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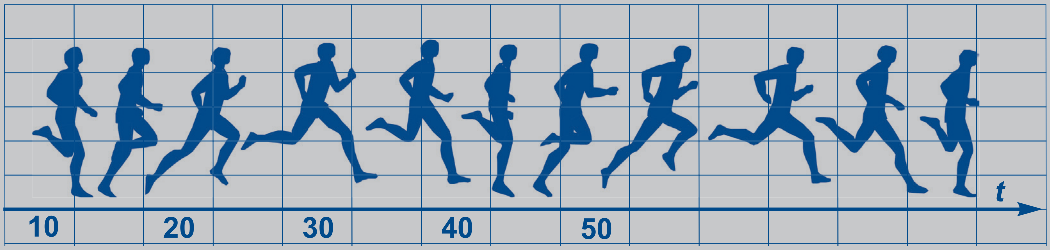

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ORIGINAL RESEARCH

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ASSESSMENT OF PHYSICAL CAPACITY LEVEL IN RECREATIONAL ATHLETES

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Authors' contribution:

A. Study design/planning
B. Data collection/entry
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Abstract:

Introduction: In the majority of the available source materials, research on the level of physical capacity of athletes concerns members of sports clubs and national teams, in a word, professional athletes. Does this mean that such research should not be conducted on recreational athletes? Of course not. The main aim of this article was to assess physical capacity (based on VO2max) in recreationally active people from the Podkarpackie region of Poland. The authors intended to determine whether practicing recreational sports without adequate technical facilities and staff influenced the course of their training and achievements.

Material and Methods: The study involved 413 participants (body height 174.5 ± 9.5 cm; body weight 73.4 ± 20.3 kg) aged 18-60 years. Each participant followed the same treadmill test protocol and completed a questionnaire survey related to the number of injuries sustained. To determine the level of fitness, AT (VT1), RCP (VT2), VO2peak, and HRmax were determined during the study.

Results: Based on the Powers and Howley classification, almost 50% of the participants were classified in the subgroup with the highest possible peak oxygen uptake (41.4%). More than one in four participants had a peak oxygen uptake at a very good level (28.3%), nearly one in five at good (18.9%), while more than one in ten reached an average (9.4%), low (1.5%), or very low (0.5%) levels. Individuals with multiple injuries achieved significantly higher scores on average in contrast to those without injuries ($p=0.004$).

Conclusions: Physically active people have a high above-normal level of physical capacity, despite the recreational form of their sport. The study showed the importance of research on physically active people not only in the context of fitness. This group includes outstanding individuals achieving high performance similar to professional athletes.

Introduction

In the majority of the available source materials, research on the level of capacity in athletes concerns members of sports clubs and national teams, in a word, professional athletes.

For many decades now, specialists have emphasized the importance of physical activity for the proper functioning of the cardiovascular system, regardless of age. [1]. Regular aerobic exercise not only improves our wellbeing but mainly reduces the risk of coronary heart disease or myocardial infarction. For this reason, policies to promote physical activity in populations are being implemented in many countries [2-16].

In one early study by JN Morris and RS Paffenberger, physical activity at work was shown to reduce the incidence of cardiovascular disease and lower mortality rates. A study of Harvard undergraduates confirmed that those who expended 1,000 to 2,000 kcal per week in vigorous activities had the lowest risk. Subsequent studies, in almost all age groups, confirmed these reports, especially with regard to the risk of overweight and obesity. For better fat metabolism, exercise should be performed at an intensity of 45 to 65% VO2max. However, this requires regular training and maintaining adequate exercise intensity. All of this is confirmed, for example, in the WHO guidelines [17]. However, there are risks associated with sports [18-20].

Cardiovascular abnormalities can be a threat to the health and life of sports people [21], not only professional athletes but also those practicing recreational sports. In a study by Italian researchers among more than 30,000 people seeking to qualify for competitive sport, a resting ECG showed abnormalities in 1,812 (6%) participants, wherein the most common abnormalities (>80%) involved minor ECG changes. An abnormal exercise ECG pattern was observed in 1,459 (4.9%) participants, and 1,227 participants showed cardiac abnormalities despite a normal resting ECG. Almost 200 people (0.6%) were not qualified for competitive sport. It was also shown that people over 30 years of age had an increased risk of disqualification due to cardiac changes during exercise tests [22].

Other studies have indicated an important diagnostic aspect of heart rate in association with cardiopulmonary indices in heart failure [23-26].

Combined with coexisting heart disease, excessive physical exercise can lead to adverse cardiovascular reactions. Sudden deaths during or immediately after physical activity are also reported, especially in people with a history of low physical activity. As many as 80% of these deaths may result from latent coronary artery disease (CAD), and, in at least 50% of cases, sudden deaths occur during exercise in asymptomatic and apparently healthy individuals [27].

This was also confirmed by a study of 79 Brazilian Paralympic athletes, who were diagnosed with a high risk of coronary heart disease: In this group, 41% had one risk factor, 4% had two, and 6% had three or more, with hypertension being the most common complaint [28], while almost 50% of male marathon runners over 45 years of age were at risk of arteriosclerosis [29].

A French study reported sports-related sudden deaths in 4.6 cases/million population/year, with 6% involving young professional athletes. More than 90% of cases were athletes of recreational sports [30].

According to the SCORE system, the assessment of the cardiovascular risk of coronary death over 10 years takes into account variables such as age, gender, blood pressure, blood cholesterol levels, and tobacco smoking [31-33].

The risk of sudden coronary death (SCD) in athletes may increase with age, especially in men. In runners or marathoners over 35 years of age, the estimated SCD rate ranges from 1:15 000 to 1:50 000 [34].

Cardiopulmonary exercise testing (CPET) also has an important role in objectively assessing functional capacity, thus evaluating training effects [35], and estimating the prognosis of patients with heart failure [36]. Mistakes made in developing a training plan, such as excessive load and insufficient recovery, can lead to overload or even overtraining syndrome (OTS) [37], manifested, for example, by a decrease in capacity or the development of a disease entity [38].

Scientific studies have shown that as many as 64% of elite athletes have experienced OTS at least once [39].

A high level of VO2max, is not only dependent on the cardiac output and the blood oxygen-carrying capacity (i.e. Hbmass) but also on mitochondrial density or muscle capillarisation. Proper endurance training can influence these parameters and hence capacity [40].

The main variables affecting VO2max include age, sex, body weight, genetic factors, red blood cell volume, and physical training [41], although it decreases by 3-6% every 10 years [42], and other cross-sectional studies have shown its linear decrease with age [43].

The concept that the rate of decline in V02max could be influenced was announced 40 years ago. In trained men, the rate of decline of VO2max with age was up to 50 percent lower compared to those with a sedentary lifestyle.

In a subsequent study by Wilson and Tanaka, it was shown that VO2 max was intrinsically and inversely related to age in each of the three populations ($r = -0.80$ to -0.88, all $P < 0.001$). The proportion in the rate of decrease in VO2max and aging of the participants was similar in the three study groups. In these groups, another proportion was noted in the percentage decrease in relation to the average level reached ~25 years [44]

Is this definitely the case? There is controversy in the correlation between age and BMI in terms of respiratory capacity. In Sun and Hansen's study, there were no significant differences in the ventilation efficiency of healthy participants in relation to sex or age. However, there was a correlation between these variables in terms of respiratory capacity. A study by Martinez, Rodrigues de Matos et al. found no differences between age groups in VE/VCO2 slope [45].

The main aim of the research was to find out whether it is possible for people who participate in recreational physical activity, without professional preparation, and without appropriate sports and coaching facilities, to achieve the best results in a progressive fitness test.

The following research hypotheses were proposed in the study:

1. People who practice recreational sports have an above-average VO_2max level.
2. Men of working age achieve the best results.

Material and Methods

Participants

The study included 413 participants (n=413, 106 women and 307 men) aged 18-60 years who were involved in recreational sports. Participants were recruited based on inclusion criteria and signed informed consent to participate in the study. The study included participants who had had injuries and those without previous damage to the musculoskeletal system for comparison. The study group consisted of physically active people (without contraindications for their respective sports) living in south-eastern Poland. They were unrelated Caucasians of both sexes, aged 18-60 years. Only people with good health status were qualified for the study. The participants had to complete the Qualifying Questionnaire, which included questions about their health. The research was conducted from February to July 2022. The participants were asked to report to the study in a 4-hour postprandial state and to refrain from strenuous exercise for at least 24 hours before the study. They were also asked to refrain from consuming caffeinated beverages for at least 4 hours before the study.

Methods

CPET is a comprehensive data analysis that translates into a complete assessment of the cardiovascular, respiratory, muscular, and metabolic systems during exercise, which is considered the gold standard for cardiopulmonary functional assessment. Normal peak VO2 is considered to be above 85% of the predicted value. It is considered a marker, reflecting the severity of disease in patients with heart failure (HF), pulmonary hypertension, hypertrophic cardiomyopathy (HCM), chronic obstructive pulmonary disease (COPD), restrictive lung disease, and a measure of physical fitness [46]. The CPET test on a h/p/cosmos 150/50 mechanical treadmill (Germany) was employed to evaluate the level of aerobic capacity. These treadmills are a well-known and respected brand on the market. A CORTEX Medical METALYZER 3B CPET device (Germany) was also used in the study. Some studies question the reliability of progressive tests to assess VO2max [47-49], as exhaustion may occur before VO2 reaches its maximum. The indirect methods, e.g. using the ACSM equation, seem to be even less reliable [50]. Based on an extensive review of the literature, it was shown that the highest possible VO2 was achieved during ascending CPET [51]

During CPET testing, it is possible to analyze exercise-related variables such as HR, blood pressure, respiratory trace, and RER. VO2 peak, which is also evaluated during CPET tests, is among the most objective measures of performance [52].

Peak heart rate is used as a tool to determine maximal aerobic capacity during exercise testing or monitoring exercise intensity [53]. As an indicator of exercise intensity, HRmax is also used in non-athletic individuals [54].

The study used a breath-by-breath test protocol using the Cortex Medical - Metalyzer 3B CPET device. After a 6-minute warm-up jog, the participants started running at a speed of 10 km/h. The first 3 minutes of the warm-up were at 6 km/h, and the next 3 minutes were at 8 km/h. The study participants had never participated in tests on a mechanical treadmill. This long warm-up, at relatively low speeds, was necessary for the participants to get used to and familiarize themselves with the treadmill. The speed was increased by 2 km/h every 2 minutes until exhaustion. The protocol was designed to induce exhaustion in the participants after 15 to 18 min. Heart rate was continuously recorded using a Polar heart rate monitoring system (Polar H10, H9).

Physical capacity was determined based on parameters such as minute ventilation (V E), respiratory exchange ratio (V˙CO2/V˙O2), O2 pulse (V˙O2/HR) and ventilation equivalents for O2 and CO2 (V˙E/V˙O2, V˙E/V˙CO2), and end-expiratory gas concentrations (PETO2 and PETCO2) to find concordance. The predicted peak V˙O2 was determined by the regression equations proposed by Wasserman et al. using the V-slope method. Peak V O2 was defined as the highest V O2 achieved during exercise [55].

Statistical analysis methods

Statistical analysis of the collected material was performed in the Statistica 13.3 package. The database and the graphical elaboration of the results were made in Microsoft Excel and Microsoft Word.

The following descriptive statistics were calculated: number, mean value, median, minimum and maximum value, upper and lower quartiles, and standard deviation. To assess differences in the average level of a numerical feature in three subgroups, the test for independent samples of one-way analysis of variance ANOVA was used, or due to the failure to meet the assumptions of the parametric test (lack of compliance of the distribution of the variable with the normal distribution verified by the Shapiro-Wilk test), the non-parametric Kruskal Wallis test was used. Statistically significant results were additionally supported by those of Tukey's post-hoc tests.

The level of statistical significance was set at $p<0.05$.

Results

Based on the Powers and Howley classification, less than half of the observation group was classified into the subgroup with the highest possible peak oxygen uptake (41.4%). More than one in four participants had a peak oxygen uptake at a very good level (28.3%), nearly one in five - at a good level (18.9%), and more than one in ten reached the average (9.4%), low (1.5%) or very low (0.5%) levels (Table 1).

Table 1. Peak oxygen uptake (VO2peak) categories based on Powers and Howley classification

VO2peak	N	N Cumulative	Percentage (%)	Cumulative Percentage
Very low	2	2	0.48	0.5
Low	6	8	1.45	1.9
Average	39	47	9.44	11.4
Good	78	125	18.89	30.3
Very good	117	242	28.33	58.6
Excellent	171	413	41.40	100

Considering the percentage values of the peak oxygen uptake norm, it was noted that the vast majority of participants reached a level above 100% of the norm (80.2%). More than one in ten participants was classified in the 91-100% range (11.9%), while nearly one in ten achieved 81-90% of the norm (6.5%), 71-80% of the norm (1.2%), or 60-70% of the norm (0.2%) (Table 2).

Table 2. Peak oxygen uptake categories based on the percentage of the norm

VO2peak (%norm)	N	N Cumulative	Percentage (%)	Cumulative Percentage
60-70%	1	1	0.24	0.2
71-80%	5	6	1.21	1.5
81-90%	27	33	6.54	8.0
91-100%	49	82	11.86	19.9
More than 100%	331	413	80.15	100.00

The distribution of the resting values in the participants was examined using descriptive statistics. The minimum value was recorded at the level of 4.0, and the maximum - at the level of 10.0, with the average value being close to 6.5 (= 6.44). It is worth noting that at least 25% of the participants achieved a value of 7.0 or higher (Q3=7.0) (Table 3).

