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Contents

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CHANGES IN BODY POSTURE PARAMETERS: A FOUR-YEAR FOLLOW-UP STUDY

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Abstract Body posture is an alignment of its segments relative to each other in a certain way and the relations between them. Abnormalities in the alignment of body segments or the cooperation of systems may cause postural defects. Scientific evidence shows that children of school age are more exposed to abnormalities in body posture, thus posture should be monitored because it is a key aspect of their body's physical health. This study aimed to evaluate changes in body posture parameters in the frontal plane in the same children at 5 and then 9 years of age.

This four-year follow-up study included 67 children (29 girls and 38 boys) in the preschool-age and school-age phases (the first examination at 5 years of age and the second examination at 9 years of age). Measurements of body weight and height were recorded. A computerized assessment of body posture was performed using the photogrammetric method (MORA 4 Generation). The normality of the distribution of variables was assessed with the Shapiro-Wilk test. Analysis of qualitative data was carried out using Pearson's chi-squared test. The highest percentage of children exhibited a deterioration in the position of the lower corners of the scapulae, taking into account the division into sex (51.7% in girls and 50.0% in boys, respectively) and the analysis of the whole group (50.7%). There were statistically significant differences in the position of the lower corners of scapulae (UL) between the first and second examinations in all examined children ($p = 0.005$). The difference in the height of the waist and the position of the shoulders improved and deteriorated in a similar percentage in children (above 30–40%).

Generally, an improvement in body posture was observed. However, the abnormalities of body posture that occurred indicate the need for continuous monitoring of the children's posture and for preventive and corrective measures to be implemented.

Key words: frontal plane, posture, children, postural deviations, photogrammetric method

Introduction

According to the Posture Committee of the American Academy of Orthopedic Surgeons, posture is the relative positioning of parts of the body. Good posture is defined as musculoskeletal balance which protects the load-bearing structures of the body against injuries or progressive deformation regardless of the position (upright, lying, or bent over) (Takasaki, 1970). Abnormalities in body posture in the form of different positions of the shoulders or the lower corners of scapulae in the frontal plane are usually the first symptoms of worrying changes in body posture that are noticed by teachers and parents. These changes in the frontal plane indicate incorrect body posture. Therefore, body posture is a key aspect of our body's physical health. Posture is exposed to many factors that can cause negative changes in the position of its segments in relation to each other. One of these factors is age.

Abnormal changes in body posture occur in children in two difficult periods when body posture develops. The first difficult period, which is discussed in this report, affects children aged 6-7 years (Bubanj et al., 2012; Gavela-Pérez et al., 2015). This age is characterized by dynamic and rapid changes in growth. These changes are because the muscular apparatus cannot keep up with the rapid growth of bones (Cosma et al., 2015). Moreover, three years of school education are conducive to the deterioration of body posture because of new conditions (sitting for extended periods at the school desk, carrying a heavy school bag, negative experiences). They also disturb the stabilization of posture, and contribute to the uneven distribution of muscle and ligament tension, which in turn leads to overloads and worsening of the asymmetry of the musculoskeletal system (Hagner et al., 2011). The second period discussed in this report occurs at the age of 9. After the age of 10, developmental changes intensify and the next growth spurt occurs. Maintaining correct body posture often requires more concentrated effort due to muscle weakness (Gavela-Pérez et al., 2015).

All these changes are negative factors that lead to the development of posture disorders. Young children adapt to changes, though not always in an appropriate way (Kratenová et al., 2007). They very quickly develop adaptation strategies (Bjorklund & Beers, 2016), compensating for the alignment of individual body segments with each other, and these adjustments can lead to posture defects in three planes (frontal, sagittal, and transverse) (Oba et al., 2015; De Vasconcelos et al., 2010).

Scientific evidence indicates that most primary school children have some degree of posture abnormalities, while 18–50% of children and adolescents have normal body posture (Kratenová et al., 2007; Pokrywka et al., 2011). A large-scale population study showed that Chinese children and adolescents had severe postural problems (65.3%) (Yang et al., 2020). Observations conducted in previous years confirm a similar percentage range of changes (Lee et al., 2010).

It is extremely important to carry out research, especially in periods difficult for the development of body posture. Systematic monitoring of children's posture at every stage of their development and taking appropriate preventive measures at an early stage when abnormalities occur is considered appropriate. The consequences of passivity and inappropriate actions are significant deformations in all body systems, pain ailments, and serious health changes (Calvota-Fonseca et al., 2019; Calvo-Munoz et al., 2013). To prevent the consequences of such changes, screening should be carried out in schools, and research should be conducted in this direction. The development of modern diagnostic methods is an opportunity to reduce the percentage of children with incorrect body posture postures.

The arguments presented here prove the validity of this research was right. The topic is still relevant and important, as evidenced by numerous research studies on school-age children. The paper characterizes changes in body posture parameters in children in two difficult periods impacting body posture. Therefore, this study aims to evaluate changes in body posture parameters in the frontal plane in the same children at 5 and then 9 years of age.

Material and methods

Subjects

The study included a group of 67 children (29 girls and 38 boys). The study was conducted twice in one group of 5-year-old children (I examination), who received follow-up after 4 years (at the age of 9) (II examination).

The inclusion criteria for the first examination of these participants were: 1) the parent's or legal guardian's written consent for the child's participation in the study, 2) the year of birth of the child (2010), 3) body mass index up to the 85th percentile according to the standards of the World Health Organization (WHO standards, 2010).

The inclusion criteria for the second examination were: (1) participation in the first study for children, (2) general good health. Exclusion criteria applied to the group included: (1) lack of complete documentation. At this stage, no one was excluded.

The present study was performed by the Helsinki Declaration and was approved by the Ethics Committee of Jozef Pilsudski University of Physical Education in Warsaw (DM. 74–SKE 01-30/2018; DS. 246–SKE 01-01/2014). All parents or guardians of the children were informed of the procedures and voluntarily gave consent to perform the measurements and use the results for scientific purposes. The parents or guardians were informed of the possibility of withdrawal at any time during the study. The study was conducted in the Body Posture Laboratory at Jozef Pilsudski University of Physical Education in Warsaw, Biala Podlaska Branch (Poland). The first examination was conducted in 2015, and the second in 2019.

Measurements

All the anthropometric measurements (body weight and body height) were performed with a stadiometer RADWAG with an accuracy of 0.1 kg and 0.1 cm. The measurements were performed in standard conditions. Children were in underwear, and standing in an upright position, without bent knees, and barefoot. Body mass index (BMI) was calculated according to the formula and was then referred to the standards proposed by the World Health Organization (WHO standards, 2010).

For the assessment of body posture, the photogrammetric method was used based on the projection of the Moire Topography (MT) (MORA 4 Generation, CQ Electronic System, Poland). MT appears to be a viable and complementary alternative to a radiographic examination. MT is a method of imaging the body surface and is very sensitive in detecting asymmetry. Research shows the technique is a reliable and repeatable method (da Silva Filho et al., 2017; Chowanska et al., 2012). Historically, MT is based on assessing the symmetry of the moire fringes projected onto the subject’s back (Takasaki, 1970; Porto et al., 2010). However, it is worth emphasizing that the method has been reported as being an invaluable screening tool (da Silva Filho et al., 2017; Watanabe et al., 2019; Silva et al., 2014). It has been proven to be a quick and cheap method, and as a technique for testing body posture, it is easy and non-invasive. The measurement time is only 0.03 seconds. MT provides parameters describing body posture with an accuracy of 1 mm and 1º (CQ Electronic System, 2007; Grabara et al., 2017).

The body posture was assessed in the morning hours by a qualified person (physiotherapist) with many years of experience. The device was calibrated and the height of the measuring station was adjusted to the child’s height before the examination. The room in which the examination was performed was darkened. During the examination, the children stood without their outerwear, with their backs to the camera at a distance of 2.6 m. The body position should be relaxed with eyes looking forward, arms along the torso, feet shoulder-width apart, and legs straight (Labecka et al., 2021).

For the MT examination, it was necessary to expose the entire surface of the back and mark the following anatomical landmarks with a dermograph: the spinous process of C7 and S1, the acromial angle of the shoulders, the inferior and superior angle of the scapula, and the posterior superior iliac spine, as suggested by the Society on Scoliosis Orthopedic and Rehabilitation Treatment (SOSORT) (Negrini et al., 2012).

In the frontal plane, the studies analyzed the following parameters presented in Figure 1:

– KNT [º]: the coronal inclination of the trunk
– KLB [mm]: the difference in the height of the shoulders
– UL [mm]: the difference in the height of the lower corners of the scapulae
– KNM [mm]: the difference in the height of the pelvis
– TT [mm]: the difference in the height of the waist (“waistlines”).

To qualitatively assess the size of changes in somatic parameters in the children, the following division into groups was made:

Group 1 – improvement body posture: parameter values below 1 mm/1 º

Group 2 – unchanged body posture: values in the range 1 mm/1 º – -1 mm/-1 º. This range was adopted as the measurement error.

Group 3 – deterioration body posture: parameter values above -1 mm/-1

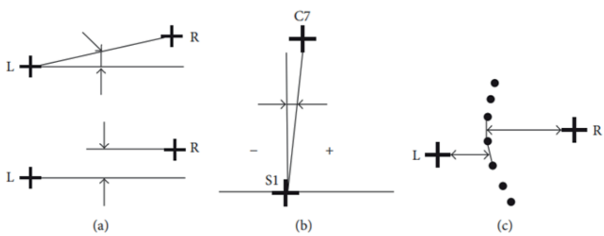

Figure 1. The method for determining parameters of body posture: (a) differences in the height of the shoulders, scapulae, and pelvis; (b) coronal inclination of the trunk; (c) difference in the distances from the lower corners of the scapulae to the spine.

Statistical analysis

The results were statistically analyzed using STATISTICA 13 (StatSoft, Poland). The normality of distribution was verified using the Shapiro-Wilk test. The analysis included a calculation of the mean, minimal and maximal values, and standard deviations of the variables, and a comparison of the results between groups using Student’s t-test for dependent variables. The analysis of qualitative data was carried out using Pearson’s chi-squared test. The accepted level of significance was $p < 0.05$.

Results

Anthropometric measures in group children of the I and II examinations are shown in Table 1.

Table 1. Anthropometric parameters in the children examined

Variables	I examination (n = 67)				II examination (n = 67)			
	M	SD	Min	Max	M	SD	Min	Max
Body weight [kg]	19.9	2.8	15.0	27.0	30.3	5.5	17.5	47.0
Body height [cm]	114.6	4.6	106.0	127.0	135.3	5.9	125.0	161.0
Body mass index [kg/m^2]	15.1	1.3	12.4	18.7	16.5	1.9	11.2	22.3

n – number of observations; M – mean values; SD – standard deviation; Min – minimal values; Max – maximum values

Over 4 years, the mean values in the coronal inclination of the trunk (KNT), the difference in the height of the pelvis (KNM), and the difference in the height of the waist (TT) decreased in all the children. Mean values in the position of the shoulders (KLB) and in the position of the lower corners of the scapulae (UL) increased. There were statistically significant differences in the position of the lower corners of scapulae (UL) between the first and second examinations in all the children (p = 0.005) (Table 2).

Table 2. Body posture parameters in all children examined

	All (n = 67)			
Variables	I examination	II examination	t	p
	M	M		
KNT [º]	1.2	0.9	1.457	0.153
KLB [mm]	5.2	5.3	–0.240	0.814
UL [mm]	3.8	5.2	–2.940	**0.005**
KNM [mm]	2.1	1.9	0.750	0.457
TT [mm]	5.8	5.2	0.890	0.377

n – number of observations; M – mean values; t – the result of Student's t-test for independent variables; p-level of probability (**p < 0.05**); KNT [º] – the coronal inclination of the trunk; KLB [mm] – the difference in the height of the shoulders; UL [mm] – the difference in the height of the lower corners of the scapulae; KNM [mm] – the difference in the height of the pelvis; TT [mm] – the difference in the height of the waist

In the group of girls, the parameters UL and TT decreased over 4 years. The parameters KLB increased slightly. In the group of boys, the parameters KLB and UL increased over 4 years, while the other parameters (KNT, KNM, TT) decreased. There were statistically significant differences in UL between the first and second examinations in the group of boys (p = 0.024) (Table 3).

Table 3. Body posture parameters in girls and boys

Variables	I examination	II examination	t	p
	M	M		
		Girls (n = 29)		
KNT [º]	1.1	1.1	–0.16	0.874
KLB [mm]	5.8	5.5	0.33	0.741
UL [mm]	3.5	4.5	–1.76	0.089
KNM [mm]	2.1	2.1	–0.06	0.950
TT [mm]	5.5	5.7	–0.19	0.854
		Boys (n = 38)		
KNT [º]	1.3	0.8	1.92	0.063
KLB [mm]	4.8	5.2	–0.71	0.481
UL [mm]	4.0	5.6	–2.35	**0.024**
KNM [mm]	2.1	1.7	1.32	0.196
TT [mm]	5.9	4.8	1.22	0.230

n – number of observations; M – mean values; t- the result of Student's t-test for independent variables; p- level of probability (**p < 0.05**); KNT [º] – the coronal inclination of the trunk; KLB [mm] – the difference in the height of the shoulders; UL [mm] – the difference in the height of the lower corners of the scapulae; KNM [mm] – the difference in the height of the pelvis; TT [mm] – the difference in the height of the waist

Also qualitative assessments of the size of changes in body posture parameters in the examined children have been made.

The highest percentage of children was characterized by the deterioration in the parameter UL, taking into account the division into sex (51.7% in girls and 50.0% in boys, respectively) and the analysis of the whole group (50.7%). The TT and KLB parameters improved and deteriorated by a similar percentage (about 30–40%) in all children, as well as broken down by gender. The parameters that did not change in more than half of the children were KNT and KNM. (Table 4, Table 5).

Table 4. Assessments of the size of changes in body posture parameters in all the children examined

All (n = 67)	Group 1	Group 2	Group 3
Variables	n (%)	n (%)	n (%)
KNT [º]	17 (25.4)	40 (59.7)	10 (14.9)
KLB [mm]	25 (37.3)	19 (28.4)	23 (34.3)
UL [mm]	20 (29.9)	13 (19.4)	34 (50.7)
KNM [mm]	20 (29.9)	35 (52.2)	12 (17.9)
TT [mm]	29 (43.3)	14 (20.9)	24 (35.8)

n – number of observations; % – percent; χ^2 – result of Pearson's chi-squared test; p-level of probability; Group 1 – improvement in body posture: parameter values below 1 mm/1 º; Group 2 – unchanged body posture: values in the range 1 mm/1 º – –1 mm/–1 º. This range was adopted as the measurement error; Group 3 – deterioration body posture: parameter values above –1 mm/–1; KNT [º] – the coronal inclination of the trunk; KLB [mm] – the difference in the height of the shoulders; UL [mm] – the difference in the height of the lower corners of the scapulae; KNM [mm] – the difference in the height of the pelvis; TT [mm] – the difference in the height of the waist

Table 5. Assessments of the size of changes in body posture parameters in the girls and boys examined

	Girls (n = 29)			Boys (n = 38)				
Variables	Group 1	Group 2	Group 3	Group 1	Group 2	Group 3	χ^2	p
	n (%)	n (%)	n (%)	n (%)	n (%)	n (%)		
KNT [º]	7 (24.1)	16 (55.2)	6 (20.7)	10 (26.32)	24 (63.16)	4 (10.52)	1.35	0.510
KLB [mm]	11 (37.9)	8 (27.6)	10 (34.5)	14 (36.84)	11 (28.95)	13 (34.21)	0.02	0.992
UL [mm]	6 (20.7)	8 (27.6)	15 (51.7)	14 (36.84)	5 (13.16)	19 (50.00)	3.22	0.201
KNM [mm]	10 (34.5)	11 (37.9)	8 (27.6)	10 (26.32)	24 (63.17)	4 (10.53)	5.05	0.081
TT [mm]	13 (44.8)	4 (13.8)	12 (41.4)	16 (42.11)	10 (26.32)	12 (31.57)	1.71	0.427

n – number of observations; % – percent; χ^2 – result of Pearson's chi-squared test; p – level of probability; Group 1 – improvement in body posture: parameter values below 1 mm/1 º; Group 2 – unchanged body posture: values in the range 1 mm/1 º – –1 mm/–1 º. This range was adopted as the measurement error; Group 3 – deterioration body posture: parameter values above –1 mm/–1; KNT [º] – the coronal inclination of the trunk; KLB [mm] – the difference in the height of the shoulders; UL [mm] – the difference in the height of the lower corners of the scapulae; KNM [mm] – the difference in the height of the pelvis; TT [mm] – the difference in the height of the waist

Discussion

This study aimed to evaluate the size of changes in body posture parameters in the frontal plane in children at 5 and then 9 years of age. This aim was achieved by observing abnormalities in body posture.

The present study revealed that over 4 years, the mean values in the position of the shoulder and the position of the lower corners of scapulae increased. Mean values in the coronal inclination of the trunk, the difference in the height of the pelvis, and the difference in the height of the waist decreased. There were statistically significant differences in the position of the lower corners of scapulae between the first and second examinations in the group of boys (p = 0.024) and all the children examined (p = 0.005). The highest percentage of children was characterized by a deterioration in the position of the lower corners of scapulae, taking into account the division into sex (51.7% in girls and 50.0% in boys, respectively) and the analysis of the whole group (50.7%). The other parameters improved and deteriorated by a similar percentage (about 30–40 %).

The results of this study revealed differences in the position of the shoulders in the children examined between the first and second examinations. With increasing age, the difference in shoulder position slightly increased. Similar results were obtained by Radzevičienė & Kazlauskas (2016). The authors observed differences in the position of the shoulders in 163 children. Our previous research on children revealed a statistically significant decrease in the position of the shoulders (Labecka et al., 2021). Research by Rusek et al. (2018) analyzing the differences between girls and boys in body posture showed statistically significant differences in shoulder tilt. The boys had a greater angle of inclination (p = 0.018). This abnormality may be the result of different rates of growth of body segments. It should also be kept in mind that this change occurred during the growth phase. In addition, the differences in shoulder position may be due to an overload caused by external factors (asymmetric sitting position, school backpack, hypermobility) or internal factors (handedness) (Hu et al., 2020; Kendalet et al., 2019)

In the present study, there was an increase in the frontal plane in the position of the lower corners of the scapulae in both sexes, with statistically significant differences in boys. Scientific evidence points to the same phenomenon. Radzevičienė & Kazlauskas (2016) examined the body posture of 1268 pupils of school age. In 163 students, differences occurred in the position of the lower corners of the scapulae. Hagner et al. (2011) also observed a 6.25% deterioration in the position of the lower corners of the scapulae in the frontal plane in boys who were observed over 3 years. Kratenová et al. (2007) provided the data that the most frequently detected defects in the study group were protruding scapulae (50%).

The findings of the present study did not reveal significant differences in body posture parameters between girls and boys of a given age. However, in the literature on the subject, abnormalities in body posture appear more often in girls at a later age, which is associated with physical development (AlenCiric, 2015; Penha et al., 2017; Yang, 2020). Moreover, these differences may have been due to gender differences in muscle development. According to Marceau (2011), girls reach their maximum muscle force earlier than boys because in girls the sexual maturation process begins earlier than in boys. Due to earlier physiological development, girls are more likely to stretch their necks and chests to reduce the change in appearance (Kendall, 2007). In addition, girls may be less active than boys, which usually leads to a lack of muscle strength, making it more difficult for girls to control their posture than boys (Klassonheggebo & Anderssen, 2003). Therefore, based on these possible causes, girls may be a high-risk group with incorrect changes in posture.

Generally, over the 4 years, a decrease in the values of most parameters in the coronal plane was observed in the study group, thus improving body posture. The same conclusions were obtained by Hagner et al. (2011). The authors monitored the body posture of the children for 3 years and observed that posture improved overall. However, there was still a large percentage of children (more than half) who had incorrect postures (Hagner, 2011). Based on their analysis of a sample of 968 preschool children, Simov et al. (2011) determined that only 10.3% of the children had postural abnormalities. A study by Bicanin et al. (2017) showed that in the frontal plane, incorrect posture is less present in children in all segments of the spinal column (5.08% in boys and 9.42% in girls). Other studies show that poor body posture occurred in 38.3% of children, more frequently in boys. A significantly different occurrence of abnormal body posture was found between 7-year-old and 11-year-old children (33.0% and 40.8%, respectively) (Kratenová, 2007). It is important to bear in mind that it is at this age that the first growth spurt occurs in children. Bones are still cartilaginous in some spots, the ligaments lack sufficient strength, and the muscles grow along with the bones (Lafond, 2007). Radzevičienė & Kazlauskas (2016) studied 1268 pupils in rural schools. Incorrect posture associated with the asymmetry of innervation tends to normalize during the child's development, and a posture defect resulting from damage to the musculoskeletal system may turn into a serious pathology of the skeletal system (Radzevičienė & Kazlauskas, 2016). Moreover, abnormal motor development may be a factor predisposing to abnormal values of the inclination of the trunk angle (Guzek et al., 2019).

Bearing in mind the prevention of various abnormalities in body posture and the prevention of three-dimensional changes (scoliosis), it is worth paying special attention to the parameters of body posture in which the greatest changes were observed (the position of the shoulders and the position of the lower corners of the scapulae in the frontal plane).

Research findings suggest that in children of younger school age, it is optimal for carrying out preventive measures that can help compensate for abnormalities in body posture and prevent posture problems through appropriate exercise programs. Children at this age tolerate more endurance exercise than expected. However, static muscle overload leads to a faster onset of fatigue in children (Kratenová, 2007). Therefore, younger school-age children should spend the same amount of time commuting to school. In addition, insufficient physical activity in free time constitutes a huge reserve of possibilities to influence the appropriate movement regime in the school environment, in which children spend a significant amount of time and are exposed to prolonged inactivity. The solution should be based on movement activities (physical education, exercises during school breaks, spontaneous movement at school and home), which may prevent future problems. It is important to monitor the attitudes of children at every stage of their development. Moreover, attention should be paid to the positions that children take during the day, especially with regard to the COVID-19 pandemic. Corrective actions are needed to prevent post-COVID syndrome. This study is the basis for further observation of body posture in the same group when children become adolescents. It is also worth analyzing the abnormalities in body posture in terms of other factors (genetics, hormones, nutritional status, etc.), and not only taking into account gender and age. The author will try to explain the variability of body posture in terms of physical activity in children in the future.

Conclusions

According to the results of our research, careful attention should be paid to the significant variability of some parameters in body posture (the position of the shoulders and the position of the lower corners of the scapulae in the frontal plane). Generally, an improvement in body posture was observed. However, the abnormalities of body posture which occurred indicate a need to monitor the children's posture continuously and to implement preventive and corrective measures.

Limitations

A limitation of the present study is the small study group. Only parameters in one plane (frontal plane) were used to assess body posture. However, these limitations did not significantly affect the value of the results. Further studies require consideration of body posture parameters in other planes (sagittal and transverse planes). Moreover, the influence of physical activity on children's body posture was not taken into account.

Study strengths

This study shows the differences in body posture parameters between the group of girls and boys. Periods that are difficult in terms of influencing body posture were taken into account. The children surveyed were from one social environment and were therefore subjected to a similar social and educational impact. The research used an objective measurement method (MT), which is both reliable and repeatable. Moreover, there is a lack of such studies showing changes in body posture without any intervention.

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COMBINED EFFECTS OF CAFFEINE AND AEROBIC EXERCISE ON LEPTIN LEVELS AND SOME INDICES OF INSULIN RESISTANCE IN DIABETICS

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Abstract The study aimed to examine the combined effects of caffeine and aerobic exercise on leptin levels and some indices of insulin resistance in diabetics

Thirty-two males with type 2 diabetes participated in a quasi-experimental and double-blind design. All participants were divided into four homogeneous groups of 8 individuals, including placebo (P), caffeine supplementation (C), aerobic training (AT), and aerobic training and caffeine (AT + C). The design protocol included eight weeks of aerobic exercise and caffeine consumption. Blood samples were taken to measure serum levels of leptin, glucose, insulin, HbA1c, HOMA-IR, and insulin sensitivity (QUICKI) indices at two phases. Data were analyzed by repeated measure ANOVA, Bonferroni posthoc, and independent T-test at a significant level of $\alpha \leq 0.05$.

The results showed that the levels of leptin, glucose, insulin, HbA1c, and HOMA-IR in the three intervention groups significantly decreased compared to the placebo group ($P = 0.001$). In addition, QUICKI was significantly increased in the three groups of caffeine (C), aerobic training (AT), and aerobic training + caffeine (AT + C) compared to the placebo group ($P = 0.001$). Also, the AT+C group has double effects on the investigated indices compared to the caffeine (C) group ($P = 0.001$).

Regular aerobic exercise and caffeine supplementation may be more effective treatments for improving insulin resistance indicators associated with type 2 diabetes.

Key words: caffeine, aerobic exercise, type 2 diabetes, leptin, insulin resistance

Introduction

The worldwide prevalence of type 2 diabetes (T2D) rises with obesity. Insulin resistance (IR), defined as a disorder in the ability of insulin to stimulate glucose uptake from surrounding tissues, is a prominent feature in metabolic disorders (Talukder, Hossain, 2020). It has been well established that individuals with IR are usually diagnosed with a decrease in glucose transportation and increased plasma-free fatty acid (FFA) concentrations with metabolic disorders of substrates (Kawada, 2013; Bergman, 2007). The sensitivity and function of insulin and beta-cell function significantly affect carbohydrate, fat, and protein metabolism; impaired regulation of these factors leads to metabolic syndrome and diabetes (Kawada, 2013).

Obesity and diabetes are accompanied by alterations in adipose tissue biology, rooted in the dysregulation of adipokines and cytokines (Frühbeck et al., 2018; Ayina et al., 2017). In summary, hypertrophy of adipocytes increases secretion of chemokines and penetration of macrophages. Hypertrophy reduces the expression of some adipokines like adiponectin and increases pro-inflammatory cytokines and other hormones secreted by white adipose tissue, such as leptin. Also, as an adipokine secreted from white adipose tissue (WAT), leptin has a role in regulating energy homeostasis and fat metabolism in interaction with carbohydrates by affecting the brain (Ayina et al., 2017).

On the other hand, the amount of free leptin in the bloodstream is proportional to the amount of body fat and reflects the state of long-term energy reserves (Frühbeck et al., 2018; Ayina et al., 2017). Therefore, the results of several studies point out the anti-obesity effects of leptin as one of its most important and prominent properties. High circulating leptin level in obese individuals is relatively common and defined as leptin resistance (Frühbeck et al., 2018). Also, changes in visceral and total fat mass and increased energy expenditure following regular exercise can adequately regulate the IR indicators (Tayebi et al., 2016). For example, it has been shown that 8 weeks of aerobic training significantly reduced weight, BMI, body fat percentage, insulin resistance, glucose and insulin compared to baseline conditions (Gharakhanlou & Bonab, 2022). It has been reported that 12 weeks of aerobic training reduced plasma leptin levels (Akbarpour, 2013). Also, it was stated that 12 weeks of aerobic training did not affect serum leptin levels (Saremi et al., 2012).

