The importance of postural analysis in injury prevention for young swimmers and footballers

Ph.D. thesis

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Contents

1 Introduction

A very crucial stage in the integrated development of movement after birth is standing on two feet. It is during this process that the tissues that will later provide postural support in the standing position are strengthened [1]. Posture, once established, can be described as a state of equilibrium that is continuously maintained, requiring the coordinated action of dynamic structures, passive elements, and the nervous system [2]. A functional approach to posture is described in the literature as core stability. The core is defined as both the control of trunk position and movement, and the control of positional feedback and movement of the limbs through the kinematic chain of force transmission in the pelvis and shoulder girdle. [3]. The importance of this in sport is that the appropriate level of core stability and strength is both a key factor for maximum performance and minimum stress on the joints.

In reviewing the etiology of the most common injuries in each sport, we can see that inadequate posture as an intrinsic factor is found in most cases as a direct or indirect cause [4, 5, 6, 7]. This may be because, in the presence of postural defects, we should expect the muscles to function inadequately, as their tension is not physiologically appropriate due to altered biomechanical conditions [8]. Numerous publications have addressed not only the performance effects of various core training interventions in athletes, but also their effectiveness in reducing non-contact injury risks and their causal relationships [3, 4, 6].

Among youth athletes, the peak growth phase is accompanied by significant physiological changes relevant to sports performance. These include alterations in body proportions and dimensions due to puberty, which may temporarily compromise motor abilities due to shifts in biomechanical conditions [1]. The importance of this developmental window for long-term athletic careers lies in the potential to optimize the biomechanics of movement through continuous monitoring of physical performance, including postural evaluation, and through the integrated development of motor skills [9]. Consequently, it is possible to reduce the incidence of sport-specific injuries.

1.1 Objectives

One aim of my research was to assess competitive youth swimmers in terms of sport-specific risk factors, with particular emphasis on postural analysis. I evaluated the effectiveness of a sport-specific training program developed according to identified factors and literature-based recommendations, using pre- and post-intervention assessments.

Another goal of the research was to explore the potential associations between frequently occurring injuries and postural deficiencies among youth football players.

My objectives also included the evaluation of the PostureScreen mobile application for postural assessment, thereby offering a practical tool for professionals collaborating with athletes.

2 The importance of postural analysis in injury prevention for young swimmers

2.1 Problem definition

Among swimmers, the most common chronic musculoskeletal complaint is anterior shoulder pain [5]. Known in the literature as "swimmer's shoulder", this symptom is not initially associated with a specific clinical diagnosis, but rather with a functional dysfunction that can negatively affect the athlete's performance [10]. According to the current literature, the prevalence of this phenomenon is remarkably high in both adult [7] and young [10, 11] competitive swimmers, ranging from 35% to 91% depending on age, gender and training volume. The first onset of pain may be as early as 11-13 years of age, which is also the age of puberty and the age of rapid growth [11]. The literature identifies high repetitive overhead arm overloads (up to 2500/day and 16 000/week [98]) as the primary cause [7], but changes in shoulder mobility, shifts in power balance and postural abnormalities [7, 12, 13] may also contribute to the onset of pain.

A characteristic postural abnormality in swimmers is described by increased thoracic kyphosis in addition to increased protrusion of the head and shoulder girdle [14, 15]. The significance of this is that athletes with poor posture are at increased risk of developing and persisting shoulder pain due to altered shoulder position and consequent muscle imbalance [13].

Research on the posture of competitive swimmers tends to focus on the upper body. Various methods (photogrammetric analysis, inclinometer) have been used in the past to analyze the posture of swimmers. As recommended by Saggini [16], these methods can be used to objectively determine the degree of incorrect posture. Botha and colleagues, using a photogrammetric method, found significant differences between female adolescent speed swimmers and non-swimmers of the same age in all the parameters they measured describing upper body posture [17]. Angles of head and shoulder girdle protraction, degrees of dorsal curvature and cervicovertebral angle were found to be more than optimal for both swimmers. This may mean that the form of swimming may predispose to poor posture.

A novel method for analyzing the whole posture is the use of the PostureScreen mobile application [12]. There are still few publications on its application, specifically for young athletes. In one study [12], this app was used to evaluate changes in total posture during a 6-week stabilization and stretching program for adult swimmers.