Table 3. Resting value

Variable	N	$\bar{x}$	Me	Min.	Max.	Q1	Q3	*SD*
Rest	413	6.44	6.00	4.00	10.00	6.00	7.00	1.03

N – number of observations; – mean; Me – median; Min. – minimum value; Max. – maximum value; Q1 – lower quartile; Q3 – upper quartile, SD – standard deviation

The average values of the anaerobic threshold AT were recorded in the study group at the level of over 31ml/min/kg (= 31.59), which corresponded to the percentage of the norm at the average level of over 80% (= 80.73). The average value of the anaerobic threshold in the group was at the level of nearly 70 ml/min/kg (= 69.62). Detailed data are presented in Table 4.

Table 4. Descriptive statistics: anaerobic threshold value AT (VT1), percentage of normal and maximum value

Variable	N	$\bar{x}$	Me	Min.	Max.	Q1	Q3	*SD*
AT (VT1) value	413	31.59	31.00	15.00	49.00	28.00	35.00	5.59
% of AT (VT1) norm	413	80.73	80.00	35.00	125.00	69.00	93.00	16.15
Max AT (VT1)	413	69.62	70.00	40.00	97.00	62.00	76.00	9.48

N – number of observations; – mean; Me – median; Min. – minimum value; Max. – maximum value; Q1 – lower quartile; Q3 – upper quartile, SD – standard deviation

The respiratory compensation point (RCP) was also examined during the study, which averaged over 41 ml/min/kg (= 41.45). Based on the percentage of the norm, the mean value was over 105% (= 105.41), and the maximum value of the respiratory compensation point was close to 91 ml/min/kg (= 90.80) (Table 5).

Table 5. Descriptive statistics - respiratory compensation point RCP (VT2), percentage of normal and maximum values

Variable	N	$\bar{x}$	Me	Min.	Max.	Q1	Q3	*SD*
RCP (VT2) vaule	413	41.45	42.00	22.00	59.00	37.00	46.00	6.66
% of RCP (VT2) norm	413	105.41	105.00	51.00	164.00	92.00	117.00	17.77
Max RCP (VT2)	413	90.80	91.00	67.00	102.00	88.00	95.00	5.97

N – number of observations; – mean; Me – median; Min. – minimum value; Max. – maximum value; Q1 – lower quartile; Q3 – upper quartile, SD – standard deviation

Peak oxygen uptake values were then analyzed. The mean value in the study group was recorded at nearly 46 ml/min/kg (= 45.72), which was 116% of the norm for the tested parameter (= 116.0) (Table 6).

Table 6. Peak oxygen uptake (VO2peak), percentage of normal and maximum values

Variable	N	$\bar{x}$	Me	Min.	Max.	Q1	Q3	*SD*
VO2peak value	413	45.72	46.00	26.00	64.00	41.00	50.00	7.13
% of VO2peak norm	413	116.00	116.00	67.00	167.00	103.00	128.00	17.49
Max VO2peak	413	40.30	40.00	23.00	186.00	35.00	45.00	9.86

N – number of observations; – mean; Me – median; Min. – minimum value; Max. – maximum value; Q1 – lower quartile; Q3 – upper quartile, SD – standard deviation

The mean maximum heart rate was over 186 bpm ($\bar{x}$= 186,14) with at least 25% of the patients reaching values of 194 bpm or more (Q3=194.0) (Table 7).

Table 7. Maximum heart rate (HRmax) in people in the study group.

Variables	N	$\bar{x}$	Me	Min.	Max.	Q1	Q3	*SD*
HRmax	412	186.14	186.00	150.00	219.00	179.00	194.00	10.68

N – number of observations; – mean; Me – median; Min. – minimum value; Max. – maximum value; Q1 – lower quartile; Q3 – upper quartile, SD – standard deviation

Discussion

The effect of endurance training on VO2max is well-established. In the study by Molinari C., Edwards J., Billat V., there were significant differences in VO2max between participants who ran 800 m and sprinters, and those running 3000 m and 10 km ($p < 0.0001$, $p < 0.0001$ and $p = 0.0002$, respectively). VO2max was significantly higher in participants who ran 10 km than in sprinters and 3000 m runners ($p < 0.0001$ and $p < 0.0001$, respectively) [56].

In a study on a group of fifty-six New Zealand cyclists, 36 men (age range 17 - 64 years; body mass 81.4 ± 11.3 kg) and 20 women (16 - 54 years; body mass 63.0 ± 5.9 kg) had VO2max scores of 56.2 and 51.3 ($mLO_2 \cdot kg^{-1} \cdot min^{-1}$) for men and women, respectively, with a total mean of 54.5 ($mLO_2 \cdot kg^{-1} \cdot min^{-1}$) [57].

Fifteen healthy moderately trained women (n = 11) and men (n = 4) (aged 25.6 ± 2.6 years) were divided into two groups: a high-intensity interval training group (HIIT-R, n = 8, 6 women, 2 men) and a high-intensity functional training group (HIIT-F, n = 7, 5 women, 2 men). The use of these two types of training, allowed the participants to achieve a capacity of 54.1 ± 5.6 ($mLO_2 \cdot kg^{-1} \cdot min^{-1}$) in the HIIT-R group and 54.4 ± 5.3 ($mLO_2 \cdot kg^{-1} \cdot min^{-1}$) in the HIIT-F group [58].

An analysis of the Low-Lands Fitness Registry from 11 centers in the Netherlands and Belgium on 4,612 healthy participants (3,671 men and 941 women) showed that in individual age groups, the participants' capacity levels were as follows: (M) 20-29 years - 47.67 ± 6.49 ($mLO_2 \cdot kg^{-1} \cdot min^{-1}$); 30-39 years - 45.50 ± 7.62 ($mLO_2 \cdot kg^{-1} \cdot min^{-1}$); 40-49 years - 42.61 ± 8.40 ($mLO_2 \cdot kg^{-1} \cdot min^{-1}$), 50-59 years - 38.50 ± 8.97($mLO_2 \cdot kg^{-1} \cdot min^{-1}$); (W): 20-29 years - 39.51 ± 8.76 ($mLO_2 \cdot kg^{-1} \cdot min^{-1}$); 30-39 years - 35.84 ± 8.03($mLO_2 \cdot kg^{-1} \cdot min^{-1}$); 40-49 years - 34.19 ± 8.66 ($mLO_2 \cdot kg^{-1} \cdot min^{-1}$), and 50-59 years - 31.00 ± 8.81($mLO_2 \cdot kg^{-1} \cdot min^{-1}$) [59]. A similar extensive meta-analysis was conducted by Niemeyer M., Knaier R., and Beneke R. [60].

In the study of 142 athletes: (93 men and 49 women) triathletes (N = 66), cyclists (N = 35), marathon runners (N = 26), adventure runners (N = 8), rowers (N = 4), and swimmers (N = 3), the women's average VO2max was 43.6 ($mLO_2 \cdot kg^{-1} \cdot min^{-1}$); while in men, it was 53.4 ($mLO_2 \cdot kg^{-1} \cdot min^{-1}$) [61].

Another study aimed to investigate the relationships between repetitive sprinting ability (RSA) indices and components of both aerobic and anaerobic capacity in team athletes. Sixteen team players from among the students of the Higher Institute of Sport and Physical Education, Kef, Tunisia participated in the study (age 23.4 ± 2.3 years; body weight 71.2 ± 8.3 kg; height 178 ± 7 cm; body mass index 22.4 ± 2 kg · m-2; estimated VO2max 54.16 ± 3.5 (ml · kg-1 · min-1) [62].

Among elite German winter sports athletes (n=9 Alpine skiers, n=10 Nordic cross-country skiers, and n=12 world elite biathletes) tested for the CPET exercise test, Alpine skiers performed better in the test with 61.6 ± 7.9 (ml · kg-1 · min-1) compared to biathletes with 64.6 ± 4.4 (ml · kg-1 · min-1) [63].

In another study of 38 healthy and physically active navy cadets, the participants' capacity was at a mean level of 56.6 ± 6.9 ($mLO_2 \cdot kg^{-1} \cdot min^{-1}$) [64].

With regard to maximum heart rate, HRmax was slightly but not significantly (P 0.05) lower in elite runners compared to long-distance university runners [65].

Many athletes and non-athletes are struggling with the consequences of COVID-19 infection, which has undoubtedly affected their performance. In the study by Moulson, Gustus et al, 86% of participants (18 athletes) reported the development of exercise-induced symptoms during CPET, 14% (3 participants) ended the test with reduced peak oxygen consumption (pVO2, <80% of the standard value) and a further 14% observed a low normal pVO2 (≥80% but <90% of the standard value). One participant developed symptoms of dyspnoea, and another discontinued the test immediately after starting due to a rapid drop in blood pressure [66].

Conclusions

Physically active people have a high above-normal level of physical capacity, despite the recreational form of their sport. The study showed the importance of research on physically active people not only in the context of fitness. This group includes outstanding individuals, achieving high performance similar to professional athletes.

Practical implication

The results of the present study may be useful for the participants to control their training process. The information obtained during the research is extremely important for further training process and it can translate into, for example, changing the zones in which the participants have been training so far, or training loads.

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Informed consent statement: Informed consent was obtained from all participants involved in the study.

Data availability statement: The data presented in this study are available on request from the corresponding author.

Conflict of interest: The author(s) declare no conflict of interest.

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PSYCHOMOTOR DETERMINANTS OF CHILDREN'S SPORTS TALENT FOR TEAM SPORTS: A CASE STUDY OF MINI-VOLLEYBALL ATHLETES

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A. Study design/planning
B. Data collection/entry
C. Data analysis/statistics
D. Data interpretation
E. Preparation of manuscript
F. Literature analysis/search
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Abstract:

Background: Psychomotor predispositions significantly impact the effectiveness of the training process and achievement in team sports. The aim of the present study was to assess the level of psychomotor indices in 12-year-old children who achieved outstanding sports successes in mini-volleyball.

Materials and Methods: The results of the tests conducted on the six medalists of the Polish Mini-Volleyball Championships were qualified for analysis. To assess psychomotor indices, a battery of computer tests was used; the following were measured: simple reaction time, choice reaction time, eye-hand coordination, divisibility of attention, and spatial orientation - accuracy of perception.

Results: Four of the six mini-volleyball medalists achieved an outstanding level of psychomotor development; the remaining two children showed an average level on the scale of sports norms. Most often, young champions are distinguished by a short choice reaction time and outstanding (against the background of sports standards) orientation indices: accuracy of perception, and divisibility of attention.

Conclusion: The analysis confirmed, as suggested in previous publications, a significant relationship between outstanding sports talent and the level of selected psychomotor and coordination indices in children practicing volleyball.

Introduction

One of the significant determinants of the effectiveness of sports training in team sports is the high level of motor coordination skills in individual players: kinesthetic differentiation, sense of balance, quick reaction, motor adjustment, time-space orientation, combining movements, rhythmization, and high frequency of movements. In the theory of motor skills, these abilities are defined as integrated psychomotor predispositions, determined by functions and control and regulatory processes, the organic basis of which is the central nervous system [1]. On the effective side, on the other hand, the level of coordination skills determines motor skills, i.e. fast, accurate, and permanent learning of new motor activities, and this, in turn, has a positive effect on the pace of learning technical skills and their effective use during the game [2]. In the field of volleyball, these relationships were confirmed in studies assessing the relationship between the effectiveness of performing technical elements during the game and the sports skill level and the magnitude of both synthetic indices of coordination abilities and the predispositions of these abilities measured in analytical tests [3-8].

The above relationship can be explained by defining sports skills as "... a set of motor habits and the ability to use them reflexively during competition" [9]. The simplest scheme of performing a motor activity divides the whole process into three phases: 1) perception (receiving and recognizing a stimulus), 2) information processing (choosing the correct response), and 3) performing an action (motor response) [10]. In the first stage, information from the environment is identified and analyzed in the centers of the central nervous system (CNS). In the second stage (information processing) the key is the accuracy of the selection and the efficiency of launching the appropriate program to control movements in specialized structures of the CNS. In the third stage, the peripheral system and the locomotor apparatus are stimulated, where the control is also regulated by feedback from mechanoreceptors (Figure 1) [2, 9-10]. Thus, the effectiveness of motor activity depends both on the quality of receptor activity and the efficiency of the neural processes of excitation and inhibition in the CNS, the quality and speed of information conducted in the peripheral system, and neuromuscular coordination. During the game of volleyball, the athlete performs technical and tactical actions as open movement habits, that is, activities that must be adapted to changing situations, such as the actions of the opponent or the course and speed of the ball [1-2].

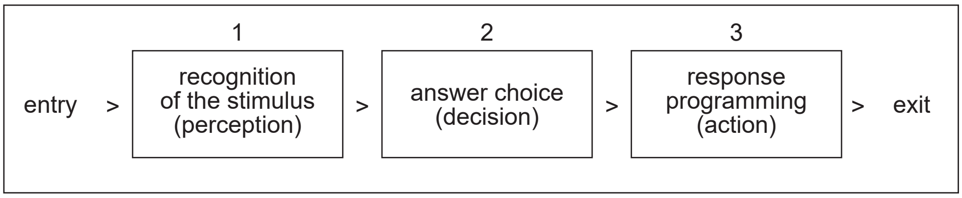

Figure 1. Diagram of performing a motor activity [6]

In sports practice, especially at the initial stages of training, the so-called motor tests are used [11]. Unfortunately, such tests are strongly determined by the movement technique (skills) and the level of energetic abilities, e.g., power of the lower limbs, which in turn strongly determines the running speed and jumping ability. These shortcomings reduce the accuracy of the synthetic measurement of coordination abilities [12-13]. In advanced athletes, the efficiency of the nervous system is more often assessed using psychomotor indices using chronometric devices such as reaction time (simple and complex), eye-hand coordination, attention traits, visual perception, anticipation (e.g., reaction time measurement, Piórkowski's apparatus, cross-body apparatus, or the Vienna Test System). Such tests allow for the estimation of the indices of the basic functions of the perceptual and analytical functions of the nervous system as coordination predispositions of motor skills [14-19].