Today, however, medical-sports researchers benefit from combining physical activity with some pharmacological interventions to control obesity and the symptoms of T2D (Alshawi, 2020). As the most popular and common beverage globally, coffee indicates weight loss and improvement of T2D symptoms (Farajpour et al., 2017). Thus, some existing literature claims that the beneficial effects of coffee are caused by caffeine which is the most crucial and active compound of it (Alshawi, 2020). Caffeine (1, 3, 7-Trimethylxanthine) is a methylated purine alkaloid derived from the methyl-xanthine family (with the chemical formula C8H10N4O2). Since caffeine has full potential for altering energy metabolism and affects glucose homeostasis in individuals with diabetes and obesity, it has been investigated in both epidemiological and experimental studies (Alshawi, 2020; Farajpour et al., 2017; Jafari, et al., 2014). Chronic consumption of caffeinated compounds, such as coffee, has also been associated with a significant reduction in the risks of T2D in cohort studies (Alshawi, 2020). For instance, in a prospective cohort study following the consumption of 5 cups of coffee, it has been noted that coffee consumption increased glucose tolerance, and insulin sensitivity compared to the control group (Wedick et al.,2011).

In addition, Sacramento et al. (2015) examined the effects of single-dose caffeine consumption on whole-body insulin sensitivity. The results showed that acute caffeine consumption reduced insulin sensitivity through a concentration-dependent effect (Sacramento et al., 2015).

Also, it is stated that acute consumption of caffeine at the rate of 1.5 mg/kg of BW with 40% HR max physical activity protocol for 40 minutes on a treadmill significantly improved peripheral glucose reduction during activity in people with T2D (da Silva et al., 2014). These contradictory findings suggest that acute and chronic caffeine administration or acute administration combined with physical activity have opposite pharmacological effects. Therefore, the positive effects of combined exercises on many different biological aspects in human studies of healthy individuals and animal studies have been studied and identified. However, the interaction of similar exercises with fat-burning supplements, such as caffeine, on glycemic index response has not been thoroughly studied in patients such as individuals with diabetes. Therefore, the present study aimed to investigate and determine the effects of long-term caffeine supplementation (3 mg/kg of BW for eight weeks) with aerobic training (three days a week walking on a treadmill with an intensity of 60–70% of heart rate reserve for 40 minutes) on levels of IR markers (leptin and adiponectin, glucose, insulin, HbA1c, HOMA-IR, and QUICKI) in men with T2D. However, sports medicine coaches and clinicians should answer some of the ambiguities regarding the interactive effects of exercise, bodybuilding, and caffeine supplementation based on the obtained data and determine whether combinations of these therapeutic interventions can reduce diabetes complications and avoid high treatment costs or not.

Materials and Methods

This study is a quasi-experimental, double-blind clinical trial with a pre-and post-test design. The study was performed on 32 men with T2D. Participants were selected from 65 patients (with a history of more than one year of diabetes) and were randomly divided into four groups of 8 individuals by available and purposive sampling methods. Groups included three experimental and one control group, with an age range of 50–55 years and body mass index range of 32–35 kg/m^2 (Table 1). The entire research was conducted according to the Declaration of Helsinki. Accordingly, all participants were first guided about cooperation and signed informed consent; before starting any physical activity, the participants answered the International Physical Activity Questionnaire (IPAQ) to be screened (Shirali et al., 2016). The amount of caffeine consumption of the subjects was evaluated and controlled using a 24-hour nutrition recall questionnaire. (Farajpour et al., 2017).

The main inclusion criteria of subjects in this study include: being in the age range of 40–60 years, fasting blood glucose between 125–250 mg/dL, no history of diseases related to diabetes (such as neuropathy, nephropathy, retinopathy), no history of using other supplements to lower blood glucose and blood pressure higher than 140/90 mm Hg, lack of regular sports activities that are more than one session per week during the last three months and having a history of diabetes for more than one year. In addition, none of the subjects were under insulin treatment and all patients were on metformin and glibenclamide orally during the research period. Also, exclusion criteria included: having complications of diabetes such as diabetic foot, history of cardiovascular diseases, uncontrolled arrhythmia. Finally, individuals who were non-compliant with the study protocol and were smoking and consuming alcohol were excluded.

In addition, the daily diet of subjects was analyzed using a 24-hour nutritional recall questionnaire to check the amount of calories and the percentage of energy received from macronutrients based on the database of the Nutritionalist IV[1] software (Table 1).

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[1] Nutritionist IV. Copyright 2004. N-Squared computing and First DataBank Inc. The Hearst Corporation 1111 Bayhill DR, San Bruno, CA 94066.

The participants' body composition, height and BW were measured with Seca217 gauge (made in Germany) with a sensitivity of one millimeter and Seca digital scale with an accuracy of 0.1 kg, respectively. Body fat percentage was also determined by Body Composition Analyzer (InBody-570, made by south korea) (Swain, 2014).

Caffeine supplement contract

Participants in the supplement group (C) equally consumed a daily dose of caffeine-containing capsules made by German Merck Company and licensed by the Ministry of Health (registration number of 0225/02584/1) according to their weight (3 mg/kg of BW). Also, individuals in the placebo (P) group consumed dextrose in the same amount (3 mg/kg of BW), similar to the supplement group.

During two months, each subject took one caffeine or dextrose capsule with 250 ml of water an hour before the activity on training days (three days a week) and half an hour after breakfast on other days without exercise (three days a week). All participants were unaware of the capsules' content (double-blind plan). According to the results of previous studies, the amount of caffeine consumed in the present study was considered in the effective range (3 to 6 mg/kg of BW) required to improve athletes' plasma levels and performance (Jafari et al., 2014). Also, during the intervention, patients were investigated regarding possible unwanted side effects and adherence to the protocol by daily calls.

Exercise protocol

The exercise protocol of the present design included walking on a treadmill (on a zero-degree slope with an intensity of 70–60% of the reserve heart rate). The baseline heart rate of participants was recorded after 10 minutes of resting (sitting) with a polar heart rate monitor made in Finland. The maximum heart rate of the subjects was calculated using the Karvonen formula given at the end of the section. In order to control the activity intensity of 60–70% of the maximum heart rate, the Karvonen method or the reserve heart rate, which is equal to the percentage of maximum oxygen consumption (aerobic capacity), was used. Based on the protocol, subjects walked on a zero-degree slope treadmill with a 60% reserve heart rate for 25 minutes from the first to the third week, a 65% reserve heart rate for 30 minutes from the fourth to the sixth week, and with a 70% reserve heart rate for 40 minutes from seventh to the eighth week. Therefore, a researcher controlled the subjects' heart rate and treadmill speed until the end of the training protocol. Participants performed stretching exercises to warm up for 10 minutes before performing the exercise protocol and executed cooling down training for 10 /minutes at the end of each training session (Shirali et al., 2016).

Method of preparing blood samples

Blood sampling was performed in two stages (first stage: 24 hours before supplementation and training protocol; and second stage: 24 hours after the last training session and eight weeks of supplementation). The samples were drawn at a rate of 5 ml from the left forearm vein (Antecubital vein) after 8–10 hours of fasting. Then, the blood samples were placed at the average laboratory temperature for clot formation and then placed in a centrifuge made by Behdad-Iran Company for serum separation at 4000-35000 rpm (RPM). All measurements were performed at 9–12 am, 26-28 °C temperature, 50–55% humidity, and the same ventilation and ambient light condition. In addition, before the test, subjects refrained from taking any dietary supplements affecting glucose and diabetic parameters for 48 hours while maintaining a regular diet. The participants also avoided strenuous exercises and activities (such as massage, sauna, anti-inflammatory, and anti-diabetic drugs) that might affect injury, cell inflammation, and blood glucose.

Laboratory analysis

The enzymatic colorimetric method was used to measure fasting serum blood glucose based on the glucose oxidase reaction (Pars Azmoun Company Kit; Iran) with a sensitivity of 5 mg/dl and employing model 902 auto-analyzer (Hitachi; Germany). Also, fasting serum insulin was measured by the competitive and sandwich ELISA method with a sensitivity of 0.5 micro-units per milliliter (μU/ml) and the coefficient of internal and external changes of 6.45% made by ELISA Reader (DIARJ; Germany). Additionally, IR and insulin sensitivity indices were calculated using the homeostatic model assessment (HOMA) and the quantitative insulin sensitivity check index (QUICKI), respectively, with the following equation (Farajpour et al.2017; Torabi & Mirzaei, 2022):

HOMA-IR = fasting plasma glucose (mmol/l) × fasting serum insulin (mU/l) / by 22.5

QUICKI = 1/ (log (fasting insulin μU/ml) + log (fasting glucose mg/dl))

Leptin was measured based on the double-antibody sandwich ELISA using a kit made by the Germany BINDER Company with RD191001100 serial number. All measurements were simultaneously performed according to the instructions using the standard curve and control at a specific time. This method has a sensitivity of at least 0.05 ng/ml, the daily coefficient of change of 0.13 in 0.32 ng/ml, and %5.8 in 2.8 ng/liter. In order to measure the serum level of adiponectin, the ELISA method was performed using a commercial kit by BINDER company (tracking code: RD195023100) with a sensitivity of 0.5 μg/ml. Also, HbA1c index was measured using a biosystem kit made in Spain and by spectrophotometric method.

Statistical methods

All data were expressed as Mean ± SD. Shapiro-Wilk (S-W) test was used to determine the normality of the initial data distribution. Then, 2 × 4 (group × steps) repeated measures Analysis Of Variance (ANOVA) was used to calculate the mean changes of each variable in the dual stages of measurement, the interaction of the groups (supplement and placebo), and blood sampling stages. In case of differences between time stages, the Bonferroni post hoc test was used. The independent t-test was used to determine the difference between groups. All the statistical analyses were performed by SPSS software version 22 at a significant level of 5%.

Results

The anthropometric and physiological characteristics of the participants (Age, VO2 MAX, Energy Received, Fat Percentage, BMI, and WHR) of each group are presented in Table 1.

The present study showed that basal serum leptin level is high in men with diabetes. Eight weeks of caffeine supplementation (C) in individuals with diabetes significantly reduced the leptin concentration by 17.87% compared to the placebo group (P) (P = 0.001). Additionally, leptin levels in the other two experimental groups, aerobic training (AT) and aerobic training + caffeine supplementation (AT + C), were significantly reduced by 22.79% and 31.82% compared to the baseline, respectively (P = 0.001). The simultaneous intervention of aerobic training and caffeine supplementation (AT + C) had far more modulatory effects compared to the separate application of aerobic training (AT) and caffeine supplementation (C) ($P = 0.001$) (Figure 1).

Also, the analysis showed that serum levels of glucose, HbA1c, insulin, and HOMA-IR in men with diabetes significantly decreased by about 13, 7, 17, and 10% compared to the placebo group after eight weeks of caffeine intake with aerobic training (AT + C), respectively ($P = 0.001$) (Figure 2 and Table 2). The further reduction in the indices related to IR in the group of aerobic training with caffeine (AT+C) was statistically significant compared to the caffeine group (C) ($P \leq 0.05$). Changes in insulin sensitivity index (QUICKI) in all intervention groups (aerobic training, caffeine and training + caffeine combination) were significantly increased compared to the placebo group ($P = 0.001$). The mentioned increase was significant in the aerobic training (AT) and aerobic training + caffeine groups (AT + C) compared to the caffeine group (C) ($P = 0.001$) (Table 2).

Discussion

The present study showed that serum leptin concentrations in diabetes were significantly higher than normal values (2.5–21.8 ng/ml). Also, the present study showed that caffeine consumption in diabetes significantly reduced serum leptin by about 18%. The existing literature has also shown that caffeine supplementation reduces leptin resistance in diabetes by modulating leptin-dependent signaling pathways. In this regard, consistent with the present study, Hosoi et al. (2014) and Yamashita et al. (2012) suggested that caffeine supplementation in overweight men had a significant lowering effect on the investigated leptin resistance indices (Yamashita et al., 2012; Hosoi et al., Leptin upregulates transcription of anorectic neuropeptides and downregulates transcription of appetite neuropeptides through phosphorylation of the JAK2/STAT3 pathway proteins. It also controls glucose homeostasis by suppressing the glycogenic gene expression in the liver and stimulating phosphorylation of the insulin receptor substrate-1 (IRS-1) (Kempf et al., 2010).

Additionally, pharmacological activation of β-adrenergic receptors, which is coupled to the stimulated guanosine protein (Gs), has been shown to reduce gene expression and leptin secretion. Therefore, it is inferred that caffeine may be a beneficial therapeutic agent to reduce leptin secretion by increasing stimulation of the PKA/cAMP signaling cascade. The cascade is stimulated through increasing levels of stress hormones (catecholamines and cortisol), inhibition of the cyclic nucleotide phosphodiesterase (PDE), and the guanine protein-coupled receptors (GPCRs), especially A1 and A3 isoforms of adenosine (Rice et al.,2000).

In contradiction with the present study, the results of some researchers indicated that caffeine and physical activity did not have any effects on the levels of leptin resistance (Kim et al., 2016; Rasaei et al., 2019; Shirali et al., 2016; Hongu & Sachan, 2000). It seems that the circumstances of participants, such as being with diabetes or healthy, the habitual status of caffeine intake, exercise protocol, and baseline levels of the measured indicators, are among possible reasons for the differences and contradictions between the present study and the results of the mentioned studies.

As seen in the present study, co-administration of caffeine with aerobic training caused a significant reduction in leptin levels, which is 4 and 6 ng/ml more than the caffeine supplementation alone and aerobic training intervention, respectively. In this regard, Kazemi et al. (2015) studied rats with T2D and stated that eight weeks of aerobic training with an intensity of 65–75% VO2max reduced leptin resistance (Kazemi & Saleh, 2015). Also, Amani et al. (2018) declared that performing advanced aerobic training for six weeks was associated with decreasing serum leptin levels (Amani et al., 2018).

Also, discoveries in other investigations have indicated an inverse relationship between circulating leptin concentrations and IR. It has been shown that leptin receptors in pancreatic beta cells inhibit insulin biosynthesis and secretion by pancreatic cells (Talukder & Hossain, 2020; Kawada, 2013).

Insulin secretion may be suppressed by leptin through a variety of mechanisms directly affecting β-cells. For β-cells to release insulin it is crucial that β-cell membrane be depolarized by closing adenosine triphosphate (ATP)–sensitive potassium (K_{ATP}) channels as a reaction against glucose or other insulin secretagogues. The cell membrane is hyperpolarized by leptin opening K_{ATP} channels, which results in a decline in intracellular Ca^{2+}, known to be involved in the β-cell releasing insulin vesicles. Additionally, insulin biosynthesis and gene expression are assumed to be affected by leptin through a transcriptional process. This seems to be independent of K_{ATP} channels activation as the K_{ATP} channel opener diazoxide does not affect the suppression of insulin gene transcription in β-cells which is brought about by leptin. So, the inhibitory action of leptin on insulin gene expression and insulin secretion has to be exerted through different signal transduction pathways (Cited in Yong-ho et al.,2011).

On the other hand, insulin also stimulates leptin secretion from adipose tissue. This hormone-regulating feedback loop has a fundamental Adipo-insular axis (Frühbeck et al., 2018), so dysfunction of the mentioned message axis plays a vital role in developing hyperinsulinemia. Another possible mechanism for modulating leptin secretion induced by physical activity can be the improvement of insulin sensitivity. Exercise improves glucose transport into adipocytes by increasing GLUT4 in the plasma membrane; glucose acts as an intracellular messenger and stimulates leptin secretion from fat cells (Saremi et al.2012).

The present study indicates a significant decrease in serum levels of glucose, insulin, HOMA-IR index, and an increase in insulin sensitivity index (QUIKI) due to long-term caffeine consumption, which is consistent with the results of some researchers (Gharakhanlou & Bonab, 2022; Conde et al., 2012; Guarino et al., 2013).

Many studies have expressed that the PI3K activation provides a central message for stimulating the transport of the GLUT4 by insulin. On the other hand, caffeine acts as an inhibitor of the PI3K, inhibiting insulin-induced GLUT4 transport (Yamashita et al., 2012). These findings suggest that inhibition of glucose uptake by caffeine may occur by stopping the IRS-PI3K-Akt/AS160 cascade (Sacramento et al., 2015; Yamashita et al., 2012; Conde et al., 2012; Kolnes et al., 2010). Other literature has shown that adenosine antagonists reduce insulin sensitivity in adipose tissue and heart muscle and, on the other hand, increase insulin sensitivity in skeletal muscle. According to a recently published study, Sacramento et al. (2015) reported that acute caffeine consumption (0.001-5 μmol) reduced insulin sensitivity (insulin resistance) (Sacramento et al., 2015). The present study results showed that daily consumption of 3 mg/kg of BW for eight weeks reduced serum glucose and insulin levels of diabetes by 13.5% and 7%, respectively.

However, caffeine consumption and aerobic training with synergistic effects (enhancement) decrease glucose index (da Silva et al., 2014; Shirali et al., 2016; da Silva et al., 2014). Researchers have claimed that chronic caffeine consumption improves the probability of glucose excretion from the bloodstream by activating GLUT4 expression pathways through increasing intracellular calcium concentration and AMPK enzyme expression (Sacramento et al., 2015; Jensen et al.,). Also, caffeine stimulates insulin secretion by pancreatic beta cells, increases cascade activity, and enhances the path of improving insulin secretion by stopping ATP-sensitive potassium channels in the pancreas and increasing calcium concentration (Wedick et al., 2011). On the other hand, Zaharieva et al. (2016) showed that caffeine with a dose of 6 mg/kg of BW 60 minutes before exercise (with the intensity of 60% VO2max for 45 minutes) in people with type1 diabetes (with HbA1C equal to 7.4%) modulated hypoglycemia during exercise compared with placebo (Zaharieva et al., 2016).

Improvements in HbA1C due to caffeine consumption and aerobic training are associated with a decrease in inflammatory markers such as adiponectin and leptin secreted by adipose tissue. HbA1C is an indicator that shows the level of blood sugar in the last 8–12 weeks (Yousefipoor et al., 2015). In the present study, the levels of HbA1C decreased significantly by 10.5% following caffeine consumption. In contrast, following a pilot study, James (2011) stated that three-month avoidance of caffeine and caffeine compounds reduced HbA1C levels by 0.56% and improved long-term glucose control in 12 coffee-addicted consumers (consuming more than two cups of coffee per day) who had T2D (James, 2011). As observed in the present study, aerobic training with a higher effect than caffeine consumption reduced glucose, insulin, IR index, and HbA1c by 19.6, 15.6, 32.5, and 10% compared to the baseline, respectively. In this regard, Yousefipoor et al. (2015) noted a significant decrease in HbA1c and fasting blood glucose levels following a quasi-experimental study examining the effects of aerobic training, including three sessions of running per week with an intensity of 60–80% of maximum heart rate for eight weeks (Yousefipoor et al., 2015). A decrease in erythrocyte glycosylation improves oxygen delivery to muscle cells and increases maximal oxygen consumption (VO2max) in patients with T2D during exercise. Thus, with an increase in HbA1c, the patients with T2D develop chronic hypoxia resulting in compensatory polycythemia, which may eventually lead to systolic hypertension in individuals with diabetes (Yousefipoor et al., 2015). The present study showed that combining caffeine supplementation with aerobic training was involved in reducing HbA1c by 16.86%, which was a more effective method than applying each of them alone.

Moosavi et al. (2016) reported that glucose concentration and IR in women with T2D participating in an 8-week exercise program (with an intensity of 50 to 70% of maximum heart rate) were reduced (Moosavi et al., 2016). Exercise decreases blood glucose and improves insulin function. Researchers suggested that the beneficial effect of exercise can be mediated by mechanism as follows:

increase in insulin receptor signaling, glucose transporter relocation from intracellular stores to plasma membranes, glycogen synthase and hexokinase enzyme activity, improvement in muscle capillary function, changes in the muscle composition for glucose uptake and decrease in the release or clearance of FFAs (Frühbeck et al., 2018; Ayina et al., 2017; Farajpour et al., 2017; Torabi & Mirzaei, 2022). However, the failure to measure the upstream and downstream pathways of insulin messaging is one of the most critical limitations of the present study. Physical activity may increase the exocytosis of GLUT4 to the cell membrane for 48 hours after activity and improve insulin sensitivity by improving the proximal insulin signaling pathway (IR tyrosine kinase activity, PI3K activity, or IRS-1 tyrosine phosphorylation) and affecting the distal parts such as AS160 (Rasaei et al., 2019; Torabi & Mirzaei, 2022). Therefore, it is recommended that there should be no break for more than two days between physical activities to maintain sensitivity to insulin transmitters (Rasaei et al., 2019).

Conclusion

Based on the result, caffeine supplementation for two months and chronic aerobic training may prevent adverse changes in the risk indices in men with T2D by improving glucose homeostasis and other anti-diabetic properties. Therefore, considering the precautionary aspects, it can be suggested to patients with pre-diabetes and diabetes and even active individuals to use caffeine supplementation and regular aerobic training to prevent and reduce undesirable glycemic levels.

Ethical approval Code of ethics in research number IR.TBZMED.REC.1398.1179 was obtained from the Vice-Chancellor for Research and Technology of Tabriz University of Medical Sciences, and the trial was registered in Iran Clinical Trial Center (IRCT- 20170116031982N2).

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Table 1. Anthropometric and physiological characteristics of the participants

Variables	Groups N	P 8	C 8	AT 8	AT+C 8	Intergroup p-value
Age (Year)	Pre-test	50.23 ±2.42	49.78 ±3.56	52.10 ±1.74	51.7 ±2.43	0.46
VO_2 Max (**ml.kg^{-1}.min^{-1}**)	Pre-test	30.04 ±5.11	31.29 ±7.09	33.51 ±2.67	32.03 ±3.42	0.28
Energy received (kcal/day)	**Pre-test**	2525.3 ±115	2550.6 ±210	2610.5 ±167	2575.2 ±185	0.87
BMI (kg/m^2)	**Pre-test**	27.56 ±3.92	28.12 ±3.40	29.11 ±1.16	28.45 ±2.58	0.74
	Post-test	28.11 ±2.15	27.45 ±2.31	28.01 ±3.32	27.13 ±2.32	0.036
	within group p-value	0.54	0.036	0.02	0.01	
WHR	**Pre-test**	1.02 ±0.05	0.98 ±0.003	1.01 ±0.02	0.99 ±0.001	0.87
	Post-test	1.003 ±0.004	0.92 ±0.002	0.91 ±0.001	0.89 ±0.002	0.03
	within group p-value	0.37	0.03	0.02	0.01	
BF (%)	**Pre-test**	30.12 ±3.16	31.42 ±2.13	31.1 ±2.62	32.43 ±4.12	0.33
	Post-test	31.23 ±2.45	30.00 ±3.32	29.14 ±3.56	29.00 ±2.10	0.03¥
	within group p-value	0.45	0.051	0.003#†	0.001#†	

The values are expressed in standard deviation ± mean. AT, Aerobic Training, C, Caffeine, P, Placebo.
¥ Independent t-test
Paired t-test
† Significance compared to the placebo group

Table 2. Mean ± standard deviation of glucose and insulin resistance indices in men with type 2 diabetes, in Pre- and Post-test

Variables	Groups	Sampling steps		Percentage of changes	Within group p-value	Intergroup p-value
		Pre-test	Post-test			
FBS (mg/dl)	**P**	150.3 ±16.15	151.54 ±15.54	0.8	0.32	0.001¥
	C	148.16 ±14.12	128.13 ±4.08	–13.5	0.023‡	
	AT	151.85 ±18.81	122.01 ±10.96	–19.65	0.001‡	
	AT+C	148.14 ±19.45	117.17 ±4.48	–20.90	0.001‡	
HOMA-IR	P	4.55 ±0.53	4.64 ±0.63	1.9	0.13	0.001¥
	C	4.64 ±0.41	3.72 ±0.27	–19.82	0.03‡	
	AT	4.65 ±0.96	3.14 ±0.41	–32.47	0.001‡	
	AT+C	4.28 ±1.15	2.70 ±0.34	–36.91	0.001‡	
QUICKI	P	0.304 ±0.005	0.301 ±0.006	–0.98	0.08	0.001¥
	C	0.305 ±0.002	0.308 ±0.003	0.98	0.034‡	
	AT	0.303 ±0.010	0.318 ±0.006	4.95	0.001‡	
	AT+C	0.306 ±0.012	0.328 ±0.005	7.18	0.001‡	
HbA1c (%)	P	6.91 ±2.21	6.93 ±2.28	0.28	0.11	0.001¥
	C	6.89 ±2.01	6.15 ±1.81	–10.74	0.04‡	
	AT	6.93 ±2.32	5.92 ±2.42	–14.57	0.001‡	
	AT+C	6.88 ±2.31	5.72 ±1.87	–16.86	0.001‡	

The values are expressed in standard deviation ± mean. AT, Aerobic Training, C, Caffeine, P, Placebo.
‡ Significance within the group (P < 0.05).
¥ Significance between the groups (P < 0.05).

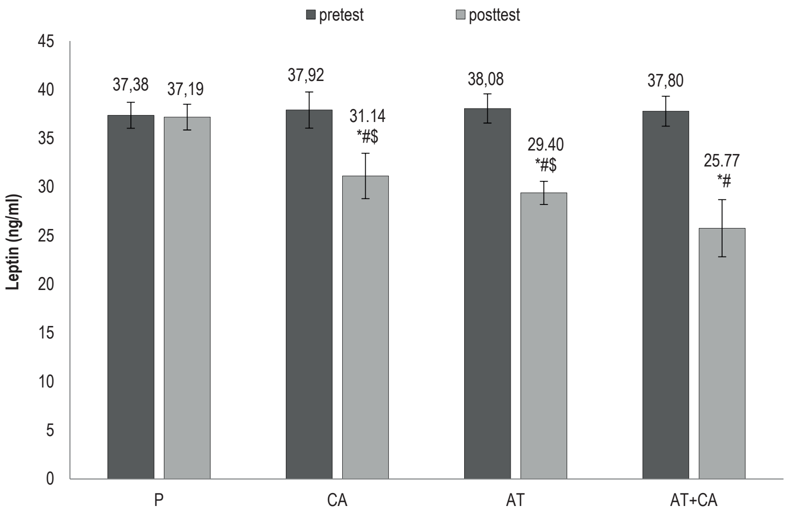

Figure 1. Serum leptin levels in men with type 2 diabetes

* Significance within the group (P <0.05). # Significance compared to the placebo group (P) (P < 0.05). $ Significance compared to the combined group (AT + CA) (P < 0.05).

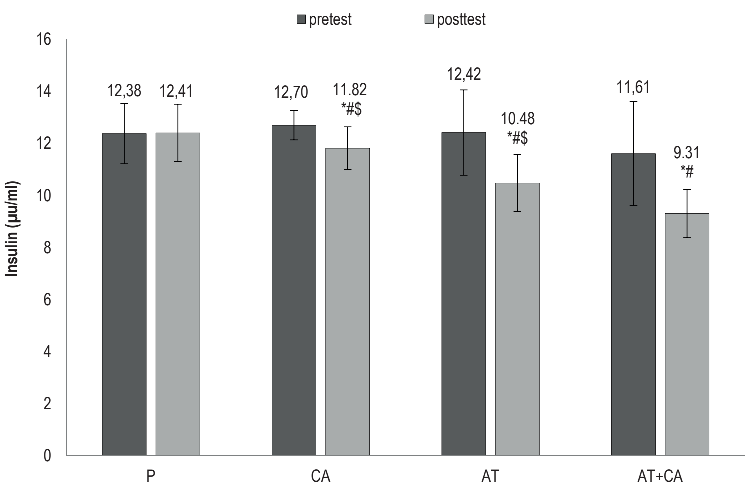

Figure 2. Serum insulin levels in men with type 2 diabetes

* Significance within the group (P < 0.05) # Significance compared to the placebo group (P) (P < 0.05). $ Significance compared to the combined group (AT + CA) (P < 0.05).