Various publications [10, 14, 15, 20, 21] have highlighted that preventive training of swimmers may have beneficial effects on shoulder position and muscle balance recovery, but less is known about the extent to which pain can be influenced. In the case of swimmers, previous publications [10, 14, 15, 20, 21] have only suggested that a combination of core training, shoulder strengthening and stretching exercises may improve posture and reduce shoulder pain. However, there is still no evidence that training aimed at correcting overall posture can reduce shoulder pain.

Therefore, in the first part of my research, I used the previously validated PostureScreen mobile application to investigate the changes induced by a 24-week posture correction program, designed taking into account the literature recommendations, and its impact on swimmers' shoulder pain.

2.2 Materials and Methods

The type of research was a prospective longitudinal study in the field of swimmers, involving competitive swimmers (n=54; 12-18 years old) from national swimming clubs. Athletes were randomly divided into experimental (EXP) and control (CON) groups to investigate the effectiveness of the program. All participants had at least four years of swimming training and attended at least four training sessions per week (mean swimming training time: 12.63±3.47 h/week). Exclusion criteria were acute injuries and surgeries in the last 6 months. No athletes were excluded by the specified criteria.

A self-administered questionnaire was designed to gather information on athletes' training and previous injuries. In addition, the presence and intensity of shoulder pain was assessed by completing the Swimmers Functional Pain Scale (SFPS) questionnaire.

Participants' height was measured with a Seca 213 stadiometer (Seca Corporation, Germany) and body weight with an Inbody 270 body composition analyser (Inbody, China), which also calculated body mass index (BMI) based on the measured data.

Posture analysis of the athletes was performed using the PostureScreen mobile application [22, 23]. During the survey, two images of the participating athletes were taken: a front view and a side view. The subject was positioned in front of a homogeneous background at 50 cm, the tablet was placed at a distance of 3 m from this line, and the camera height was set at 1.37 m [23]. When taking the photographs, it was required that they be barefoot and wore only underwear for better visibility.

The analysis of the habitual posture was automatically performed by the application after marking the required orientation points. During the application, the software characterizes the posture with a so-called "total" value from both sides under test, which is the cumulative deviation of the selected body parts (head, shoulders, pelvis, knees) from the optimal axis. The "total" deviations are described by the term's displacement (translation-T) and tilt (angulation-A). The displacement is expressed in cm and the angulation in degrees.

During the study period, CON performed her usual exercise program while EXP, in addition to regular swimming training, also performed a full posture-enhancing land-based training program for 30 minutes three times a week for 24 weeks. Two measurements (before and after the program) were taken during the study period to determine the presence of static standing posture and anterior shoulder pain.

The exercises have been designed with the recommendations of the literature in mind, to provide a progressive series of exercises adapted to the specificities of the sport, which can help prevent the development of swimmer's shoulder in the long term. The program consisted of a progressive series of exercises over a period of 3 to 8 weeks. Descriptive statistics (mean, standard deviation, frequency) were used for the measured parameters. Kolmogorov-Smirnov test was performed to test normality and Mann-Whitney and independent samples t-test were used to detect significant difference between EXP and CON.

A two-way mixed-effects consistency model was used for the inter-test reliability analysis of the posture analysis data. Pre-interaction coefficients (preICC) of posture analysis variables ranged from 0.65 to 0.98, and post-interaction coefficients (postICC) ranged from 0.88 to -0.99. To qualify the effect sizes, Cohen's d-values were calculated based on significantly changed variables.

The calculated changes in variables were calculated between pre- and post-training values. Pearson correlation test was used to examine the relationship between change in PostureScreen data and change in SFPS score. Statistical analysis was performed using IBM SPSS version 28.0. The level of significance was $p<0.05$.

2.3 Results

No significant difference in the frequency and intensity of shoulder pain was found between the two groups before the program. After the program, a significant change in the frequency of shoulder pain was observed among the EXP group. The difference in SFPS scores was significantly different between the EXP and CON groups after the program.

In the post-program period, significant differences in the change in several postural parameters (TK, CVA, KF, TFAA, TSJA, TFAT, TSJT change) were observed between EXP and CON. All these postural parameters improved for EXP.

Significant associations were found between changes in Posture Screen parameters and changes in SFPS score.