The article verifies the hypothesis that children who play mini-volleyball most effectively are distinguished by an outstanding level of psychomotor predispositions compared to the norms for peers – athletes of team sports.

Material and Methods

The research was carried out among volleyball players aged 11 to 12 years in a coeducational group of more than a dozen (girls and boys) in the sports section of the Student Sports Club "22" in Krakow. Recruitment to the training group was natural as the children spontaneously participated in extracurricular activities developing their sports interests.

The testing was carried out during sports camps directly before the championships in August 2007 and August 2008. In the three-year period preceding the study, the children took part in specialized sports activities: regular training, competition, and training camps, with the frequency of 3-4 sessions per week (6-8 hours per week). This volume of targeted training is standard for this age category both in club sections and sports classes. Additionally, the children participated in physical education lessons as part of a typical school curriculum 3 hours weekly.

Only the results of tests carried out on three girls and three boys, who won medals in the final tournament of the Polish Mini-Volleyball Cup of the Polish Volleyball Federation (an event equivalent to championships in the earlier age categories) in 2007 and 2008 were included in the analysis. All participants were leading athletes in their teams as they had the highest technical and tactical skills.

A battery of computer tests was used [20] to assess psychomotor indices such as simple reaction time, complex reaction time (with choice), eye-hand coordination, divisibility of attention, and spatial orientation-perception accuracy. Additionally, the measurements were supplemented with the measurement of body height and the measurement of vertical jump height (jumping index).

The results were compared to sports norms calculated based on a study of over 300 people of 12-year-old children who qualified for sports training in team sports under the so-called voivodeship teams [20-21]. The individual results of each child from a group of 6 medalists were converted into relative values of standardized indices (Isd) according to the formula:

$$I_{sd} = \frac{\overline{x} - x_1}{SD}$$

where:

$\overline{x}$ the arithmetic mean of the group results
x_1 individual test result
SD standard deviation of the group results

For example, the difference between his or her score for reaction time and the average value of reaction time scores on the sports norms scale for the age category of 12-year-olds was calculated for each child. Then, the obtained difference was relativized by dividing it by the standard deviation of the results of the population of athletes published in the normative tables. Additionally, the calculated relative measurement values in the field of psychomotor skills (computer test) were averaged as the general level of psychomotor skills in individual children [22-23].

The sign of the index (Isd) was chosen so that the above-normal results had a positive sign, and below-normal results had a negative sign. This procedure yielded unitless quantities (devoid of measurement units), which can be compared directly, e.g., in a graphical form. The calculated Isd also estimates the position of the individual result on the scale of population norms. For example, an Isd of 1 or more proves that the test result is outstanding, as only 15% of peers (selected athletes who practice team sports) reach a similar level.

Results

Four of the six children studied (girl 1, girl 2, boy 1, and boy 2) achieved an outstanding level of psychomotor predispositions, whereas the remaining two (girl 3 and boy 3) had average indices on the sports norms scale (Table 1). Most often, in four cases, young champions are distinguished by a short complex reaction time (reaction with a choice); also in four cases, they achieved an outstanding or close to the outstanding index in the orientation-perception test. Also, divided attention tests and stimulus analysis time tests during the complex reaction test often classify the results of the male and female volleyball players at the top of the sports norms scale (Figure 2, Figure 3).

Table 1. Psychomotor indices of the medalists of the Polish mini-volleyball championship and the standardized values of these indices (Isd) against the standards for young athletes [16]; results that are outstanding against the background of norms are marked in bold

	Simple Reaction [s]	**Choice Reaction [s]**	**Eye-Hand Coordination [s]**	**Perception diversity (Index) [% max]**	**Orientation (Index) [% max]**
Sports norm					
Av	0.269	0.485	89.5	58.9	53.7
SD	0.031	0.080	10.9	15.3	9.5
Measurement					
girl 1	0.256	**0.362**	**76.4**	**77**	55
girl 2	**0.238**	**0.397**	86.4	67	**69**
girl 3	**0.240**	0.440	86.5	56	49
boy 1	**0.243**	**0.399**	87.0	**82**	**65**
boy 2	0.262	**0.379**	83.0	**72**	**65**
boy 3	0.289	0.515	91.5	51	**63**

Standardized Index (Isd)	Simple Reaction	Choice Reaction	Eye-Hand Coordination	Perception diversity	Orientation	Av Isd
girl 1	0.42	**1.54**	**1.20**	**1.18**	0.18	**0.90**
girl 2	**1.00**	**1.10**	0.28	0.53	**1.58**	**0.90**
girl 3	**0.94**	0.56	0.28	-0.19	-0.47	0.22
boy 1	**0.84**	**1.08**	0.23	**1.51**	**1.17**	**0.96**
boy 2	0.23	**1.33**	0.60	**0.86**	**1.17**	**0.83**
boy 3	-0.65	-0.38	-0.18	-0.52	**0.93**	-0.16

Isd – deviation of a single result (number of SD) from the average of the results on the scale of sports norms
Av Isd – arithmetic mean of standardized scores (Isd) calculated for individual children

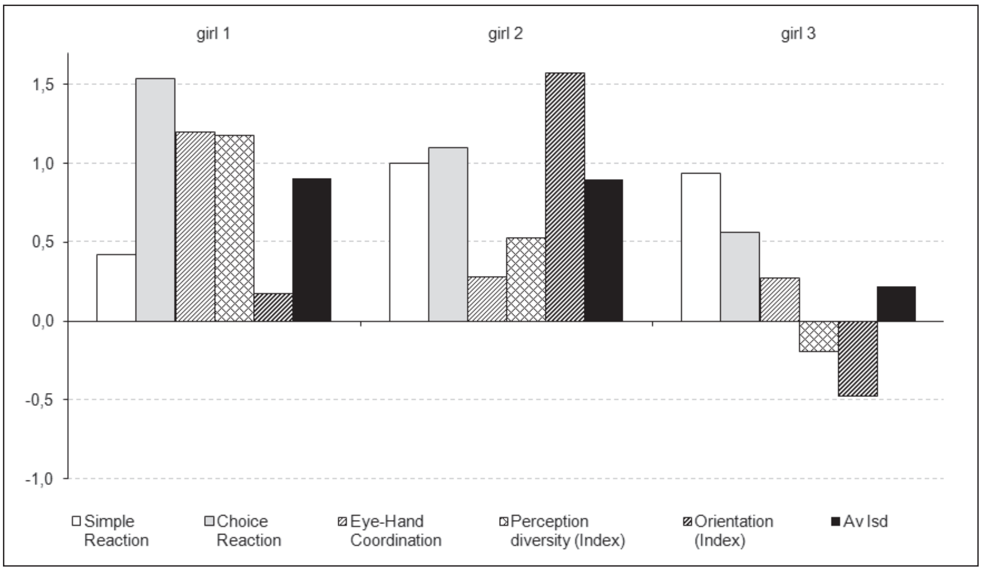

Figure 2. Girls – medalist of the Polish mini–volleyball championship; psychomotor indices – measurement results standardized to the mean and SD of sports norms

Isd – deviation of a single result (number of SD) from the average of the results on the scale of sports norms
Av Isd – arithmetic mean of standardized scores (Isd) calculated for individual children

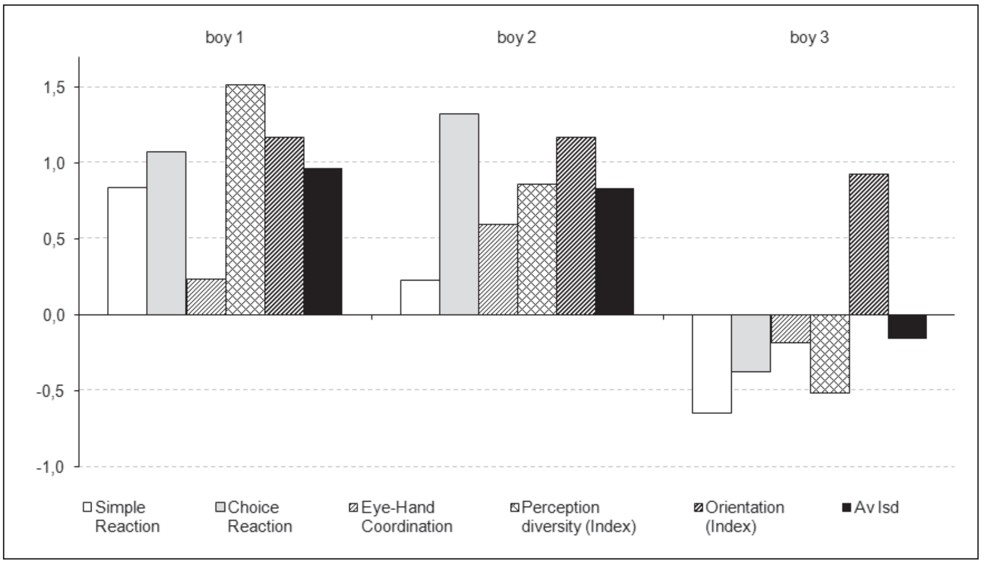

Figure 3. Boys – medalists of the Polish mini-volleyball championship; psychomotor indices – measurement results standardized to the mean and SD of sports norms

Girls and boys from the study group of mini-volleyball champions were characterized by above-average indices of body height and jumping ability (Table 2). This may indicate that these are earlier maturing children, and above-average and outstanding psychomotor indices may be a consequence of earlier maturation. This effect is often observed in youth sports, when the so-called development accelerators achieve sports successes. However, in the case of the participants, their final body sizes, measured in adulthood, indicated that this effect did not occur. Almost every study participant maintained a somatic advantage also in adolescence (a developmental channel on the population norm scale) that was recorded in childhood. All boys and two girls (girl 1 and girl 2) currently qualify as tall individuals against the population norm, their current body height is as follows: boy 1 – 191cm, boy 2 – 192cm, boy 3 – 198cm, girl 1 – 181cm, and girl 2 – 176cm.

Table 2. Indices of jumping and body height of the medalists of the Polish mini-volleyball championship – results standardized to the norms for young athletes and absolute differences in relation to the norms [17]; results that are outstanding against the background of norms are marked in bold

	Vertical Jump [cm]		**Body Height [cm]**	
Sports norm	girls	boys	girls	boys
Av	35.7	35.1	158.8	154.7
SD	6.1	5.4	6.6	7.7
	Standardized Index (Isd) and Difference [cm] compared to sports norms			
	Isd	Difference [cm]	Isd	Difference [cm]
girl 1	0.54	3.3	**1.24**	**8.2**
girl 2	0.38	2.3	0.64	4.2
girl 3	**0.87**	**5.3**	**0.79**	**5.2**
boy 1	0.54	2.9	**1.08**	**8.3**
boy 2	**1.09**	**5.9**	0.04	2.3
boy 3	**1.28**	**6.9**	0.30	0.3

Discussion

Similar positive relationships between the sports skill level and the indices of psychomotor predispositions have been confirmed in numerous publications on team and combat sports. In a study of a group of judokas, Lech et al. [24] observed that a short complex reaction time had a positive effect on the effectiveness of actions during combats. Kwiatkowski [25], who examined taekwondo players, found that the variables of differential reaction time and reaction time in a situation of surprise differed statistically significantly between the groups of the best and the worst adult athletes. Kajdan and Świtała [26], in the study of football players of various subgroups (beginners, younger juniors, and older juniors), emphasized that shorter reaction times were obtained by players with a higher sports skill level. In the publication by Spieszny et al. [27], it was shown that selected handball players from the Sports Championship School achieved significantly higher indices of divisibility of attention and orientation-perception than their peers from the student sports club. Jadaczak et al. [28] found that in the group of adult sitting volleyball players, the indices of orientation-perception, divisibility of attention, and complex reaction showed the strongest relationships with the effectiveness of the basic elements (play, accepting the play, attacking, blocking, setting, defending). Klocek and Żak [29], who conducted research among girls and women professionally practicing volleyball, considered the outstanding level of reaction time and the above-average level of spatial orientation and eye-hand coordination as the basic determinants of the effectiveness of the game (in laboratory eye-hand tests).

In the opinion of both sports practitioners and authors of scientific papers, muscle strength and the ability to develop power are also key determinants of effectiveness in team sports. The physiological foundation of many specialized activities in volleyball is to use maximum muscle power. Such activities include two-legged and one-legged jumps performed during the attack and block; hitting the ball, and sudden changes of direction while moving on the pitch [3, 30].

Girls and boys from the study group of mini-volleyball champions were characterized by above-average indices of body height and jumping ability. This may indicate that these were earlier maturing children, and therefore developed above-average and outstanding psychomotor indices. This effect is quite often observed in youth sports when sports successes are achieved by the so-called development accelerators. However, in the case of the study participants, their final body size, measured in adulthood, indicated that this effect did not occur. Almost all participants maintained their somatic advantage also after adolescence (a developmental channel on the population norm scale), which they recorded in childhood. All boys and two girls (girl 1 and girl 2) are currently qualified as tall against the population standards, with their current body height of: boy 1 – 191cm, boy 2 – 192cm, boy 3 – 198cm, girl 1 – 181cm, and girl 2 – 176cm.