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EFFECTS OF SENSOMOTOR COMMUNICATION SYSTEM BASED EXERCISES ON STATIC BALANCE AND SELF-ESTEEM IN 7–12 YEARS OLD KARATE PUPILS

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Abstract Karate is a martial art that require a high level of motor and functional abilities, discipline and mental concentration as well. Practicing Kata improves self-awareness and focus, but is not always included in a class agenda. The author's of sensomotor communication system based exercises have combined principles of movement from martial arts for body awareness. The purpose of this study was to examine the effects of 12 weeks intervention program of sensomotor communication system based exercises on static balance and self-esteem in karate pupils.
In the study 24 karate pupils in the age of 7–12 were included. Training years in karate varied from 1 to 4 years of practice. To assess static balance the Flamingo balance test was used, to evaluate self-esteem, a modified Rosenger self-esteem scale was used. The findings of this study showed a positive effect on static balance and a minor positive effect on self-esteem in karate pupils after the intervention. Sensomotor communication system based exercises could be used for balance and self-esteem improvement. Also, being a more understandable and clearer exercise system, the sensomotor communication exercise program could be a Kata alternative for younger children practicing karate.

Key words: balance, self-esteem, karate, sensomotor communication system

Introduction

Karate for children in Western societies

Martial arts are body, mind, and spiritual practices that have their traditions and philosophy with a common goal to defend oneself from a threat (Bu et al., 2010). Karate is a Japanese martial art that involves repeated sequences of strikes and defenses, that require a high level of motor and functional abilities such as muscle strength, agility, speed, flexibility, balance, and movement coordination (Zago et al., 2015). Karate requires discipline and mental concentration as well (Zetaruk, 2000). It is important to mention that karate consists of Kihon (basic skills), Kumite (sparring), and Kata (forms – sequence of movements without opponent) (Molinaro, 2020).

Studies report martial arts besides improving physical abilities have a positive effect on the mental health of children and adults: increases well-being, reduces aggression, and positively affect self-control and self-esteem (Greco et al., 2019; Harwood et al., 2017; Moore et al., 2018).

Bu et al. (2010) argue that nowadays martial arts evolve into the fitness industry, losing its deep sense of spirituality. Practitioners of martial arts traditionally practice meditation as a part of self-improvement, however, in western societies martial arts students focus exclusively on physical exercise, losing the context of these arts, and focusing on the competition while traditional practitioners view competition as a major distraction. As a result self-defense instead of self-improvement is emphasized. Although Harwood et al. (2017) argue that eastern combat arts were adapted for western societies retaining eastern philosophy, which aims to achieve such a state of mind when the participant is capable of fighting without aggressive feelings. This is carried out through Kata, respect for the teacher, self-restraint, and meditation (Harwood et al., 2017).

Kata refers to a detailed choreographed pattern of movements. It is practiced to memorize and perfect movements, to improve focus and discipline. In a basic class agenda for beginners, ¼ of the time is devoted to Kata. Kata is challenging for children, especially beginners because they easily get bored (Kleiman, 2012). However, it is worth mentioning that children practicing karate, both Kumite and Kata, have higher speed, strength, better coordination, and better cognitive function (working memory and attention) compared to their sedentary peers (Alesi et al., 2014).

Balance importance in karate

Acquiring stability and balance involves multiple physiological systems including the neuromuscular and sensory systems. At a cortical level, it is essential to integrate a number of afferent signals to maintain balance. Therefore balance, both static and dynamic, is often assessed to determine the status of neuromusculoskeletal control. Moreover, balance is often assessed as part of general motor development in standardized tests for children where balance is considered as a composite of overall motor coordination (Condon & Cremin, 2013).

In martial arts static and dynamic balance is a key performance determinant, especially in elite-level athletes. Karate provides a powerful stimulus to the neurological development of balance control, improves proprioception, and corrects body alignment. Karate training includes a lot of complex motor tasks that challenge balance and coordination – body rotation, bodyweight shifting, and single-leg stances (Zago et al., 2015). Also, while Kumite focuses more on dynamic balance, Kata focuses both on dynamic and static balance (Hadad et al., 2020).

Self-esteem & body awareness among children practicing karate

Positive self-esteem in children is a key element in developing a healthy personality (Haney & Durlak, 1998). Physical appearance and achievement are one of the self-esteem domains (León et al., 2021). By Drummond (2012) physical competence in a critical domain of self-esteem and physical abilities ensures that children are more accepted which is especially true for boys for whom physical fitness is more important because it enables them to demonstrate masculinity.

It is proven that martial art practitioners have higher self-esteem and self-control (Fabio & Towey, 2018). Martial arts also improve resilience in children (Moore et al., 2021). One of the techniques that is aimed specifically to improve self-control and self-awareness is Kata, because it provides inhibitory control and demands mindfulness (Lima et al., 2017). Hence body awareness has a positive correlation with performance emotional state in athletes (Erden & Emirzeoglu, 2018).

Most studies on body awareness are focused primarily on adults and people with acute or chronic medical conditions, but it is worth mentioning that body awareness based interventions have positive effects on movement quality, static and dynamic balance, and self-perception (Olsen et al., 2020; Bravo et al., 2019). Body awareness focused exercises improve postural control by enhancing proprioreception (especially in the knee and ankle joints), reorganizing muscular tension, improving muscle recruitment and co-contraction (Yagci et al., 2018; Xing et al., 2023; Fogaça et al., 2021).

Sensomotor Communication System

Sensomotor Communication System (MoComm) is a program in which authors – Tarass Ivaščenko (psychotherapist MD, PhD) and Sergejs Žukovs (karate coach) have synthesized the principles of movement and interaction from different disciplines of martial arts (Capoeira, Aikido, Wushu) gymnastics, and other systems (Tai Chi, Feldenkrais method) for physical body development and body awareness. The objectives of MoComm are to focus on body sensations and improve body awareness, reduce stress, and restore body and mind connection. Every MoComm exercise is smooth and within a normal physiological range of motion and it can be adapted to different populations (e.g. children, elderly, and people with chronic conditions) or used as an additional training method. It is the first research conducted on MoComm system and international papers on this topic has not been published yet. The Latvian Patent Office issued a certificate in 2021 Nr. 15632 for the rod, used in MoComm exercises.

By definition, sensomotor (or sensorimotor) means pertaining to, or concerned with both the sensory and the motor impulses of an organism (Merriam-Webster, 2022). Therefore sensomotor in this case refers to both the sensory and the motor impulses and is associated with body movement. Communication is an exchange of information and in MoComm communication is provided through movement and attention to perceived sensory information. The main principle of MoComm is paying attention to body movement and breathing, thus improving body awareness. There are no strict rules on exercise range of motion, pace, sets, and reps, on the contrary, a person is encouraged to choose these features him/herself according to well-being and body sensations. Unlike karate, there are no destructive, violent, or confrontational elements in MoComm. As a result, an individual focuses on self-exploration and self-experience safely, receiving positive body experience by gaining the freedom and choice to regulate features of given exercises. Moreover, focusing on perceived sensations from the body and its conscious integration improves communication between body and mind (Probst et al., 1997). The ability to be aware of own actions and perceived body sensations as well as being present, which is typical for mindfulness techniques, has proven to reduce stress-related symptoms and activate brain regions involved in emotional regulation (Boscarino, 2004). Paying attention to body sensations helps to recognize emotional changes and therefore increases control over them (Pavirzi & Damasio, 2001).

Aim

The purpose of this study was to examine the effects of 12 weeks of MoComm intervention on static balance and self-esteem in karate pupils. It was hypothesized that MoComm intervention program have positive effects on self-esteem and static balance in karate pupils.

Methods

Permission to conduct the study was granted by the Medical research ethics committee of the Latvian University.

Study design

The study was a 12-week intervention that has been evaluated using a randomized controlled study. Data were collected and recorded at baseline (pre-test) and after 12 weeks (post-test). After the pre-test and randomization, the experimental group received an intervention program. The control group received the same intervention program after the post-intervention assessment.

Participants and setting

The study site was a karate school located in Salaspils, Latvia. Participants were recruited by distributing information and consent forms to parents and children. Parents received a complete explanation in advance about the purpose of the experiment and parents provided written consent to the study. The procedures followed were in accordance with the ethical standards of the responsible institutional committee on human experimentation and with the Declaration of Helsinki. The study was conducted from July to September 2022.

In the study children in the age of 7–12 who were attending karate training regularly were included,, those with normal body mass index, with no acute injuries, and no chronic conditions. Initially, 26 children were recruited, but two of them dropped out. A total of 24 children aged 7–12 took part in the study. All of them were karate school pupils, attending 5 karate training per week: 13 children in the test group (TG) and 11 in the control group (CG). Training years in karate varied from 1 to 4 years of practice. During the intervention, every group continued with 5 karate trainings per week. TG additionally had two intervention sessions per week. After the second assessment, CG group had the same intervention on the same terms to reduce risk of possible feeling of inequality among children.

Measures

To evaluate static balance Flamingo balance test was used (FBT). In the FBT the subject stood upright on his or her fully stretched leg on a special wooden beam (50 cm long, 4 cm high, 3 cm wide), flexed the free leg at the knee, and gripped the foot with the hand on the same side. The timekeeper starts the watch and stops it each time the person loses balance, then starts over until the person loses balance again. The total number of losses of balance in one minute is recorded. The test is terminated if there are more than 15 losses of balance in the first 30 seconds. Participants performed FBT on both feet with a two-minute pause in between tests (Sember et al., 2020).

To evaluate self-esteem (SE) modified Rosenger self-esteem scale (CRSES) was used. Rosenberg self-esteem scale is widely used to assess self-esteem in adolescents and adults, modified version was adapted for use for schoolchildren aged 7–12 (Wood et al., 2021). It includes 10 items – five positive and five negative statements just like the original Rosenger self-esteem scale, but with altered terminology and simplified language, for example, instead of "I feel like I am a person of worth, at least on an equal plane with others" modified scale includes "I feel that I'm as good as everyone else". Also, response options are altered to "very true", "true", "not true", and "definitely not true". Each response scored from one to four and the scoring is reversed for negative statements, so the higher score indicates higher overall self-esteem. CRSES scores range from 10 to 40. The results of the confirmatory factor analysis revealed that the CRSES provided an adequate fit for the global SE factor; meeting the criteria on all goodness of fit statistics and displaying respectable reliability (Wood et al., 2021). Participants were asked to complete the questionnaire independently and honestly, based on their feelings at that precise moment. Questionnaires were completed inside the karate school environment. Also, a well-being score was used to evaluate overall well-being using a 0-10 point numerical scale, anchored by verbal labels: 0 – worst imaginable and 10 – best imaginable (OECD, 2013). Overall well-being score was used in order to identify possible issues that may affect the course of the study and result interpretation.

Intervention program

The intervention lasted for 12 weeks, twice per week, 45 minutes each session outdoors on nature trails. Intervention included:

1. Warm-up exercises, including breathing, coordination, and balance exercises (5 min);
2. Walking with simultaneous performing of exercises using a special rod (35 min). A rod is similar to a Taji Bang stick (or Tai Chi ruler). During this part, participants were encouraged to synchronize walking pace with arm movements, thus uniting movement, breathing, and attention;
3. Cool-down exercises: stretching, breathing, coordination, and balance exercises (5 min).

Statistical analysis

Data were analyzed using SPSS 23.0 officially licensed software. Non-parametric tests were used because of the small sample. Spearman's correlation test was used for non-parametric data. Related-samples Wilcoxon Signed Rank test was used to test the null hypothesis. Results are considered statistically significant if $p < 0.05$.

Results

Sample description

24 karate pupils participated in this study – 5 (20.8%) girls and 19 (79.2%) boys aged 7–12 (mean age 9.62). 17 (70.8%) children had a history of injury due to karate. The mean age in TG was 9.92 (SD ±1.60), mean age in CG was 9.27 (SD ±1.67). In TG 10 children out of 13 (76.9%) and 7 children out of 11 (63.6%) in CG had a history of a karate-related injury. The sample was too small to measure differences within groups by sex, age, and previous injuries reliably, although it is worth to mention statistically significant differences between the groups were not revealed. There was high adherence to the intervention program with a 91% average attendance. The main reasons for skipping were competition and sick days.

Flamingo test

The mean number of mistakes in TG before the intervention was 13.38 for the left foot and 14.31 for the right foot. The mean number of mistakes in the CG was 14.55 for the left foot and 14.18 for the right foot. There were no significant differences between the groups before the intervention ($p = 0.92$ for the lef foot and $p=0.65$ for the right foot). There was a noticeable improvement in the FBT scores in TG: the number of mistakes dropped for both feet – mean number of mistakes for the left foot was 10.77 and for the right foot – 10.92. The median differences between pre-intervention and post-intervention test results for the left and for the right foot were statistically significant ($p = 0.003$ and $p < 0.001$ accordingly). In CG the mean number of mistakes didn't change significantly ($p = 0.65$ for the left foot and $p = 0.34$ for the right foot) (Table 1, Figure 1).

Table 1. Mean number of mistakes in Flamingo balance test

Variable	Test group				Control group			
	Pre-test		Post-test		Pre-test		Post-test	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Left foot	13.38	2.81	10.77	2.74	14.55	2.91	14.73	3.16
Right foot	14.31	3.06	10.92	2.69	14.18	3.12	13.91	2.84

SD – standard deviation

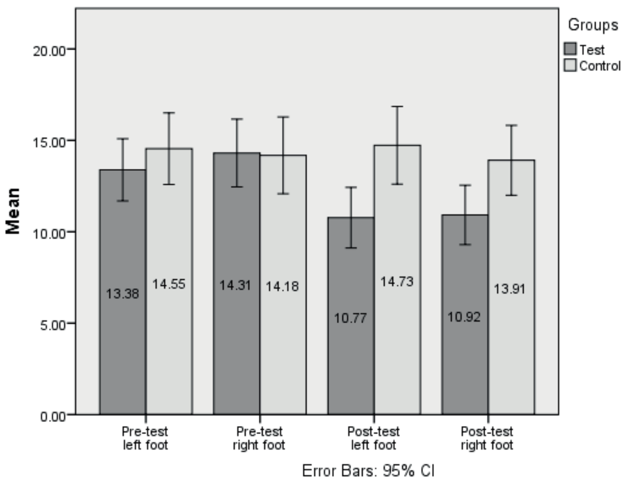

Figure 1. Mean number of mistakes in Flamingo balance test stratified by groups

Well-being and self-esteem

In TG mean well-being score was 7.77 before and 8.31 after the intervention. In CG mean pre-test score was slightly higher – 8.18 and the post-test score was almost the same as in TG – 8.36. There were no statistically significant changes in well-being scores before and after intervention (p = 0.227).

The mean SE score in TG before the intervention was 27.92 and un CG it was 27.27. There were no statistically meaningful differences between the two groups (p = 0.51). After retesting the results were 30.15 and 27.36 accordingly (Table 2, Figure 2). The median differences between self-esteem scores before and after intervention were statistically significant (p = 0.019). Also, there was a statistically significant difference in a specific CRSES item: “I’m happy with myself” with higher results among TG (p = 0.020).

Spearman’s rho calculation for FBT for the left foot and SE scores differencies ($r_s = –0.36$ and $p = 0.08$) showed week and statistically insignificant correlation. Similar calculations for the right foot FBT result differencies and SE scores ($r_s = –0.47$ and $p = 0.0019$) showed moderate and statistically significant correlation.

Table 2. Self-esteem scores in both groups before and after the intervention

Variable	Test group				Control group			
	Mean	Max	Min	SD	Mean	Max	Min	SD
Pre-test	27.92	34	24	2.28	27.27	31	24	2.49
Post-test	30.15	35	23	3.48	27.36	32	24	2.06

SD – standard deviation

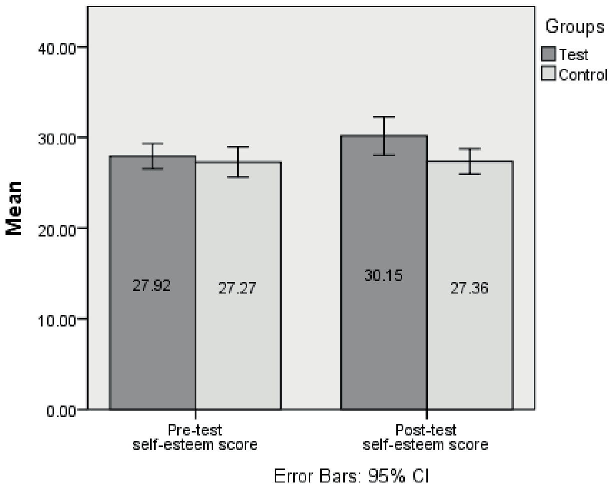

Figure 2. Mean self-esteem score before and after intervention stratified by groups

Discussion

The main purpose of this study was to determine if there are positive effects of MoComm intervention. The findings of this study show statistically significant improvements in FBT performance and in SE score.

To maintain a controlled upright posture, the central nervous system regulates sensory information and produces adequate motor output. Postural control deals with two tasks simultaneously – distribution of muscle activity and compensation for internal or external perturbations. The nature of movement and postural control is still being studied (Ivanenko & Gurfinkel, 2018). Body awareness can also be described as the sensitivity to bodily signals and being aware of bodily states and reactions to internal and environmental conditions. Body awareness-based interventions facilitate this mind-body connection by focusing on bodily sensations thus improving balance (Ginzburg et al., 2014).

Literature data show children develop body awareness primarily through motor experiences that require complex sensory stimuli perception and interpretation (Ahn, 2022). Hence, the positive effects of MoComm intervention on static balance might be explained by its features and emphasis on body awareness, paying attention and movement coordination. MoComm program has multiple advantages, that help to improve balance. Walking on uneven surfaces and manipulating the object simultaneously, requires coordination, attention, maintaining balance, and a better understanding of own body signals to control it. Fabio & Towey (2018) stress that cognitive factors such as attention are essential to analyze, select and respond to stimuli, any interruption in one of these processes can have negative effects on sports performance. The more stimulus the athlete can pay attention to, the more the connections that he can create between them thus improving their performance.

However, it is challenging to compare FBT results with other statistical data due to differences in methodology, age of participants, small sample, and years of practice.

Moreover, for the study participants, the intervention program was the only training without competitive elements (thus removing both physical and emotional tension) and children could focus on themselves entirely. This might explain the improvement in self-esteem, because it was one of the activities children could enjoy freely, choosing their rhythm and speed, taking pauses as they please. Also, the intervention program didn't include comparison and ranking by achievement. Haney & Durlak (1998) claim it is possible to improve self-esteem by specifically focusing on it rather than trying to modify it indirectly (Haney & Durlak, 1998). Exploring oneself through movement could be one of the keys to improve self-esteem indirectly, without special psychological interventions.

There are studies that show the positive effects of Kata. For example, a 10-week karate intervention program included 5 min meditation and 10 min Kata for 11–13 years old healthy children proved to improve resilience among children (Moore et al., 2021). The motor strategies used to maintain balance depend on a number of sensory inputs – visual, vestibular, and somatosensory. It is important to mention that balance control development continues up to late periods during childhood (Assaiante, 1998). Kata improves dynamic and static stability (Ansari et al., 2021). Studies also show that Kata students have greater ankle stability compared to Kumite students (Molinaro, 2020).

However, as it was mentioned before, Kata is challenging for children and many Western schools do not include Kata in their usual karate training (Kleiman, 2012). Study participants didn't have Kata practice in their usual karate training routine. Even though evidence shows that any resistance training and bimanual coordination in karate require attention, work memory, and discipline (Lima et al., 2017), skipping Kata means missing opportunity to improve. There are lack of studies and opinions on what could substitute Kata for children, to gain the same positive effects but in a more understandable and acceptable way for children from western societies.

For example, there are Tai Chi routines developed for children. Tai Chi, for example, proved to enhance postural responses by improving neural mechanisms controlling ankle joints and reducing muscle co-activation, which reduces energy expenditure and thus makes balance responses faster (Gatts & Wolllacoot, 2006). Also, Kleiman (2012) suggests various games as a part of a warm down, including activities that involve balance training, that are more fun and increasing desire to participate.

Bu et al. (2010) pointed out that the most difficult point for researchers of martial arts is the investigation design and evaluation criteria of body-mind exercises, as they do not always match standards for medical studies. Also, there are no specific measurements to evaluate body-mind connection, especially among children. By measuring static balance we can make assumptions about children motor development and body controls, but by measuring self-esteem we can make assumptions about positive effects of a particular intervention program.

In addition, it is important to mention that despite the sample of this study being small, it showed a concerning tendency of the majority of young children to have a history of karate-related injuries. Generally, karate for children is considered safe in terms of injury risks. The risk of injury increases with each training year with most injuries occurring in tournament settings and free-sparring. Also, more than 3 hours of training per week increases the risks of overuse injuries by repetitive microtrauma (Zetaruk, 2000). Most common injuries occur around age 12 to lower leg and wrists, strains or sprains mostly (Yard et al., 2007).

The main limitation of this study is it's rather a small sample that could affect the results. It is worth to mention that there are no specific tests that could be applied to measure body awareness in karate pupils, especially in children. Many of currently available observation and evaluation tools for body awareness are not applicable to children (Probst, 2018). Of course using modern methods for the equilibrium evaluation would increase the reliability of the results, but unfortunately authors were limited in resources. Also, years of practice were not taken into consideration, which too, has an effect on static balance and self-esteem.

Conclusions

Sensomotor communication system exercise program has a positive effect on static balance and minor positive effect on self-esteem in karate pupils after the 12-week intervention program. Therefore it could be used for various purposes – balance, body awareness and self-esteem improvement. Also, being a more understandable and clearer exercise system, the sensomotor communication system exercise program could be a Kata alternative for younger children practicing karate.

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MENTAL STATE AND MOTIVATION TO PHYSICAL EXERCISE IN UNIVERSITY STUDENTS DURING COVID-19 PANDEMIC IN POLAND

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Abstract The COVID-19 pandemic brought consequences for many aspects of people's lives all over the world, such as lockdown, social distancing and reduced accessibility to sports and recreational facilities. The aim of this study was to assess mental state, physical well-being, and motivation to exercise among Polish students of Physical Education and other fields of study, considering their gender, place of living and financial situation. The study involved 1424 students from different universities in Poland. Two questionnaires were used – the EMI-2 to measure motivation to exercise and an original questionnaire to assess daily physical activity, physical and mental well-being. While 31.7% of the students assessed their access to recreational facilities as very poor, 71.8% of them rated their financial situation to be average or quite good. Over one-third of the students declared that both their physical and mental well-being (nearly 37% and 33% respectively) were very poor. Among all analyzed motivating factors to exercise, positive health, appearance and strength and endurance were classified as the most important. The importance of different motivating factors differed between the Physical Education students and those of other faculties. To conclude, physical and mental well-being of Polish students during the pandemic was poor. The main reasons were very poor access to recreational facilities, too much time spent in a sitting or lying position daily and insufficient physical activity.

Key words: COVID-19, lockdown, motivation, physical exercise, student, recreation, pandemic

Introduction

Background

The SARS-CoV-2 causes a severe respiratory syndrome disease (COVID-19) and was first encountered in Wuhan, China, in January 2020 (Zhou et al., 2020). After a few weeks, despite the lockdown ordered in Wuhan, the COVID-19 cases were detected in many countries all over the world and a global pandemic started (Spina et al., 2020). On 11 March 2020 The World Health Organization announced the global COVID-19 pandemic. The coronavirus and its variants have caused serious consequences all over the world – health problems, such as psychological and mental disorders, an increase in the number of deaths, including suicides, health care failure, economic and educational crisis (Ahmad et al., 2020; Bashir et al., 2020; Devoe et al., 2023; Pokhrel & Chhetri, 2021; Sher, 2020). One of the major implications of the pandemic was lockdown introduced in many countries worldwide, though the lockdown policy differed in its character, duration and limitations between different countries. The closure of educational institutions was one of the most serious restrictions, although universities and high schools adopted online methods to continue teaching-learning process (Fernández Cruz et al., 2020). In Poland the lockdown started on 13 March 2020 and stronger limitations were introduced during following months. After the most critical period of the pandemic the restrictions were successively taken off. Stationary education at universities and higher schools was stopped on 13 March 2020 and shortly afterwards it was transferred to online conditions. The detailed chronology of the lockdown in Poland is presented in the fig.1.

Due to the pandemic restrictions introduced between 13 March 2020 and 30 August 2021 Polish students were obliged to study online, were allowed to leave their homes for essential reasons only, such as going to work or to pharmacy, were not able to meet outside, sports and recreational facilities, including sports clubs, swimming pools, gyms and fitness clubs were closed. During a part of that period entrance to parks, beaches and even forests was prohibited. The restrictions were taken off during the second wave of the COVID-19 pandemic, but financial problems of the society were getting worse. Though gyms, swimming pools, fitness clubs were allowed to reopen – lots of them stayed closed due to various reasons (e.g. too few customers, incomplete staff, increasing costs of energy). The Polish government offered help to sports entrepreneurs hit by the COVID-19 pandemic and provided them with financial support during the period of suspension of their business activity – in some cases it was the main reason why they did not reinitiate their functioning. Moreover, despite the fact that stationary education was reopened for toddlers, kids and teenagers on 19 April 2020, most universities decided to continue online learning and complete the academic term via online conditions. Therefore, distance education actually lasted till the end of September 2021 (including examined universities) or even longer in some cases.

