Relationship of Knee and Hip Joint Proprioception with Competition Success in Aerobic Gymnastics[*]

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Abstract

The aim of the study was to (1) evaluate the joint position sense development in young aerobic gymnasts of different age groups and (2) investigate the relationship of position sense with execution success in competition. 112 competition athletes from four different age groups participated in the study. Joint position sense tests with a smartphone and phone app fixed to the lower extremities were performed during the Aerobic Gymnastics Turkey Championship competitions. Correlation and linear regression analysis were performed on the participant data, which showed normal distribution within the competition age groups. There were negative and significant correlations between 45º knee extension absolute errors and competition execution points. The 45º knee flexion absolute score correlated to competition execution points. 90º hip flexion absolute error scores were significantly associated with competition execution points. A positive correlation was found between the age of the gymnasts and the competition execution points. Considering the entire sample, results demonstrated that a final model consisting solely of hip extension absolute scores was able to explain a significant amount of variance in competition execution points. When the data is partitioned according to gender, the model fails to explain variation in competition execution scores in the male sample. However, a final model consisting of joint position sense error scores of hip flexion and knee extension could explain a significant proportion of variance in competition execution points of the female sample. In conclusion, gymnasts who made more positional errors had lower execution scores. Target position replication accuracy in gymnasts improved with age. The effect of joint position sense accuracy in predicting the outcome of the competition was significant. Training that develops joint position sense can improve gymnasts' competitive results.

Keywords: Aerobic gymnastics, Proprioception, Joint position sense, Age groups.

Aerobik Cimnastikte Diz ve Kalça Eklemi Propriyosepsiyonunun Müsabaka Başarısı ile İlişkisi

Öz

Bu çalışmanın amacı, (1) eklem pozisyon duyusunun farklı yarışma gruplarındaki genç aerobik cimnastikçilerde gelişimini araştırmak ve (2) pozisyon duyusunun yarışmadaki uygulama başarısı ile ilişkisini değerlendirmekti. Çalışmaya dört farklı yaş grubundan 112 müsabaka sporcusu katıldı. Aerobik Cimnastik Türkiye Şampiyonası müsabakalarında alt ekstremitelere sabitlenen akıllı telefon ve telefon uygulaması ile eklem pozisyon duyusu testleri uygulandı. Müsabaka yaş grupları içinde normal dağılım gösteren katılımcı verileri üzerinde korelasyon ve lineer regresyon analizi yapıldı. 45º diz ekstansiyon mutlak hataları ile yarışma uygulama puanları arasında negatif ve anlamlı korelasyonlar vardı. 45º diz fleksiyonu mutlak hata skoru, yarışma uygulama puanlarıyla ilişkiliydi. 90º kalça fleksiyonu mutlak hata skorları, yarışma uygulama puanlarıyla önemli ölçüde ilişkiliydi. Cimnastikçilerin yaşı ile yarışma uygulama puanları arasında pozitif bir ilişki bulundu. Örneklemin tamamı göz önüne alındığında, sonuçlar, yalnızca kalça ekstansiyon mutlak puanlarından oluşan nihai bir modelin, yarışma yürütme puanlarındaki önemli miktarda varyansı açıklayabildiğini gösterdi. Veriler cinsiyete göre ayrıldığında, model erkek örneklemdeki yarışma uygulama puanlarındaki değişimi açıklayamadı. Bununla birlikte, kalça fleksiyonu ve diz ekstansiyonunun eklem pozisyon duyusu hata puanlarından oluşan nihai bir model, kadın örneklemin yarışma uygulama puanlarındaki önemli bir varyans oranını açıklayabildi. Sonuç olarak, daha fazla pozisyon hatası yapan cimnastikçilerin uygulama puanları daha düşüktü. Cimnastikçilerde hedef konum tekrarlama doğruluğu yaşla birlikte arttı. Müsabaka sonucunu tahmin etmede eklem pozisyon duyusu doğruluğunun etkisi önemliydi. Eklem pozisyon duyusunu geliştiren antrenmanlar, cimnastikçilerin yarışma sonuçlarını iyileştirebilir.