Conclusions

The above analysis confirms the relationship between outstanding sports talent and the level of selected psychomotor and coordination indices in young athletes. The outstanding efficiency of perception and analysis of visual signals, confirmed in a group of mini-volleyball medalists studied, is conducive to faster and more accurate mastering of complex motor activities which occur during the game. On the other hand, the results of two champions in the study group (girl 3, boy 3) indicate that already at the initial stage of training, and at later stages, even a relatively average level of psychomotor predispositions of motor coordination can be effectively compensated, supplemented, and reinforced by a higher level of other indices of motor efficiency (e.g., muscle power) [31].

Relatively high plasticity (the susceptibility of the tested predispositions to stimulation), especially during the natural biological development of the human body, allows for the formulation of practical conclusions. Targeted training of coordination skills and psychomotor predispositions can increase the effectiveness of developing special volleyball skills in young novice athletes. However, this conclusion does not fall within the scope of this article, limited to examining the relationships between the level of indices of motor coordination predisposition and the level of special skills in youth athletes practicing mini-volleyball.

The presented results concern a relatively small group of outstanding athletes from one training group, but they seem reliable and accurate when compared to numerous reports by previous authors that have documented similar relationships in other groups of athletes. Obtaining a larger set of data about young volleyball athletes standing out from their peers requires further research in other centers throughout the country, which was not possible due to the financial limitations of the research project.

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Institutional Review Board Statement: The research was approved by the bioethical Committee at the Regional Medical Chamber (No. 8/KBL/OIL/2017). The study was conducted in accordance with the Declaration of Helsinki, and approved by the Institutional Ethics Committee.

Informed consent statement: Informed consent was obtained from all subjects involved in the study.

Data availability statement: The data presented in this study are available on request from the corresponding author.

Conflict of interest: There is a conflict of interest because one of the co-authors is an editor of the journal. We assure that in such cases, the manuscript has been processed by an independent editor in accordance with the principles of ethics, peer review, and publishing.

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RELATIONSHIPS BETWEEN SELECTED PERFORMANCE PARAMETERS AND BODY COMPOSITION IN KARATE

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B. Data collection/entry
C. Data analysis/statistics
D. Data interpretation
E. Preparation of manuscript
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G. Funds collection

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Abstract:

Introduction: Studying the somatic characteristics of karate athletes can provide specific details on the morphological and functional factors best suited for this combat sport. The aim of the present study was to assess the relationship between selected aerobic and anaerobic parameters and the body composition of karate athletes.

Materials and Methods: The study included 6 male karate athletes, medalists from European and world championships in senior categories, with a mean age of 28 ± 3 years. The inclusion criteria were training experience and sports skill level. Body composition was assessed using bioimpedance analysis. To evaluate special aerobic endurance parameters, a specific karate-specific aerobic test was used, along with monitoring of heart rate and changes in blood lactate levels. The Wingate test was chosen to determine the level of anaerobic performance.

Results: The findings of the present study indicate that body composition is correlated with aerobic and anaerobic variables of karate athletes.

Conclusions: These results indicate that karate athletes with a lower body fat mass perform techniques during the fight with higher intensity but with less power. On the contrary, those with a higher percentage of body fat perform techniques with less intensity but they use more power to perform a punch or kick. A low percentage of body fat and body fat mass have a positive effect on the level of anaerobic capacity, which increases with decreasing percentage and amount of body fat.

Introduction

Currently, the ever-increasing volume and intensity of the training load, along with the effort to maximize sports performance, require monitoring and an innovative approach to all factors that affect sports performance.

Since karate athletes are divided into weight categories, their common approach is to try to maximize functional muscle mass and at the same time reduce body fat, so that they compete in the lowest possible weight category and thereby increase the probability of their success [1]. Several studies [2-4] have investigated differences between karate athletes of different performance levels based on body fat percentage, but none showed a difference between more and less successful karate athletes. However, experts agree that mesomorphic and mesoectomorphic types are predominant among karate athletes [5-8]. Pietr and Bercades [9] revealed that karate athletes are more ectomorphic, which confirms the findings of Giampietro et al. [3] concerning male Italian karate fighters. Research on the body composition of female karate athletes is scarce. Among the methods adopted to assess body composition, bioelectrical impedance analysis (BIA) has been widely used since the 1990s to evaluate bioelectrical properties [10].

It has been found that, from the physiological standpoint, due to the intermittent nature of kumite, aerobic metabolism is the main source of energy but anaerobic sources are also involved [11].

In karate kumite, it is necessary for the athlete to be able to perform a series of defensive and offensive actions in a short time without reducing the intensity and efficiency. Therefore, aerobic capacity and aerobic power are important factors [1,12]. To assess aerobic performance in karate, the karate-specific aerobic test (KSAT) was created [13], with its validity and reliability confirmed on a sample of elite karate athletes [14].

The Wingate test is most often used to assess the anaerobic capacity of karate athletes [1]. Maximum power measured at a specific load represents the ability to generate energy in a very short time and expresses the level of maximum anaerobic power. In sport karate kumite, this ability is used primarily in offensive and defensive actions that determine the outcome of the fight. Average anaerobic performance reflects the ability to resist fatigue at an intense short-term load, such as a karate fight, and characterizes the maximal anaerobic capacity [1,6,15].

The aim of this study was to assess the relationship between selected aerobic and anaerobic parameters and the body composition of karate athletes.

Material and Methods

The research sample consisted of 6 black belt male karate athletes from Poland, with a mean age of 28 ± 3 years, mean body mass of 86.9± 6.05 kg, and mean body height of 183.5± 6.50 cm They were elite athletes who fought on average 15 karate bouts a year in national and international tournament and had won medals in European and world championships. They had practiced karate for 8 to 10 years depending on their age and trained 7-8 times a week. The research sample was selected according to the following criteria: training experience of karate athletes of at least 5 years, kumite as a sports discipline, active competitor with success at international competitions, and no injuries. The exclusion criteria were: kata as a sport discipline, injuries, female, no success at international competitions, and training experience of less than 5 years.

Diagnosis of body composition

The current body composition of karate athletes was assessed using a Tanita DC 430 body composition analyzer. We measured total body water (TBW), body fat mass index (BFMI), percentage of body fat (PBF), fat-free mass (FFMI), and body mass index (BMI).

Diagnostics of aerobic and anaerobic parameters

A karate-specific aerobic test proposed by Nunan [13] was used to evaluate the level of aerobic parameters. The test is composed of a repeated sequence of punches (kizami tsuki, gyaku tsuki) and kicks (mawashi geri and kiza mawashi geri), which must be performed within 7 seconds. The progression of the test occurs by increasing the intensity by reducing the active recovery periods between exercises, according to the levels and stages of the test protocol.

A Polar Team Pro monitor was used to measure heart rate as an auxiliary indicator for monitoring load intensity during the KSAT.

The measurement of blood lactate levels was performed using a Biosen C-line Clinic device, by taking a blood sample by fingerstick. The lactate clearance rate was evaluated as a difference between blood lactate concentration at 5 and 15 minutes of the recovery phase.

The Wingate test on a Cyclus 2 bicycle ergometer was used to evaluate the level of the anaerobic parameter. Based on the literature [16-17], the mechanical resistance was set at 7.5% of the participant's body weight. The test was performed according to the protocol described by InBar O., Bar Or O., Skinner J. S. [18]. The Wingate anaerobic test is widely used as one of the most accepted and accurate tests for assessing anaerobic power characteristics [1].

The testing was divided into two days during one week with a two-day break between them. On the first day, karate athletes participated in the measurements of body composition and the Wingate test. On the second day, aerobic parameters were evaluated using the karate-specific aerobic test.

Statistical Analysis

The statistical analysis was conducted using Statistica 13.5. Non-parametric tests were used due to the small sizes of the groups. We used Spearman's correlation coefficient (rs) to determine the relationship between selected aerobic and anaerobic parameters and body composition. The level of statistical significance was set to $p < 0.05$. The evaluation of ES index r was interpreted as small ($r = 0.10$), medium ($r = 0.30$), or large ($r = 0.50$) based on Cohen's d [19].

Results

The results of body composition are presented in Table 1. The body fat level of elite karate athletes was below the average for physically active individuals [10].

Table 1. Somatic characteristics

	Karate athletes (n=6)	
	Me	**Q**
FFM [kg]	70.35	3.35
BFM [kg]	13.20	4.30
BMI [kg. m^{-2}]	24.90	1.05
PBF [%]	15.60	3.40
TBW [%]	47.40	1.35

Note: FFM – free fat mass index; BFM- body fat mass index; BMI – body mass index; PBF – percentage of body fat; TBW – total body water; Q – quartile deviation; Me – medián

The indicators of aerobic endurance parameters are presented in Table 2. Ttime to exhaustion achieved in the karate-specific aerobic test was considered an aerobic endurance parameter. Auxiliary indicators of aerobic endurance were maximal and average heart rates recorded during KSAT, lactate recorded at 3 minutes after the KSAT test, and lactate clearance rate calculated as a difference between 5 and 15 minutes after loading.

Table 2. Indicators of aerobic endurance parameters

	Karate athletes (n=6)	
	Me	**Q**
Time to exhaustion [s]	927.00	39.00
Maximal HR [pulse]	194.00	8.00
Average HR [pulse]	177.00	850
Lactate clearance rate [mmol/L]	3.80	0.23
Lactate after 3 min. [mmol/L]	12.07	2.14

Note: KSAT – karate-specific aerobic test, Maximal HR – maximal heart rate; Average HR – average heart rate; Q – quartile deviation; Me- medián

The results of the Wingate test as indicators of anaerobic power are presented in Table 3. Performance parameters were the peak power, average power, anaerobic power, anaerobic capacity, average force, and fatigue index expressing the decrease in performance during the Wingate test.

Table 3. Indicators of anaerobic power

	Karate athletes (n=6)	
	Me	**Q**
Peak power [W]	953.98	76.45
Average power [W]	735.69	53.80
Anaerobic power[W.kg^{-1}]	11.00	0.15
Anaerobic capacity[W.kg^{-1}]	8.75	0.15
Fatigue index [%]	37.15	6.75
Average force [N]	372.50	25.50

Note: Q – quartile deviation; Me – medián

Based on the value of the Spearman correlation coefficient a negative correlation was found between body mass index and time to exhaustion achieved in the karate-specific aerobic test. Negative correlations were also shown between body mass index and anaerobic capacity and between free fat mass and lactate clearance rate. Positive correlations were found between fat-free mass index and average power. Body fat mass index negatively correlated with maximal heart rate and at the same time with anaerobic capacity. Furthermore, positive correlations were observed between body fat mass index and average force. The same positive correlation was demonstrated between the percentage of body fat and average force. Percentage of body fat negatively correlated with maximal heart rate and anaerobic capacity. A positive correlation was found between total body water and average force. All these correlations were statistically significant at $p<0.05$. The effect sizes were evaluated as large (table 4).

Table 4. Effect of body composition on the aerobic and anaerobic parameters

Peak power	0.66 (0.16)	0.41 (0.42)	0.77 (0.07)	0.77 (0.07)	0.20 (0.70)
Average power	0.31 (0.54)	0.93 **(0.01;l)**	0.66 (0.16)	0.66 (0.16)	0.89 **(0.02;l)**
Anaerobic power	-0.12 (0.83)	-0.34 (0.51)	-0.58 (0.28)	-0.58 (0.23)	-0.55 (0.26)
Anaerobic capacity	-0.85 (**0.03;l**)	-0.19 (0.71)	-0.85 **(0.03; l)**	-0.85 **(0.03;l)**	-0.18 (0.74)
Fatigue index	0.60 (0.21)	-0.12 (0.83)	0.49 (0.33)	0.49 (0.33)	-0.20 (0.70)
Average Force	0.60 (0.21)	0.32 (0.54)	0.94 (**0.01;l)**	0.94 **(0.01;l)**	0.43 (0.40)

Note: KSAT – karate-specific aerobic test, Maximal HR – maximal heart rate; Average HR – average heart rate;

Discussion

Assessing the body composition of karate athletes requires special attention because in sports activities like sports fighting in karate, with athletes competing in well-defined weight categories, a weight increase due to fat accumulation may lead to poor athletic performance or competing in heavier weight category, which dramatically reduces the performance of karate athletes [3,12]. The percentage of body fat of top-level male karate athletes has been found to be 13.0 ± 3.9% in Sao Paulo Karate athletes [10], 13.3 ± 7.9 % in Brazil karate athletes [20], 14.7 ± 4.3 kg in Colombian national team members [21], and 16.8 in Polish top-level karate athletes [22], which is consistent with the results of this study, where median values of karate athletes reached 15.60 ± 3.40 %. At the same time, the results of this research confirmed that a low percentage of body fat together with a small total amount of fat in the body has a positive effect on the level of anaerobic capacity, which increases with decreasing percentage and amount of body fat. This is likely to affect the course of the fight since anaerobic capacity helps maintain maximum performance during the entire fight [6].

If we look at the results of our study, positive statistically significant correlations with a large effect size were shown between maximum heart rate and percentage of body fat together with the total amount of fat in the body. On the contrary, negative statistically significant correlations with a large effect size effect were demonstrated between average strength and a percentage of body fat together with the total amount of fat in the body. These findings indicate that karate athletes with a lower amount of body fat perform techniques during the fight at a higher intensity but with less power. On the contrary, karate athletes with a higher percentage of body fat perform techniques with less intensity but the power generated to perform a punch or kick is greater.