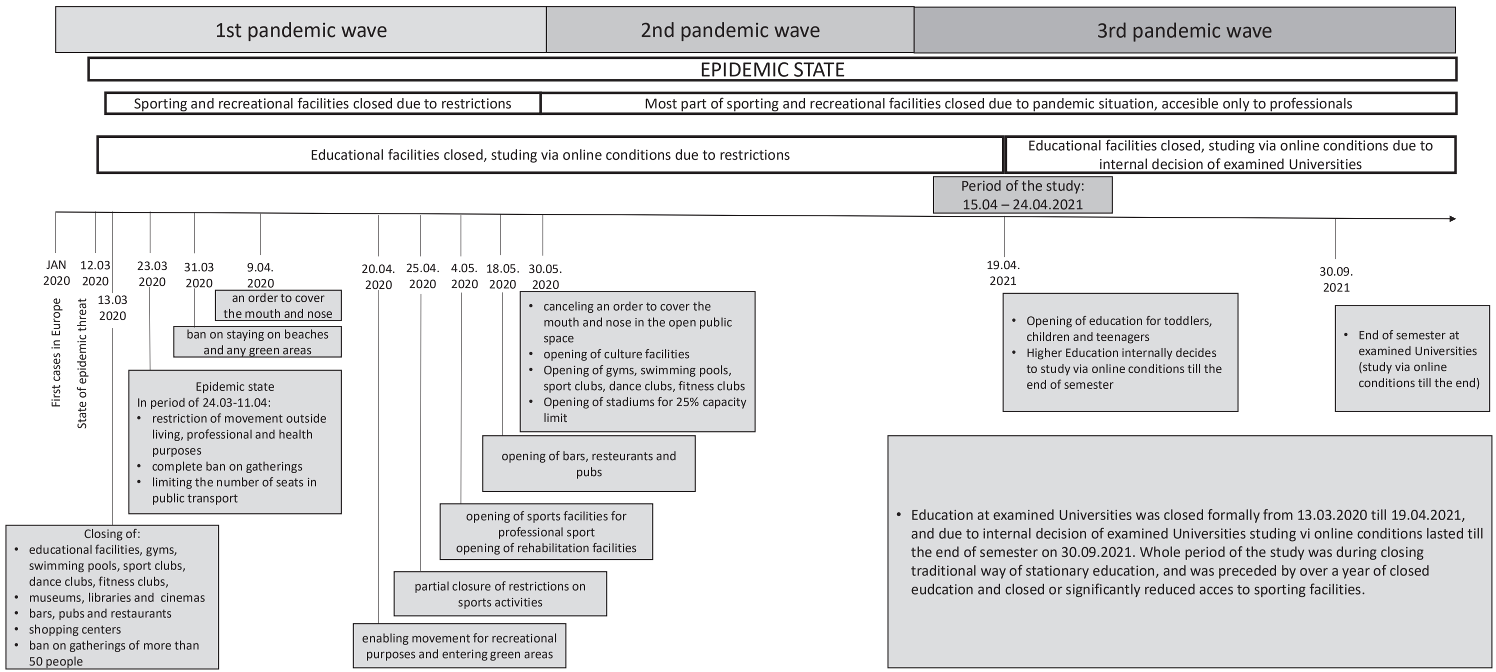

Figure 1. Chronological scheme of the pandemic situation and its consequences as restrictions and lockdowns

Social isolation was reported to have significant consequences for many aspects of people's health, including their mental health (Fernández Cruz et al., 2020; Xiong et al., 2020). The psychological well-being of societies in many countries has deteriorated in recent years also due to the COVID-19 pandemic. This is confirmed, among others, by research on depression which has remarkably strong impact on motivation. There is a correlation between a person's mental well-being, motivation and their functioning in many aspects of everyday life (Deci & Ryan, 2000). A negative impact of the COVID-19 pandemic on daily physical activity, time spent in a sitting position and unhealthy food consumption was observed among people in different parts of the world (Ammar et al., 2020). The same was confirmed among students from many countries (López-Valenciano et al., 2021), including neighboring countries of Poland, such as Hungary (Ács et al., 2020), southwestern countries which were the most affected by pandemic, such as Spain (Sañudo et al., 2020) and Italy (Gallè et al., 2020), as well as countries located far from Poland, e.g. Australia (Gallo et al., 2020).

Although there are many articles describing the impact of the COVID-19 pandemic on Polish students, most of them concentrate on investigating a decrease in physical activity, general or mental health. However, they do not offer an insight into students' motivation and do not take different fields of study or students' financial situation into account.

The aim of this study was to assess the mental state of Polish students and their motivation to exercise during the COVID-19 pandemic lockdown conditions, considering the students' gender, financial situation and place of living. We hypothesized that students of Physical Education would differ in the examined aspects from students of other faculties.

Materials and Methods

There were 1424 participants involved in the study: 925 females (65%) and 499 males (35%). They were students of four polish universities, including 318 Physical Education (PE) students (22.3%) and 1106 (77.7%) students of other fields of study (non-PE). Over half of the students lived in rural areas (55.8%) and 44.2% in urban areas. All the participants agreed to take part in the study of their own free will, signed a written consent and were informed about the purpose of the study. The participant anonymity was assured and all of them were informed that they can resign at any time without any consequences. The study was conducted according to the Declaration of Helsinki.

The data were acquired in stationary conditions from 15 April 2021 and 24 April 2021. The participants were filling two questionnaires - the first was the Exercise Motivations Inventory – 2 (EMI-2, University of Wales, Bangor) introduced by Markland in 1997 (Markland & Ingledew, 1997). The EMI-2 consists of 51 items and is a widely used, reliable and validated tool for assessing motivation to exercise. The data had been fully anonymized before the researcher obtained them. The respondents were choosing their answers on a 0-5 scale. For the purpose of this study the Polish version of the questionnaire was used (originally provided by the authors of the EMI-2). The second questionnaire was an original questionnaire prepared for this study and consisted of 17 questions about basic demographic data (age, gender, career, place of living), daily time spent on physical activity, access to recreational facilities, health self-assessment, financial situation, daily time spent sitting or lying down, physical well-being, mental well-being, changes in consumption of alcohol, changes in smoking cigarettes, changes in body mass. The questionnaire was originally prepared in Polish language.

The data acquired from these two tools were digitalized with the use of Microsoft Excel to build a database and then processed with statistical analysis.

Statistical analysis

Since the survey responses were structured in a discrete, ordinal manner, we used the Likert scale to obtain the estimates of expected values and standard deviations. The former was calculated as:

$$E(A) = \sum_{i=1}^{m} V_i \frac{v_i}{T}$$

where $E(A)$ was the expected value (mean value) of the response, V_i was the Likert-scale value (from 1 to m-th answer) for the i-th answer, and n_i/T was the observed frequency for the i-th answer. Standard deviation was calculated as the square root of:

$$var(A) = \sum_{i=1}^{m} \left(V_i - E(A)\right)^2 \frac{v_i}{T}.$$

The differences between examined parameters were tested with Welsh paired t-test, the level of significance was $p > 0.005$. All the results are presented as mean ±standard deviation (SD).

Results

The respondents' answers to the original questionnaire were assigned numbers on a scale from 1-5, where 1 means very poor, 2 – poor, 3 average, 4 – quite good and 5 – very good. Most of the respondents (528) stated that their access to recreational facilities was very poor. Only 62 of them declared it to be very good. The average response was 2.114 ±1.127. Two hundred forty three students assessed their financial situation as very good, 160 of them as poor and very poor, while most of the participants (1021) declared average or quite good financial situation. The average response was 3.606 ±0.956. A large number of respondents (526) evaluated their physical well-being as very poor. Similarly, as many as 469 students stated that their mental well-being was very poor. The average response amounted to 2.274 ±1.151 for physical well-being and 2.488 ±1.293 for mental well-being. Only 43 respondents, i.e. 3.0% of all, declared their physical well-being to be very good and only 102, i.e. 7.2%, described their mental well-being as very good (table 1).

Question	Accessibility of recreational facilities		Financial situation		Physical well-being		Mental well-being	
response	n	%	n	%	n	%	n	%
1 (very poor)	528	37.1%	38	2.7%	526	36.9%	469	32.9%
2 (poor)	446	31.3%	122	8.6%	216	15.2%	234	16.4%
3 (average)	272	19.1%	445	31.2%	491	34.5%	383	26.9%
4 (quite good)	116	8.1%	576	40.4%	148	10.4%	236	16.6%
5 (very good)	62	4.4%	243	17.1%	43	3.0%	102	7.2%

Table 1. Accessibility of recreational facilities, financial situation, physical and mental well-being declared by respondents

The largest number of respondents (24.9%) stated that they spent daily between 20–40 (min) doing physical activity. 24.7% of them declared that they performed 40–50 (min) of physical activity per day, while only 10.7% reported that they were physically active for over 90 (min) every day (7.9% females and 15.8% males). Out of the total respondents, 8.1% (116) declared not doing any physical activity at all (8.6% females and 7.2% males). The greatest number of respondents (33%) declared that they spent 5-6 (h) sitting or lying down, none of the respondents declared not spending any time in these positions during the day. Out of women 24.1% and 19.8% of men reported that they spent over 8 (h) in a sitting or lying position every day (table 2).

Table 2. Daily time spend on physical activity and in sitting or lying positions

question	Time daily spent on physical activity						question	Time daily spent in a sitting or lying position					
	female		male		total			female		male		total	
response	n	%	n	%	n	%	response	n	%	n	%	n	%
none	80	8.6%	36	7.2%	116	8.1%	none	0	0.0%	0	0%	0	0.0%
0–20 (min)	148	16.0%	56	11.2%	204	14.3%	1–2 (h)	28	3.0%	34	6.8%	62	4.4%
20–40 (min)	245	26.5%	109	21.8%	354	24.9%	3–4 (h)	118	12.8%	98	19.6%	216	15.2%
40–60 (min)	241	26.1%	111	22.2%	352	24.7%	5–6 (h)	305	32.9%	166	33.3%	470	33.0%
60–90 (min)	138	14.9%	108	21.6%	246	17.3%	7–8 (h)	251	27.2%	102	20.4%	354	24.9%
Over 90 (min)	73	7.9%	79	15.8%	152	10.7%	Over 8 (h)	223	24.1%	99	19.8%	322	22.6%

Nearly half of the respondents (49.7% of women and 51.3% of men) declared they did not notice an increase in their body mass. The results were similar when the participants were divided into two groups according to their place of living, i.e those living in rural areas and those living in urban areas, and amounted to 49.7% and 51% respectively. Out of the Physical Education students 48.6% and 56.3% of the students of other faculties did not observe an increase in their body mass. Out of the non-PE students 36.8% participants, 39.9% of females, 40.4% of those living rural, 40.5% those living urban, 41.5% males and 41.5% PE students declared higher body mass (table 3).

Table 3. Increase in the body mass

Question	Have you noticed increase of your body mass?					
response	female	male	rural	urban	PE	Non-PE
no	49.7%	51.3%	49.7%	51.0%	48.6%	56.3%
I do not know	10.4%	7.2%	9.9%	8.4%	9.9%	6.9%
yes	39.9%	41.5%	40.4%	40.5%	41.5%	36.8%

PE – Physical Education students, Non-PE – students of other faculties.

Table 4 (below) presents the mean values of the EMI-2 questionnaire and p-values of the means between different motivating factors to exercise among all of the examined students. There were significant differences between most of the compared aspects except for: stress management and challenge ($p > 0.652$), revitalization and weight management ($p > 0.126$), enjoyment and nimbleness ($p > 0.075$), ill-health avoidance and strength and endurance ($p > 0.068$), appearance and strength and endurance ($p > 0.840$).

Table 4. EMI-2 scores for motivating factors, mean and Welch t-test p-values. In case there are statistically significant differences between most of the motivators, we put p-values over 0.005 in bold meaning that between them there were no statistically significant differences

Motivating factors		Stress Management	Revitalisation	Enjoyment	Challenge	Social Recognition	Affiliation	Competition	Health Pressures	Ill-Health Avoidance	Positive Health	Appearance	Weight Management	Strength & Endurance	Nimbleness
	mean	3.100	3.382	3.188	3.113	2.257	2.394	2.169	1.821	3.616	4.004	3.673	3.333	3.668	3.243
Stress Management	3.100		0.000	0.003	**0.652**	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Revitalisation	3.382	0.000		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	**0.126**	0.000	0.000
Enjoyment	3.188	0.003	0.000		0.011	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	**0.075**
Challenge	3.113	**0.652**	0.000	0.011		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Social Recognition	2.257	0.000	0.000	0.000	0.000		0.000	0.006	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Affiliation	2.394	0.000	0.000	0.000	0.000	0.000		0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Competition	2.169	0.000	0.000	0.000	0.000	0.006	0.000		0.000	0.000	0.000	0.000	0.000	0.000	0.000
Health Pressures	1.821	0.000	0.000	0.000	0.000	0.000	0.000	0.000		0.000	0.000	0.000	0.000	0.000	0.000
Ill-Health Avoidance	3.616	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000		0.000	0.049	0.000	**0.068**	0.000
Positive Health	4.004	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000		0.000	0.000	0.000	0.000
Appearance	3.673	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.049	0.000		0.000	**0.840**	0.000
Weight Management	3.333	0.000	**0.126**	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000		0.000	0.003
Strength & Endurance	3.668	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	**0.068**	0.000	**0.840**	0.000		0.000
Nimbleness	3.243	0.000	0.000	**0.075**	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.003	0.000	

The female participants (average 4.035 ±1.172), those living in both rural (3.977 ±1.193) and urban areas (4.038 ±1.158), PE (4.324 ±0.916) and the non-PE students (3.911 ±1.1228), those declaring very poor (3.298 ±1.420) and good or very good financial situation (4.178 ±1.204) as well as all the respondents in total (4.004 ±1.178) declared that positive health was the top motivating factor for them. The highest average for this motivator was reported among a subgroup of the Physical Education students (4.324 ±0.916). For the male participants the aspect of strength and endurance (3.977 ±1.167) was more important than positive health (3.946 ±1.186) which they ranked in the second place. Two other motivating factors classified in the second and the third place by all the respondents were appearance (3.673 ±1.432 for total and from 3.263 ±1.605 to 3.895 ±1.303 for subgroups) and strength and endurance (3.668 ±1.355 for total and from 2.941 ±1.488 to 4.185 ±1.022 for subgroups). All the respondents in total (1.821 ±1.870) and five subgroups: males (1.665 ±1.828), those living both in rural (1.822 ±1.867) and urban areas (1.821 ±1.873), the PE students (1.809 ±1.894) and those declaring good or very good financial situation (1.916 ±1.892) stated that they were the least motivated by health pressures. The aspect of competition was the least important for females (1.735 ±1.674), the non-PE students (1.819 ±1.691), and for those who declared very poor financial situation and achieved the lowest average note of all (1.342 ±1.643) (tables 5 and 6).

Table 7. (below) presents the motivating factors ranked from the greatest to the smallest difference between the subgroups of the respondents. The female and male students reported the most significant difference in the aspect of competition (–1.237) which was much more important for men. Similarly, the largest difference between the PE and non-PE students (1.566) and between the participants living in rural and urban areas (0.262) related to this motivating factor – for both the PE students and the students living in rural conditions competition was more important. The slightest differences, thus the greatest accordance in the responses, were noted for health pressures (–0.016, 0.001 and 0.0434 for the PE, and non-PE students, rural-urban and very poor-good or very good financial situation respectively). There was no difference between females and males regarding the average responses about nimbleness (0.000).

Table 5. Mean score in 0–5 scale for different motivating factors to exercise among female, male, rural and urban living Polish students. The motivators were ranked from the highest to the lowest average for each category

Total	mean±SD	female	mean±SD	male	mean±SD	rural	mean±SD	urban	mean±SD
Positive Health	4.004 ±1.178	Positive Health	4.035 ±1.172	Strength & Endurance	3.977 ±1.167	Positive Health	3.977 ±1.193	Positive Health	4.038±1.158
Appearance	3.673 ±1.432	Appearance	3.772 ±1.391	Positive Health	3.946 ±1.186	Appearance	3.678 ±1.408	Strength & Endurance	3.791±1.326
Strength & Endurance	3.668 ±1.355	Ill-Health Avoidance	3.669 ±1.420	Ill-Health Avoidance	3.519 ±1.469	Ill-Health Avoidance	3.605 ±1.420	Appearance	3.668±1.462
Ill-Health Avoidance	3.616 ±1.439	Weight Management	3.525 ±1.528	Appearance	3.490 ±1.489	Strength & Endurance	3.571 ±1.370	Ill-Health Avoidance	3.631±1.463
Revitalisation	3.382 ±1.524	Strength & Endurance	3.501 ±1.419	Revitalisation	3.476 ±1.475	Weight Management	3.360 ±1.562	Revitalisation	3.459±1.550
Weight Management	3.333 ±1.605	Revitalisation	3.330 ±1.547	Challenge	3.363 ±1.491	Revitalisation	3.320 ±1.500	Nimbleness	3.323±1.505
Nimbleness	3.243 ±1.463	Nimbleness	3.243 ±1.483	Nimbleness	3.243 ±1.427	Nimbleness	3.179 ±1.426	Weight Management	3.299±1.659
Enjoyment	3.188 ±1.578	Enjoyment	3.082 ±1.583	Enjoyment	3.133 ±1.552	Enjoyment	3.089 ±1.541	Challenge	3.221±1.597
Challenge	3.113 ±1.583	Stress Management	3.055 ±1.500	Stress Management	3.100 ±1.510	Stress Management	3.038 ±1.541	Enjoyment	3.314±1.608
Stress Management	3.100 ±1.572	Challenge	2.979 ±1.615	Weight Management	2.977 ±1.682	Challenge	3.029 ±1.568	Stress Management	3.179±1.608
Affiliation	2.394 ±1.705	Affiliation	2.192 ±1.701	Competition	2.972 ±1.669	Affiliation	2.330 ±1.680	Affiliation	2.475±1.733
Social Recognition	2.257 ±1.695	Social Recognition	2.048 ±1.677	Affiliation	2.769 ±1.649	Social Recognition	2.208 ±1.658	Social Recognition	2.319±1.738
Competition	2.169 ±1.774	Health Pressures	1.906 ±1.887	Social Recognition	2.644 ±1.658	Competition	2.053 ±1.719	Competition	2.315±1.829
Health Pressures	1.821 ±1.870	Competition	1.735 ±1.674	Health Pressures	1.665 ±1.828	Health Pressures	1.822 ±1.867	Health Pressures	1.821±1.873

Table 6. Average points in 0–5 scale for different motivating factors to exercise among Physical Education and non-Physical Education students, and students with poor and very poor or very good economic situation. The motivators were ranked from the highest to the lowest average for each category

PE	mean ±SD	Non-PE	mean ±SD	Eco-1	mean ±SD	Eco-4/5	mean ±SD
Positive Health	4.324 ±0.916	Positive Health	3.911 ±1.228	Positive Health	3.298 ±1.420	Positive Health	4.178 ±1.204
Strength & Endurance	4.185 ±1.022	Appearance	3.610 ±1.461	Appearance	3.263 ±1.605	Strength & Endurance	3.783 ±1.404
Revitalisation	4.041 ±1.177	Ill-Health Avoidance	3.549 ±1.448	Strength & Endurance	2.941 ±1.488	Appearance	3.773 ±1.347
Appearance	3.895 ±1.303	Strength & Endurance	3.520 ±1.402	Ill-Health Avoidance	2.842 ±1.641	Ill-Health Avoidance	3.748 ±1.372
Ill-Health Avoidance	3.850 ±1.382	Weight Management	3.343 ±1.595	Weight Management	2.783 ±1.686	Revitalisation	3.545 ±1.568
Challenge	3.843 ±1.202	Revitalisation	3.192 ±1.559	Enjoyment	2.704 ±1.769	Weight Management	3.425 ±1.571
Nimbleness	3.727 ±1.250	Nimbleness	3.104 ±1.490	Stress Management	2.700 ±1.799	Nimbleness	3.380 ±1.354
Enjoyment	3.687 ±1.322	Enjoyment	2.960 ±1.607	Revitalisation	2.570 ±1.811	Challenge	3.240 ±1.514
Stress Management	3.627 ±1.314	Stress Management	2.949 ±1.607	Nimbleness	2.184 ±1.750	Enjoyment	3.229 ±1.691
Competition	3.385 ±1.495	Challenge	2.904 ±1.617	Challenge	2.039 ±1.758	Stress Management	3.229 ±1.691
Weight Management	3.298 ±1.642	Affiliation	2.205 ±1.700	Affiliation	2.039 ±1.795	Affiliation	2.499 ±1.675
Affiliation	3.053 ±1.553	Social Recognition	2.035 ±1.658	Social Recognition	1.743 ±1.760	Social Recognition	2.324 ±1.657
Social Recognition	3.030 ±1.590	Health Pressures	1.825 ±1.862	Health Pressures	1.482 ±1.687	Competition	2.282 ±1.945
Health Pressures	1.809 ±1.894	Competition	1.819 ±1.691	Competition	1.342 ±1.643	Health Pressures	1.916 ±1.892

Table 7. Differences between females and males, Physical Education students and students of other faculties, those living rural and urban, those declaring poor and good or very good financial situation. Number with "–" sign means that the second mentioned subgroup had higher average, the number without "–" sign mean that the first mentioned subgroup had higher average Statistically significant differences were marked with * (p > 0.005).

Average difference between female and male		Average difference between PE and non-PE students		Average difference between those living urban and rural		Average difference between those declaring poor and good or very good financial situation	
Competition	–1.237*	Competition	1.566*	Competition	0.262*	Challenge	–1.201*
Social Recognition	–0.596*	Social Recognition	0.995*	Enjoyment	0.225*	Nimbleness	–1.196*
Affiliation	–0.577*	Challenge	0.939*	Strength & Endurance	0.220*	Revitalisation	–0.975*
Weight Management	0.548*	Revitalisation	0.849*	Challenge	0.192*	Competition	–0.940*
Strength & Endurance	–0.476*	Affiliation	0.848*	Affiliation	0.145*	Ill-Health Avoidance	–0.906*
Challenge	–0.384*	Enjoyment	0.727*	Nimbleness	0.144*	Positive Health	–0.880*
Appearance	0.282*	Stress Management	0.678*	Stress Management	0.141*	Strength & Endurance	–0.842*
Health Pressures	0.241*	Strength & Endurance	0.665*	Revitalisation	0.139*	Weight Management	–0.642*

Average difference between female and male		Average difference between PE and non-PE students		Average difference between those living urban and rural		Average difference between those declaring poor and good or very good financial situation	
Ill-Health Avoidance	0.15*	Nimbleness	0.623*	Social Recognition	0.111*	Social Recognition	–0.581*
Revitalisation	–0.146*	Positive Health	0.413*	Positive Health	0.061	Stress Management	–0.529*
Positive Health	0.089*	Ill-Health Avoidance	0.301*	Weight Management	0.061	Enjoyment	–0.525*
Enjoyment	–0.051*	Appearance	0.285*	Ill-Health Avoidance	0.026	Appearance	–0.510*
Stress Management	–0.045	Weight Management	–0.045	Appearance	0.010	Affiliation	–0.460*
Nimbleness	0.000	Health Pressures	–0.016	Health Pressures	0.001	Health Pressures	–0.434*

Discussion

Our study results showed that the physical and mental well-being of Polish students during the COVID-19 pandemic was very poor. Although most of the participants declared quite good (40.4%) or very good financial situation (17.1%), their access to recreational facilities was poor (31.3%) or very poor (37.1%) and their physical well-being mostly poor (15.2%) or very poor (36.9%). Moreover, a great number of students reported that their mental well-being was poor (16.4%) or very poor (32.9%). Only 10.7% of them stated that they spent daily more than 1,5 (h) performing physical activity, and over 80% declared spending over 5h sitting or lying down daily. Some differences between females and males were noticed. Males declared to be more active – 37.4% of them stated that they spent over 1 hour daily performing physical activity versus 22.8% of females. Simultaneously, fewer males (73.5%) than females (84.2%) reported that they spent over 5h daily in a sitting or lying position. Slightly fewer men declared not having noticed an increase in their body mass – 51.3% versus 49.7% females. There are a number of differences between men and women considering the factors which motivated them to exercise. Whereas, men indicated strength and endurance as the most important motivator, women ranked positive health in the first place. Competition was less motivating for women while men reported health pressures to be of less importance. The most significant differences between men and women were found in competition which was ranked higher by men than women.

Some differences were also observed between the Physical Education students and those of other fields of study. Most of the non-PE students did not notice an increase in their body mass (56.3%). Similarly, the PE students (48.6%) stated that they did not gain weight. Both groups agreed that positive health is the most important motivating factor to exercise, though their responses were different regarding other motivators. While the non-PE students ranked appearance and ill-health avoidance in the second and third place, for the PE students strength and endurance and revitalization were so important. Competition was less important motivating factor to exercise for the non-PE students (14^{th} place), while the PE students ranked it in the tenth place. The most significant differences between the PE and non-PE students were observed for the following motivators: competition (1.566, $p > 0.000$), social recognition (0.995, $p>0.000$) and challenge (0.939, $p>0.000$) which all were much more important for the PE students. There were some differences between the participants declaring very poor and good or very good financial situation, although they ranked motivating factors to exercise in a very similar way – for both groups positive health was the top factor, and health pressures and competition were of less importance. The biggest differences were noted between challenge (–1.201, p > 0.000), nimbleness (–1.196, p > 0.000) and revitalization (–0.975, p > 0.000) which all were reported as much more important for the students who declared good or very good financial situation. The slightest differences were noticed between the participants living in rural and urban conditions – the greatest one concerned competition and equaled only 0.262 (p > 0.000). Both groups of students reported that positive health was the most important and health pressures the least important motivating factor.

Low levels of mental state registered in the present study could result from the lack of socialization i.e. the conditions imposed by distance learning which created barriers in communication between classmates and teachers, and which negatively affected the students' psychological well-being and increased feeling of loneliness (Lyubetsky et al., 2021; Rizun & Strzelecki, 2020; Wieczorek et al., 2021), and uncertainty about the future, graduation, or quality of curricula (Lyons et al., 2020). In fact, studies have shown that the interaction with colleagues increases involvement, motivation, and benefits academic performance (Wang et al., 2020). In contrast, prolonged isolation has been linked to psychopathological symptoms and behaviors, such as anxiety, depression (Chandratre, 2020), burnout, fatigue, psychotic episodes (Hajdúk et al., 2020), and even suicide (Lathabhavan & Griffiths, 2020). It is worth noting that previous pandemics have demonstrated that individuals without a history of anxiety disorders or panic attacks may develop depressive symptoms, varying degrees of anxiety disorders, and posttraumatic stress disorders, in addition to those who already experience such conditions (Göl & Erkin, 2021).

Those changes to daily life imposed by COVID-19 have influenced students of various faculties worldwide (Maciaszek et al., 2020), and showed that young adult populations are generally similar considering the psychopathological responses to the pandemic (Wieczorek et al., 2021). In a study with medical students of the third year in Russia (Lyubetsky et al., 2021), a prevalence of 29.97% and 24.03% was reported for depressive and anxiety symptoms, respectively. In addition, the same study revealed that 55% of the students changed their usual sleep pattern, which could be influenced by the prolonged use of digital tools (reported by more than 80% students). In the USA, with different student populations, it was noticed a prevalence of 48.14% and 38.48% was noted for depressive and anxiety symptoms, respectively. In the same study, 18.04% of the students mentioned that they had suicidal thoughts (Wang et al., 2020). Also in France, 43% of the participants reported significant depressive, and 39.19% anxiety symptoms (Essadek & Rabeyron, 2020). In Poland, with a sample of different students, higher results were registered, i.e. 65% of the students reported mild to severe anxiety, and 56% of them declared high levels of perceived stress (Wieczorek et al., 2021).

However, as we deal with university students, it should be considered that the level of such feelings could be increased because a great amount of students returned to their family home during confinement. It was suggested that this could be especially problematic for students whose families are not supportive, tolerant, or possibly even dysfunctional (Wieczorek et al., 2021). Moreover, it should be noted that factors, such as female sex (Ibrahim et al., 2013) and financial insecurity were pointed as main contributors to higher levels of depression, anxiety and distress, while living alone was mostly associated with more severe depressive symptoms (Essadek & Rabeyron, 2020). Nevertheless, it should be highlighted that even before COVID-19, the student population had been considered to be an 'at risk' population regarding mental health. Indeed, a systematic review on this topic showed that 30.6% of the students revealed to suffer from depression, which is greatly higher than the prevalence in the general population of many countries which amounted to 9–11% (Wieczorek et al., 2021).

The COVID-19 pandemic negatively affected the examined students in terms of their physical and mental well-being, which is in accordance with other studies from different countries. Positive health is the most important motivating factor to exercise for Polish students, while competition is scored the lowest. There are some differences observed between genders as well as between Physical Education students and students of other faculties. The analysis of the results in a broad context may yield specific and practical recommendations and guidelines for further research which are presented below.

Practical application

The present study highlighted the importance of monitoring the students' mental health status over time. In fact, this population is normally susceptible to mental health declines while the pandemic conditions even intensify behavioral health concerns. Therefore, it is crucial to maintain constant mental health assessments, and improve accessibility to recreational facilities for students. Also, recommendations for early psychosocial intervention should be developed and increasing access to mental health care is needed. Such actions should aim to facilitate the maintenance of students' mental and physical well-being.