Anahtar kelimeler: Aerobik cimnastik, Propriyosepsiyon, Eklem pozisyon duyusu, Yaş grupları.

INTRODUCTION

Proprioception, which is very important in movement control, consists of joint position sense, force sensing, velocity, and kinesthesia sub-models; it is necessary for sports and daily activities (Han et al., 2016). It is essential to maintain joint position awareness to prevent injury in conscious and unconscious situations (Kaynak et al., 2020). Reasonably controlling force and joint position in aerobic gymnastics are essential for top scores. Conversely, poor proprioception may lead to an increased likelihood of injury (Kaynak et al., 2020).

Aerobic gymnastics, which emerged from traditional aerobic exercises, requires performing continuous high-intensity and complex movement patterns accompanied by music (FIG, 2022). Gymnasts must flawlessly execute the use of continuous movement, flexibility, strength, and basic steps during the competition with the elements of difficulty. In aerobic gymnastics, balance and joint control abilities are decisive in performing various elements (Busquets et al., 2018). All elements must be demonstrated precisely and without errors. Thus, execution success requires well-controlled muscle strength with force and position sense, and especially hip and knee joint control are vital to success in suitable and coordinated movement patterns. However, to date, repositioning tests of the knee joint have never been carried out in aerobic gymnastics, and the joint position sense of the hip joint was examined in only one study (Tıkız & Altun, 2022). A study evaluating joint position sense among adolescent aerobic gymnasts was completed on the elbow joint (Niespodziński et al., 2018). While gymnastics is considered a fundamental sport, more attention should be paid to the proprioception that controls joint position reproduction, and the contribution of its training to proprioceptive progress has not been adequately explored (Niespodziński et al., 2018; Park & Kim, 2013; Park et al., 2010). Sensory repositioning processes may be affected by age-advancing movement skill development, particularly in sports where top-level control of movement is emphasized, such as aerobic gymnastics (Han et al., 2016).

Force and joint position sense assessments examine joint proprioception (Li et al., 2016; Olsson et al., 2004; Smith et al., 2013; Wang et al., 2016). The joint position sense test measures the accuracy of adjusting the joint position. Similarly, the force sense test measures how precisely the motion force is reproduced. However, force and joint position sense tests of proprioception lack ecological validity as the test conditions differ significantly from natural function (Han et al., 2016). Therefore, they cannot contribute enough to understanding proprioception's role in sports. Studies of joint proprioception have focused on joint position sense assessment without any loads (Altun, 2020; Foch & Milner, 2013; Kaynak et al., 2020). The load on the joints and muscles varies according to the speed, angle, and severity of the athlete's movement (Carr, 1997). During movements in aerobic gymnastics, resistances such as slowing down, accelerating, and jumping to varying heights affect the muscles differently (Carr, 1997). Previously, joint position sense tests in other sports branches were performed in unnatural laboratory environments without considering the effects of body weight and competition ground. Therefore, joint position sense should be tested under body weight load (Foch & Milner, 2013). Joint position sense tests on aerobic gymnasts' hip and knee joints have never been done before in a competition setting. The success of gymnasts in the competition indirectly reveals their level of development. This study aims to evaluate the relationship

between joint position sense and execution success in the competition of young aerobic gymnasts in different competition groups. It has been hypothesized that aerobic gymnastics training improves the sense of active joint repositioning and that older gymnasts will show greater accuracy in the sense of joint position than younger gymnasts.

MATERIAL AND METHODS

Research Model
An experimental study was carried out with relationship analysis.