2.4 Discussion

2.4.1 Changes on shoulder pain

The prevalence of anterior shoulder pain, the focus of our study, is estimated in the international literature to be between 35-91%, depending on gender, age, and level of competition. However, the first onset of pain can be as early as 11-13 years of age [9]. In our study, 70% of the participating swimmers had pain in the anterior region of the shoulder before the program and this value did not differ between the two groups. Our current study results are consistent with data from previous international and national studies. Tessaro [10] and colleagues (2017) described a higher prevalence of shoulder pain among young female swimmers (aged 12-18 years), which they suggest may be associated with shorter arm strokes, lower pain thresholds and differences in laxity. Other studies have attributed a greater role to functional deficits in the development of high rates of shoulder pain [24]. The swimmers in our study had not previously participated in any preventive training program, which may explain the high prevalence of shoulder pain prior to the intervention. After our program, we observed a reduction in pain incidence in the experimental (EXP) training group, whereas in CON there was no notable change in pain presence. Some authors [14,15] have described a positive effect of intervention training on protrusion head and/or shoulder/shoulder girdle position and shoulder muscle strength, while the incidence of shoulder pain showed a decreasing trend. The short duration of their study may have been behind the only decreasing but not significant changes in shoulder complaints. In our case, the 24-week program was found to be able to significantly reduce the incidence of floating shoulder.

Since pain intensity has a physiotherapeutic relevance for the therapeutic options to be applied, it was also important to know the participants' subjective pain perception. According to the pre-program survey, this score corresponded to 3 in both groups according to the pain scale developed for swimmers. The meaning of this score is that the swimmer's shoulder pain lasts for more than 2 hours during the day and negatively affects their performance during training. The score on the survey sheet therefore places the swimmer in the white zone, a category for which the authors of the survey sheet recommend the inclusion of preventive exercises. In terms of pain intensity, only EXP swimmers were found to have a significant ($p<0.05$) change in SFPS score following the program. Their SFPS score dropped from 3.1 to 1, while the CON group's score remained unchanged. Fewer studies have examined the degree of pain and its changes. Most of the work found no major difference in the change in shoulder pain after their program, presumably also due to the short duration of the training. The combined 24-week program we implemented also had a positive effect on pain intensity,

ensuring smoother training and the potential for a long-term athletic career for athletes.

2.4.2 Changes on posture

Postural abnormalities are seen in the form of "swimmers' posture", which is more characteristic of swimmers and is described as a picture of poor posture. In the presence of postural abnormalities, we should expect muscle dysfunction with agonist-antagonist muscle imbalances. This condition may both maintain the established grip dysfunction and play a role in the persistence of shoulder pain in swimmers. The reversibility of the condition provides the opportunity to correct the abnormality through targeted intervention. Correct posture is particularly important in adolescence, as rapid physical development can increase the chances of poor posture, thereby increasing the risk of injury. Botha and colleagues (2021) [22] found that adolescent swimmers performed worse on sagittal plane photogrammetric postural analysis than non-swimmers, and this may lead to imbalances in the upper body muscles, which may carry the potential for shoulder pain.

In my research, there was a high prevalence of postural inadequacy in swimmers prior to the program, but as a result of the training program implemented, a significant improvement was observed. Postural parameters (dorsal kyphosis, cervical vertebral angle, cranial flexion, total anterior angulation, total lateral angulation, total anterior translation, total lateral translation) measured by PostureScreen showed significant improvement in EXP, while no positive changes were observed in the control group. Our results are consistent with those of other studies, which focused on the shoulder girdle and head region during postural analysis. Some authors have described significantly improved head and shoulder girdle protrusion [14, 15] after 6-8 weeks of intervention training. Our results suggest that implementing a sport-specific training program consisting of exercises targeting risk factors for the swimmer's shoulder may have a positive effect on improving posture and reducing shoulder pain in post-intervention swimmers.

The analysis and continuous monitoring of the athlete's posture using the PostureScreen mobile application has the advantage of indicating changes in posture at the onset of pain and allowing timely intervention [12]. The assessment of swimmers' posture using a mobile application is a novel method that can be used in the field due to its portability and can detect deviations from optimal posture using objective data. PostureScreen is an evidence-based posture analysis software that can be used in clinical practice and for research purposes in the field of sport [12, 22]. In our study, the use of PostureScreen was found to be an effective method for tracking changes in swimmers' posture.