Since positive health is the most important motivating factor to exercise for different subgroups and in total and as competition is considered to be the least important motivator by most of different subgroups and in total, actions aiming to promote physical activity and facilitate participation in activity of 'health-related fitness' character are needed. The authors recommend joint actions aimed at activation in terms of physical activity and provision of professional psychological support to prevent the consequences of insufficient physical activity and social isolation.

Perspective

The COVID-19 pandemic came unexpectedly and many countries were not ready to manage with health and social problems it brought. Now, having in mind that such a situation can occur in the future, as scientists, we have the opportunity to be better prepared to undertake future research. Basing on present state of knowledge, future research should use well established methodology and proceed comparative studies. Future research should include similar groups of students, both from Poland as well as from other countries, which will enable the interpretation of differences and formulation of more general conclusions.

Limitations of the study

The main limitation of this study is the fact that we do not have similar database from the time before the pandemic therefore we cannot conduct comparative analysis. The use of self-report questionnaires can always face criticism. However, in our study we used a well-established and validated tool, and the use of other methods was strongly restricted during the pandemic lockdown.

Conclusions

The Polish students' mental health and well-being during the COVID-19 pandemic was poor, which mainly resulted from very poor accessibility to recreational facilities, spending too much time in sitting or lying positions daily and not performing enough physical activity. Very few students assess their accessibility to recreational facilities and their physical and mental well-being as very good, though the majority of them declare their financial situation to be good or very good. This observation implies that while finance is not a problem for many, poor accessibility and poor psychological care can be the reason why the participants do not feel emotionally and physically well. During the pandemic lockdown the male students were more active and spent less time in a sitting position than females, which suggests that women may be more likely than man to suffer from obesity and other consequences of physical inactivity. The most significant differences between males and females as well as between the Physical Education students and students of other faculties were observed in competition, as one of motivating factors to exercise, which was much more important for males and the PE-students comparing to females and the non-PE students. The participants living in rural and urban areas assessed motivating factors in a very similar way.

Supplementary Materials: The EMI-2 questionnaires in Polish and English can be downloaded here: http://exercise-motivation.bangor.ac.uk/emi/foreign.php

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EFFECTS OF INTEGRATED THERAPEUTIC EXERCISES ON PAIN AND DISABILITY IN MEDIAL KNEE OSTEOARTHRITIS

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[A] Study Design; [B] Data Collection; [C] Statistical Analysis; [D] Manuscript Preparation

Abstract The purpose of this study was to compare the effect of quadriceps isometric exercises along with hip abductors isometric exercises as integrated exercise with quadriceps exercises in reducing pain, disability in medial knee osteoarthritis. The Total of 54 patients (both male and female) were recruited in this study but on the basis of inclusion and exclusion criteria, only 32 were included in this study. Womac index was opted as outcome measures to collect the data of pain, disability and functional limitation. Participants were randomly assigned to integrated exercise group; (n = 16) (mean age 52) who performed exercises [Quadriceps isometric along with hip abductor isometric exercises] and quadriceps isometric exercises group (n = 16) (mean age 49) performed for 3 weeks. 32patients were analyzed and the effect of integrated exercises [Quadriceps isometric along with hip abductor isometric exercises] showed a statistically significant difference in pain, disability and functional limitation ($p < 0.000$). Total duration to collect the pre and post data of pain, disability and functional limitation was 3 weeks. 3 weeks of exercise protocol was effective in both groups in terms of reducing pain and disability but integrated exercises were found to be more effective than quadriceps exercise in improving the pain, disability and functional limitation over the time at the level of significance.

Key words: knee osteoarthritis, integrated exercises, pain, disability

Introduction

Osteoarthritis is a bone and joint degenerative disorder that affects the large peripheral joints such as hip and knee joints in the human body. It is a chronic degenerative joint disease with progressive destruction of articular cartilage and decreases in the synovial fluid that lubricates those joints (Dieppe & Lohmander, 2005). Knee osteoarthritis is a degenerative arthritis occurs in the intra-articular and extra-articular surface of the knee joint. It progresses slowly with usual sign and symptoms being pain and limitation of the range of motion of the knee joint. Age is a one of the strongest risk factors for OA of all joints (Xiao et al., 2019).

The increase in the prevalence and incidence of osteoarthritis with age is probably a consequence of cumulative exposure to various risk factors and biologic changes that occur with aging that may make a joint less able to cope with adversity, such as cartilage thinning, weak muscle strength, poor proprioception, and oxidative damage (Mayoral Rojals, 2021). As a person ages, the water content of their cartilage decrease, thus weakening it and making it less resilient and more susceptible to degradation (Wittenauer et al., 2013). There are strong indications that genetic inheritance is a factor, as up to 60% of all osteoarthritis cases are through to results from genetic factor(Spector & MacGregor, 2004). The latest evidence to date indicates that half of the risk of developing osteoarthritis of the hand and hip (approximately 25% for the knee) can be attributed to genetic factors (Allen et al., 2022).

During examination, slight thickening is often found on palpation; it is mainly a bony thickening caused by the marginal osteophytes (Serban et al., 2016). Movements are impaired slightly or markedly according to the degree of arthritis; in the larger joints movement is accompanied by palpable or audible repetition of a rather coarse type (Rossi et al., 2020). Fixed deformity is often found in the hip, and sometimes in the knee and in other joints (Bhan et al., 2008). The radiological feature of osteoarthritis knee are the joint space narrowing, and sclerotic margins and osteophytes formation at the margin of the joint, with the slight flattening of the condyles (Ahmad et al., 2009). Magnetic resonance imaging can demonstrate early cartilage changes (Jazrawi et al., 2011). Arthroscopy can reveal early fissuring and surface erosion of the cartilage (Hattori et al., 2005).

Physiotherapy consists of major two approaches: electrotherapy and exercise therapy. In electrotherapy, there are various physical agents or modalities which help in reducing pain, swelling or associated symptoms related to the injury (Hanks et al., 2015). On the other hand, there are various forms of exercise such as strengthening exercise progressive resisted exercise isometric and isotonic exercise which help in building the muscle strength and mobility of the joint. They also help in building the independence level of the patients (Hanratty et al., 2012)strength, function, and quality of life. Data were summarized qualitatively using a best evidence synthesis. Treatment effect size and variance of individual studies were used to give an overall summary effect and data were converted to standardized mean difference with 95% confidence intervals (standardized mean difference (SMD. This study was conducted to evaluate the comparative effect of integrated exercises [Quadriceps isometric along with hip abductor isometric exercises] and quadriceps isometric exercises program on pain and disability in patients with medial knee osteoarthritis.

Materials and Methods

This study was conducted after approval from research committee of Swami Vivekanand Subharti University, Meerut, Uttar Pradesh, India. This is a simple pre and post experimental design study. The purpose and procedure of the study were explained in detail and consent form was taken from each participant and participants were free to withdraw any time without giving any reason. The participants were selected according to the inclusion and exclusion criteria and divided into 2 groups – Integrated exercises group (Group-A) and Isometric exercises group (Group B).

Selection criteria

Out of 54, 32 participants took part in this study, including 7 male and 25 females. The participants were randomly allocated into 2 groups i.e. group A (n = 16) and the group B (n = 16) respectively as explained in the flowchart of Figure 1. Patients having a complaint of knee pain at medial aspect with age group between 45–65 years who referred from Orthopedic OPD of Subharti hospital were included in this study. The stage of knee osteoarthritis was determined by X-ray. Patients having a history of recent injury of the knee joint, bone and joint tumor, bone tuberculosis, severe knee pain due to trauma, infection, fracture and no history of any kind of medication for pain were excluded from selection criteria.

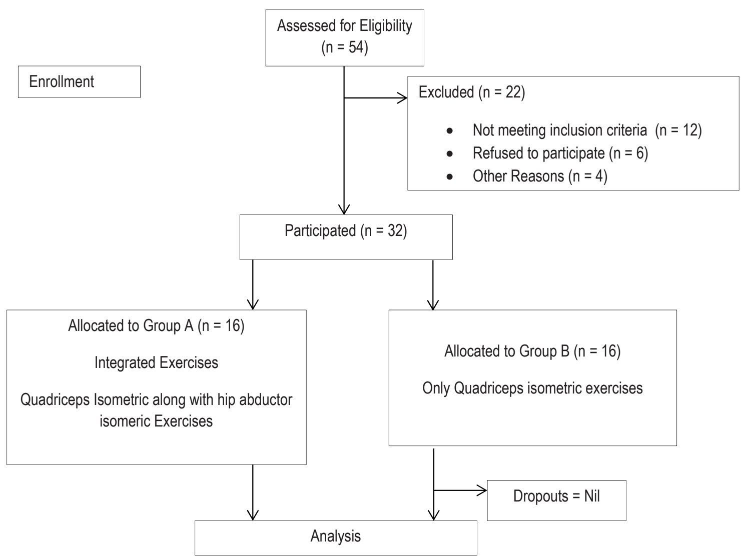

Figure 1. Methodology adopted in this study

Outcome Measure

WOMAC Scale

Pain, disability and function were assessed by the WOMAC(Western Ontario and McMaster Universities Arthritis Index) scale including all three subscales (measured by a Likert version and the possible range of scores is 0 = none to 4 = extreme) were used to determine the degree of functionality of the knee (Riddle & Perera, 2020).

Intervention

Based on the patient assessment, the treatment for both groups involved applying a moist heat pack to the knee joint for 15–20 minutes in order to reduce muscle spasms and pain, while improving tissue extensibility. Group A received sessions of integrated exercises program; quadriceps isometrics exercise along with hip abductor isometric exercises for six days in a week for three weeks. Group B received sessions of only quadriceps isometrics exercise with for six days in a week for three weeks. Initially according to the patient's condition the number of repetitions of exercises may be less or decreased but upgraded or increased later on. After 3 weeks post intervention of quadriceps and hip abductor strength and knee pain and functions were re-evaluated. Pre- and post- intervention data was analyzed for any statistical significance.

Data Analysis

First of all, baseline characteristics i.e. age, height, BMI and body mass of all patients were analyzed. Outcome measures: pain, disability, functions and muscle strength were analyzed for statistical significance. SPSS version 22.0 was utilized to analyze the data. The mean change of WOMAC score at baseline and after 3rd week of intervention within the groups was compared. Assessment for the significant difference at predetermined significant level between pre-and post WOMAC score of both groups was done by Paired t-tests. P value was set at ≤ 0.05 level.

Results

Overall compliance of subjects to the integrated exercise program was 100% as optional session was arranged if a subject could make any of the sessions and also there were no dropouts during the study. There were no significant differences between groups for age, body mass, height, and BMI at baseline ($P < 0.05$) in Table-1. Assessments were done at baseline and after 3 weeks of interventions, and the results presented in Table 2 and 3. There were only a few reports regarding muscle soreness in the first week of exercises.

Table 1. Characteristics of patients with knee osteoarthritis in both groups

Groups	Age (year)	Height (cm)	Body Mass (kg)	Body Mass Index (kg/m^2)
Group A	52	162	71	27.05
Group B	49	158	68	27.23

Table 2. Pre and post WOMAC score of group A

Variable	Pre-score (1st Day)		Post-score (20th Day)		t-value	p-value
WOMAC Domain	Mean	S.D	Mean	S.D		
Joint Pain	12.3	4.3	5.1	3.4	4.698	0.000
Joint Stiffness	5.4	1.9	3.1	1.6	3.703	0.000
Functional Limitation	41.7	5.4	26.3	11.7	4.780	0.000

Table 3. Pre and Post WOMAC score of group B

Variable	Pre-score (1st Day)		Post-score (20th Day)		t-value	p-value
WOMAC Domain	Mean	S.D	Mean	S.D		
Joint Pain	11.3	3.1	8.3	3.9	2.408	0.022
Joint Stiffness	5.4	1.8	3.9	1.6	2.491	0.018
Functional Limitation	39.7	6.9	30.6	13.1	2.458	0.019

Pain and Disability

Group-A

The mean comparison within the group at different time points is shown in Table 2. The effect of integrated exercise level illustrated that there was a statistically significant difference between baseline data and after 3 weeks of data of WOMAC. On the basis of mean difference, WOMAC sore at baseline with calculated value i.e. joint pain (12.3), joint stiffness (5.4) and functional limitation (41.7) significantly improved after performing the integrated exercise for 3 weeks and reported as WOMAC score with joint pain (5.1), joint stiffness (3.1) and function limitation (26.3). Paired t-test of treatment at baseline and after 3rd week was performed and the result of within group comparisons indicated that quadriceps isometrics exercise along with hip abductor isometric exercises compared at baseline to 3rd week ($P < 0.05$) of intervention was statistically significant.

Group-B

The mean comparison with in the group at different time points is shown in Table 3. The effect of quadriceps isometric exercise level illustrated that there was a difference between times between baseline data and after 3 weeks of data of WOMAC. On the basis of mean difference, WOMAC sore at baseline with calculated value i.e. joint pain (11.3), joint stiffness (5.4) and functional limitation (39.7) significantly improved after performing the integrated exercise for 3 weeks and reported as WOMAC score with joint pain (8.3), joint stiffness (3.9) and function limitation (30.6). Paired t-test of treatment at baseline and after 3rd week was performed and the result of within group comparisons indicated that quadriceps isometrics exercise along with hip abductor isometric exercises compared at baseline to 3rd week ($P > 0.05$) of intervention was not statistically significant as compared to group-A who received integrated exercises for 3 weeks.

Discussion

The purpose of this study was to find out the combined effects of quadriceps isometric exercise with hip abductor isometric exercise as integrated exercises approach in subjects with medial osteoarthritis of the knee. Effects of quadriceps isometric exercises were studied and revealed the effectiveness in reduction of pain and improvement in functions (Suzuki et al., 2019). Hip strengthening exercise can be added with quadriceps strengthening exercises for improving pain and quality of life in knee osteoarthritis as supplementary content over the quadriceps exercises alone if it is found to be more effective (Xie et al., 2018). Hip abductor muscles exercises along with quadriceps isometric exercise were of interest as integrated exercises for medial knee osteoarthritis.

Significant improvement in pain, disability and functional limitation was displayed following integrated exercises at baseline and after 3 weeks compared to quadriceps isometric exercises. Our findings agree with previous literature; however, it is the first exploratory study to analyze the effect of integrated exercise protocol in medial knee osteoarthritis. A significant decrease in pain, disability and functional limitation following integrated exercises were delivered for medial knee osteoarthritis both, over the period of 3 weeks compared to baseline. The results of our study are consistent with previous work over the 6 weeks of intervention (Shah Sohil Yunusbhai, 2023; Aalaa et al., 2020). Findings have implications on the clinical decision process of physiotherapists in the context of standard exercise protocol applications pitch side and the resultant or lasting effects on pain, disability and functional limitation in knee osteoarthritis. Physiotherapists should however consider the outcome measures that can impact multiple factors of response to exercises and the context of their application. The current study reflects the necessity of research required in the topic of optimizing integrated exercises application and the impacts on pain and disability that support the functional improvement.

Data of WOMAC index for measuring pain, disability and functional limitation of the subjects of both groups for pre and post interventional study expressed in terms of mean and S.D shown in table 2 and 3. Within the group pre and post values were assessed by paired t-test in both the groups which has mentioned in table 2 and 3. In both groups, p-value was significant i.e., $p < 0.05$ with WOMAC, score; joint pain (0.0000), joint stiffness (0.0000) and functional limitation (0.0000). The 3 weeks protocol quadriceps isometric exercise with hip abductor isometric exercise and quadriceps isometric exercise alone showed significance in both group in terms of decreasing pain and disability but group A, quadriceps isometric exercise with hip abductor isometric exercise showed statistically more significant difference in decreasing pain and disability.

A study was conducted on the role of quadriceps exercise in osteoarthritis of knee joint. In their study total number of 100 subject aged of 40–65 years suffering with mild to moderate O.A of knee joint were enrolled. Subjects were equally divided into two groups. Group 1 & 2; group 1 received drug therapy and group 2 received physiotherapy alone with drug therapy in the form of quadriceps exercise. The patients were assessed often two weeks of protocol. This study shows that group 2 who received drug therapy along with quadriceps strengthening exercise had significant improvement in order to decrease pain and increase ROM and function (Ansari & Asimuddin, 2014).

Another study was conducted on the effect of the exercise of lower limb strengthening as treatment for knee osteoarthritis. Total 88 participants with painful radio-graphically affirmed medial compartment knee osteoarthritis and section enrolled form the network and were randomly assessed to a hip strengthening or control group utilizing concealed allocation stratified by disease severity. The hip strengthening group performed to strengthen the hip abductor and adductor muscles at home 5 times per week for 12 weeks and the control group was requested to continue with their usual care.

Blinded follow up assessment was conducted at 12 weeks after randomization. This study showed that the hip strengthening exercise was significantly effective on knee loads and symptoms in people with medial compartment knee osteoarthritis and has the potential to slow the disease progression (Uthman et al., 2013)two hip, 14 mixed. As the authors expected in this study, the result supported the previous studies that examined the different exercise program concerning reduction of pain and disability in knee osteoarthritis.

It is worth noting that different studies have linked in reduction in pain and disability to an increase function to mobility in the patients with knee osteoarthritis. This was likely due to the intrinsic factors associated with ageing, such as degenerative processes in musculoskeletal systems that lead to muscle weakness and limit the mobility of knee joint. Hence also in this study an improvement in muscle strength as well as functions was observed which can support the previously published studies.

Conclusion

Integrated exercises for quadriceps and hip abductor muscles have a significant effect on pain and disability of the elderly population with medial knee osteoarthritis. After 3 weeks of integrated exercise protocol, there has been a significant improvement on pain and disability as well as functional limitation. This result showed that even short-term integrated exercise protocol can be effective in the elderly population to improve their function via reducing the pain and disability. Integrated exercises were found to be more effective than quadriceps exercise in improving the data of joint pain, joint stiffness and functional limitation over the time at the 5% level of significance.

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ASSESSMENT OF CHANGE OF DIRECTION AND AGILITY. RUNNING AND DRIBBLING AMONG SOCCER, BASKETBALL AND HANDBALL PLAYERS: THE CONCEPT OF "AGILITY DEFICIT"

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Abstract The primary objective of this study is to conduct a comparative analysis of change of direction (COD) and agility among players engaged in soccer, basketball, and handball. Additionally, the researchers introduced the novel concept of "Agility deficit", aimed at evaluating distinctions between COD and agility during running (COD-R; Agility-R) and dribbling (COD-D; Agility-D). The participant cohort comprises 38 individuals with an average age of 20.63 years, distributed across 13 handball players, 12 soccer players, and 13 basketball players. Statistical analyses, specifically ANOVA accompanied by Tukey's post hoc comparisons, have been employed to discern significant differences among subgroups. While no noteworthy disparities among groups were observed in both COD-D and Agility-D when participants manipulated the balls using their hands, a marked superiority in performance emerged for soccer players when the balls were manipulated with their legs. Soccer players exhibited expedited responses compared to their basketball and handball counterparts when confronted with a visual stimulus during the Agility-R test (reduced Agility-R deficit). Furthermore, the Agility-D deficit underscored the heightened visual challenge to react in visual stimuli during dribbling in soccer. Independent of the type of ball handling, soccer players consistently demonstrated a diminished Agility-D deficit, affirming their superior visual ability. The performance in Agility-D further revealed that visual ability plays a pivotal role in influencing dribbling ability. The study posits that, for a comprehensive assessment of a player's visual ability during running or dribbling, interpretations of both Agility-R deficit and Agility-D deficit are imperative. Consequently, the proposed indexes of Agility-R deficit and Agility-D deficit present valuable tools for evaluating players' COD and Agility abilities during running or dibbling. However, the efficacy of these assessments in real-game situations remains undetermined, requiring further investigation.

Key words: soccer, basketball, handball, COD, agility

Introduction

Success in team sports depends on various factors including players' psychological, physical, cognitive, technical, and tactical abilities. The interaction of these factors determines performance (Chamari et al., 2004; Reilly et al., 2000; Sporiš et al., 2014). Most team sports exhibit an intermittent nature where multi-directional, linear and repeated sprint abilities have garnered significant interest in the literature (Gray & Jenkins, 2010; Murr et al., 2018). Additionally, team sports such as soccer, basketball, and handball involve multiple movement patterns that necessitate sudden and rapid changes of direction by players (Özgür et al., 2016).

While past studies have primarily focused on assessing change of direction (COD) ability and its specific requirements (e.g., straight-line sprint, leg muscle qualities, running technique), it is essential to note that COD involves only pre-planned movements (Gioldasis et al., 2022; Šimonek et al., 2017; Young et al., 2015). Currently, COD tasks are also categorized into force and sprint-oriented based on the angle of direction change and the required physical mechanism (Bourgeois et al., 2017). Consequently, various testing protocols are employed to evaluate COD performance in team sports. However, many of these tests primarily measure the ability to quickly change the direction without accounting for responses to external unpredictable stimuli (Krolo et al., 2020). In contrast, most COD movements in team sports are not pre-planned but executed in response to an external stimulus, a skill defined as agility (Sheppard & Young, 2006). It is widely recognized that agility is a multi-dimensional ability dependent on the optimal combination of physical (e.g., strength, power, speed, balance, coordination, running technique) and cognitive (e.g., anticipation, reaction time, decision making, visual scanning) abilities of players (Krolo et al., 2020; Lloyd et al., 2015; Özgür et al., 2016; Sekulic et al., 2017; Young et al., 2015). Specifically, agility is defined as a rapid, whole-body change of direction or speed in response to sport-specific stimuli (Shepard & Young, 2006).

At this juncture, it is evident that both COD and agility are crucial factors for the future success of players in soccer, basketball, and handball (Little & Williams, 2003; Loturco et al., 2018; Šimonek, et al., 2017; Young & Rogers, 2014). Players need to effectively perform various complex dynamic movements with or/and without the ball in response to unpredictable environments influenced by opponents, teammates, and ball possession (Cortis et al., 2013; Esfahankalati & Venkatesh, 2013). Players with high agility levels gain a defensive or attacking tactical advantage, reducing opponents' chances of an appropriate response (Iacono et al., 2015; Nimphius et al., 2017; Sisic et al., 2016). Moreover, they perceive relevant information about opponents' activities and react with higher accuracy and velocity than players with lower agility levels (Jackson et al., 2006; Serpell et al., 2011). While COD enables players to outperform opponents with pre-planned movement patterns, they must also respond and use non-planned movements in response to unpredictable opponents' reactions (Sisic et al., 2016). Consequently, agility and COD abilities vary among sports due to different sport requirements and rules. For instance, soccer, basketball, and handball differ in playing field, goal or point-scoring methods, general rules, and participating body limbs during dribbling, all of which likely influence sport-specific requirements. Among the skills related to agility and COD abilities, running with the ball (dribbling) constitutes a significant portion of gameplay and is crucial to the outcome of a game (Scanlan et al., 2018; Trecroci et al., 2016). This skill likely advances player's agility and COD abilities, introducing the additional challenge of maintaining ball possession under unpredictable stimuli (Bekris et al., 2018a). Additionally, this skill may partially explain the significant differences in observed agility among players in various team sports (Horička et al., 2014).

Although numerous studies have identified different types of COD (e.g., zig-zag, lateral, forward-backward running), investigate different types of agility is also essential (Sekulic et al., 2013). In soccer, agility primarily involves non-stop running scenarios, while in handball and basketball, players often perform stop-and-go reactive-agility patterns (Karcher & Buchheit, 2014; Spasic et al., 2015). Players with superior agility in team sports can outperform their opponents in 1vs1 duels, blocking, defensive and offensive positioning, and quickly reacting to opponents' changes in direction (Delextrat et al., 2015; Hammami et al., 2015; Krause & Nelson, 2018; Spasic et al., 2015). In soccer, weak agility and low balance during dribbling can lead to opponents easily capturing the ball. Therefore, agility significantly influences speed and dribbling skills, and a low agility level makes it challenging to outperform opponent's defense (Abidin et al., 2020).

A relevant factor explaining agility differences among team sports is the development of different visual strategies used by high and low-skilled players (Bekris et al., 2018a; Rivilla García et al., 2013; Turner, 2011; Wu et al., 2013). The crucial role that agility plays in performance emphasizes the importance of the fundamental element of visual scanning. Consequently, sports' structure influences visual demands and improves players' visual behavior at different levels. More skilled players produce more accurate and quicker responses due to their ability to pick up anticipatory cues about the posture and kinematics of an opponent (Turner, 2011). Visual training is suggested to enhance visual processing, cognition of visual information, and attention to read environmental changes such as teammates' and opponents' activities as well as the ball's trajectory (Afshar et al., 2019; Chaalali et al., 2016; Hatzitaki et al., 2009). Despite the distinctive role of visual behavior in playing level, it is important to note that most players have never received specific visual training (Alves et al., 2015). In this study, the researchers explore the difference between COD and Agility with a ball (Agility-D deficit) and the difference between COD and Agility without a ball (Agility-R deficit) to isolate perceptual strategies (e.g., visual scanning) likely affecting these abilities. The term "deficit" from COD testing is used to isolate change of direction ability from straight-line sprint ability (Nimphius et al., 2013). The researchers decided to apply this definition to isolate the cognitive patterns of COD and Agility, abilities crucial in team-sports.

The objective of this study was to investigate: (a) the subtraction between COD and Agility abilities (i.e. Agility-R and Agility-D deficits) aiming to assess the perceptual components of Agility; (b) the perceptual challenges inherent in various sports, as indicated by differences in Agility deficits within each sport, both with and without the presence of a ball; (c) the identification of players exhibiting superior performance under distinct ball-handling rules and exploring the potential impact of technical proficiency on perceptual abilities; and (d) the identification of players demonstrating heightened Agility deficit performance. The researchers posited two main hypotheses: (a) that sports exhibit variability in agility demands due to distinctions in perceptual requirements; and (b) that soccer players encounter greater challenges during dribbling compared to running, while concurrently demonstrating heightened perceptual adaptations.

Methods

Participants

A total of thirty-eight male players (aged 20.63 ±1.94 years, training experience 8.9 ±2.0 years) participated in the study. Specifically, thirteen Handball Players (HP; aged 21.00 ±2.31 years, training experience 8.12 ±2.21 years), twelve Soccer Players (SP; aged 20.08 ±1.44 years, training experience 9.28 ±2.05 years), and thirteen Basketball Players (BP; aged 20.77 ±1.96 years, training experience 9.51 ±1.93 years), all members of amateur adult teams, were included. Participants engaged in three training sessions and one day game per week. None of them had received specific visual training in the past, and all were undergraduate students at the Sports Sciences University. Informed written consent, approved by the university ethics committee (National and Kapodistrian University of Athens; Department of Physical Education and Sport Science; Dafni; Wednesday 11 March 2020; Protocol Number: 1173/11-03-2020), was obtained from all participants. Additionally, participants completed a questionnaire identifying any potential lower extremity injuries, vestibular and visual problems gained in the last competitive season, and those not meeting the criteria were excluded from the study.

Procedures

The study occurred during the transition period of soccer, basketball, and handball amateur leagues. Participants underwent two familiarization trials a week before the main recorded trials. Researchers randomly assigned players to testing groups and evaluated them in all tests (four in total) on different days and times to prevent extended breaks. Two main trials were conducted per day, with the superior performance chosen for further analysis. Each day featured a different test, ensuring a 48-hour rest period between trials (Asadi et al., 2016). In dribbling tests, players executed the tasks by hands for basketball and handball measurements and by legs for soccer measurement. Participants donned athletic attire and non-spiked footwear while undergoing assessments on a wooden court surface. Before the assessments, each participant was verbally encouraged and instructed to perform a maximal effort during the tests. Furthermore, before testing participants completed a 15-minute without-ball warm-up (jogging, running, sprinting, and stretching) and a 10-minute with-ball warm-up (passing, dribbling, duels, and shoots).

