function" and "Bernoulli distribution". Besides, the qualitative variables are entered as markers in the model. The reason for using these advanced models was the "Repeated Measurements" in elite male divers. This analysis was used to calculate the "correlation of measurements" using a Compound Symmetry Covariance structure. Data analysis was performed using SPSS 25 software at the significant level of 0.05. This analysis and "Compound Symmetry covariance structure" were used to determine the "correlation of measurements". Data analysis was performed using SPSS 25 software at the significant level of 0.05.

Results

The results of GEE modeling showed that there was a significant inverse relationship between FDS score and "L. Ankle Eversion" (6.93±14.73) in "HPF" step (P=0.001, β=-0.010) that was Swing Leg (Table 3). There was a significant inverse relationship between FDS score and "R. Ankle Inversion" (6.42±11.23) in "HF" (P=0.016, β=-0.009) that was Swing Leg (Table 4). Moreover, the results of GEE modeling showed that there is no significant difference between the pattern effect of TRD (5.62±0.609) and HPF (6.81±1.047) approach on "R. Ankle Inversion" (or swing leg) during "Hurdle Flight" step (P=0.326) (Table 3). However, the mean ankle inversion in the HPF approach was higher than the TRD. There was a significant inverse relationship between FDS score and "R. Knee Valgus" (13.31±10.08) in "HPF" step (P=0.044, β=-0.019) that was Stance Leg. There was a significant inverse relationship between FDS score and "R. Knee Varus" (4.01±8.431) in "Take-off" step (P=0.044, β=-0.019) (Table 3). Thus, the results of GEE modeling showed that there is no significant difference between the pattern effect of TRD (5.91±3.65) and HPF (3.32±0.61) approach on "R. Knee Varus" during "Take-off" step (P=0.485) (Table 4). There was a significant inverse relationship between FDS score and "R. Hip Add." (11.75±10.01) in "Hurdle Pre-Flight" step (P=0.049, β=-0.017) that was Stance Leg.

Table 3: The Results of Generalized Estimating Equation (GEE) Modeling for Investigation of the Relationship between Scores and Dynamic Malalignment of Hip, Knee and Ankle by Steps Type

Step	DEVIATION	95% Wald Confidence Interval				Hypothesis Test	
		β	Std. Error	Lower	Upper	Wald Chi-Square	Sig.
HPF	L. Ankle Eve. (Swing)	-0.010	0.0031	-0.016	-0.004	10.763	0.001*
	R. Knee Val. (Stance)	-0.019	0.0101	-0.039	-0.001	3.8500	0.044*
	R. Hip Add. (Stance)	-0.017	0.0086	-0.034	-4.389	3.861	0.049*
HF	R. Ankle Inv. (Swing)	-0.009	0.0038	-0.017	-0.002	5.835	0.016*
	L. HipAdd. (Stance)	-0.063	0.0298	-0.121	-0.004	4.402	0.036
Take-Off	R. Knee Var.	-0.034	0.0080	-0.050	-0.018	18.043	0.000*

Generalized Estimating Equation" (GEE); Hurdle Pre-Flight (HPF);Hurdle Flight (HF)

Table 4: The Results of Scores Distribution and Dynamic Malalignment of Hip, Knee and Ankle by Steps Type

Dynamic Malalignment		HPF		
		N	**Mean**	**Std. D.**
L. Ankle	Score	1666	4.8863	1.00679
Eve. (Swing)	Dev.	1666	6.9384	14.73791
R. Knee	Score	2115	5.1924	.93868
Val. (Stance)	Dev.	2115	13.3178	10.08437
R. Hip	Score	3430	5.1499	1.09494
Add. (Stance)	Dev.	3430	11.7531	10.01448
R. Ankle	2341	5.3095	1.11680	2341
Inv. (Swing)	2341	6.4224	11.23750	2341
L. Hip	6925	5.3338	1.03744	6925
Add. (Stance)	6925	5.3835	3.43270	6925
R. Knee	724	4.9075	1.09589	724
Varus	724	4.0180	8.43169	724