2.4.3 Relationship between changes in posture and shoulder pain

Publications [7, 29] have reported that shoulder pain in swimmers is an etiologically multifactorial problem, with overhead repetitive motion in high numbers being identified as the primary cause [7]. In the present study, we focused on the habitual posture of adolescent competitive swimmers as one of the intrinsic factors that may lead to the development of shoulder pain. In adolescence, good posture is even more important because rapid growth changes may increase the propensity for poor posture, which increases the risk of injury [20]. After our program, we also observed a reduction in the frequency and subjective magnitude of pain in the experimental group, whereas in the CON group, there was no significant change in the quantitative or qualitative presence of pain. No international publications were found on the association between changes in total postural parameters and pain. The focus of the available studies is only on training for upper-body postural insufficiency and its improvement. In these studies, the authors [14, 15, 21] described a positive effect of training

for preventive purposes on protrusion head and/or shoulder/shoulder girdle position and shoulder muscular strength, while the incidence of shoulder pain showed a decreasing trend. The present study demonstrated a relationship between anterior shoulder pain severity score and changes in postural parameters during 24 weeks of combined exercise training in young swimmers. The results of this study suggest that more optimal biomechanical conditions may indirectly reduce the risk of developing swimmer's shoulder.

3 The importance of postural analysis in injury prevention for young footballers

3.1 Problem definition

Football is one of the most popular sports worldwide in terms of the number of athletes, with millions of players participating at all levels of competition (adult, junior, competitive, and recreational) [25, 26]. As such, the number of injuries in sport is also extremely high, not only due to the contact nature of football, but also due to the sport-specific workload. Adolescent footballers are at particularly elevated risk of injury due to the combined effects of the physical demands of the sport and the changing biomechanical conditions associated with growth [27]. During the period of peak growth, significant physiological changes occur in terms of sport performance, which may result in a temporary decline in motor skills [9]. The literature suggests that footballers' injury risks increase during the fast adolescent growth period and the subsequent 6 months. If monthly height gain exceeds 0.6 cm, it can increase the likelihood of injury to 1.63x [28]. Poor posture is a frequent problem among adolescents. Several publications [29, 30] have suggested that it may be a risk factor for injuries in football players.

According to the results of research with footballers, the highest injury incidence is in the U14-U15 (13-14 years old) age group. Most injuries (78%) involve the lower limb, of which approximately 45-72% fall into the non-contact injury category [28]. The most common non-contact injuries in this sport include soft tissue complaints of the inguinal area and hamstring muscle injuries [30]. Inadequate fitness, previous injury and muscular imbalances are commonly cited in the literature as risk factors for injury. However, changes in posture, such as asymmetries in the trunk and pelvis and sagittal deviations of the spine, have also been identified as factors that increase the risk of lower limb injury [6, 31]. These facts point to the importance of postural assessment and follow-up as a periodic injury prevention assessment, which may be of significant importance in the prevention of non-contact injuries in football.

To prevent poor posture and associated injuries in adolescent football players, coaches and player care professionals use a variety of methods [32]. By improving posture as a proactive approach to injury prevention, adolescent football players can reduce their risk of injury, improve their performance and enjoy a safer, more successful sporting experience.

Both growth and injury data for domestic youth football are scarce and the literature on the topic is poor. The number of studies on the relationship between postural abnormalities and injury incidence in adolescent footballers is also scarce at international level. Furthermore, the research on posture among footballers has focused on sagittal plane deviations and does not address the influence of frontal plane deviations on injury. While it would be appropriate to investigate those differences.

The aim of my research was to shed light on the possible correlations between injuries and postural deficits (sagittal and frontal plane) in adolescent football players.

3.2 Materials and methods

We conducted our cross-sectional survey using convenience sampling. The inclusion criteria were age between 11 and 18 years, a minimum of four years of sporting experience and participation in at least four training sessions per week (average football training time: 6 hours/week). Only boys participated in the study. Exclusion criteria were the absence of informed consent. The study was conducted among youth players of a national football talent center.

The players were divided into eight groups according to chronological age (age groups U12 to U19) and 2 groups according to academic age (preacademic: U12 to U14, academic: U15 to U19). Competitors and their parents received written and verbal information about the survey. They then gave their consent to participate in the program by signing a written consent form.