Testing

Body mass and height were measured with a weight and height scale to the nearest 0.1 kg/cm (BC1000, Tanita, Japan). COD Running (COD-R) and COD Dribbling (COD-D) were assessed using an adapted format of the Dribbling Agility Test (DAT) (Bekris et al., 2018b). Specifically, researchers “constructed” a 7X7m square-shaped area, including another small square (1-m long on each side) in the centre. Four gates, 80cm wide between the cone and the light of the agility test, were positioned in the middle of each side of the large square (Figure 1). A dual infrared reflex photoelectric cell system (Polifemo, Microgate, Bolzano, Italy) was used to measure the time.

One pair of photocells was initially placed in the middle of the small square and removed by researchers after the participants' first pass. Another pair was placed at the 3rd gate. The COD-R and COD-D tasks involved running on a preplanned path (either with or without a ball) from the small central square and passing through the gates between the cones and photocells. The test began with players in the central small square, facing the researchers standing behind gate N°1. The specific route used was from the centre to gate N°1 (straight), from gate N°1 to gate N°2 (right), from gate N°2 to gate N°3 (right), from gate N°3 to gate N°1 (straight), from gate N°1 to gate N°4 (left), from gate N°4 to gate N°3 (left), from gate N°3 to gate N°2 (left), and from gate N°2 to gate N°3 (right). Participants always had to pass through the small central square before reaching the next gate.

The same square-shaped area was used to evaluate Agility Running (Agility-R) and Agility Dribbling (Agility-D) with DAT (Bekris et al., 2018b). Researchers removed photocells and utilized four lights from the FitLight trainer (Sport Corp.; Ontario, Canada), positioned in the middle of each side. At the beginning of the agility tests, participants were placed inside the central square (either with or without a ball), and all lights were turned on in different colors (red, yellow, blue, green). Following a visual signal, participants had to run and pass through the gate with the blue light. Immediately after passing the gate, the light was turned off, and the light of another gate turned blue. Agility tests included two different but equal protocols with a specific number of direction changes (three to the left and three to the right) and the same total distance. Participants were informed that the test used a random pattern, making it pointless to memorize the sequence. They were encouraged to react to the blue light as quickly as possible. Additionally, players were not allowed to observe the trials of their teammates.

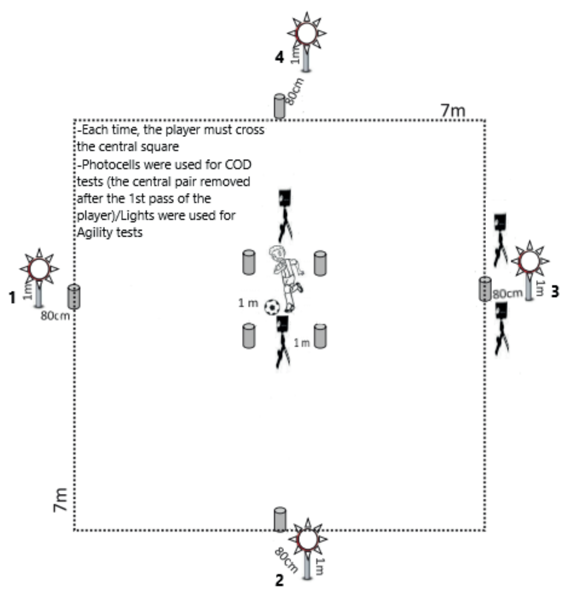

Figure 1. Adapted COD and Agility DAT tests with and/or without the ball [derived from Bekris and colleagues (2018b)]

Analysis

All statistical analysis were performed using the SPSS statistical package (IBM corporation released 2019; IBM SPSS Statistics for Windows, Version 26.0; Armonk, NY: IBM corporation), and the level of significance was set at $p < 0.05$. G*Power 3.1 software was utilized to calculate statistical power (=0.67). Descriptive statistics are presented as means (M) and standard deviations (SD). Tests for normal distribution and homogeneity (Shapiro-Wilk and Levene's, respectively), conducted with a significance level of $p > 0.05$ before analysis, indicated a normal and homogeneous distribution of the dataset. One-way analysis of variance (ANOVA) was chosen to examine differences among sports concerning COD-R, COD-D, Agility-R, and Agility-D (Sheskin, 2000). Tukey's post hoc comparisons were conducted where significant main effects were observed. Effect sizes for main effects and interactions were determined by calculating partial eta squared (η^2) values. Effect sizes were categorized as small (0.01–0.06), moderate (0.06–0.14), and large (≥0.14). Pearson correlation analyses (*r*) were performed, and the significance level was classified as very weak (0.0 to 0.2), weak (0.2 to 0.4), moderate (0.4 to 0.7), strong (0.7 to 0.9), and very strong (0.9 to 1.0) (Rowntree, 2000; Tomczak & Tomczak, 2014).

Results

The following table presents the descriptive statistics of the sample, as well as the one-way analysis of variance (ANOVA) of the variables and the Tukey's post hoc comparisons.

Table 1. Descriptive statistics and comparisons of COD and Agility abilities among handball, basketball, and soccer players

Sport	Total	Handball HP	Soccer SP	Basketball BP	ANOVA	df	η^2	Tukey's
N	38	13	12	13				
Age	20.63 ±1.94	21.00 ±2.31	20.08 ±1.44	20.77 ±1.96				
Body height (cm)	171.70 ±7.2	165.9 ±6.30	174.5 ±6.90	174.70 ±7.80				
Body weight (kg)	69.90 ±8.90	65.10 ±9.10	73.1 ±8.20	71.50 ±10.10				
BMI (kg/m²)	23.60 ±2.40	23.60 ±2.70	23.9 ±2.10	23.20 ±2.40				
COD-R	18.61 ±0.74	18.39 ±0.74	18.94 ±0.61	18.52 ±0.78	4.379	2	0.11	
COD-D					25.573***	2	0.62	SP>HP;SP>BP
Handball Ball	20.42 ±0.99	20.58 ±0.91	20.64 ±0.90	20.04 ±1.11				
Soccer Ball	28.56 ±4.10	30.37 ±4.93	24.91 ± 1.22	30.13 ±2.55				
Basketball Ball	20.29 ±1.16	20.61 ±1.25	20.52 ±0.99	19.76 ±1.09				
Agility-R	20.13 ±0.93	19.91 ±0.94	20.03 ±0.81	20.43 ±1.00	1.713	2	–0.07	
Agility-D					26.360***	2	0.64	SP>HP;SP>BP
Handball Ball	21.87 ±1.20	22.02 ±1.03	21.91 ±1.60	21.68 ±1.00				
Soccer Ball	31.15 ±4.07	33.09 ±4.42	27.23 ±1.55	32.82 ±2.62				
Basketball Ball	21.59 ±1.12	21.92 ±0.96	21.68 ±1.45	21.17 ±0.84				
Agility-R deficit	1.52 ±0.75	1.52 ±0.62	1.09 ±0.71	1.91 ±0.75	4.379*	2	0.11	SP<BP

Sport	Total	Handball HP	Soccer SP	Basketball BP	ANOVA	df	η^2	Tukey's
Agility-D deficit								
Each Sport's Ball	1.71 ±0.98	1.45 ±0.86	2.32 ±1.18	1.41 ±0.63	3.935*	2	–0.02	SP>HP;SP>BP
Handball Ball (same ball all the players)	1.46 ±0.88	1.45 ±0.86	1.27 ±0.90	1.64 ±0.91	1.42	2	–0.07	
Soccer Ball (same ball all the players)	2.59 ± 1.36	2.72 ± 1.67	2.32 ±1.18	2.69 ± 1.21	0.323	2	–0.11	
Basketball Ball (same ball all the players)	1.30 ±0.74	1.32 ±0.82	1.16 ±0.80	1.41 ±0.63	0.757	2	–0.09	

Notes: sig. p < 0.05 *, p < 0.01 **, p < 0.001 ***
Effect size (η^2): <0.06 = small effect, 0.06–0.14 = moderate effect, ≥0.14 = large effect.
Abbreviations: Handball Players (HP, Soccer Players (SP), Basketball Players (BP), COD-Running (COD-R), COD-Dribbling (COD-D), Agility-Running (Agility-R), Agility-Dribbling (Agility-D).

ANOVA tests were conducted to examine differences in COD-R, COD-D, Agility-R, and Agility-D among different sports (Table 1). Specifically, the ANOVA analysis revealed non-significant differences among handball, soccer, and basketball players in COD-R. However, a significant difference was found among handball, soccer and basketball players in COD-D. Tukeys' comparisons indicated that SP (24.91 ±1.22) significantly differed from HP (20.58 ± .91) and BP (19.76 ±1.09). Furthermore, the ANOVA analysis revealed non-significant differences among handball, soccer, and basketball players in Agility-R. Conversely, a significant difference was found among handball, soccer, and basketball players in Agility-D. Tukeys' comparisons showed that SP (27.23 ±1.55) significantly differed from HP (22.02 ±1.03) and BP (21.17 ±0.84). Concerning Agility-R deficit, the ANOVA analysis revealed a significant difference among handball, soccer, and basketball players, with Tukeys' comparisons indicating that SP (1.09 ±0.71) significantly differed only from BP (1.91 ±0.75). Additionally, the ANOVA analysis revealed a significant difference among handball, soccer, and basketball players in Agility-D deficit when specific sport players used the ball of their sport. Tukeys' comparisons showed that SP (2.32 ±1.18) significantly differed from HP (1.45 ±0.86) and BP (1.41 ±0.63). On the contrary, the ANOVA analysis revealed a non-significant difference among handball, soccer, and basketball players in Agility-D deficit when assessed with the handball ball, soccer ball, and basketball ball.

The following table reports the correlations between the measured abilities for the entire sample, as well as each sport separately.

Table 2. Correlations of COD and Agility abilities, with and/or without the ball, among handball, basketball, and soccer players

	COD-R	COD-D	Agility-R	Agility-D
Total sample				
COD-R	1			
COD-D	0.492**	1		
Agility-R	0.610***	–	1	
Agility-D	–	0.946***	0.097	1
Soccer				
COD-R	1			
COD-D	0.327	1		
Agility-R	0.535	–	1	
Agility-D	–	0.653*	0.664*	1

	COD-R	COD-D	Agility-R	Agility-D
Basketball				
COD-R	1			
COD-D	0.802***	1		
Agility-R	0.670**	–	1	
Agility-D	–	0.819***	0.829***	1
Handball				
COD-R	1			
COD-D	0.522	1		
Agility-R	0.756**	–	1	
Agility-D	–	0.616*	0.112	1

Notes: sig. $p < 0.05$ *, $p < 0.01$ **, $p < 0.001$ ***
COD-R and Agility-D as well as COD-D and Agility-R were not interpreted.
Magnitude (r): <0.20 = very weak correlation, 0.20–0.40 = weak correlation, 0.40–0.70 = moderate correlation, 0.70–0.90 = strong correlation, 0.90–1.00 = very strong correlation.

Table 2 illustrated the correlations among abilities within each examined sport. Specifically, COD-D and COD-R abilities in team sports were moderately positively correlated. More specifically, in soccer and handball, these abilities were not correlated, while in basketball, they were strongly positively correlated. Agility-R and COD-R abilities in team sports were moderately positively correlated overall. Specifically, in soccer, they were not correlated, while in basketball and handball, they were moderately positively and strongly positively correlated, respectively. Agility-D and COD-R abilities in team sports were moderately positively correlated overall. However, in subgroup correlations, no significant relationship was found. Agility-R and COD-D abilities in team sports were not correlated overall. In particular, in soccer and handball, no correlation was found, while in basketball, they were strongly positively correlated. Agility-D and COD-D abilities in team sports were very strongly positively correlated overall. Although in soccer and handball, they were moderately positively correlated, in basketball, they were strongly positively correlated. Finally, Agility-D and Agility-R abilities in team sports were not correlated overall. However, in soccer, they were moderately positively correlated, in basketball, they were strongly positively correlated, and in handball, they were not correlated.

Discussion

The primary objective of this investigation is to discern variances in both physical and technical capabilities among the examined soccer, basketball, and handball players, measured with COD-R, Agility-R, COD-D, and Agility-D tests. Furthermore, the study seeks to elucidate the factors that impact the relationships among these abilities. In an innovative approach, the researchers introduce the concept of “agility deficit”, a metric contingent upon the temporal disparity between change of direction (COD) and agility, with and/or without the presence of a ball.

The significance of this study is underscored by the dynamic nature inherent in these sports, wherein players are compelled to execute complex movement patterns in response to external stimuli. These stimuli encompass diverse factors such as ball movement, interactions with teammates and opponents, and evolving game scenarios (Sheppard & Young, 2006). Significant emphasis lies in the prompt identification of visual stimuli by participants, exerting influence on perceptual and cognitive parameters, notably decision-making abilities. This, consequently, assumes a pivotal role in shaping the overarching performance of the individuals.

The principal findings of this study reveal that both COD-R and Agility-R did not exhibit significant differences among various sports. These outcomes align with earlier research, indicating either no differences or slight variations in COD-R and Agility-R among players engaged in diverse team sports (Horička et al., 2014; Šimonek et al., 2017). Literature review suggests the independence of COD and Agility as physical abilities. It underscores the significance of incorporating perceptual components in defining agility, thereby contributing to the differentiation between these two abilities (Sheppard & Young, 2006; Young et al., 2002). This finding allows researchers to compare and interpret differences in dribbling based on the observation that participants did not significantly differ in physical parameters encompassed by COD and Agility running. Consequently, any distinctions observed are attributed to the required technique and associated perceptual cues. Specifically, the examined soccer, basketball, and handball players significantly differed in both COD-D and Agility-D abilities. Soccer players exhibited longer COD-D and Agility-D durations compared to their basketball and handball counterparts. This suggests that, with the introduction of a dribbling task, soccer places higher demands on players, requiring complex movement patterns involving ball manipulation with the legs, thereby accentuating the sport's unique demands. In contrast, basketball and handball players, manipulating the ball with their hands, potentially find it easier to perceive environmental changes.

The inquiry pertains to the impact of augmented visual stimuli on the preplanned movement patterns of players during agility assessments. In this context, it was imperative to calculate the disparity between Agility-R and COD-R (Agility-R deficit), as well as Agility-D and COD-D (Agility-D deficit) in each sport. While a significant difference among sports was identified, only soccer players exhibited a significantly smaller deficit compared to basketball players, and a smaller, albeit non-significant, disparity compared to handball players. The interpretation of these outcomes suggests that soccer players demonstrated superior responsiveness to a visual stimulus during the Agility-R test in comparison to basketball and handball players. This finding likely indicates that the examined soccer players had already developed heightened visual abilities, including peripheral vision and visual recognition, along with an enhanced adaptability to unpredictable visual stimuli (Chaalali et al., 2016). Consequently, soccer players' performance on Agility-R deficit was not reduced as pronounced as observed in basketball and handball players. In summary, within the specific population under investigation in this study, these differences can be attributed to the inherently more demanding and dynamic nature of soccer. Soccer necessitates more frequent and rapid motor reactions to visual stimuli, particularly under conditions of high intensity speeds, within the confines of smaller court dimensions with a greater number of competing players. Collectively, a soccer player must not only possess the requisite physical capabilities to effectively navigate the sport's demands but also the cognitive abilities to perceive and react within a constrained timeframe (Sariati et al., 2020).

Similarly, when assessing Agility-D deficit in each sport, considerable differences were found, particularly for the examined soccer players compared to basketball and handball players. These differences underscore the increased visual difficulty when reacting to visual cues during dribbling in soccer. Despite testing of all players with balls from other sports, no significant differences were noted, except from the examined soccer players who exhibited shorter Agility-D deficit, independent of the ball. While the performance of the examined soccer players exhibited similar outcomes in terms of COD-D when utilizing with basketball and handball ball, their performance manifested a lesser degree of negative impact than that observed in other players with respect to Agility-D. This observation substantiates the superior visual ability that the examined soccer players have developed in the context of dribbling ability, irrespective of their primary sport. Presumably, this proficiency can be attributed to an augmented perceptual acumen and an elevated level of adaptation of soccer players who have previously undergone training under analogous visually demanding conditions. The extant literature aligns with these findings by positing the heightened relevance of agility to soccer, given that COD movements seldom occur in isolation from external stimuli, as noted by Chaalali et al. (2016). Consequently, it is inferred that the proficiency in dribbling does not wield a commensurate influence on Agility-D, thereby recommending training interventions that incorporate perceptual and visual components, as advocated by Young et al. (2015).

In contrast, the examined basketball and handball players subjected to assessment while manipulating the ball with their legs demonstrated a comparatively lesser degree of adaptability. This suggests that the proposed parameters of Agility-R deficit and Agility-D deficit may serve as valuable metrics for evaluating players' COD and Agility abilities, both with and without ball. However, the translational efficacy of these assessments to real-game scenarios remains uncertain and warrants further investigation. It is imperative to underscore that these differences necessitates a comprehensive analysis by practitioners, considering not only the outcome in Agility-R and Agility-D but also in COD-R and COD-D, to derive a holistic perspective and optimize players' performance. Notably, when all players employed a soccer ball, the examined soccer players exhibited a substantial Agility-D deficit. Nevertheless, their overall time in Agility-D was considerably shorter than that of their basketball and handball counterparts. This discrepancy is explicable by the soccer players' superior initiation time in COD-D, resulting in accelerated movement, rendering it impractical to diminish difference in Agility-D.

The data analysis also disclosed a non-significant correlation between Agility-R and Agility-D in the total sample. This finding suggests that the introduction of a ball during the dribbling test induces alterations in visual behavior and elevates the level of test complexity relative to running tests. However, upon disaggregating this relationship within each sport, notable disparities emerged, revealing a high correlation in basketball and a moderate correlation in soccer. Presumably, these distinctions are elucidated by the divergent technical requisites inherent to each sport and the techniques employed by individual players. It is conceivable that the examined basketball players remained unaffected by ball handling during the dribbling test, suggesting that this particular task did not introduce additional difficulty. This outcome underscores the imperative to devise a different evaluation protocol for assessing Agility-D in basketball. Conversely, in the context of handball, no discernible relationship was observed between Agility-R and Agility-D abilities.

Evidently, for the examined handball players, the aptitude to interact and respond with a ball amidst visual stimuli represents a skill distinctly disparate from executing dribbling maneuvers along a pre-planned trajectory. This finding is likely attributed to the sport's technical demands and the smaller size of the ball. Moreover, the examined handball players are presumably unaccustomed to protracted periods of dribbling without ball catching to explore the court. Consequently, the formulation of distinct assessment protocols tailored to the unique requirements of handball may be imperative for appraising Agility-R and Agility-D abilities.

In the domain of soccer, the manipulation of the ball exerted a moderate influence on the examined players' performance in the Agility-D test. This observation implies that the Agility-D test can serve as a viable metric for evaluating the agility ability of soccer players, including the differentiation between Agility-D and Agility-R, a pivotal performance indicator necessitating improvement during training. Furthermore, a moderate relationship between COD-R and COD-D was observed for the whole sample. Nevertheless, upon closer scrutiny within each sport, a high positive relationship was only discernible for the examined basketball players. This alignment with prior research (Scanlan et al., 2018) underscores the notion that incorporating a dribbling task during COD imposes comparable additional time demands, highlighting the significance of dribbling ability in COD movements within basketball. This finding underscores the significance of dribbling within COD movements, particularly within the context of basketball, which encompasses extensive multidirectional actions necessitating the execution of dribbling maneuvers while altering directions in various in-game scenarios, such as crossover maneuvers and evading opponents (Abdelkrim et al., 2007; Torres-Unda et al., 2013). While limited studies specifically investigate the relationship between COD-R and COD-D, extant evidence indicates low or non-significant associations in soccer and handball (Islam & Kundu, 2020; Zapartidis et al., 2018). Notably, it has been posited that among various motor abilities potentially influencing dribbling skill in handball, running does not contribute significantly to this relationship, likely attributable to the different sport requirements (Kelmendi et al., 2016).

It is imperative to note that the current test needs validation in subsequent studies, particularly in the context of basketball, where a player's quickness appears to correlate with performance during the dribbling test, irrespective of technical proficiency. It was further shown that the better the COD-R is the moderately more the Agility-R improves when the whole sample was examined. Additionally, the findings affirm that while a swift player is more likely to excel in Agility-R, these variables remain relatively independent, sharing minimal common variance (Coh et al., 2018; Dugdale et al., 2020; Nimphius et al., 2017; Sheppard et al., 2006). The strength of the correlation varies within each sport, with soccer exhibiting marginal non-significance and basketball and handball showing moderate significance. The degree of these correlations indicates that Agility-R exhibits a relatively independent relationship with the COD-R, a finding substantiated by prior research in the domains of basketball and handball (Hallberg Lyggemark, 2018; Spiteri et al., 2014). These outcomes lend support to the proposition that COD and agility should not be construed as the same ability (Sattler et al., 2015; Spasic et al., 2015) supporting the notion that physical and physiological factors, such as linear speed and lower-body muscular activity, play a more pronounced role in COD as a component of agility (Hojka et al., 2016). The suggestion is further posited that improvements in agility hinge predominantly on enhanced perceptual abilities to respond to external stimuli, rather than on actual movement speed, which exhibits a stronger correlation with COD (Young & Rogers, 2014).

Finally, the interpretation of results underscores that superior COD-D corresponds to a more pronounced enhancement in Agility-D when considering the entire sample. This observation unequivocally implies that, irrespective of the presence of a visual stimulus, technique development remains a pivotal factor in augmenting Agility-D proficiency. Nonetheless, when scrutinizing this relationship within each sport, the strength of the association was notably robust for the examined basketball players but markedly weaker for the examined soccer and handball players. This finding, as previously mentioned, is likely attributable to disparities in ball manipulation, player skill level, and the inherent challenges posed by the test within each group of players.

Conclusions

Agility and COD abilities constitute integral determinants of performance in team-sports, serving as discriminators between players of varying skill levels. It is imperative to scrutinize these abilities distinctly, encompassing evaluations both with and without the incorporation of dribbling. Consequently, the examination of these abilities necessitates discrete testing, coupled with a meticulous interpretation of the outcomes. Notably, the principal findings of the study unveiled that the examined soccer players demonstrated a diminished Agility-R deficit, indicative of a heightened capacity for adapting to unpredictable visual stimuli during running.

The assessment in soccer conditions is notably demanding in relation to COD-D and Agility-D, as evidenced by the extended duration required by the examined soccer players to complete these evaluating measures. Additionally, their protracted Agility-D deficit underscored the difficulty of soccer players executing dribbling maneuvers while concurrently responding to visual stimuli. Nevertheless, they demonstrated the shortest Agility-D deficit when employing consistent ball dribbling rules across all participants, regardless of their respective sport domains. This observation suggests that soccer players, irrespective of their individual technical proficiency-a factor deemed inconsequential in determining Agility-D-manifested superior visual abilities compared to their counterparts.

This study introduces the potential performance indexes of Agility-R deficit and Agility-D deficit, which necessitate interpretation alongside performance in Agility-R, COD-R, Agility-D, and COD-D tests. The study acknowledges certain limitations, including the application of the DAT test in basketball and handball players for a first time. While the researchers maintained consistency in test structure with the soccer DAT test, validation of the test across diverse team sports is recommended for future investigations. Additionally, the study's limitation in terms of a relatively small sample of adult males underscores the necessity for future research to encompass larger, more diverse, and younger populations, including both genders. Furthermore, future research endeavors are encouraged to extend beyond controlled settings, exploring variables such as Agility-D within more realistic game scenarios, such as 1vs1 sport conditions. In essence, the presented data offers valuable insights for coaches and practitioners, aiding in the evaluation of players' abilities and informing the design of training sessions geared towards holistic development. A concluding recommendation for soccer practitioners is to intensify the complexity and visual stimuli within training exercises to foster enhanced motor and perceptual competencies among players.

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Appendix

DAT protocols

The protocols' sequence of gates for DAT testing was as follows: The first path was running or dribbling from the centre to the light N°1 (straight), from the light N°1 to the light N°2 (right), from the light N°2 to the light N°3 (right), from the light N°3 to the light N°1 (straight), from the light N°1 to the light N°4 (left), from the light N°4 to the light N°3 (left), from the light N°3 to the light N°2 (left), and from the light N°2 to the light N°3 (right). The second path was running or dribbling from the centre to the light N°4 (straight), from the light N°4 to the light N°1 (right), from the light N°1 to the light N°2 (right), from the light N°2 to the light N°4 (straight), from the light N°4 to the light N°3 (left), from the light N°3 to the light N°2 (left), from the light N°2 to the light N°1 (left), and from the light N°1 to the light N°2 (right).

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THE SHAPE OF THE SAGITTAL CURVATURES OF THE SPINE IN A HIGH-LEVEL ACROBATIC GYMNASTS – COMPARISON BY SEX

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Abstract: Specific loads on the spine and the very young age at which acrobatic gymnastics training is undertaken require monitoring the shape of the spine curvatures in gymnasts to detect possible postural abnormalities. The aim of this descriptive study was to assess and compare the shape of the spine in the sagittal plane in acrobatic gymnasts of both sexes and their associations with demographic and somatic variables.

The study group included 159 acrobatic gymnasts aged 12–19 (106 females and 53 males) from 16 European countries. The study was designed as a survey and measurements of somatic variables and the angles of inclination (using the Baseline Bubble inclinometer) at four topographic points of the spine: S1, L5/S1, Th12/L1, C7/Th1. Based on the angles of spinal inclination, the sizes of the sacral slope (SS), lumbar lordosis (LL), and thoracic kyphosis (TK) were calculated. Body posture was assessed based on Wolański's modified typology.

The angles of SS and LL were significantly higher in females, and TK did not differ between sexes. Training experience positively correlated only with the size of the SS in both sexes. Age and somatic variables were significantly correlated with the size of the sagittal curvatures, mainly in females. The majority of gymnasts had a normal angle of SS and TK and a flattened LL. The equivalent and lordotic types of body posture were more frequent in females, and the kyphotic type in males. The incorrect body posture was noted in 19.8% of females and 43.4% of males.

We concluded that acrobatic gymnasts are not at risk of increasing the size of spinal curvatures in the sagittal plane, but males show a tendency toward flattened LL and kyphotic type of body posture.

Key words: body posture, competitive sport, gymnastics,lumbar lordosis, thoracic kyphosis, sacral slope, spine

1. Introduction

The shape of the spine is the basic factor determining the human body posture, which is an integrated system of bone-joint and fascio-ligament-muscle structures controlled by the central nervous system (Drzał-Grabiec et al., 2016; Wilczyński et al., 2020). The correct body posture is characterized by symmetry in the frontal and transverse planes. In the sagittal plane, the spine has four physiological curves: the cervical and lumbar lordosis, and the thoracic and sacral kyphosis (Czaprowski et al., 2017; Grabara et al., 2017; Wilczyński et al., 2020). These curvatures are formed at successive stages of posturogenesis and are constantly changing. They are ultimately determined by a combination of movement habits and conditional reflexes for defying gravity that are created on the basis of unconditional postural, positional, support, static-kinetic, and motion-based reflexes (Czaprowski et al., 2017; Drzał-Grabiec et al., 2016; Wilczyński et al., 2020).