Participants
112 participants of the present study were Turkey Gymnastics Federation licensed competition athletes. According to the information from the Turkish Gymnastics Federation, the population size was considered 150 since an average of 150 licensed athletes participated in the Turkish Aerobic Gymnastics Championships in the 2022 competition season. The sample size was calculated as 109 at a 95% confidence level, a 5% margin of error, and a 50% population proportion (Sample Size Calculator, 2022). According to this sample size calculation, 112 (23 male, 89 female) gymnasts were included in the study. 44 participated in the competition in the 9-11 age group (5 male and 39 female, $10.68 \pm .47$ age, body weight 38.12 ± 4.71 kg, height 142.81 ± 4.12 cm, and body fat ratio 12.55 ± 4.11 %), 46 in the 12-14 age group (11 male and 35 female, $12.67 \pm .67$ age, body weight 41.12 ± 4.86 kg, height 150.14 ± 4.25 cm, and body fat ratio 13.36 ± 4.11 %), 17 in the 15-17 age group (6 male and 11 female, $16.00 \pm .79$ age, body weight 57.12 ± 5.48 kg, height 165.41 ± 4.34 cm, and body fat ratio 15.43 ± 4.32 %), and 5 in the 18+ age group (1 male and 4 female, 20.20 ± 1.92 age, body weight 66.42 ± 5.34 kg, height 170.54 ± 9.34 cm, and body fat ratio 15.21 ± 4.82 %). Before breakfast, body composition was analyzed using the InBody 230 (Biospace Ltd., Seoul, Korea) bioelectrical impedance analyzer (von Hurst et al., 2016). One hundred one of the competitors were athletes who participated in national competitions and had at least five years of aerobic gymnastics training history. Eleven of them were elite national team athletes who participated in international competitions, and most got top grades. Those with orthopedic or neurological disorders in the hip and knee joints were not included in the present study. They were asked not to use any medication and not engage in exhausting physical activity in the last two days.

Ethic Approval
This research was approved by the Manisa Celal Bayar University Health Sciences Ethics Committee (20.07.2022 – 20.478.486/1414). All participants agreed to volunteer for the research by giving written and verbal details about the procedure and aims of the research. Also, families approved the voluntary participation of participants under 18. In addition, voluntary participation permissions were obtained from the trainers of all athletes. Permission was obtained from the Turkish Gymnastics Federation to test the athletes in the competition and to use the competition scores in this study.

Study Design and Procedures

In position sense tests, joint angles were measured with the proven Clinometer + Bubble Level (Google Play, 0.1º sensitive) smartphone application (Cox et al., 2018; Monreal et al., 2021; Wang et al., 2019; Werner et al., 2014). One of the phones used in the tests was the Oppo Reno 5, and the other was the Samsung Galaxy A7 2017. Before the measurements, 2-way calibration of the program was performed on the phones. Then, joint position sense measurements were made in the application "relative angle" mode. During the familiarization before the competition, two trials were made for each condition. In order to prevent the results from being affected by learning effects, the trials were deliberately performed with different angles from 45 and 90 degrees.

All tests were performed during the 2022 Aerobic Gymnastics Interschool Turkey Championship and Aerobic Gymnastics Turkey Championship competitions after the routine warm-up was done in the warm-up area before the competition, approximately 15 minutes before the competition. The tests were applied to the dominant legs of all participants, which were determined by the kick-a-ball test (van Melick et al., 2017). The knee and hip flexion tests were completed in the standing basic stance position, and the knee extension test was conducted by sitting on the chair with the hip and knee joints in the 90º flexion position. Initial angles at these positions were accepted as 0º. The phones were fixed on the outside of the thigh and leg according to the measured area by two hook and loop tapes, one above and one below, that adhered to the phone case. In the knee measurements, the phone was in the direction of the knee joint rotation axis (femur lateral epicondyle - approximately 3 cm behind the patella) and the lower prominence of the fibula (lateral malleolus). In the hip measurement, the phone was placed in the direction of the hip joint rotation axis (approximately 1 cm above the Trochanter Major) and the knee joint rotation axis (Femoral Lateral Epicondyle). First, the researchers taught gymnasts the 90º target angle for knee and hip flexion and the 45° target angle for knee extension. They waited for 4 seconds at each target angle and told the athlete to memorize this angle. Then, the athlete was asked to find the taught target angle and to say "Yes" aloud. The gymnasts' eyes were closed during the teaching and testing phases, and they tried each test twice. Participants rested for 60 seconds between joint position sensing attempts to prevent the effect of fatigue (Dover & Powers, 2003; Niespodziński et al., 2018). The absolute error score was calculated from the difference between the reproduced and target values, and the lowest error score achieved in two trials was included in the analysis. After the tests, the gymnasts took part in the competition. International and national judges evaluated them. Execution scores of gymnasts in competitions were recorded for analysis.