A self-designed questionnaire was created to find out the athletes' age and training frequency. Injury information was collected using the TalentX injury registration database used by the participating sports club. This system is a mandatory program for talent centers to use, as required by the Hungarian Football Association. These are used to categorize injuries by type of injury (sports injury, sports injury), joint involved (shoulder/shoulder girdle, elbow, wrist/hand, hip, knee, ankle/foot, spine), muscle involved (front of thigh, back of thigh, inside of thigh, leg, inguinal region, gluteal region, trunk), the subtype of injury (fracture, ligamentous injury, sprain, muscle injury, pain, inflammation, osteochondritis, cartilage injury), the side of the injury (right, left, both, central) and the body region affected (lower limb, upper limb, trunk) were recorded.

Participants' height was measured using a Seca 213 stadiometer (Seca Corporation, Germany) and body weight was measured using an Inbody 270 body composition analyzer (Inbody, China), which also calculated body mass index (BMI) from the measured data.

During the survey, 4 images of the participating footballers were taken and analyzed using the PostureScreen mobile app: one front view, one back view and two side views (right, left). In addition to the previously described parameters, the analysis also provided information on the deviations (translation, angulation) from the optimal line of each body part (head, shoulder-shoulder girdle, pelvis, knee). These parameters were recorded as follows: head translation (FT) and head tilt (FA), shoulder-to-shoulder-belt translation (VT) and shoulder-to-shoulder-belt tilt (VA), pelvis translation (MT) and pelvis tilt (MA), and knee translation (TT) and tilt (TA). The analysis was performed using SPSS 28.0 (IBM, USA). Descriptive statistics were generated for each variable, where mean and standard deviation data were determined according to group assignments and for the total study sample. The grouping criteria used in the study were chronological age and academic classification. After testing the normality of the posture data, univariate analysis of variance with Tukey post-hoc test and Kruskal-Wallis test were performed to examine the differences in each parameter between age groups. An independent samples T-test was used to examine differences between groups by academic age for postural parameters.

Based on the averages of the postural parameters by age group, two categories (above average and below average) were created. Chi-squared tests were performed to analyze the relationships between nominal variables formed from means of postural parameters and injury frequencies in both age - and academic age groups, as well as in the total study sample. A predictive model was constructed using discriminant analysis to predict the potential risk of muscle injury as a function of postural parameters. The significance level was $p<0.05$.

3.3 Results

The results were evaluated and 84.4% of the 116 subjects reported some kind of injury. As there was more than one injury per individual, this gave a total of 145 injuries. All injuries that were not associated with acute structural lesions of the tissues were included in the sports injuries.

In terms of total injuries, 91% involved the lower limb and the remaining 8% were split equally between the trunk/spine and the various injuries of the upper limb. Among the injuries involving joints (63 in total), 50% involved the knee, 34.9% the ankle/foot, 11% the joints of the spine and 4.1% were distributed between several joints of the body. Knee injuries were most common among 14- and 15-year-olds (61.3% overall). Among the injury subtypes we identified, 70.6% of athletes suffered a muscle injury (U15-14, U16-21, U17-15, U19- 17), 18.9% a ligament injury, 14.6% a chronic pain of the tuberosity tibiae or heel (U14-4, U15-3, U16-6) and 13.8% reported persistent pain of a joint. Most muscle injuries (80%) occurred in the front and back of the thigh.

Most of the injuries mentioned above (54.1%) required missing training for 1-3 weeks, 27.6% for 4-6 weeks, 7.1% for 7-9 weeks and 8.2% for more than 10 weeks. Looking at all injuries, 64 (44.1%) had a recurrence of the same injury over the one-year study period.

Posture analysis using the PostureScreen mobile app found significant differences between age groups by age group for 3 of the eight "total" parameters (TFAT, TFDT, TSJT, TSBT, TFAA, TFDA, TSJA, TSBA).

When comparing between age groups, we found significant differences in pelvic translation (MT) between U13 - U17, U13-U19, U14-U17 and U14-U19. Of these, the largest difference was found between the means of U13 and U17 ($p=0.005$). We also found a difference in pelvic tilt (MA) between age groups. For this parameter too, the U13 value was significantly lower than that of the U17 ($p=0.011$) and U19 ($p=0.043$) age groups. The degree of head displacement (FT) showed a significant difference between the U12 and U19 age groups ($p=0.033$), where the value for U19 was higher.