There are two critical periods when the risk of posture defects leading to spinal deformation increases. The first critical period of posturogenesis occurs at the age of 6–7 and is associated with a change in the child's lifestyle resulting from entering school. The second critical period occurs at the age of 11–13 in girls and 13–14 in boys and is associated with the pubertal leap (rapid changes in height and weight). The prepuberal phase and puberty are periods of life when the posture undergoes many adjustments and adaptations due to changes occurring in body proportions and to demanding psychosocial factors (Drzał-Grabiec et al., 2016; Grabara et al., 2017; Wilczyński et al., 2020; Twarowska-Grybałow & Truszczyńska-Baszak, 2023).

The shape of the spinal curvature also plays an important role in athletic performance and the health of athletes. Improper distribution of mechanical loads significantly affects spinal structures and can affect the stability of an athlete's body, as well as result in spinal injuries (Keller et al., 2005; Sainz de Baranda et al., 2020). Hence, these curvatures should be neither flattened nor increased to maintain a physiological, harmonic, and balanced posture. In this sense, having sagittal spinal curvatures within the normal ranges could favor the athlete's trunk mobility as well as improve their stability due to the lower center of gravity and the better distribution of the load. Therefore, sports professionals should be aware of the loads and overloads associated with sports training and their impact on the young athlete's spine (Sainz de Baranda et al., 2020).

A review of the scientific literature does not indicate clearly whether competitive practice in sport has a positive or negative impact on the shape of the spine. Some studies indicate that practiced sports don't determine spinal shape in a relax standing position (Muyor et al., 2013; López-Miñarro et al., 2017), while others show that the sagittal curvature of the spine can gradually adapt to the sport played if training is conducted intensively over a long period of time (Wojtys et al., 2000; Stošić et al., 2011; Sanz-Mengibar et al., 2018). Some predominantly "feminine" sport such as gymnastics, are characterized by an extremely large range of motion (ROM), and due to the repetitive flexion, extension, and rotation, gymnasts are particularly at risk for spine overloads (Kums et al., 2007; Stošić et al., 2011). Gymnastics requires from athletes a high level of flexibility, conditioning and complete body recruitment that is matched infrequently by other sports (Makovitch & Eng, 2020). In addition, these are sports in which intensive training begins in early childhood, with specialization soon afterward. Therefore, athletes who practice gymnastics may have a higher risk of improper development of the spine (Kruse & Lemen, 2009; Grabara, 2010).

Acrobatic gymnastics is the sport in which athletes compete on a floor area, performing routines composed of individual and group skills synchronized to music, presenting perfect body control, flexibility and artistry. Just like other gymnastics, this sport is managed in the global dimension by the International Gymnastics Federation (FIG) and in the European dimension, by European Gymnastics (until 2020 called the European Union of Gymnastics – UEG).

Competitive acrobatic gymnastics consists of five group formations: women's pair and men's pair, mixed pair (male and female), women's group (three females) and men's group (four males). In both pairs and groups, two fundamental roles are differentiated: "bases", who mainly carry out supporting, pitching, and catching roles, and "tops", who perform elements of flexibility, balance, and combinations thereof or dynamic elements with turns and rotations in the aerial phase (Taboada-Iglesias et al., 2017). The nature of acrobatic gymnastics means that the smaller partner of a pair and the smallest of a group act as the "top" that balances on the partner(s) or is the main flier in a dynamic exercises, assisted by the "base(s)" (Purnell et al., 2010; FIG, 2016).

The majority of acrobatic skills performed by skeletally immature and actively growing gymnasts require extreme spine mobility. Serious stretching of gymnasts often begins as early as age 5–6, and the required range of motion and level of flexibility increase as training progresses (Purnell et al., 2010; Sands et al., 2016). Body positions in different balance and dynamic acrobatic skills are based on a varied amount of hyperflexion, hyperextension, or vertical loadings that require great stability of the spine (Kruse & Lemen, 2009). Some skills, such as moving to and from the back-bend position from feet to hands or holding the handstand with a deep back-bend position, require repetitive hyperflexion and hyperextension of the trunk (Sands et al. 2016). Other skills, such as mounting, holding, and dismounting pyramids or catching, pitching and throwing in dynamic skills, require stability of the spine. Such specific spinal loads require monitoring of the posture of acrobats to detect possible postural abnormalities or diseases. To perform at a high level and meet the high technical demands, acrobatic gymnasts need to undertake sport training at a very young age and train for many hours (Vernetta-Santana et al., 2022). At competitive levels, acrobatic gymnasts frequently train for 4 to 6 hours per day, 5 to 6 days per week.

Previous research related to the shape and mobility of the spine or posture in gymnasts has focused on female and male artistic gymnastics athletes (Grabara, 2010; Radaković et al., 2016; Sanz-Mengibar et al., 2018), rhythmic gymnastics (Tanchev et al., 2000; Kums et al., 2007) and trampoline gymnastics (Sainz de Baranda et al., 2009; Sainz de Baranda et al., 2010; Grapton et al., 2013). Studies on this topic have rarely been conducted in acrobatic gymnastics. The exception is the study by Anwajler et al. (2005), in which one of the objectives was to assess the impact of acrobatic training on the mobility of the spine. The lack of studies indicating whether practicing acrobatic gymnastics affects the shape of the sagittal curvature of the spine prompted us to take up this topic.

The aim of this descriptive study was to assess and compare the shape of the spine in the sagittal plane in acrobatic gymnasts of both sexes and their associations with somatic and demographic variables.

2. Methods

2.1. Participants and study design

The study was approved by the Bioethics Committee at Rzeszow University, Poland (No. 10/6/2017) and followed by the guidelines of the Declaration of Helsinki.

This study was conducted during the European Age Group Competitions and the European Acrobatic Championships held in Poland. Participants of this study competed in all age groups (Age Groups 11–16, Age Groups 12–18, Juniors, and Seniors) and event categories provided by the FIG and UEG regulations. After prior approval of the study by the European Union of Gymnastics Technical Committee and local organizing committee, 667 gymnasts were invited to participate in this study.

The inclusion criteria were as follows: participation in the European Age Group Competitions or the European Championships in acrobatic gymnastics; written consent of the official or coach of the national team; and voluntary consent of the gymnasts.

The gymnasts' participation in the study was approved by the officials or coaches of the 16 national teams. After giving informed and voluntary consent to participate, 178 gymnasts joined the study. The exclusion criteria were age over 19 years and less than 3 years of training experience. For the final analysis, the results of 159 athletes aged 12–19 (with a mean age of 15.7 ±2.0, training experience of 7.4 ±2.7, and age of starting training of 8.3 ±2.3 years) were used.

The measurement protocol consisted of surveys, measurements of somatic variables (weight, height, percentage of body fat, estimated percentage of muscle), and measurements of the inclination at four topographic points of the spine (S1 vertebra and the intervertebral spaces L5/S1, Th12/L1, and C7/Th1).

2.2. Demographic and somatic variables

The survey and all measurements were taken during pre-competition training sessions. The tool used in the study was a questionnaire containing personal data including gender, age, training experience, country, role in a pair or acrobatic group and the category of competition in which they compete.

The somatic variables that were measured were body height, weight, total body fat percentage (Fat%), and predicted muscle mass percentage (PMM%). Gymnasts were measured barefoot, in competition attire or in a T-shirt and shorts. The body height measurement was made in accordance with the FIG rules (FIG, 2016) and with an accuracy of 0.1 cm. Each subject was in a lying position (on a line marked on the table) with the feet resting against the vertical wall, as presented in Figure 1.

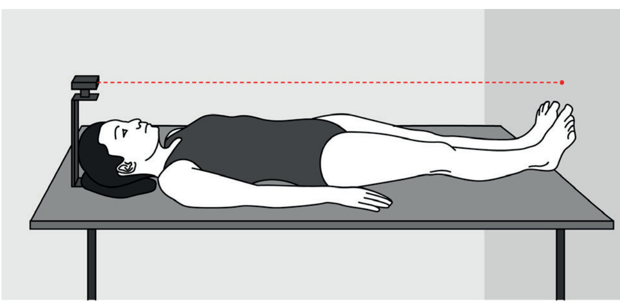

Figure 1. Body position during height measurement according to International Gymnastics Federation standards

Measurement was made with an electronic laser length measuring device (Bosch professional GLM 50 C; Robert Bosch GmbH, Germany) attached to a tripod so that the end of the device and the top of the gymnast's head were in the same vertical plane. The measurement result was a horizontal distance from the top of the gymnast's head to the wall, against which her/his feet were resting (FIG, 2016).

Weight was measured by a four-contact body composition analyzer, the Tanita MC-780MA S (Tanita Corporation, Tokyo, Japan), with an accuracy of 0.1 kg. Measurements made with the bioelectrical impedance method using GMON software (Medizin & Service, Chemnitz, Germany) provided, among others, values of total body fat percentage (Fat%) and predicted muscle mass percentage (PMM%).

2.3. Measurements and assessment of the shape of spinal curvatures

Among the available methods for measuring the size of the sagittal curvatures of the spine, the inclinometer method was chosen. The advantages of this method are its non-invasiveness, low costs and the short time needed to obtain objective results determining the size of sagittal curvatures as well as spine mobility. Numerous authors (Saur et al., 1996; Czaprowski et al., 2012; Muyor et al., 2013; Walicka-Cupryś et al., 2018) have shown high reliability and the usefulness of this tool in both clinical assessments and screening examinations.

The spinal curvatures were measured by the Baseline® Bubble Inclinometer (Fabrication Enterprices Inc., New York, USA) with an accuracy of 2 degrees. The measurements were carried out by a physiotherapist with 15 years of professional experience in body posture testing in accordance with the methodology proposed by Walicka-Cupryś & Drużbicki (2016). Each gymnast was asked to stand in a relaxed, habitual posture with bare feet, lower limbs hip-width apart, and upper limbs freely alongside the torso (Walicka-Cupryś & Drużbicki, 2016). The following oral instructions were given: “stand in a comfortable manner”; “do not bend your knees”; and “look straight”. The subjects were not instructed to straighten up (MacIntyre et al. 2014; Walicka et al. 2018). During the measurements, the inclinometer was placed at four topographic points of the spine (presented in Figure 2) found by palpation. The inclinometer was targeted vertically and the measurement observation was carried out perpendicular to the device.

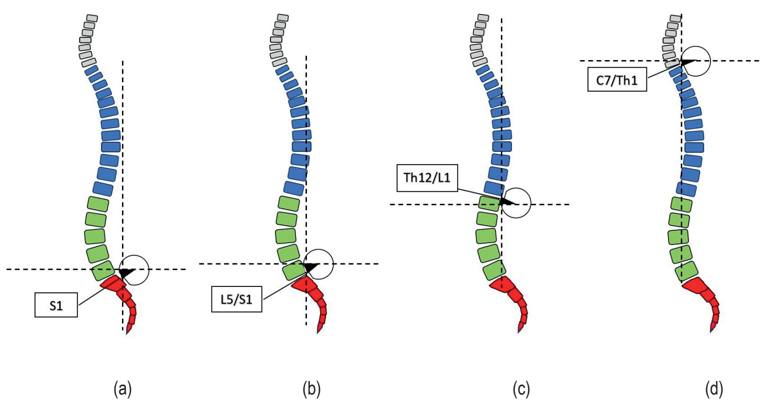

Figure 2. Inclinometer measurements at four topographic points of the spine: (a) midpoint of the S1 vertebra; (b) L5 and S1 intervertebral space; (c) Th12 and L1 intervertebral space; (d) C7 and Th1 intervertebral space

The four angles of inclination were determined:

- ALPHA 1 – the sacral slope angle (the center of the inclinometer was placed on the midpoint of the S1 vertebra in the line connecting the lower aspects of the posterior superior iliac spines);
- ALPHA 2 – the angle of inclination of the lumbosacral junction (the center of the inclinometer was placed on the L5/S1 intervertebral space in line connecting so-called Venus dimples);

- BETA – the angle of inclination of the thoracolumbar junction (the center of the inclinometer was placed on the Th12/L1 intervertebral space);
- GAMMA – the angle of inclination of the cervicothoracic junction (the top of the inclinometer foot was placed on the C7 vertebra).

The measurement was performed three times at each point, and then the extreme values were discarded. Middle measurement values were used to calculate the angle of the sacral slope (SS), the lumbar lordosis (LL), and the thoracic kyphosis (TK) by the following formulas:

$$SS = ALPHA\ 1 \qquad (1)$$

$$LL = ALPHA\ 2 + BETA \qquad (2)$$

$$TK = BETA + GAMMA \qquad (3)$$

To determine the sexual dimorphic differences in the range of the analyzed variables, the so-called dimorphism index (DI) based on Mollison's method (Ziółkowska et al., 2012), which was calculated according to the formula:

$$DI = (M_F - M_M) / sd_M \qquad (4)$$

Where: DI – Dimorphic index; M_F – Mean value of females; M_M – Mean value of males; sd_M – standard deviation of males.

For the assessment of spinal curvatures, the following ranges were used: 15°–30° for SS and 30°–40° for LL and TK (Saunders & Stultz, 1994). The values of angles less than the lower limit of the above ranges were interpreted as flattened curvature and those greater than the upper limit as increased curvature.

The differences in angular values of LL and TK were used for determining Wolański's types of body posture, modified by Zeyland-Malawka (Zeyland-Malawka, 1999). The following evaluation criteria were used:

- the equivalent type (E) - the difference between TK and LL in the range from 0 to 5° with subtypes: 0–2° = E I, 3–4° = E II, and 5° = E III.
- the lordotic type (L) in which LL was greater than TK by over 5° with subtypes: 6–10° = L I, 11-15° = L II, and 16–20° and above = L III.
- the kyphotic type (K) in which TK was greater than LL by over 5° with subtypes: 6–10° = K I, 11-15° = K II, and 16–20° and above = K III.

The body posture subtypes in which the difference between the values of LL and TK did not exceed 10 degrees were considered correct. The subtypes in which the difference was 11 or more degrees were classified as incorrect.

2.4. Statistical analysis

The normality of variable distributions was verified with the Shapiro-Wilk test and the homogeneity of variable variances with the Levene test. It was found that the assumptions of a normal distribution of the analyzed variables and homogeneity of variance in some variables were not met. In addition, the lack of equality among the subjects in the compared groups decided on the choice of the non-parametric Mann-Whitney U test. This test was used to assess differences in the values of quantitative variables between the groups. To determine the potential impact of age, training experience, and somatic variables on the angular value of the spinal curvatures, Pearson's r correlation coefficient or the Spearman correlation coefficient was applied. Differences among categorical variables were evaluated using the Pearson chi-square test.

All statistical analyses were performed using Statistica 13.0 (TIBCO Software Inc., Palo Alto, California, CA, USA) and Microsoft Office 365 (Redmont, Washington, DC, USA). The level of significance was set at α = 0.05.

3. Results

3.1. Analysis of age, training experience, and somatic variables

In the group of gymnasts included in the final analysis, 106 (67%) were females and 53 (33%) were males. Considering the role played in the acrobatic pairs or groups, the female group contained 48 (45%) "tops" and 58 (55%) "bases", and the male groups contained 14 (26%) "tops" and 39 (74%) "bases".

The female gymnasts represented 15 countries: Austria (n = 12), Azerbaijan (n = 1), Belarus (n = 10), Belgium (n = 6), Bulgaria (n = 3), Estonia (n = 4), Finland (n = 6), France (n = 13), Germany (n = 3), Italy (n = 9), Poland (n = 24), Portugal (n = 1), Spain (n = 4), Switzerland (n = 1), and Ukraine (n = 9). The male gymnasts represented 13 countries: Austria (n = 1), Azerbaijan (n = 2), Belarus (n = 8), Belgium (n = 6), Estonia (n = 1), France (n = 2), Germany (n = 2), Israel (n = 2), Italy (n = 1), Poland (n = 12), Spain (n = 1), Switzerland (n = 1), and Ukraine (n = 14).

The data collected in this study were used to compare age, training experience and somatic variables across groups based on sex. The results of these analyses are presented in Table 1.

Table 1. Baseline demographic and somatic characteristics of the sex groups

Variables	Group	n	M	sd	Min–Max	p	DI
Age (years)	Females	106	15.3	1.9	12.1–19.6	0.001*	–0.60
	Males	53	16.5	2.0	12.0–19.7		
Training experience (years)	Females	106	7.2	2.6	3.0–15.0	0.129	–0.25
	Males	53	7.9	2.8	3.0–14.0		
Height (cm)	Females	106	158.3	9.8	134.0–177.0	≤ 0.001*	–1.00
	Males	53	170.7	12.3	141.0–186.0		
Weight (kg)	Females	106	48.4	12.2	27.3–77.6	≤ 0.001*	–1.00
	Males	53	63.4	14.9	32.5–84.5		
Fat%	Females	106	19.25	3.27	11.20–28.10	≤ 0.001*	1.91
	Males	53	12.49	3.54	4.50–19.20		
PMM%	Females	106	76.63	3.09	68.30–84.31	≤ 0.001*	–1.91
	Males	53	83.07	3.37	76.81–90.83		

Note: *M* – mean; *sd* – standard deviation; *Min–Max* – minimum and maximum values; *DI* – dimorphism index; *p* – Mann–Whitney U test probability value. * – Differences were found to be statistically significant when $p \leq .05$.

Significant differences were noted between gender groups in terms of age and all somatic variables. The difference in training experience was not statistically significant. The mean values of age, height, weight and PMM% were higher in males than in females. Only the value of Fat% was higher in females than in males. The dimorphic index data suggest that the biggest variations between sexes were found in Fat% and PMM%.

3.2. Analysis of the spinal curvatures and their relations with demographic and somatic variables

Four angles of spinal inclination were determined: ALPHA 1, ALPHA 2, BETA and GAMMA. The values of these angles were substituted into formulas (1), (2), and (3) to calculate the sizes of SS, LL, and TK. The comparison of descriptive statistics for these variables is presented in Table 2.

Table 2. Descriptive statistics of the angles of spinal inclination and curvatures of the spine

Variables	Group	n	M	sd	Min–Max	p	DI
ALPHA 1 (°)	Females	106	19.9	5.1	8–30	0.019*	0.37
	Males	53	17.6	6.2	4–32		
ALPHA 2 (°)	Females	106	18.4	5.6	4–32	0.001*	0.52
	Males	53	15.4	5.8	6–30		
BETA (°)	Females	106	12.0	6.5	2–30	0.066	0.35
	Males	53	10.0	5.7	0–26		
GAMMA (°)	Females	106	20.4	5.9	8–34	≤ 0.001*	–0.56
	Males	53	24.0	6.4	4–40		
SS (°)	Females	106	19.9	5.1	8–30	0.019*	0.37
	Males	53	17.6	6.2	4–32		
LL (°)	Females	106	30.3	8.8	12–52	0.001*	0.73
	Males	53	25.4	6.7	14–46		
TK (°)	Females	106	32.4	10.4	10–60	0.301	–0.16
	Males	53	34.0	10.2	10–66		

Note: ALPHA 1 – angle of inclination of the sacrum on S1 vertebra; ALPHA 2 – angle of inclination of the lumbosacral junction; BETA – angle of inclination of the thoracolumbar junction; GAMMA – angle of inclination of the cervicothoracic junction; SS – the sacral slope angle; LL – the lumbar lordosis angle; TKA – the thoracic kyphosis angle; *M* – mean; *sd* – standard deviation; Min–Max – minimum and maximum values; *p* – Mann–Whitney U test probability value; *DI* – dimorphism index;. * – Differences were found to be statistically significant when $p \leq 0.05$.

This data presented in Table 2 indicate that statistically significant sex differences were noted in the angles of inclination at all measured points of the spine, with the exception of the BETA angle. A sex comparison of spinal curvatures showed that the angular values of SS and LL were higher in females than in males. The mean values of TK turned out to be slightly higher in the male group, but this difference was not statistically significant. The values of dimorphic indexes suggest that the angle of LL has the greatest difference between sexes.

The relations between the angular values of each spinal curvature and the values of age, training experience, and somatic variables were calculated. Correlation coefficients across sex groups are presented in Table 3.

Table 3. Correlations between angular values of spine curvatures and age, training experience, and somatic variables

Group	Spinal curvature	Age	Training experience	Height	**Weight**	**Fat%**	**PMM%**
Females	SS	**0.303***	**0.311***	0.047	0.127	–0.046	0.050
	LL	**0.233***	0.155	**0.240***	**0.303***	0.182	–0.178
	TK	0.084	–0.000	**0.224***	**0.275***	**0.360***	**–0.360***
Males	SS	0.117	**0.294***	**–0.290***	–0.114	0.180	–0.184
	LL	0.136	–0.002	–0.056	0.006	0.071	–0.068
	TK	0.130	0.010	0.265	**0.359***	0.188	–0.181

Note: * - Differences were found to be statistically significant when $p \leq .05$.

Only weak correlations between the size of spinal curvatures and the analyzed variables were noted. In females, the angle of SS was positively correlated with age and training experience, and the angle of LL with age, height, and weight. The angle of TK was positively correlated with height, weight, and Fat%, and negatively correlated with PMM%. The highest value of the correlation coefficient was noted in the relations between TK and Fat% as well as between TK and PMM%.

In males, the value of SS was positively correlated with training experience and negatively with height, and the angle of TK was positively correlated with weight only. The highest value of the correlation coefficient was noted in the relations between TK and weight.

3.3. The assessment of sagittal curvatures of the spine and body posture

To classify the analyzed curvatures of the spine as flattened, normal, or increased, the Saunders standards were used. The prevalence of normal and pathological (flattened or increased) curvatures of the spine is shown in Figure 3.

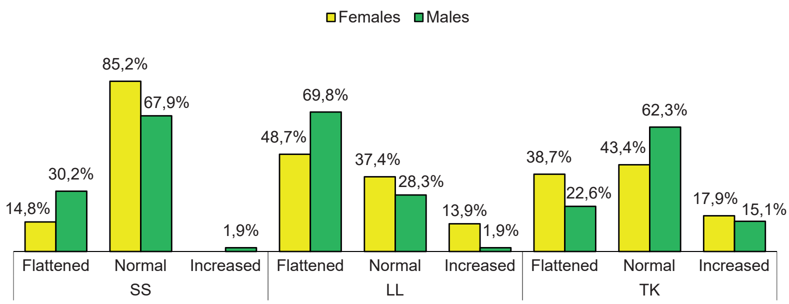

Figure 3. Percentage distributions of normal and pathological angular values of spinal curvatures in the sex groups
Note: SS – the sacral slope; LL – the lumbar lordosis; TK – the thoracic kyphosis.

The results presented above (Figure 4) indicate that in gymnasts of both sexes, the normal SS, flattened LL, and normal TK were noted as the most frequent. The prevalence of flattened SS and LL was more frequent in males, and flattened TK was more frequent in females. Increased SS was more frequent in males, and LL and TK in females.

Based on Pearson's chi-square test of independence, the prevalence of flattened, normal, or increased angles of SS (x^2 = 7.062; p = 0.008) as well as LL (x^2 = 9.520; p = 0.009) significantly differed between females and males. The prevalence of flattened, normal, or increased angles of TK did not differ between sexes (x^2 = 5.425; p = 0.066).

The difference between the angular values of LL and TK was used to classify the types and subtypes of body posture that characterized the acrobatic gymnasts. Comparison of the percentage distributions of body posture types and subtypes considering sex is presented in Figure 4.

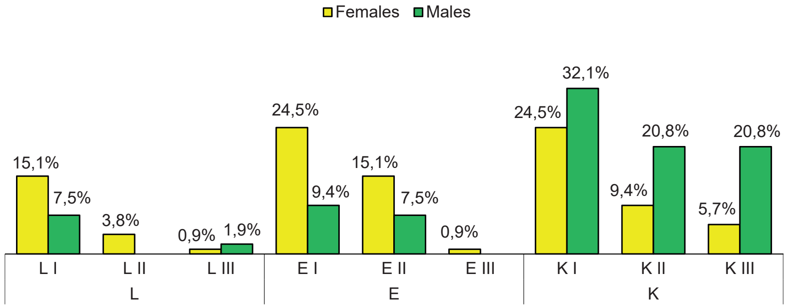

Figure 4. The percentage distributions of body posture types in the sex groups

Note: E is the equivalent type of posture with subtypes I, II, and III; K is the kyphotic type of posture with subtypes I, II, and III; and L is the lordotic type of posture with subtypes I, II, and III.

The analysis of body posture types showed that the lordotic type was found in 19.8% of females and 9.4% of males, the equivalent type in 40.5% of females and 16.9% of males, and the kyphotic type in 39.6% of females and 73.7% of males. Body posture subtypes E I, E II, E III, L I, and L II were more frequent in females, and K I, K II, K III, and L III in males.

According to Wolański's typology, modified by Zeyland-Malawka, it was assumed that subtypes E I, E II, E III, K I, and L I mean correct posture, and subtypes K II, K III, L II, and L III mean incorrect posture. The incorrect body posture was found in 43.4% of males (n = 23, including 4 "tops" and 19 "bases") and 19.8% of females (n = 21, including 7 "tops" and 14 "bases"). The prevalence of correct posture was more frequent in females (n = 85; 80.2%) than in males (n = 30; 56.6%). Based on Pearson's chi-square test of independence, the prevalence of correct or incorrect body posture in standing position was significantly differentiated by sex (x^2 = 9.820; p = 0.002).

4. Discussion

This descriptive study shows the characteristics of the shape of the spinal curvatures in sagittal planes in acrobatic gymnasts with a training experience of more than 3 years who competed at the international level. We also analyzed the differences in relations between spinal curvatures and age, training experience, and somatic variables in the compared groups.

Previous studies confirm that excessive physical exercise can have a negative effect on immature bone morphology and its mechanical integrity and may lead to the formation of postural disorders (Kruse & Lemmen, 2009; Grabara, 2010; Makovitch & Eng, 2020). Understanding the problem of how sport training affects the shape of the spine in young athletes is important because, over years of practicing sports, changes in their bodies become permanent and affect the next stages of ontogenesis. Any uncorrected deviations within the spine may lead to lower back pain, spine injuries, and overloading of the musculoskeletal system (Kruse & Lemen, 2009). This is because a reduction or increase in spinal curvatures may damage the different elements that make up the functional unit of the spine, such as vertebrae, intervertebral discs, ligaments, and muscles (Sainz de Baranda et al., 2010). These risks are especially relevant when sports training is undertaken in early childhood, such as in acrobatic gymnastics.

Previous studies have shown that one integral component of postural assessment is the measurement of pelvic position in the sagittal plane due to its significant association with pathologies in the spine and lower limbs (Schmidt et al., 2018). The physiological pelvic tilt in a relaxed standing position is approximately 14° (0–23°) on average (Preece et al., 2008) and is dependent on the structure of the pelvis and the action of muscular and ligament forces acting between the pelvis and the surrounding structures. It is closely related to the course of curvatures of the spine, which are responsible, among others, for the amortization of axial loads (Schmidt et al., 2018; Preece et al., 2008). In this study, the position of the pelvis was determined on the basis of the angle of the SS, which was significantly larger in females than in males. The prevalence of flattened, normal, or increased angles of SS differed between females and males. The normal SS was more frequent in females than in males, and the flattened SS was more frequent in males than in females. The increased SS was noted only in 1.9% of males. Similar correlations were found by Muyor et al. (2013) who noted that female tennis players aged 13-18 had a significantly larger SS than males (20.94° ±5.36° vs. 13.38° ±5.57°). The female acrobatic gymnasts also had a lower angle of SS compared to elite rhythmic gymnasts aged 13–17, whose SS was 23.1° ±7.6° (Kums et al. 2007).