The active mass of skeletal muscles, critical to performance in karate due to the close relationship of this parameter with a number of physiological parameters related to performance, reached a mean value of 70.35 ± 3.35 kg. Compared with other studies that have reported the values of active mass in elite karate athletes, higher values of active mass in the body were recorded in the group analyzed in this research than those reported by Rossi [10] and Spigolog et al. [20], while Brazilian karate athletes reached a value of 65.5 ± 6.3 kg [10] and 56.4± 13.5 kg [20]. The results of the present study showed that a higher amount of active mass in the body can contribute to a faster decrease in blood lactate levels. This was demonstrated by a negative statistically significant correlation between active mass and lactate clearance rate with a large effect size. A statistically significant relationship between the active mass of the skeletal muscles and the average performance in the Wingate test was also found, which indicates that a higher representation of active mass in the body can improve average performance in the Wingate test and thus the performance in a sports fight. This is also related to the positive statistically significant relationship that was demonstrated between total body water and average power since a high content of total body water is also linked to a high representation of active mass in the body. The mean value of TBW in the group of karate athletes studied was 47.40± 1.35%. Similar values were also recorded in the studies by Gloc et al. [23] (53.66± 3.21%) and Rossi [10] (56.9 ±5.1%). However, in the case of an abrupt adjustment of body weight for a competition in order to fit into a lower weight category, there may be significant differences in the percentage representation of total water in the body due to sudden weight loss and dehydration due to limited food and fluid intake and thus a change in TBW [24].

BMI is considered the most widely used indicator of obesity [25] and indicates the ideal range of body weight [26]. The mean BMI values of karate athletes were 24.90 ± 1.50 kg. m^{-2}. Elite karate athletes from similar research achieved similar values: 26.8 ± 2.00 kg. m^{-2} [22], 24.99± 3.30 kg. m^{-2} [27], and 24.51± 2.33 kg. m^{-2} [10]. A negative statistically significant correlation was demonstrated between BMI and the time to exhaustion achieved in the KSAT test as well as anaerobic capacity. Based on these results, lower BMI values are correlated with higher specific anaerobic endurance as expressed by time to exhaustion in the KSAT test. This was also confirmed in the research by Silva et al. [27] in which negative relationships were found for total fat mass and body fat percentage with results of the karate-specific aerobic test.

Limitations of the study:

A small research group can be considered the main shortcoming of this research but it should be noted that this group consisted of karate athletes who had won medals in the European and world championships.

Conclusions

Body composition indices are part of the biological variables related to sports performance. This research assessed the relationships of selected aerobic and anaerobic parameters with the body composition of karate athletes. The findings of the present study indicated that body composition is correlated with aerobic and anaerobic variables of karate athletes. The results showed that a low percentage of body fat together with a total low amount of fat in the body has a positive effect on the level of anaerobic capacity. Positive statistically significant correlations with a large effect size effect were demonstrated between maximum heart rate and percentage of body fat together with the total amount of fat in the body, as well as between total body water and average power. Conversely, negative statistically significant correlations with a large effect size were shown between average strength and a percentage of body fat together with the total amount of fat in the body, as well as between active mass, lactate clearance rate, and average performance achieved in the Wingate test, and between BMI and time to exhaustion achieved in the KSAT test and anaerobic capacity.

Practical implications:

The findings of the present study suggest that monitoring body composition variables during the entire training to ensure optimal body composition can help prevent poor performance in competitions and improve the quality of the training process. Body composition monitoring, however, should not rest merely on the observation by researchers but should also be used as a useful option for diagnosing karate athletes at different performance levels, while its advantage lies precisely in the fast and easy testing of athletes in both field and laboratory settings.

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Data availability statement: The data presented in this study are available on request from the corresponding author.

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Appendix 1

I. **BIA** – bioelectrical impedance analysis – the resultant electri – cal impedance of the body, its essence is the measurement of the resistance to the flow of an electric current through body tissues [23]
II. **BMI** – body mass index- an index for assessing overweight and underweight, obtained by dividing body weight in kilograms by height in meters squared: a measure of 25 or more is considered overweight [28]
III. **Kumite** – *noun* is a karate competition in which two karatekas perform different techniques of kicking, punching and blocking against each other according to specific rules in order to score and win the match. The range of techniques that can be used in a competition is limited due to the safety of karatekas. Destruction is a fiction. Today, there are four systems of sports competition in kumite: semi-contact, full contact, mix fighting, knockdown [29]
IV. **Anaerobic capacity** – *noun* – the maximum amount of energy that can be produced by anaerobic metabolism [28]
V. **Fatigue index** – A concept used in the study of fatigue during anaerobic activities. The fatigue index is expressed as the power decline divided by the time interval in seconds between peak power and minimum power [30].

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QUANTIFYING INTRINSIC ANKLE STIFFNESS IN QUIET STANDING: A SYSTEMATIC REVIEW

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Authors' contribution:

A. Study design/planning
B. Data collection/entry
C. Data analysis/statistics
D. Data interpretation
E. Preparation of manuscript
F. Literature analysis/search
G. Funds collection

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Abstract:

Introduction: Ankle stiffness is a factor that contributes to maintaining balance and counteracts the forces of gravity as the body sways. Stability while standing quietly depends on its value. Intrinsic ankle stiffness refers to (i) the passive resistance provided by the structural components of the ankle joint itself, such as the ligaments and joint capsules, (ii) a property of the joint that remains constant regardless of the external forces applied, (iii) a characteristic that affects the stability and control of the ankle joint. The aim is to present compilation of the results published in the researchers' work makes it possible to analyze changes in the value of ankle stiffness for perturbations of different amplitude.

Material and Methods: The review is based on articles identified through searches of Pubmed, Web of Science, and Scopus. There were no restrictions on the publication date. The Boolean search strategy was used.

Results: Ankle stiffness changes with increasing sway amplitude. Its values are greater for perturbations of smaller amplitudes and, therefore, cannot be represented by a single value. Passive stiffness reduces sway and allows time for the active system to respond. The interaction of these two mechanisms ensures the stability of an upright posture.

Conclusions: Ankle stiffness is a parameter that can be applied in clinical practice. The exact determination of the range of stiffness values is a useful tool to define a motor organization/reorganization.

1. Introduction

Estimating ankle stiffness during quiet standing is a key issue for understanding the basic mechanisms of motor control. Stabilization of the upright body posture is an example of the many complex tasks aimed at maintaining balance [1]. These tasks are found in everyday and professional life, as well as in more demanding sports situations characterized by repulsive forces that tend to tilt the body away from its intended position. The asymptotic stability of this position would be achieved if the destabilizing moment, which is usually proportional to the displacement, was compensated by a stronger recovery moment generated by the intrinsic stiffness of the muscles and other load-bearing tissues [1]. In the quiet standing position, the body has a slight tendency to lean forward, and instability is mainly caused by gravity [2]. Previous research has shown that people can have very different intrinsic ankle stiffness [1,3-4].

The rate of increase of the rollover moment (i.e. rollover moment per unit of angle factor) determines the critical level of stiffness [1]. Stability is maintained without control if stiffness exceeds a critical level. Below this level, insufficient stiffness requires active stabilization.

Two systems generate ankle torque. The first passive mechanism uses viscoelastic forces from stretching the ankle's muscles, tendons, and ligaments to work instantly as an ankle intrinsic stiffness [3]. The second is nervous system-controlled muscle activity modulation. In a standing position, anticipatory mechanisms of the nervous system reduce the delay in the response to unexpected perturbations. "Separating the reflexive and intrinsic contributions to the overall ankle stiffness during standing might give insight into neuromuscular disorders and help in clinical balance control assessment" [4]. The intrinsic ankle intrinsic stiffness cannot stabilize the body in a standing position, according to research. However, it introduces a passive, immediate response to fall risk, allowing neuronal interventions when balance is lost [5]. Acting as springs, the Achilles tendon and triceps surae cause ankle stiffness [3].

Quiet standing reduces Achilles tendon and triceps surae stretching and ankle joint torque. A long, prone tendon and almost stationary nearby muscles with short fibers determine ankle stiffness [5]. The maximum ankle stiffness is determined by the tendon, which is 15 times weaker than the muscles in quiet standing [6]. In high-torque conditions like walking, jumping, and running, muscle stiffness only matters for ankle stiffness if tendon stiffness increases. Active twitch or passive resistance, stretching and changing the recent history of muscle activity (e.g., leaving the muscle motionless for 10-15 s), can cause thixotropy and stiffen muscles [7].

The Achilles tendon connects the triceps surae to the heel bone and can be extended by an active contraction or passive ankle dorsal flexion. Both types of tendon elongation lead to its stiffening. Torque increases ankle stiffness in standing. Tilting forward or dorsiflexing the foot increases ankle torque [3].

Understanding the foot and ankle joint's mechanisms requires understanding the intrinsic ankle stiffness. The present review's measurements can estimate intrinsic ankle stiffness during standing posture stabilization. This review covers the latest methods for measuring intrinsic ankle stiffness in the anterior-posterior plane.

Literature extensively discusses intrinsic ankle stiffness. There are many ways to estimate this parameter and interpret its mechanism [1,3-4,8,10] Although a unified methodology would be ideal, each author analyzes this phenomenon differently. Ankle stiffness research is evolving due to measurement technology and interdisciplinary approaches. This review presents current research results and phenomena that significantly affect such measurements. This systematic review also investigates how ankle stiffness changes with perturbation amplitude. We aim to find a trend or pattern in ankle stiffness measurements from selected publications to draw general conclusions about ankle stiffness variability under sagittal plane perturbations.

The paper describes measurement methods and ankle stiffness values from tests. This will enable parameter and trend presentation.

2. Material and Methods

2.1. Search strategy

The current review is based on articles identified through searches of Pubmed, Web of Science, and Scopus. There were no restrictions on the publication date. Based on the Boolean search strategy, database searches were conducted using the following keywords: "foot training" AND "postural control" AND "training" AND "balance" AND "postural sway" AND "functional ankle instability." In the subsequent stage of the search, the terms "ankle stiffness" AND "standing" OR "balance" OR "gait" OR "postural control" OR "sway" were utilized to refine the subject and search terms. The search was restricted to English articles in their entirety in their original language.

2.2. Inclusion criteria

Only studies meeting the following criteria were considered for inclusion in the review: 1) included a protocol for measuring ankle stiffness, 2) described the measuring device, 3) described the method for estimating ankle stiffness, and 4) presented the results of ankle stiffness measurements.

Studies that lacked a detailed description of the method, design, and results of measuring ankle stiffness were excluded. The review of the literature was based on inclusion and exclusion criteria.

3. Results

3.1. Search results

An electronic search of the previously mentioned online databases identified 4,755 potentially relevant manuscripts. On the basis of the title, 4,435 articles were excluded from the research. Based on the abstracts, 18 articles were retained for full-text analysis. In the next stage of the search, lists of the 12 selected full-text articles were added. A total of 6 studies were eligible for review (see Figure 1).

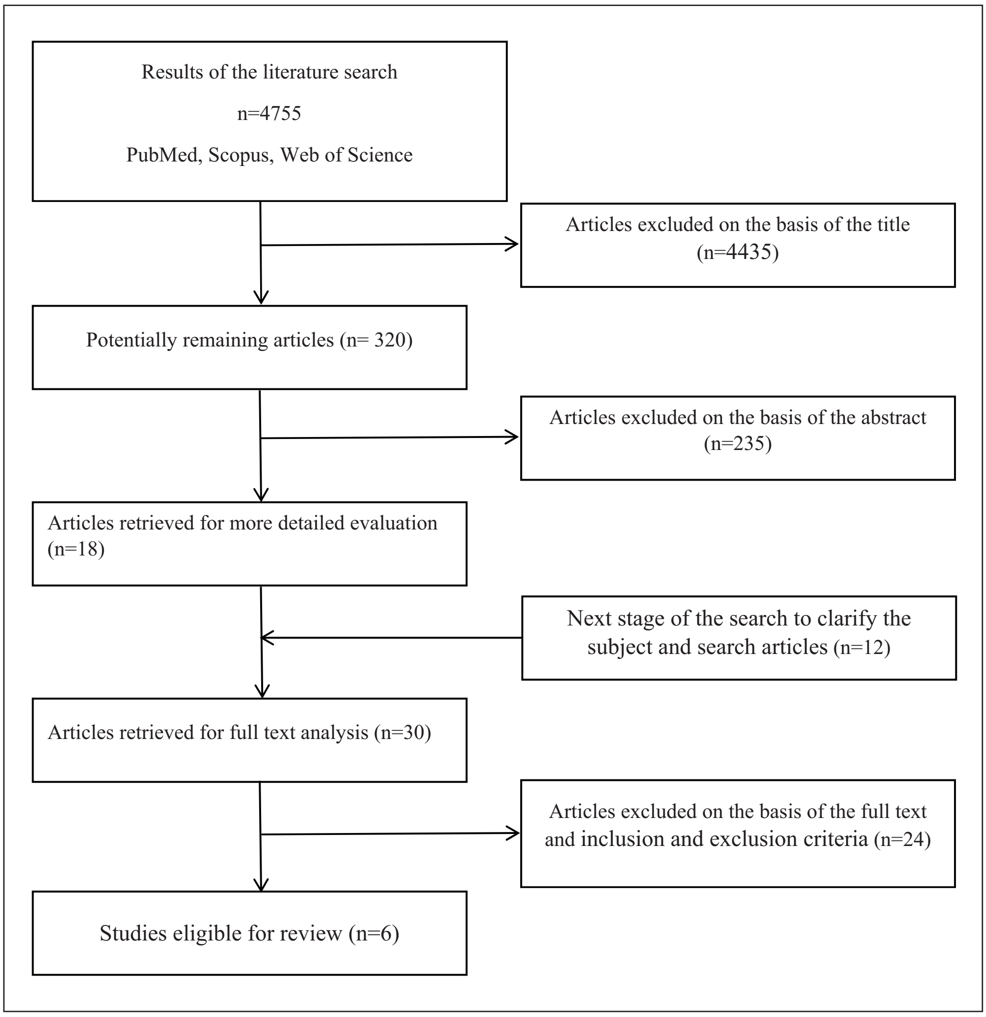

Figure 1. Flowchart

3.2. Measurement results of ankle stiffness

Table 1 shows the results obtained from the normal condition, making a comparison between experiments possible. Lang et al. (2004) presented average values for all conditions in total.