Hurdle Pre-Flight (HPF)

Table 5: The Results of Distribution of Dynamic Malalignment of Ankle, Knee, Hip by Steps and Hurdle Pre-Flight (HPF)/Traditional (TRD) Type

Estimates					*Tests of Model Effects*		
Approach Type	**Mean**	**Std. Error**	**95% Wald Confidence Interval**		**Source**	**Type III**	
			Lower	**Upper**		**Wald Chi-Square**	**Sig.**
HPF	5.6793	.33254	5.0276	6.3311	(Intercept)	229.045	.000*
TRD	4.3973	.33328	3.7441	5.0505	Hurdle Type	469915.449	.000*

Hurdle Pre-Flight (HPF); Traditional (TRD)

There was a significant inverse relationship between FDS score and “L. Hip Add.” (5.38±3.43) in “Hurdle Flight” step (P=0.036, β=-0.063) that was Stance Leg. Hence, the results of GEE modeling showed that there is no significant difference between the pattern effect of TRD (4.97±0.33) and HPF (5.63±0.75) approach on “L. Hip Add.” during “Hurdle Flight” step (P=0.425). The results of GEE modeling showed that there was a significant difference between mean scores of TRD-FDS (4.39±0.33) and HPF-FDS (5.67±0.33) approach (P=0.000) (Table 5).

Discussion

According to this study’s findings, dynamic ankle malalignment in both “HF” and “HPF” steps had a significant inverse relationship with Coach Score. That is, by decreasing coach score, the swing ankle eversion in HPF step and the Swing ankle inversion in HF step increased. The data show that the mean dynamic deviation from the static anatomical alignment is not high in the ankle, knee, and hip joints, but it seems that the low malalignment can affect a simple dive score. It seems like there are critical points for each of these joints as they progress on the springboard, although the mean of Inversion (11.72±18.304) and eversion (9.41±16.537) ankle were higher in the take-off phase than HF and HPF steps; however, there was a significant inverse relationship between FDS score and the malalignments during HF and HPF phases. According to the evidences, the attentional demand necessary to regulate postural sway increased as the postural task increased in difficulty, but this effect was smaller for the gymnasts during unipedal stance. These findings suggest a decreased dependency on attentional processes to regulate postural sway during unipedal stance in gymnasts with respect to non-gymnasts [24]. Because they, like divers, focus on stability training, and functional performance on an unstable surface such as a springboard may be related to the quality of their physical performance. According to our findings, the HPF step had more effects on the FDS scores than the other steps. Moreover, the mean of effective malalignments on FDS score was higher in the HPF step than in other steps. Although, it was said before that dive height is almost exclusively the function of the vertical velocity at take-off [25]. But, malalignment during the Hurdle can reduce the “Take-off” quality before the flight. The importance of Hurdle step in diving performance was previously mentioned in other studies, both in terms of its functionality characteristics [26] and its importance as a risk factor [27, 28] . There is more Base of Support in take-off than HF and HPF, it seems to maintain postural stability in take-off is easier than HF and HPF if there is a challenge to postural alignment. Thus, the stance leg affected the FDS score more than the swing leg. During the HPF step, knee valgus and hip adduction on stance leg (right) had a significant inverse relationship with FDS score. These results suggest that functional pronation movements may be one of the risk factors on the HPF step and one of the causes of reducing the FDS score. Despite all postural malalignment, the mean FDS score was significantly higher in the HPF approach than in the TRD. This probably indicates that achieving higher altitude in Hurdle and Take-off pre-flight is an important factor to enhance the diving quality and gaining success. Whereas there are differences between the biomechanical and physiological properties of each sport technique and similar task in a laboratory environment that is mentioned by authors’ as researches limitations.

Conclusion

It seems that, in addition to evaluating diver performance on the sagittal plane, coaches should be evaluated diver's dynamic postural alignment in the frontal plane, and as well as evaluating the divers is critical in the lateral view, in both the anterior and posterior view.

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Conflict of Interest: None declared.

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