Data Analysis

Data were analyzed using the SPSS 23.0 (SPSS Inc., Chicago, IL) package program, and the significance level was defined at $\alpha = 0.05$ in all examinations. Kolmogorov-Smirnov test was used for normality test. The competition age groups' age, height, body weight, and body fat ratio variables showed normal distribution ($p>.05$). We used correlation and linear regression analysis in a stepwise fashion to analyze obtained data. In the linear regression analysis, we entered the 45º knee extension, 45º knee flexion, and 90º hip flexion absolute error scores into the model as independent variables. The dependent variable was the competition execution points. All analyses were performed for the entire sample and the gender groups separately.

FINDINGS

Participants' mean absolute error scores were 3.83 ±4.05 degrees for 45° knee extensions, 4.64 ±4.44 degrees for 90° knee flexions, and 3.67 ±3.93 degrees for 90° hip flexions. There were negative and significant correlations between 45° knee extension absolute errors and competition execution points (r=-.242, p=.010). Similarly, the 45° knee flexion absolute score correlated with competition execution points (r=-.195, p=.040). Finally, 90° hip flexion absolute error scores were significantly associated with competition execution points (r=-.252, p=.007). A positive correlation was found between the age of the gymnasts and the competition execution points (r=.450, p=.000). In other words, the competition execution points (7.46 ±.71 points) obtained increased with age.

In the next step of the analysis, we conduct a set of linear regression in a stepwise fashion to explore whether the regression model consisting of joint position sense errors might explain a significant amount of variance in competition execution points. Considering the entire sample, results demonstrated that a final model consisting solely of hip extension absolute scores was able to explain a significant amount of variance in competition execution points (Table 1).

Table 1. Coefficients for all samples

	B	Beta	t	R	R^2_{adj}
Constant	7.62		85,30	,252	,06
Hip Flexion Error Score (degree)	-.046	,25	-2,74*		

*: p=.007

When the data is partitioned according to gender, the model fails to explain variation in competition execution scores in the male sample. However, a final model consisting of joint position sense error scores of hip flexion and knee extension could explain a significant proportion of variance in competition execution points of the female sample (Table 2).

Table 2. Coefficients by gender

	B	Beta	t	R	R^2_{adj}
Constant	7.81		63,76		
Hip Flexion Error Score (degree)	-.057	-,25	-2,41*	,35	,10
Knee Extension Error Score (degree)	-.038	-.22	-2.16**		

*: p=.018, **: p=.034

DISCUSSION

The current study's first finding was that those gymnasts who made more positional errors had lower execution scores. The second finding is that target reposition accuracy in gymnasts improves with age. In other words, the sense of joint repositioning was less inaccurate at older than younger ages. For example, knee flexion error scores were observed to be 4.8, 4.61, 4.53, and 4.00 degrees in the 9-12 age group, 12-14 age group, 15-17 age group, and 18+ age group, respectively. The second finding explains the reason for the first finding. Neuromuscular coordination and strength improve with age (Proske & Gandevia, 2012). An efficient afferent

proprioceptive input from the periphery provides a good sense of joint position (Alshahrani et al., 2022; Asiri et al., 2022). The higher accuracy observed during joint position sense testing at older ages may result from further stimulation of mechanoreceptors with increased muscle contractions (Busquets et al., 2018; Lutz et al., 1993; Speers et al., 2002; Wilk et al., 1996). Effort sense contributes to the accuracy of joint position sense (Phillips & Karduna, 2018). More mechanoreceptor stimulation results in improved conscious joint position accuracy. (Drouin et al., 2003; Kaynak et al., 2020; Proske, 2006). In gymnasts, the central nervous system develops with advancing age, and with it, increased weight increases mechanoreceptor stimulation (Busquets et al., 2018; Busquets et al., 2021). In that case, movements made under body weight that gets heavier with advancing age may provide an advantage over activities performed under light body weight.