In many studies, the basis for posture assessment is the size of the LL and TK. This is because the shape of the LL is associated with the appropriate distribution of shear and compression forces and the protection of the lumbosacral spine against overload. In turn, the shape of the TK is of key importance for the proper mobility of the chest and, consequently, for the efficiency of the circulatory and respiratory systems. It also plays an important role in the rotational stabilization of the spine (Czaprowski et al., 2012). Previous studies show that there are some gender patterns in the development of LL and TK in the growing spine. Gardner et al. (2018) showed that between males and females there is a difference in the size of LL (females have a greater LL versus males at the same age), but no difference in the size of TK. This study of 194 children aged 5–16 concluded that the size of LL and TK increases in a nonlinear fashion with age.

The results of our study show similar sex regularities. We noted that the LL angles were significantly higher in females than in males, but the TK angles were very close in both sexes. Such differences are partially consistent with those found by Sanz Mengibar et al. (2018) in the study conducted with an international group of 47 artistic gymnasts. They noted that LL was greater in females than males (30.5° ±11.1° versus 27.8° ±10.7°), but TK was greater in males than females (39.7° ±6.7° versus 31.9° ±8.7°). The difference between the sex groups in artistic gymnasts is close to that obtained in our study in LL, but much greater in TK. The study by Sainz de Baranda et al. (2009) of 69 trampoline gymnasts also shows that females tend to have a greater LL and males a greater TK. The female trampoline gymnasts were characterized by 40.3° ±10.0° of LL and 43.1° ±8.9° of TK and the male group by 32.1° ±7.7° of LL and 46.9° ±7.1° of TK. Also in this study, the angular values of LL and TK were greater in both men and women than those obtained in the gender groups of acrobatic gymnasts.

We also verified whether the size of spinal curvatures is related to the values of demographic or somatic variables. The previous studies (Wojtys et al., 2000; Stošić et al., 2011; Sanz-Mengibar et al., 2018) showed a positive correlation between LL and TK with the length of training experience, but in acrobatic gymnasts, such a relation was not found. There was only a weak positive correlation between the length of training experience and the size of the SS in both sexes. Age was positively correlated with SS and LL only in females. Body height was correlated positively with LL and TK size in females and negatively with the size of SS in males. Weight was positively correlated with the size of LL in females and with the size of TK in both sexes. It was found that only in females, the size of TK was correlated positively with Fat%, and negatively with PMM%. Similar relations have been reported by Mauricienė & Bačiulienė (2018), who found that in the group of non-athletes aged 11–13, height was correlated with the angle of TK in both sexes. Weight and fat mass were correlated with LL only in males and with TK in both sexes. Tizabi et al. (2012) noted that in the group of boys aged 12–18, weight was correlated with LL and TK, and height with TK only. Taspinar et al. (2017) found that in young adults aged 18–25, LL and TK angles had a positive relation with body fat ratio and a negative relation with muscle ratio.

The results presented in this study showed that sex significantly differentiates the prevalence of flattened, normal, or increased sizes of SS and LL. The prevalence of correct and incorrect sizes of TK is not sex-dependent. Normal SS, normal TK, and flattened LL (with the lowest value of 12° in females and 14° in males) were the most frequent in both sexes. The opposite findings were noted in a study of trampoline gymnasts, where normal LL and increased TK were the most frequent (Sainz de Baranda et al., 2009). The presented study may suggest that acrobatic gymnasts are not at risk of increasing their LL or TK. Such a problem was noted, for example, in a study by Wojtys et al. (2009), who observed that the athletes practicing gymnastics had the highest values of both LL (52.1° ±16.7°) and TK (42.4° ±13.4°) when compared with athletes practicing other sports. They observed that athletes aged 8–18 years who practiced soccer, gymnastics, hockey, swimming, and wrestling had higher values of LL and TK compared to those who practiced athletics or volleyball. These scientists also noted that age and sex did not appear to affect the size of spinal curvatures, but athletes participating in sports that required long-term maintenance of rigorous body positions were at higher risk of thoracic hyperkyphosis (Wojtys et al. 2000).

But it should be emphasized that so far, despite many attempts, it has not been possible to identify unambiguous normative ranges for the size of the sagittal curvatures of the spine and to clearly define the norm and pathology. In addition, the matter is complicated by the variety of measurement tools and methods used (Walicka-Cupryś et al., 2018). Different studies used different normative ranges for LL and TK in standing positions. In the radiographic and photogrammetric assessments, the range of 20−40 or 20−45 degrees for LL and TK is taken as norm (Wojtys et al., 2000; Sanz-Mengibar et al., 2018). When the assessment is based on the inclinometer measurements, the normative range 30−40 degrees is assumed (Saunders 1994).

The last comparisons of the sex groups concerned the typology of body posture, which was based on differences in the values of LL and TK. We noted that the equivalent and lordotic types of body posture were more frequent in females and the kyphotic type in males. Such results may indicate a more frequent occurrence of body posture errors in male gymnasts, associated with an increased angle of TK. However, in most of the subjects, the kyphotic type of body posture resulted from flattened LL, not increased TK. This study provides important information that indicates that long-term involvement in competitive acrobatic gymnastics increases the risk of flattening lordosis, especially in males.

The kyphotic posture was also the dominant type of body posture in athletes practicing sports other than gymnastics. Twarowskia-Grybałow & Truszczyńska-Baszak (2023) compared in their work the habitual posture of 247 athletes aged 9–14 and practicing various sports by using the Moiré method and a modified typology of Wolański. They noted that the kyphotic posture was less frequent in females than in males who practiced biathlon, taekwondo, football, and swimming. In the group of volleyball players, an equivalent posture was dominant. The tendency to flatten LL in acrobatic gymnasts may be related to the large amount of time spent in training on improving dance skills and mastering choreography in their routines. Previous studies have shown that in sports related to dancing abilities, the angular values of TK tend to be much lower than in other types of sports (Kums et al., 2007; Sainz de Baranda et al., 2020), and the size of LL and TK is smaller in people with longer dance experience (Castillo & Obregón, 2018).

The health consequences of such an abnormality have been demonstrated in previous studies. Kluszczyński et al. (2017) noted that reduction of LL can be a risk factor for lower back pain or degenerative spinal pathologies, particularly in men. This is because the lumbar section, as the base of the spine, takes over all the axial loads of the trunk and, at the same time, with high intersegmental mobility, it is exposed to non-physiological vectors of forces and overloads. Flattening of the LL may lead to degenerative and traumatic changes associated with the physiological processes of intervertebral disc degeneration and osteoporosis, as well as sudden damage to the fibrous ring with hernias. The lumbar region borders a very stiff pelvic girdle and sacroiliac joints, which causes shear force vectors to concentrate on the border between the movable and immobile parts, i.e., on the L5/S1 segment. This place is predisposed to the occurrence of damage to the intervertebral joints, spondylolisthesis, and even overload fractures of the intervertebral part of the vertebral arch (Kluszczyński et al., 2017; Gardner et al., 2018).

The results presented in this paper can provide evidence of the effectiveness of the FIG and the global gymnastics community's efforts to promote the proper development of young people who practice gymnastics. As in other sports of gymnastics, the FIG constantly modifies the official rules and the Code of Points applicable in acrobatic gymnastics (FIG, 2022a). In recent years, there has been a noticeable reduction in the emphasis on the extreme ROMs required of acrobats and their replacement with poses that emphasize the natural flexibility of the spine performed in partnering and choreographic combinations. The current demands of acrobatic gymnastics place less emphasis on extreme ROMs in poses, postures and skills while increasing the physical demands for strength and stability of the spine (Sands et al., 2016). The official FIG rules that govern competition in acrobatic gymnastics contain restrictions on exercises that could increase the risk of hyperlordosis and spinal injuries. These prohibitions take into account the different nature of spinal overload that occurs in "tops" and "bases". And so, the ban directed mainly at the "tops" applies to handstands with excessive arching of the back, in which the feet are lower than the point of hand support and Mexican handstands with gluteal muscles or legs resting on the head (FIG, 2022a). Restrictions aimed at the "bases" apply to the competition of age groups and juniors, i.e., gymnasts aged 11–19 years. The competition rules for these categories prohibit the following balance elements for groups: standing in a column of at least three gymnasts; standing on the shoulders with the "base" in split without hands on the floor; standing on the hips and chest of the "bases", which is in bridge with only two points of support; and support on the hips or buttocks with the "base" in excessive LL (FIG, 2022b).

However, while the direction of development of acrobatic gymnastics set by the FIG is correct, it should still take into account the risk of the negative impact of practicing this sport on the immature spine and body posture of young gymnasts. The fact that this problem in high-level acrobatic gymnasts is still present is confirmed by the results of the body posture assessment, which showed that incorrect body posture was present in 19.8% of females and 43.4% of males. Such findings show that coaches and medical staff working in competitive acrobatic gymnastics, should still remember that the spine of young athletes is in a very vulnerable stage of development. The planning of the training process should be approached with respect to the principles of growth and development.

The value of our study lies in the use of a new method of measuring body height, proposed by the FIG. It is also worth emphasizing that the presented study is the first to be devoted entirely to the sagittal shape of the spine in acrobatic gymnasts. This study was limited by the disproportion between the number of subjects in the sex-based groups. However, it reflects the typical proportion in the acrobatic gymnast population, where women are always the majority. Future research should be done with groups of comparable numbers of female and male gymnasts so that the results of comparisons become more reliable. Another limitation was that measurements of spinal curvatures were performed only in a relaxed standing position, which resulted from the limited time that gymnasts could devote to our study. The possibility of performing additional measurements, e.g., assessing the ROMs of the spine or performing three-dimensional assessment of the spine, would certainly provide new, interesting results. Therefore, we hope that further research on the shape of the spine and body posture in acrobatic gymnasts will include a larger range of measurements. It is certainly worth making an attempt to perform a long-term study that would show how the shape of the spine changes in acrobatic gymnasts over the years of training.

5. Conclusions

This study shows that in acrobatic gymnasts females had higher angular value of sacral slope and lumbar lordosis than males, and a similar value of thoracic kyphosis. Training experience positively correlates only with the size of the sacral slope in both sexes. Only in females weak-strength correlations between somatic variables and the size of spinal curvatures were found. Sex significantly differentiates the prevalence of incorrect size of sacral slope and lumbar lordosis. The equivalent and lordotic type of body posture was more frequent in females and kyphotic type in males. The incorrect body posture was noted in 19.8% of females and 43.4% of males.

It can be concluded that acrobatic gymnasts are not at risk of increasing the size of spinal curvatures in the sagittal plane but males show a tendency to flattened lumbar lordosis and kyphotic type of body posture.

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VIRTUAL-BASED AQUATIC PLYOMETRIC TRAINING: HOW IT IMPACTS LOWER EXTREMITY MUSCLE STRENGTH?

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Abstract The low achievement of long jump athletes and the limited virtual-based aquatic plyometric exercises to increase lower extremity muscle strength are the gaps in this study. This study aims to increase lower extremity muscle strength of long jump athletes through virtual-based plyometric aquatic training. This research adopted a mixed methods research. This study involved participants from long jump athletes at the University of Tanjung Pura in Indonesia (n = 20). Participants were divided into two groups, namely an experimental group (n = 10) and control group (n = 10). The quantitative instrument involved a leg dynamometer for measuring lower extremity muscle strength. While, the qualitative instrument used in-depth interview. Quantitative data analysis was carried out through IBM SPSS to calculate descriptive statistics and normality, while the paired sample t-test to test differences in lower extremity muscle strength values in the experimental and control groups. Qualitative analysis was carried out through recording, describing and coding stages, which categorized into three themes. Based on quantitative results, it showed that virtual-based plyometric aquatic training was proven significantly increase lower extremity muscle strength ($p \leq 0.05$), but there was no significant effect in the control group ($p \geq 0.05$). Qualitative results found out that most of the participants gave a positive opinion regarding virtual-based plyometric aquatics. Thus, this study confirms that virtual-based plyometric aquatic training can be used to increase lower extremity muscle strength.

Key words: virtual-based plyometric aquatic, lower extremity, muscle strength, mixed methods research

Introduction

Cases of COVID-19 were first reported in Wuhan city, China (González et al., 2021) and had negatively affected to several sectors, including business, tourism, sports activities in elementary, middle and high schools until universities at the national (Juliantine & Setiawan, 2022) and internationally level (Grix et al., 2021; Marshall et al., 2022). At the end of 2022, this condition was recovered and transmission rates decreased in several countries. However, the consequence that need to be resolved was the difficulties in carrying out training because the physical condition of athletes was decline significantly (Gani et al., 2022), one of which related to lower extremity muscle strength in long jump athletes.

Long jump is track and field athletic event that need an athlete to jump as far as possible. The long jump consists of 4 phases namely run, take off, flight and landing. According to Taher et al. (2021) to obtain a good long jump performance, it was depended on horizontal speed, take-off technique and landing on the sand. A study reports that long jump performance is highly correlated with lower extremity muscle strength (Zhou et al., 2020). Lower extremity muscle strength is an important component for athletes in several types of sports (de Villarreal, Requena & Newton, 2010) for example in soccer, large muscle strength can generate hard kicks (Zghal et al., 2019) and in sports swimming, large lower extremity muscle strength could accelerate the speed (Gani et al., 2022). In addition, lower muscle strength has an important role to produce hard kicks in karate (Ioannides et al., 2020). Meanwhile, in long jump, lower extremity muscle strength resulted in long take-offs (Ren et al., 2022). Therefore, proper training was needed to increase lower extremity muscle strength during the COVID-19 pandemic crisis through virtual-based plyometric aquatic training.

Plyometric training is a type of muscle strength training that has been widely used in team and individual sports. Plyometric training has movement characteristics involving eccentric phases, isometric phases and concentric phases (Ramírez et al., 2022). According to Arazi, Mohammadi & Asadi, (2014), plyometrics is an exercise that consists of jumping, bounding or hopping. In addition, this training can be conducted on land such as sand, grassy ground or water (Chomani et al., 2021; Biswas & Ghosh, 2022; Biswas & Ghosh, 2022b). Virtual-based plyometric aquatic training was carried out virtually in water. Previous studies had documented the benefits of plyometric training, for example the effectivity in increasing muscular power and speed (Ameer, 2020), leg mobility, joint stability and leg muscle strength (Chomani et al., 2021) and motor performance skills (Peitz, Behringer & Granacher, 2018). A recent study reported evidence that plyometric training for 6 weeks was effective in increasing several components such as power, muscle strength, and rate of force development (Ioannides et al., 2020).

There were various research on plyometric training that had been documented internationally (Behm et al., 2017; However, there was no previous research that reported about the effect of virtual-based plyometric aquatic training in increasing lower extremity muscle strength in long jump athletes. In addition, this study tries to present a novelty, which is to analyze the effect of virtual-based plyometric aquatic training through a mixed methods research. It is expected that this research could contribute to the development of virtual based plyometric training methods or involved technology application, so that trainers can use this training during the COVID-19 crisis. Therefore, the purpose of this study was to analyze the effect of virtual-based plyometric aquatic training to increase lower extremity muscle strength.

Methods

The researcher had asked for permission from the Tanjung Pura University Committee with number: 230/UTP/10/2022 before started this study. In addition, this research was conducted based on the guidelines of the World Medical Association Code of Ethics (Declaration of Helsinki for Humans). This study adapted the mixed methods research type, namely a combination of quantitative and qualitative research. An explanatory sequential design was conducted in two stages, the first stage was carrying out research and collecting quantitative data, then the second stage was conducting research and collecting qualitative data (Gani et al., 2022). The detail of mixed methods design is presented in Figure 1.

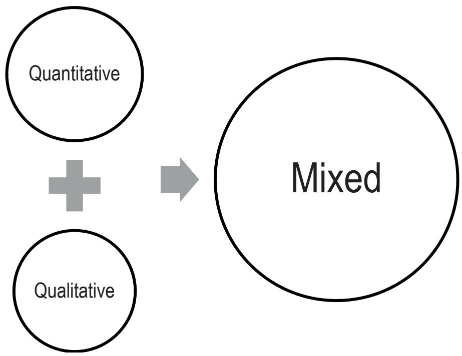

Figure 1. Mixed methods research design

Participants

All participants were long jump athletes from Tanjungpura University in Indonesia (n = 20). All participants agreed to be involved and had signed thee written informed consent before the experiment started. The participants were selected through random sampling by sending emails to 30 athletes and only 20 athletes responded and willing to be involved. Participants were randomly divided into two groups, the experimental group that received the aquatic virtual plyometric training program consisted of 5 males and 5 females (age: 21.05 ±2.3 year, weight: 55.68 ±6.4 kg, height: 1.62 ±0.5 cm) and the control group consisted of 5 males and 5 females (age: 20.47 ±0.9 year, weight: 50.65 ±7.8 kg, height: 1.60 ±0.4 cm). The inclusion criteria for participants included: the profile of participants in participating plyometric training, physically active, healthy and must be free of musculoskeletal injuries in the past year. Before the research started, all participants were given information about the rules of this research. Then, they were required to create and sign a statement about their willingness to participate this research. Participants involved in this study were given a reward of 20 USD to appreciate their involvement.

Instruments

Quantitative Instruments

A quantitative instrument was used to measure lower extremity muscle strength using a leg dynamometer (Cha & Lee, 2022). This test was carried out through squats, with 90° knee flexion and the measurement were repeated 2 times with an interval of 2 minutes. The highest leg muscle strength score was taken to analyze.

Qualitative Instruments

A qualitative instrument was used to investigate the effect of a virtual-based plyometric aquatic training program through in-depth interviews for 30 minutes per individual. The interview was intended for athletes in the experimental group only, to obtain their opinion about the effects of using virtual-based plyometric training. This instrument has proven to be effective based on the previous studies results (Gani et al., 2022; Juliantine & Setiawan, 2022).

Research procedure

This research was conducted from October to November 2022 at Tanjung Pura University in Indonesia. The quantitative research was conducted in thirteen meetings, at the first meeting (1 October, 2022), all participants carried out an initial test (leg dynamometer test). Then, participants carried out a virtual-based plyometric training program from the second meeting (4 October 2022) until the 12th meeting (29 October 2022). After that, in the last meeting (8 November 2022) all participants carried out the final test, which was in the form of a leg dynamometer test.

Whereas the qualitative research was carried out on 10 and 12 November 2022, all participants in the experimental group were interviewed about their experiences when participating in virtual-based plyometric aquatic training. In one day the researchere interviewed 5 participants.

Virtual-based plyometric aquatic training Program

The participants carried out 12 virtual-based plyometric aquatic training sessions in 3 times a week, namely on Tuesday, Thursday and Saturday. Before the training started, the participants watched aquatic plyometric exercises for 10 minutes on virtual reality (Figure 2), then carried out a dynamic warm-up for 5 minutes, such as jogging and stretching the calves, hamstrings, quadriceps. Each set of plyometric aquatic exercises took 10–15 minutes to complete and 2 minutes break before continued to the next set. Finally, cool-down activities was conducted for 5 minutes. The virtual-based plyometric training program is presented in Table 1.

Figure 2. Virtual-based plyometric training
Source: Author's own.

Table 1. Virtual-based plyometric training program

Week	Repetition	Sets	Activities
1	2	3	Tuck Jump
2	3	3	Squat Jumps
3	4	3	Lunges
4	3	3	Jooging
5	5	3	Kick front

Control group program

In contrast, the control group performed regular daily exercises, including stair climbing, side lunges, and split squats. The control group participants were subjected to monitoring procedures to ensure their presence did not influence the study outcomes.

Statistic analysis

Quantitative analysis

All data from the quantitative research results were analyzed via IBM SPSS 25.0 (Armonk, NY: IBM Corp). The analysis was conducted in following steps. First, determining the statistical descriptive values (mean and standard deviation), data normality (Shapiro-Wilk). Second, the Paired sample t-test was used to test differences in lower extremity muscle strength values in the pretest and posttest in the experimental and control groups (Juliantine & Setiawan, 2022). The significance level was 0.05.

Qualitative analysis

Data from in-depth interviews were analyzed through qualitative thematics, through 4 stages, including: recorded, described, coded and categorized into three themes (Gani et al., 2022) details of each theme are as follows:

Theme 1: Advantages of virtual-based plyometric aquatic training.

Theme 2: Difficulties of virtual based plyometric aquatic training.

Theme 3: Impact of virtual based plyometric aquatic training.

Results

Quantitative results

The normality test results in this study were normally distributed (Table 2). While the descriptive statistical result is presented in Table 3. Table 4 shows that the experimental group that received virtual-based plyometric aquatic training had a significant effect on increasing lower extremity muscle strength in both men and women ($p \leq 0.05$), but there was no significant effect in the control group ($p \geq 0.05$).

Table 2. Normality test

	Gender	Shapiro-Wilk			
		Statistic	df	p	Keterangan
Experimental Group					
Pre-test	Boy	0.970	5	0.876	Normal
	Girl	0.932	5	0.607	Normal
Post-test	Boy	0.914	5	0.490	Normal
	Girl	0.854	5	0.206	Normal
Control Group					
Pre-test	Boy	0.980	5	0.937	Normal
	Girl	0.928	5	0.585	Normal
Post-test	Boy	0.935	5	0.627	Normal
	Girl	0.630	5	0.201	Normal

Table 3. Descriptive statistics

Dependent Variable	Experimental Group				Control Group			
	Boys (n = 5)		Girls (n = 5)		Boys (n = 5)		Girls (n = 5)	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post
	M(SD)	M(SD)	M(SD)	M(SD)	M(SD)	M(SD)	M(SD)	M(SD)
Extremity muscle strength	32.00(3.74)	45.80(1.64)	30.40(2.19)	39.90(5.26)	27.00(4.30)	31.00(3.93)	27.00(5.82)	31.80(4.60)

Table 4. Differences in pretest-posttest scores on limb muscle strength in experimental and control group

Dependent Variable	Experimental Group (n = 10)						Control Group (n = 10)					
	Pre-Post Boys M(SD)	t	p	Pre-Post Girls M(SD)	t	p	Pre-Post Boys M(SD)	t	p	Pre-Post Girls M(SD)	t	p
Extremity muscle strength	13.80(3.42)	9.021	0.001	9.40(4.82)	4.354	0.012	4.00(6.96)	1.284	0.268	4.80(9.91)	1.083	0.340

Qualitative results

The results of qualitative research through in-depth interviews are as following:

Theme 1: Experience in participating in a virtual-based plyometric training program

The first theme of this study was the experience of athletes in participating in virtual-based plyometric aquatic training. Based on these perceptions, the researcher can obtain important result. In this case the participants argued that:

"I am very lucky to be able to take part in this program, because it was very fun and we got a lot of experiences" (interviewed with participants 1, 3, 5).

"I enjoy this virtual plyometric aquatic training, because we can carry out the exercises by watching animation on virtual reality before training on water" (interviewed with participants 2, 4, 7).

This was a valuable experience for us, because we can do plyometric aquatic exercises which were carried out in a swimming pool by watching virtual reality. The plyometric training from virtual reality energized us to be excited and enthusiastic (interviewed with participants 6, 4, 9). We gained a lot of movement experience from this program, for example kick front and tuck jump exercises in water absolutely more fun than exercise on land (interviewed with participants 8, 10).

Theme 2: Advantages of virtual-based plyometric training

The advantage was the first aspect that must be clearly stated, because it has an important role to show factors that contribute to the benefit of virtual-based plyometric aquatic training. Participants argued that:

"This training has an advantage in increasing lower extremity muscle strength, because it was carried out in water. The load in water was much greater, so our muscle strength increased gradually" (interviewed with participants 3, 6, 7, 10).

"In my opinion, performed training in the water by watching plyometric movements on virtual reality has significant advantages, for example encourage our enthusiast, passion and motivation, so that it can obtained the maximum training results " (interviewed with participants 1, 2, 4).

"I can't imagine that I could perform a further leap, that was because of the impact I had on joining this program" (interviewed with participant 9).

"It can be said that this program has several advantages, such as (i) we learned plyometric exercises on virtual reality, (ii) then we did the plyometric exercises in the water and it was proven that we had much better jumping abilities than previous" (interviewed with participant 3, 5, 6, 7).

Watching plyometric movements on virtual reality, help us to understand some movements such as tuck jumps, squat jumps, lunges, jogs and front kicks that was performed in the water, so that we can perform the exercises optimally (interviewed with participant 8, 10).

Theme 3: Difficulty of virtual based plyometric training

The last theme in this study related to difficulties or obstacles in carrying out virtual-based plyometric training. In this case the participants revealed their opinion that:

> "This training cannot be done if you don't have a virtual reality, because plyometric movements are presented via virtual reality" (interviewed with participants 5, 7, 9, 10).

This virtual-based plyometric training will be less effective if it is used in large numbers of athletes, for example more than 50 people, because it is difficult to control and it will be difficult for athletes to watch plyometric movements presented on virtual reality, because it's limited (interviewed with participants 1, 2, 3, 4, 6, 8).

Discussion

The purpose of this study was to investigate the effect of virtual-based aquatic plyometric training to increase lower extremity muscle strength.

The quantitative findings in this study indicated that the virtual-based plyometric aquatic training program has positively proven to increase lower extremity muscle strength, because plyometric training in water have a bigger load. Basically, plyometrics performed in water could change the elastic ability of the muscles much better, because the lower extremity muscles could contract with more force due to water resistance and body weight. According to Biswas & Ghosh (2022b)aqua plyometric training and weighted vest aqua-plyometric training, when carrying out plyometric aquatic training, the muscle workload increased during the concentric phase so that it could increase muscle strength. This finding was in line with previous studies which reported that plyometric training can significantly increase leg muscle strength in volleyball athletes (Gjinovci et al., 2017; Dell'Antonio et. al, 2022), futsal (Zekri, Tajali & Ghotbi, 2019), football (Chomani et al., 2021), judo (Kurniawan et al., 2021). In addition, plyometric aquatic training can also increase muscle strength in basketball athletes (Asadi & Arazi, 2012). However, the opposite finding occurred in the control group, which showed no significant increase in lower extremity muscle strength.

Qualitative findings in this study showed that most of participants agreed that virtual-based plyometric aquatic training had a positive effect on the development of lower extremity muscle strength, for example tuck jumps, squat jumps, lunges, jogging and kick fronts were more fun and challenging when they carried out it in the water, because the density of water is greater. Thus, this research proved that virtual-based plyometric aquatic training was effective in increasing lower extremity muscle strength in long jump athletes (Taher et al., 2021)specific-motor and functional abilities. The aim of this study was to examine the response effect of vertical and horizontal plyometric training on explosive capacity and kinetic variables in long jump athletes. Material: The participants of this study were twenty professional jumpers.

Finally, the uniqueness and novelty found in this study is that virtual-based aquatic plyometric exercises have been shown to have a positive effect on increasing the lower extremity muscle strength of long jump athletes based on both quantitative and qualitative research.

Conclusions

Based on these results, it can be concluded that virtual-based plyometric aquatic training was effectively used to increase lower extremity muscle strength in long jump athletes. This research contributes to existing knowledge about the importance of using virtual-based plyometric aquatic training and athletes can continuously use this training to maintain and improve lower extremity muscle strength. However, several limitations need to be acknowledged, in terms of using limited number of participants and only involved long jump athletes, so it had not been proved whether this training was effective when implemented in other sports. Future research needs to be conducted by involving more participants and implementing virtual-based plyometric aquatic training in swimming, pencak silat or dominant sports that often use lower extremity muscle strength.

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