We divided the children into 2 groups by academic age (preacademic U12 to U14, academic U15 to U19). Significant differences were found between the two groups for the means of TFAT ($p=0.009$), TSJT ($p=0.004$), TSBT ($P=0.004$), FT ($p<0.001$) and FA ($p=0.014$).

First, the averages of the postural parameters by age group were determined and then classified into two categories (above and below average). The associations between injury incidence (verb/non) and nominal variables based on postural parameters were examined both within the respective groups and for the whole sample.

The highest correlations between postural parameters and injury occurrence were found in the U13 age group. In almost all age groups (regardless of grouping), it was observed that the fact of injury and the appearance of injury type were most influenced by "total" frontal plane deviations of the total postural parameters (TFAA, TFDT, TFDA) on the one hand, and by larger deviations of the pelvis (MT) on the other.

The occurrence of repetitive injuries was also influenced by the "total" deviations detected in the frontal plane (TFDA, TFAT, TFAA) and by the position of the pelvis (MT, MA). The quality of the association ranged from moderate to strong depending on age group.

For the full study sample, the most important observation is that "total" frontal variations in posture (TFAT) and pelvic displacement (MT) can be considered as risk factors for re-injury. The quality of the relationship in this case is classified as moderate.

To clarify whether muscle injury is more likely to occur for a given variation of a given postural parameter, discriminant analysis was used (Wilks lambda 0.54). Considering standardized canonical discriminant coefficients, the variables with the highest absolute value are the most effective in discriminating between types of muscle injury. HT, ST, PT, KT, and

HA played the most important role in injury classification. Lumbar injuries were the most correctly classified (57.1%), indicating that these injuries had well-defined postural correlates.

3.4 Discussion

The aim of our research was to investigate the relationship between poor posture and injury characteristics in adolescent football players. Our new results highlight that sagittal and frontal plane changes in posture may have an impact on the development/evidence of various injuries. Since adolescence is a critical period for growth and thus for changes in body biomechanics, we considered it important to compare the growth data of athletes with those of the general population. The anthropometric results were compared with reference data from the National Longitudinal Study of Child Growth, in which the reported means and percentiles of the dimensions they examine from birth to age 18 are national benchmarks [33]. These showed that the population of athletes studied were higher than the national average at all ages, especially for the U13, U14 and U15 age groups during the growth spurt.

There is a growing number of studies looking at injuries in athletes of the age group we have studied [26, 27]. All of these agree that a faster growth period affects injury rates. We can conclude that the rapid growth period and the biomechanical deficits associated with longevity increase the risk of injury in the immature organism. This is confirmed by Wik et al's [30] review of 53 publications evaluating injury patterns in adolescent football players. Like the findings of the present study, Towlson [27] described that knee (Schlatter-Osgood) and heel (Sever) progressive complaints are more common in the U12-U14 age group. On the other hand, the body, which has already undergone length growth but has not yet adapted, is more prone to muscle injuries, for which both the upset of force balance during biological maturation and setbacks in various motor performances may be responsible [34]. This is supported by our findings, in our study the U15 and U16 age groups are associated with an increase in the number of muscle injuries. Due to various injuries, 54.1% of the athletes were forced to miss training for 1-3 weeks and 27.6% for 4-6 weeks, which partially parallels the available literature [27], which shows that injuries lasting longer than 4 weeks account for 21-26% of all cases, while shorter absences account for 31-43% of cases.

3.4.1 Relationship between postural parameters and injuries

In several studies [35, 36], we find results of postural analysis of young football players, which characterize young football players with sagittal deviations. In general, based on our findings, both sagittal deviations and frontal plane deviations are typical in this sport and are associated with the development of injuries. In the analysis performed with the PostureScreen application, we found that postural parameters showed the greatest deviation in the older age groups (U17-U19). Based on our results, we can conclude that the habitual postural abnormalities of football players were negatively influenced by years of playing the sport. In a study by Theodoru et al., the impact of incorrect posture on specific motor skills was investigated. The results showed that the poorer the posture, the poorer the performance on certain physical tests (sit-and-reach test, high jump from a standing position test, isokinetic maximum force test). This may indicate that altered biomechanical conditions may cause functional deficits that may indirectly lead to certain injuries. According to Chromik (2017), a complex assessment of the posture of athletes can be key to injury prevention [35]. Unilateral loads in football training can often lead to musculoskeletal disorders and affect the posture of athletes [37, 38]. This can not only lead to pain but also to injuries.