As the disorder amplitude increases, ankle stiffness decreases (Figure 2). Loram and Laki et al. [10] found the highest percentage of mgh for quiet standing and perturbations with the smallest amplitude of 0.055 degrees. This threshold flattens the percentage mgh curve. Loram and Lakie [10] found that smaller and slower ankle movements increase ankle stiffness. Quiet standing's upper limit may be 0.055-amplitude perturbations. Casadio et al. [1] note that Loram and Laki et al. [10] found stiffness close to the critical level and independent of torque due to the measurement method. We can better understand the ankle joint and foot mechanism by studying the foot mechanism during freestanding perturbations. The graph shows point determination mean values, but their spread is much larger. Vertical lines ending in points define the perturbation's percentage mgh range. Vlutters et al. [4] confirmed the graph's

Table 1. Intrinsic ankle stiffness during quiet standing

References	N/Sex/Age	Height/ Weight	Time window	Platform position	Perturbation amplitude	P/N	Average relative pseudo intrinsic ankle stiffness (%).
Loram & Lakie (2002)	15 subjects between 20-68 years	–	140 ms	H	0.055 deg.	30	91% *mgh* for free standing. 80% *mgh* for 0.055 deg perturbation. Direction: DF
Casadio et al. (2005)	9 female 9 male, between 21-31 years	1.55 - 1.88 m./ Between 47 kg and 88 kg.	150 ms	H	1 deg.	20	Female: 0.608 *mgh*. Male: 0.672 *mgh* For DF: 0.649, PF: 0.63
Lang et al. (2014)	6 male 3 female Between 23-29 years	–	500ms	H	0.03 rad.	2	For one leg: 26-45% *mgh* For two legs: 52-80% *mgh.* Positive position pedals indicate DF.
Vlutters et al. (2015)	1 female 7 male 23±1years.	1.85±0.07 m. / 75±8 kg	40 ms	H	0.08, 0.04, 0.02, 0.01 and 0.005 rad.	8	67% *mgh* for 0.005 rad., 65-53% *mgh* for 0.01 rad., 63-46% *mgh* for 0.02 rad., 52- 37% *mgh* for 0.04 rad., 42% *mgh* for 0.08 rad. Pooled values for PF and DF.
Amiri et al. (2017)	3 subjects, between 18-40 years.	–	Lasting until 40 milliseconds after the peak velocity, before reflex response.	H	0.02 rad.	–	106 Nm/rad at background torque of -5 and increase to Nm 253 Nm/rad in the background torque of -22 Nm for DF perturbation.
Sakanaka et al. (2018)	6 female 4 male, 28.1±4.4 years (mean±SD)	1.68±0.1m./ 65.9±8.3 kg.	70 ms	H	0.1 deg., 0.3 deg. and 0.7 deg.	30	For normal position: 77% for 0.1 66.3% *mgh* for 0.3 and 51% *mgh* for 0.7 deg. Combined values of both directions.

– Lack of information, % *mgh* – percentage of toppling torque per unit angle. DF – dorsiflexion. PF – plantar flexion, H – horizontal. P/N – perturbation number.

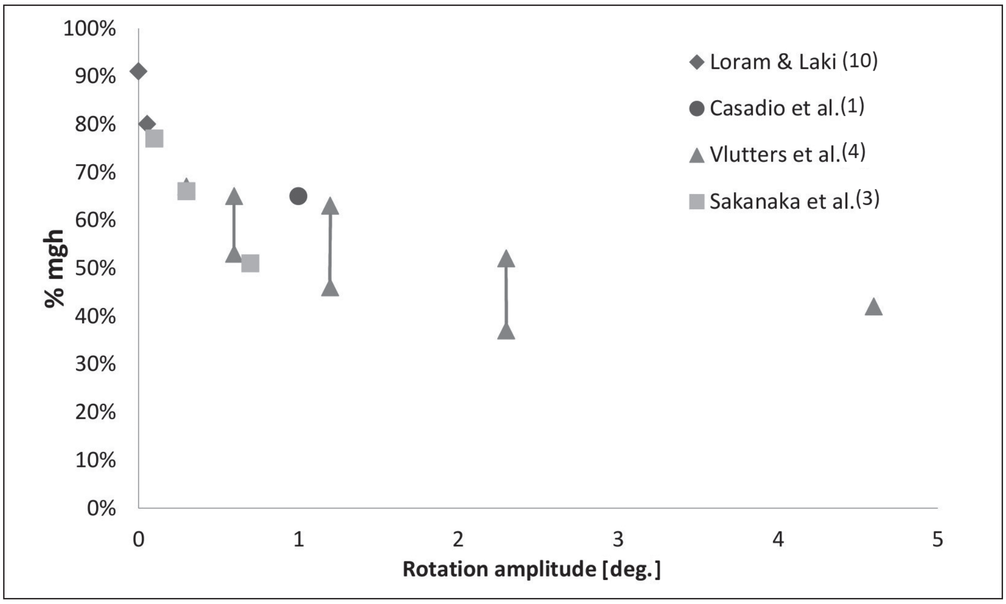

Figure 2. Ankle stiffness value data for a specific rotation amplitude value

steep descent, but their higher amplitude measurements showed a less steep decline. For the 2.3 degree perturbation, values were 52–38 percent mgh (data from the chart in the paper). The mean value was 42% mgh for a 4.6-degree perturbation. The Casadio et al. [1] study's 1 degree amplitude of perturbation outlier may be due to the measurement method. The intrinsic ankle stiffness was divided by the torque difference by the lower leg-platform angle. This method yields higher ankle stiffness values than the [pseudo] ankle stiffness estimated by dividing the difference in torque by the platform encoder angle. Loram and Lakie [1] and Vlutters et al. [1]. The latter estimated ankle stiffness using the two methods above, proving the measurement difference theorem.

Figure 2 shows the ankle stiffness data for a specific rotation amplitude value. The signs from the legend represent the average value for publication. In the case of the publication by Vlutters et al. [4], the authors presented the value range from the lowest to the highest recorded for the perturbation. In the chart, this data is presented by the range of values.

Stiffness was calculated as the difference in torque divided by the difference in the angle between the lower leg and the platform. This method shows higher values for ankle stiffness compared to the (pseudo) ankle stiffness estimated by dividing the difference in torque by the difference in the platform encoder angle and compared to the measurements obtained by Loram and Lakie [10] and Vlutters et al. [4]. The latter estimated the value of ankle stiffness with the two methods mentioned above, proving the theorem about the difference in measurement value.

4. Measuring devices

For estimating ankle stiffness, the authors created their own machines. These machines were designed to apply specific types of perturbations. We believed it would be more comprehensible to present the components of the measuring devices as a table.

Table 2. The components of the measuring devices

References	Platform	EMG- measured muscles	Measuring devices and simplified procedures
Loram & Lakie (2002)	Piezo-electric translator that drives two footrests.	M. soleus, tibialis anterior, m. gastrocnemius medial and lateral head.	Two areas of ankle stiffness (foot, ankle) were estimated by 15-degree Hall's precision potentiometer and a fixed gain amplifier. An inclinometer measured the absolute angular position. A piezoelectric vibrating gyroscope measured the angular velocity of the pendulum. Load cells recorded torque. Variable reluctance displacement sensor estimated rotation of the left footrest relative to the platform. The piezoelectric gyroscope estimated the speed of the platform relative to the ground. The rotation of the footplate and the data sampling of the left footrest torque was 1000 Hz. Other sensors were sampled at 25 Hz. A laser rangefinder was used to measure foot deformity, ankle rotation, and Achilles length.
Casadio et al. (2005)	Force platform and motorized footplate. Torque motor rotated the platform	Scientists didn't measure EMG activity.	A differential transformer (LVDT Schaevitz mod. E 1000) measured footplate rotation. The PID module controled the motor position with the Pulse Width modulation output. Control loop calculations (including LVDT signal acquisition) were performed at 2 kHz. The load cell was used to estimate the COP shift in the sagittal plane and was sampled at 200 Hz.
Lang et al. (2014)	Foot pedals and bilateral hydraulic actuator used to apply position perturbation to the ankle.	M. soleus, tibialis anterior, m. gastrocnemius medial and lateral head.	Potentiometers were used to measure angular position of the foot pedals. Torque transducers were used to collect torque. Redundant safety mechanisms ensure safety.
Vlutters et al. (2015)	Foot pedals and bilateral hydraulic actuator used to apply position perturbation to the ankle.	M. soleus, tibialis anterior, m. gastrocnemius medial and lateral head.	Potentiometers were used to measure angular position of the foot pedals. Torque transducers were used to collect torque. Redundant safety mechanisms ensure safety.

Amiri et al. (2017)	Two independent foot pedals driven by electro-hydraulic rotatory actuators.	M. soleus, tibialis anterior and lateral head of m. gastrocnemius.	Transducers measured torque generated by each actuator and the angle of pedals. Two laser range finders measured shank angles. A range finder recorded linear displacement of the back. All signals were filtered at 400 Hz and sampled at 1KHz.
Sakanaka et al. (2018)	Motorized platform supporting two footplates. Liner motor rotated the platform.	M. soleus, tibialis anterior and gastrocnemius EMG activity but only from medial head.	Load cells measured torque for each ankle. A potentiometer measured the anteroposterior rotation of the footplate. The accelerometer measured left footplate acceleration. Two laser-reflex sensors tracked the level of the anteroposterior shin and body tilt.

5. Discussion

The objective of this systematic review of the measurement of intrinsic ankle stiffness was to synthesize the research findings in order to draw broad conclusions.

The highest values were reported for free standing and perturbations with an amplitude of 0.055 degrees. As the amplitude of the perturbation increases, the stiffness of the ankle joint decreases significantly. This trend continues up to a value of 0.6 degrees. After exceeding this value, one can observe a flattening tendency. This indicates a smaller decrease in ankle stiffness. In the work of Vlutters et al. [4], the maximum amplitude of platform rotation was 0.08 rad. Its value falls within the range obtained for perturbations of 0.02 rad amplitude. We hypothesize that the decrease in intrinsic ankle stiffness is smaller for perturbations with larger amplitudes, specifically for perturbations with amplitudes greater than 0.6 degrees. The research findings indicate that ankle stiffness is greater for movements that are slower and shorter.

In Chapter 3, results from four publications were used. This is because Amiri et al. [8] reported the values from their work using Nm/rad when background torque was considered. Due to the lack of anthropometric data on the subjects, we are unable to present these findings in the form of a frequency distribution (percentage mgh). A paper by Lang et al. [9] is the second most widely discussed publication in this review due to its innovative measurement method. The authors separated the procedure into three parts (Intrinsic Stiffness, Reflex Stiffness, and Background Muscle Activation). Two trials of each type were presented: normal, backward leaning, and forward leaning. According to the results provided by the authors, the overall value for stiffness was as follows: the maximum contribution of each leg to the critical value varied between 26 and 45 percent across subjects. When the maximum observed stiffness values for each leg were added together, the sum of the intrinsic stiffness values ranged from 52 to 80 percent of the critical value. However, this prevents us from comparing the results with the remaining measurements.

5.2. Effect of background torque on the estimation of ankle stiffness

The section on measurement procedures describes the measurement methods that account for the subject's initial position on the platform. There were substantial differences in the research procedures of Casadio et al. [1] and Vlutters et al. [4]. Estimates are affected by the standardization of the starting position and its effect on the background torque. Due to individual differences in height and weight, it was not possible to establish a single target torque that would cause all participants to behave like a rigid body (Sakanaka et al. [3]). The authors then described the variations in ankle and body angle for each experiment. In the first experiment, as participants leaned forward, their ankle and body angles increased. As reported, these angles did not increase by the same amount, indicating that the subjects did not act as rigid bodies. Therefore, the authors decided to calculate the average torques for each subject and plot them as separate traces. Typically, tests of ankle stiffness assume that intrinsic stiffness is constant when standing; this value was estimated in the study by averaging the responses. Loram and Lakie [10] found little change in intrinsic stiffness with an increase in active torque, with an average increase of 13.9 Nm in ankle torque from the normal to the leaning condition. Casadio et al. [1] discovered a 33.5% increase in intrinsic stiffness mgh. Consequently, with a marginally smaller increase in ankle torque, they discovered a greater increase in intrinsic stiffness. On the other hand, Loram & Lakie et al. [10] and Sakanaka et al. [3] described the observed situation, which highlights the need for the precise determination of background torque. They anticipated a smaller difference in stiffness for the smallest perturbations as the active ankle torque increased; however, this interaction was not observed.

The increased ankle stiffness during measurement is caused by the ankle angle rather than ankle torque [3]. As a hypothetical explanation, the authors refer to the consequence of either the coactivation of antagonist muscles, increase of calf muscle moment arm, unmeasured change in the knee angle acting on the biarticular gastrocnemius muscle, or the increased resistance of other tissues [3].