The third important finding is the effect of this joint position sense accuracy in predicting the outcome of the competition. When the whole group is considered, it can be expected that those with less hip joint positional error will achieve higher application scores. When considered separately according to the genders (23 men and 89 women), it was predicted by the regression that the women with fewer hip and knee joint errors would get a higher application score. The reason why this significant predictive power is low in men may be due to the small number of men participating in the study. This study should be repeated with more male participation.

Tıkız and Altun (2022) reported a mean 90° hip flexion error of 3.50 degrees (Tıkız & Altun, 2022). The current study found the mean 90° hip flexion error to be 3.67 degrees. Kaynak et al., (2020) and Altun (2020) reported the mean knee extension error in athletes of the same age group as 3.90 and 3.51 degrees, respectively (Altun, 2020; Kaynak et al., 2020). The current study found a mean knee extension error of 3.83 degrees. The findings were consistent. There is no study in the literature examining the knee flexion error score. It was investigated for the first time in this study. The joint position sense error data presented in this study can be used to evaluate healthy gymnasts' return to sports after injury.

Past knee joint position sense studies evaluated proprioception without applying external load to lower extremity muscles (Foch & Milner, 2013). On the other hand, external loads such as jumping to specific heights, landing on the floor, deceleration, and acceleration affect the muscles and joints differently in the aerobic gymnastics execution series (Kaynak et al., 2020; Struzik et al., 2017). If movements and tests are not performed under these conditions, the execution cannot fully express its performance. During aerobic gymnastics, knee joints are greatly affected by variable external loads (Desai et al., 2019). Therefore, proprioceptive acuity in gymnastics should be tested by considering the effect of body weight or movement. When a person must accurately sense the position of their joints in space, joint load variables can affect the degree of afferent input (Bullock-Saxton et al., 2001).

The central nervous system processes the proprioceptive information from various mechanoreceptors to carry out functional movements in most sports training, competitions, and daily activities (Shumway-Cook & Woollacott, 2016). Motor commands are produced by centrally sourced signals regarding the senses of effort, force, and weight (Röijezon et al., 2015). Peripheral sensory receptors provide these sensations, including muscle spindles, tendon organs, and pressure-sensitive skin receptors (Han et al., 2015; Smith et al., 2013). As the age of competition progresses in aerobic gymnastics, the variety of movements and

repetitions applied in training increases considerably. Over the years, gymnasts receive constant feedback from their trainers in training and the gymnastics judges in competitions. With the greatly increased number of feedback in training, repositioning errors could be more accurately detected, and the acuity of movement improved (Sweeney et al., 2018). The improved results of the joint position sense test with advancing age in this study may be due to the fact that the proprioceptive information sent to the central process has improved over time.

Previously Foch and Milner (2013) and Kaynak et al., (2020) reported that the knees should be tested under body weight since they are angularly positioned poorly in the non-weight-bearing position and better positioned in the weight-bearing position (Foch & Milner, 2013; Kaynak et al., 2020). In this study, gymnasts were tested in a standing but non-weight-bearing position. This is because executed movements in aerobic gymnastics are usually performed with extremities that are not in contact with the floor.

The most important limitation of this study is the low number of joint movements measured. If other joint movements were also examined, the measurement time would be too long, worsening the gymnast's pre-competition warm-up performance. For this reason, the three most critical joint movements subject to the most execution cuts in competitions were selected. The second limitation is that the measuring instrument does not isolate a single joint movement like other advanced laboratory instruments. However, this measurement method is more suitable for the nature of the sport.

CONCLUSION

The findings of this study should be supported by other studies with the same or different joint movements. It should also be examined in studies where the number of male athletes is higher. The findings of this study can be used in the preliminary assessment of hip and knee joint proprioception and health status before the injury. Training that develops joint position sense can improve gymnasts' competitive results.

Disclosure statement
The authors do not have any potential conflicts of interest.

Researchers' Contribution Rate Statement
The first author carried out the design of this study. The second author made measurements.

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