When investigating the associations between injury categories and postural parameters, sagittal and frontal plane differences were found to be influenced differently across age groups.

Despite our hypothesis based on the aggregation of injury incidence and postural parameter averages, we found more significant correlations in the lower age groups than in the higher age groups.

It should also be highlighted that in the analysis by age group, most of the relationships between the variables examined showed moderate to strong relationships, i.e., the greater the degree of deviance, the greater the increase in the risk of injury. In the preacademic and academic groupings, we found fewer significant correlations between postural deviations and injury incidence, and they showed weaker relationships, which may explain why there may be greater variation in postural parameters across the entire population than within each age group.

It should also be highlighted that the odds of recurrent injury were also associated with postural parameters. Frontal plane "total" deviations and pelvic position, which occur in several age groups, may play a key role in the recurrence of injuries. Our study found that injury risk may be caused by both individual deviations in each body part and deviations in aggregate 'total' parameters, up to the pre-peak growth period and into older ages.

As a novelty, we found that certain postural parameters predicted the susceptibility of muscles to injury, and these are the parameters to watch out for during training. Injury to the groin showed the strongest negative correlation with postural parameters, suggesting that this injury is related to pelvic and shoulder girdle abnormalities. The development of anterior and posterior thigh injuries was moderately positively correlated with postural parameters, indicating that they are influenced by head and pelvic abnormalities. Although inner thigh injuries show a weaker (even slightly negative) correlation, the involvement of these muscles may be related to pelvic deviations. and calf injuries are likely to be due to deviations of the knee from the midline. In conclusion, the most important postural parameters associated with muscle injuries were pelvic tilt and translation (PA, PT), head and shoulder position (HA, ST), and knee and ankle displacement (KT). Our study is incomplete, because no studies investigating the extent of postural abnormalities and the correlation between different injuries were found in the national or international literature, in addition to sagittal deviations, we demonstrate and emphasize the importance of frontal plane deviations and their correction in postural alignment in football.

4 Summary of our new results

In the first part of our study, we investigated the effectiveness of combined training in adolescent swimmers in terms of changes in posture and shoulder pain. In the second part of our work, we analyzed the postural performance of adolescent football players and examined its relationship with injuries in this age group. For both subtasks, we studied the suitability of the PostureScreen mobile application.

1. In our study of swimmers, we demonstrated that the combined, sport-specific program resulted in an improvement in swimmers' posture.
2. We demonstrated that the improving trend in postural parameters also positively influenced the reduction of shoulder pain.
3. In the case of football players, we demonstrated that postural parameters can cause altered biomechanical conditions, and hence functional deficits, which may indirectly lead to certain non-contact injuries.
4. We are the first to use the PostureScreen mobile application in a national study not only to analyze posture but also to explore its association with sports injuries.
5. We demonstrated that the PostureScreen app is a suitable method for screening adolescent athletes for injury risk.

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6 Own publications, list of conference presentation

6.1 Scientific publications on which the thesis is based

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Szabó D., Lázár I., Mintál T., Gőcze K. Az úszóváll hatékony prevenciójának sportfizioterápiás vonatkozásai MAGYAR TRAUMATOLÓGIA ORTOPÉDIA KÉZSEBÉSZET PLASZTIKAI SEBÉSZET 62: 1-2 pp. 47-53., 7 p. (2019)

6.2 Conference presentations and posters related to the topic of the thesis

Szabó D., Kiss G., Tékus É., Fekete J.D., Vermes Cs., Mintál T. Assessment of Injuries in Youth Soccer Players in Relation to Body Posture ECSS konferencia Rimini e-poszter (2025)

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6.3 Other scientific publications

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6.4 Other conference presentations and posters

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Cumulative impact factor of the publications on which the thesis is based: **5,4**
Total impact factor of other publications: **0,9**
Cumulative impact factor: **6,3**
Total number of independent citations: **6**