The correct separation of background torque will allow for a more precise evaluation of ankle stiffness. Amiri and Kearney [8] presented an innovative solution to the problem of background torque. The development of an IBK model demonstrated, in the opinion of the authors, that the ankle exhibits a range of stiffness values during stance and is, therefore, a time-varying system. The torque recorded during the intrinsic phase is a combination of background torque (i.e., the torque due to postural sway) and the response of the intrinsic ankle stiffness. In the pre-response phase, a linear regression was performed with COM angle as the independent variable and total torque as the output, assuming a linear relationship, in order to estimate the background torque in each response. After extrapolating the estimated line to the intrinsic response phase, the total torque was subtracted to obtain the intrinsic torque. The average joint torque during the pre-response was used as a measure of the response's background torque [8]. Separating background torque, according to the authors, is essential for accurately assessing ankle stiffness. The results indicate that there is a wide range of ankle background torque due to postural sway, which is accompanied by wide variations in the elastic component of intrinsic stiffness (K) [8].

Lang and Kearney [9] also emphasized the significance of separating the background torque for each individual measurement. In their publication, the answer was separated into four periods. The first served to model the background torque trend by fitting a linear model to the first 25 milliseconds of torque data. Reflex responses were separated by at least 500 ms and lasted less than 300 ms after a perturbation, according to the authors. Therefore, they did not influence the estimation of background torque. This pattern was extrapolated to 100 milliseconds and subtracted from the torque response [9]. For all subjects, intrinsic rigidity increased as background torque decreased (i.e., as the COP moved toward the toes).

5.3. EMG activity during perturbation and in the free-standing position

Muscle activation during the intrinsic ankle foot stiffness measurement affects the measurement values. To study this parameter, researchers use EMG to estimate the response time of the muscles in the lower leg and foot. Casadio et al. [1] used 150 ms perturbations for their research, with the perturbation evoking the short-latency reflex activation of the muscle. The authors stated that the effect of muscle activation on the final stiffness estimate is minimal. This conclusion was supported by the absence of statistically significant differences in three estimation methods that attributed a different weight to the final part of the response, as well as by the fact that the estimates were symmetric in relation to the perturbation direction [1]. This claim was not corroborated by Stein and Kearney [11] as they reported that for an ankle stretch reflex, the raw gastrocnemius EMG would have a latency of ~ 40 ms and the torque response would have an onset latency of ~ 75 ms reaching a peak value after ~170 ms. Information on the earlier activation of the muscles of the lower leg was also provided by Grey et al. [12]. The authors found that a short-latency reflex activity in the human soleus muscle occurs approximately 40 ms after the onset of the stretch.

In the work of Loram and Lakie [10], the duration of the disturbance was 140 ms, thereby also exceeding the above-described limit of the activation of the calcaneus muscles. However, the authors reported that the EMG used in the study did not show any evidence of muscle activity during the application of perturbations. On the other hand, when the examined subjects stood in quiet standing, they recorded the slight activity of the soleus and gastrocnemius medialis and the possible activity of the tibialis anterior. In the integrated EMG record, this reaction started approximately 100 ms after the start of the dorsiflexion and reached a peak approximately 200 ms after the start of the dorsiflexion. For the standing activity, there was a corresponding torque reaction in both the right and left leg. As the reaction occurred in both legs, it was not a stretch reflex. However, when the subjects were standing or balancing the inverted pendulum, but not when strapped and maintaining constant levels of torque, there was a very interesting longer latency reaction in the triceps surae and tibialis anterior [10]. Vlutters et al. [4] presented in their study the view that until now, reflex activity has not been ruled out from the ankle stiffness estimates by applying sufficiently fast rotations during the stance. The authors used a 40 ms perturbation in the experiment. When examining the activity of the GM muscle, they showed a short latency reflex activity starting 45 ms after the perturbation onset. The authors explained that muscle reflex activity could not influence the torques used to estimate stiffness. Although the onset of the stretch reflex started within the time windows used for the estimates, it did not bias the torque in those windows due to the muscle's electromechanical delay [4]. This delay was shown to be in the order of 30 ms for the knee extensor muscle [13]. The authors noted the need to shorten the disturbance time in future measurements of ankle stiffness.

5.4. Unmeasured change in knee angle

Sakanaka et al. [3] noted that when leaning forward, there may have been a slight, unintended, and unmeasured extension of the knee joint, which could have caused a pull on the biarticular gastrocnemius muscle and contributed to increased ankle stiffness. Nevertheless, the contribution of the knee is probably minimal. Herbert et al. [14] demonstrated that the correlation between the lengthening of the gastrocnemius muscle-tendon unit and joint rotation was significantly weaker for the knee than for the ankle [3]. Ankle rotation stretches the gastrocnemius by an average of 0.83 mm per degree, while knee rotation stretches it by only 0.23 mm per degree [14]. Sakanaka et al. [3] reported that the gastrocnemius would be lengthened by significantly less than 3 mm under the perturbations used in calculating the possible ranges of knee extension. The authors also stated that it is very small compared to the intended lengthening produced by ankle dorsiflexion, which would be nearly 17 mm. The effect of knee deflection on the estimation of ankle stiffness should be considered in future studies.

5.5. Participation of the foot in the estimation of ankle stiffness

In an article published by Loram and Lakie [10], the authors measured the stiffness of the foot. They reported that foot stiffness tended to decrease and become more consistent with increasing torque and that this partly offsets an increase in true ankle stiffness. The authors suggested that in using perturbations smaller than a certain critical size, the increasing compliance of the foot and soft tissues conceals the rise in stiffness associated with torque-induced tendon stiffening, setting a rather high and constant level of stiffness. The authors stated that this may be particularly relevant to quiet standing where many of the spontaneous sways tend to be very small in size. In this regimen, ankle stiffness may be effectively independent of torque level (muscle activity) and perhaps for very tiny perturbations or sways, stiffness maintains a constant level because the compliance of the foot and soft tissues acts as a relatively constant stiffness buffer [3]. In a study published by de Vlugt et al. [15], a model fitted to the human wrist was developed. The authors showed that the short-range stiffness of the entire musculotendinous complex did not change at angular velocities ranging from 1 to 4 rad/s. Their data showed that regardless of the stretching speed, the short-range stiffness was maintained for 30 ms. The authors suggested that the short-range stiffness is also independent of the rotational amplitude within this velocity range. Assuming this property holds in our velocity range (0.125–2 rad/s), the observed decrease might be attributed to changes in muscle stiffness occurring after short-range stiffness effects. Initially, the entire muscle-tendon complex might behave as a spring with constant stiffness, after which the muscle stiffness decreases due to detaching cross-bridges [4]. Loram and Lakie [10] suggested that the compliance of the foot means that the axis of rotation of the body COM is not a fixed center through the ankle joint. The visual observation seems to confirm that the axis of rotation moves forward as the body sways forward and more torque is transmitted through the foot. The authors also stated that this may mean that for small sways close to vertical, the toppling torque per unit angle is less than it would be if the center of rotation did not move. Thus, for such sways, the intrinsic mechanical stiffness could confer more stability than their calculations show. The authors further suggested that this mechanism should be measured and included for further estimation.

5.6. Plantarflexion and dorsiflexion in the measurement of intrinsic ankle stiffness

The influence of the direction of the perturbation on ankle stiffness has been investigated. The authors emphasized that they did not note the influence of plantarflexion and dorsiflexion direction on the estimation values. Therefore, they combined perturbations of both directions for the final calculation [3]. Vlutters et al. [4] agreed with this statement. However, the authors noted an exception for perturbations with an amplitude of 0.005 rad. For the remaining conditions, there were no differences between plantarflexion and dorsiflexion. Casadio et al. [1] also confirmed the lack of a significant correlation between gender and ankle stiffness. They found no significant effects for gender and the direction of the perturbation.

6. Conclusion

The primary goal of estimating ankle stiffness was to evaluate and understand the effect of this parameter on balance loss and recovery. Establishing what determines the intrinsic ankle stiffness required a thorough analysis of the tissue properties combined with the concept of stabilizing the inverted pendulum in the ankle joint. Joint stiffness defines the relationship between the position of a joint and the torque acting on it. According to Sakanaka et al. [3], ankle stiffness is the sum of the compliances of the structures that are deformed when the ankle is rotated. Loram and Lakie [10] consider intrinsic ankle stiffness to be the instantaneous mechanical stiffness provided by the combination of active muscle, tendon, connective tissue, and foot, and when one is measuring the stiffness combination of springs in a series, such as the muscle fibers and the tendon, the value of stiffness is limited by the weakest spring stiffness. Sakanaka et al. [3] claimed that stiffness is associated with ankle angle rather than ankle torque, thus an alternative explanation for the rise in stiffness is necessary. The authors concluded that this could be a consequence of either the coactivation of antagonist muscles, increase of calf muscle moment arm, unmeasured change in knee angle acting on the biarticular gastrocnemius muscle, or the increased resistance of other tissues crossing the ankle. The entire muscle-tendon complex can act as a spring until the value at which the myosin bridges detach is exceeded.

In rehabilitation diagnostics, ankle stiffness has become a crucial variable. Its contribution to equilibrium is evident. Further research into passive stiffness and the correlation between the passive and active systems may bring us closer to comprehending the intricate mechanism underlying the operation of the entire system. Ankle stiffness is important in numerous areas of research, and the parameter can be utilized effectively in physiotherapy. Utilizing a training intervention and studying its effect on ankle stiffness across age groups is an intriguing concept (e.g. in seniors). Additional research is required to implement the stiffness parameter of the ankle joint.

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SHORT COMMUNICATION

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PROPOSAL OF PHYSICAL EXERCISES FOR CHARCOT MARIE TOOTH DISEASE PATIENTS: A TAILORED APPROACH

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Authors' contribution:

A. Study design/planning
B. Data collection/entry
C. Data analysis/statistics
D. Data interpretation
E. Preparation of manuscript
F. Literature analysis/search
G. Funds collection

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Abstract:

Background: Charcot-Marie-Tooth disease (CMT) is a neurological condition of genetic etiology classified among rare diseases. The aim of the study was to subject two CMT-1A patient sisters to an ad-hoc training program of 6 weeks (18 sessions) and to record and obtain improvements in proprioception, stability, balance, mobility, and strength.

Methods: Two sisters aged 32 and 30 respectively, with moderate disability (CMT-Neuropathy Score (CMTNS) of 11/36), with pes cavus, hindfoot varus, and a limited ankle range of motion in foot dorsiflexion. General weakness, early fatigue, and impaired gait were also present in the two patients. Both patients, with the same initial deficits, underwent this new intense training program consisting of 60-minute workouts 3 times a week any other day for 6 weeks (a total of 18 sessions).

Results: The study showed positive results on the following scales: Romberg test; 6 MWT; 30-ACT; 30 CST; TUG; Q-Walk-12, and Q-SF-36.

Conclusion: The study aimed to underline the importance of an early disease training approach to limit its progression. The study demonstrated a positive impact of a 6-week gym training program based on monopodalic standing and quadrupedal exercises on proprioceptive abilities, postural stability, and improved balance.

Introduction

Charcot-Marie-Tooth disease (CMT) is a neurological disease of the peripheral nervous system (PNS), with a genetic etiology that affects 1 in every 2,500 people [1]. From a clinical point of view, it is a sensory-motor, length-dependent, slowly progressive polyneuropathy characterized by symmetrical distal weakness of the lower limbs, as well as tactile hypoesthesia, gradually worsening proximally and distally, and causing an alteration of the feet, which become cavus-shaped and floppy [2, 3]. Over time, patients are forced to raise their knees more than normal to avoid tripping with their toes: this gait, which resembles that of the horse, is called "stepping" or equine. Weakness in the upper limbs mainly involves the hands, with particular difficulty in buttoning up and unbuttoning shirts, opening a bottle, and turning the keys in the lock. There is typically a reduction or absence of deep tendon reflexes [4] and muscle atrophy. Distal upper limb tremor, muscle cramps (especially in the feet and legs), acrocyanosis, and cold feet may also occur, and rarely, there may also be central nervous system impairment [5]. In most patients, Charcot-Marie-Tooth disease does not affect life expectancy, but significantly worsens the quality of life and reduces motor autonomy, especially in older adulthood [6].

The age of onset of the disease varies but in most cases, the first signs appear at the end of the first decade or during the second decade of life, with a chronic and slowly progressive evolution. It is well known that in healthy individuals, exercise has countless health benefits, including a reduced risk of obesity, osteoporosis, heart disease, and diabetes [7]. Exercise for people with Charcot-Marie-Tooth (CMT) disease can help maintain strength and function, especially using muscle-strengthening exercises, stretching, and functional exercises. Wallace et al. found that for people with CMT, aerobic training in community gyms was safe and improved aerobic capacity [8]. The purpose of this research is to propose a new training program with the goal of achieving motor, functional, and balance improvement in CMT patients. For the first time, this new training was applied to two sisters affected by CMT-1A.

Methods

E. and J. are two sisters aged 32 and 30 respectively, with moderate disability (CMT-Neuropathy Score (CMTNS) of 11/36), with pes cavus, hindfoot varus, and a limited ankle range of motion in foot dorsiflexion. General weakness, early fatigue, and impaired gait were also present in the two patients. Both patients, with the same initial deficits, underwent this new intense training program consisting of 60-minute workouts 3 times a week any other day for 6 weeks (a total of 18 sessions). The training protocol focused on improving muscle strength of the lower and upper limbs, mobility, and stretching. The participants were subjected to 7 tests: Romberg test; Six Minute Walk Test (6 MWT); 30-Arm Curl Test (ACT); 30-Chair Standing Test (CST); Time Up and Go (TUG); Twelve Item Walking Scale Questionnaire (Walk-12) and Quality of Life Assessment Questionnaire (SF-36). The improvement was defined as the difference between T1 (after 6 intensive weeks of training) and T0 (before training) split into 4 degrees of improvement: 0 (T1-T0 <5%); 1 (T1-T0 5-10%); 2 (T1-T0 10-15%); 3 (T1-T0 15-20%) and 4 (T1-T0 >20%).

Results

The proposed training exercises and the results obtained from the tests before and after the training are presented in Table 1.

Table 1. Training program followed by the participants in the gym under the supervision of a neurologist and a clinical kinesiologist and the results obtained in the various tests at baseline (T0) and after 6 weeks of training (T1)

TRAINING PHASES	3 SESSIONS A WEEK ANY OTHER DAY	EXERCISE	REPETITION / SET
INITIAL Session duration 15′	Lower/upper limb mobility Neck, shoulders, pelvis and ankles	– Circumduction – Passive tibio-tarsal dorsiflexion with elastic band – Achilles tendon stretching	30″ for 3 sets each exercise
CENTRAL Lower limbs Session duration 20′	Strengthening of the tibial and peroneal muscles	In active isometrics, maintaining dorsiflexion in supine decubitus position and while seated	10″ each side x 10 times x 3 series
	Glutes, quadriceps and hamstrings	Squat-free and with fitball	3x12
		Hip thrusts	3x10
		Leg extensions	3x12
		Leg curls	3x12
Upper limbs Session duration 15′	Strengthening the flexors and extensors of the elbow and shoulders	Dumbbell curls	3x16
		Pushdowns/double kickbacks	3x12
		Lateral raises	3x12
FINAL Session duration 10′	Abdomen ed equilibrium	Plank	3x 30″
		Alternate lunges	3x10
		Contralateral limb extension in quadrupedal position	3x10

TEST	PATIENT, T_0 [1]	PATIENT, T_1 [2]	PT. IMPROVEMENT (%) ; (0-4)[3]
Romberg Test	E. Positive	E. Positive	0
	J. Negative	J. Negative	0
Six-Minute Walking Test (6 MWT)	E. 538 m	E. 546	E. 1,5% ; 0
	J. 517 m	J. 562	J. 8,7% ; 1
30-Arm Curl Test (ACT)	E. 21[4]	E. 27	E. 28,6% ; 4
	J. 21[4]	J. 29	J. 38,1% ; 4
30-Chair Stand Test (CST)	E. 21[4]	E. 25	E. 19,0% ; 3
	J. 20[4]	J. 30	J. 50,0% ; 4
Time Up and Go (TUG)	E. 5.36''	E. 5.38''	E. - 0,4% ; 0
	J. 5.85''	J.5.40''	J. 7,7% ; 1
Twelve Item Walking Scale Questionnaire (Walk-12)	E. 22	E. 22	E. 0% ; 0
	J. 25	J. 23	J. 8,0% ; 1
Assessment of Quality of Life Questionnaire (SF-36)	E. 54,86	E. 55,70	E. 1,5 % ; 0
	J. 71.52	J. 75	J. 4.9 % ; 0

[1] T0 represents the patient's capabilities before starting training

[2] T1 represents the patient's capabilities after successfully completing the 6-week intensive training program.

[3] The improvement was defined as the difference between T1 and T0 split in 4 categories: 0 (T1-T0 <5%); 1 (T1-T0 5-10%); 2 (T1-T0 10-15%); 3 (T1-T0 15-20%) and 4 (T1-T0 >20%).

[4] Repetitions

Figure 1 illustrates the improved ability to perform a deeper squat without heel-lifting compensation obtained following the exercises designed to reduce the level of muscle recruitment between the anterior and posterior muscle fibers of the distal part of the lower limb. The training program applied in this study allowed patients to achieve improvements in both mobility and strength.

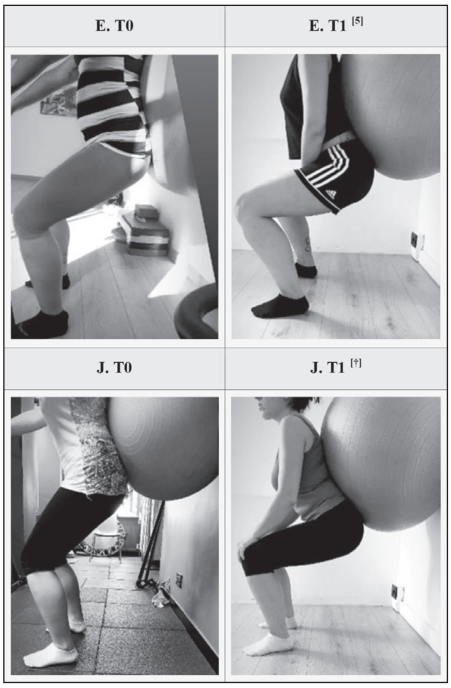

Figure 1. Illustration of mobility of the ankle joints before and after the 6-week intensive training program

[5] Improved ability to perform a deeper squat without heel-lifting compensation after successful completion of the training program

Discussion

In the scientific community, exercise has been commonly discouraged in neuromuscular diseases, primarily due to theoretical considerations rather than adverse outcomes [9]. Without supporting data, it has been postulated that a weak muscle is more susceptible to damage due to overwork because it is already functioning close to its maximal capabilities [10]. This study aimed to demonstrate that a 6-week gym training program using controlled exercises has a positive impact on proprioceptive abilities, in particular the perception of the body position in space and the state of contraction of muscles. It also improved postural stability, by restoring the balance between the accentuated retraction of the Achilles tendon and the capacity of the ankle dorsiflexor and pronator muscles, by focusing on stretching these structures. Moreover, this study showed balance improvements with monopodalic standing and quadrupedal exercises.

This study is not without limitations. Both patients had various osteoskeletal abnormalities, such as pes cavus, hindfoot varus, tibiotarsal reduced range of motion, and callosities at the head of the 1st and 5th metatarsals. Furthermore, patient E. complained of generalized quadriceps cramps during the first training sessions, while J. developed some lower extremity edemas which subsequently resolved. These may have been caused by the sedentary lifestyle of both patients. The slight improvement in the quality of life perceived by E. could be influenced by the patient's clinical comorbidity of mood disorder.

Conclusion

This report aims to contribute to the need to develop uniform exercise guidelines for people with CMT, highlighting the clinical benefits and improvements in performance in patients performing tailored exercises.

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REVIEW

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HUMAN MOTOR BEHAVIOUR. AN OUTLINE OF A SYSTEM-THEORETICAL APPROACH

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Authors' contribution:

A. Study design/planning
B. Data collection/entry
C. Data analysis/statistics
D. Data interpretation
E. Preparation of manuscript
F. Literature analysis/search
G. Funds collection

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Abstract:

Background: The organisation of motor action is a psychological process, while its implementation takes place through neurophysiological and physiological structures in the environment. Motion observable in the environment is the basis for inferring the work of the mind.

Materials and Methods: The author presents a system-theoretical approach (STA) to the issue of the construction and control of motor operations in humans. It is based on the theory of Nikolai Bernstein, who developed a neurophysiological model called the 'brain skyscraper', of a systemic nature. Taking it as a model, a functional equivalent of a skyscraper, a modalities' ladder, was developed. The common denominator of both these mental structures is the system-theoretical basis for the construction and control of motor operations in humans. The science of human motor behaviour – anthropokinetics – eludes mathematical description and explanation, which works well in physics.

Results: STA, however, seems to be a promising method of revealing specific aspects of anthropokinetics. This is one of the possible perspectives that allows us to analyse such a multifaceted and complex problem as human motor behaviour, which is the only observable manifestation of any mental activity. This is probably the greatest intellectual challenge for all modern science.

Conclusion: STA is an original method of thinking about human motor behaviour, which probably reveals its specific aspects and thus may contribute to a better understanding of anthropokinetics. It also enables the construction of an original, novel family tree of science as a whole.

Introduction

According to Nikolai Bernstein [1-4], the motor behaviour of a living being is the only 'keyhole' that allows indirect observation of the workings of the mind. Indirect – because the organisation of motor action is a psychological process (mind), while its implementation takes place through neurophysiological (brain) and physiological (muscle) structures in the environment (physics). Motion observable in the environment is the only basis for inferring the work of the mind [5]. Although there are other aspects of behaviour [6], it is the movements of the living creature that make it possible to build any understanding of the production of motor operations and indirectly to 'peek' at the general mechanisms of the mind.

Why system-theoretical?

From the mid-17th century, when Isaac Newton developed a mathematical description of the inanimate world, the triumphant march of physics began, which was – and still is – the main engine of all science. Its natural language is mathematics, hailed as the 'Queen of the Sciences'. It is an excellent tool for describing behaviour of physical bodies that have no inner purposefulness and passively obey physical laws external to them. Thus, when a scientist describes these laws mathematically, it is quite easy to exactly predict the behaviour of a physical body. However, Jack Cohen and Ian Stewart argued:

> *Physics deals with invented, simplified world. This is how it derives its strength, this is why it works so well … Sciences like biology are less fortunate* [7].

Niels Bohr argued:

> *… the existence of life must be considered as an elementary fact that cannot be explained, but must be taken as a starting point in biology… [8].*

A similar opinion was expressed by another Nobel Prize winner in physics, Erwin Schrödinger, who wrote:

> *… living matter, while not eluding the 'laws of physics' as established up to date, is likely to involve 'other laws of physics' hitherto unknown, which, however, once they have been revealed, will form just as integral a part of this science as the former [9].*

This may be – at least in part – due to what another Nobel Prize winner, Roger Penrose, described as follows:

> *There are two other words I do not understand – awareness and intelligence. Well, why am I talking about things when I do not know what they mean? It is probably because I am a mathematician and mathematicians do not mind so much about that sort of thing. They do not need precise definitions of the things they are talking about, provided they can say something about the connections between them [10].*

In physics, the internal structure of inanimate bodies does not affect their behaviour. Hence, their superficial relationships – which can be described mathematically – fully determine their behaviour. However, even the simplest living structure, the chemoton [11], has an intrinsic advisability that determines its behaviour on a par with external physical laws. Unfortunately, it escapes the mathematical description. Jack Cohen and Ian Stewart stated:

> *By definition, mathematical statements are tautologies. Their conclusions are logical consequences of their hypotheses. The hypotheses already 'contain' the information in the conclusions. The conclusions add nothing to what was implicitly known already. Mathematics tells you nothing new [7].*

This is probably why Israel Gelfand, a prominent mathematician and expert on Bernstein's achievements, formulated this statement:

> *Eugene Wigner (Nobel Prize winner in physics – WP) wrote a famous essay on the unreasonable effectiveness of mathematics in natural sciences. He meant physics, of course. There is only one thing which is more unreasonable than the unreasonable effectiveness of mathematics in physics, and this is the unreasonable ineffectiveness of mathematics in biology [12].*

Mark Latash called this statement the '*Wigner-Gelfand principle'* [13].

Unlike a mathematical equation, a system is capable of producing a qualitatively new, unpredictable, emergent system effect that does not result from the properties of any of the system's components [14-18]. Its illustrative description can be found in "Faust". Johann Wolfgang von Goethe wrote:

Wer will was Lebendigs erkennen und beschreiben,
Sucht erst den Geist heraus zu treiben,
Dann hat er die Theile in seiner Hand,
Fehlt leider! nur das geistige Band.
Encheiresin naturae nennt's die Chimie,
Spottet ihrer selbst und weiß nicht wie.

To understand some living thing and to describe it,
the student starts by ridding it of its spirit;
he then holds all its parts within his hand
except, alas! For the spirit that bound them together –
which chemists, unaware they're being ridiculous,
denominate encheiresin naturae (Transl. Stewart Atkins).

In terms of systems theory, the 'geistige Band' (spirit that bound them together) can be considered a system effect.

In this context very symptomatically sound the words by Frederic Wood Jones, who stated that "*whoever wins to a great scientific truth will find a poet before him in the quest*."

Bernstein and the brain skyscraper

Nikolai Bernstein knew eight languages, but wrote mainly in Russian. He published very few works in other languages. In 1967, a collection of his works translated into English was published [19]. Bernstein died in 1966, but he managed to authorise this book. It contained an article on the basic principle of transforming an unmanageable system into a manageable one; in English, this is referred to as '*reduction of degrees of freedom*'. However, this is not an appropriate translation of Bernstein's phrase '*preodoleniye*'. It means '*overcoming*,' not '*reducing*.' It was this term that Mark Latash used in the English translation of Bernstein's masterpiece "*On the Construction of Movements*" [4]. Latash speaks both Russian and English perfectly. He is also an outstanding expert on anthropokinetics. Previously, he also translated Bernstein's more popular book "*On Dexterity and Its Development*" [3]. Nevertheless, until the advent of translations of both of Bernstein's books into English, his ideas (excluding purely mechanical '*degrees of freedom reduction*') were not widely known throughout the world. Mihai Nadin stated that they were "*rather under-, not over-, whelming*" [20].

By the way. The book on dexterity was written by Bernstein in 1947, but for unscientific reasons it was not published in Russian until 1991, twenty-five years after his death. Five years later, an English translation was published.

Perhaps Bernstein's most important achievement was the brilliant systemic ordering of structures in the central nervous system, combined with the specific motor abilities of living creatures. He called this mental structure the 'brain skyscraper' [2-3]. Unfortunately, in the English book from 1967 there was no description of it. For the first time, its rather detailed description appeared in English only in 1996 [3]. In fact, this is a systemic description, not a mathematical one [23-25].

Bernstein tracked the joint development of sensory organs (situation identification), locomotor organs (the ability to produce movement) and the central nervous system (motion control) during evolution. He distinguished six levels of the skyscraper: A, B, C1, C2, D and E. This can be seen in Figure 1 [21-22, 26]. By the way: Bernstein himself has never drawn such a diagram, but nevertheless it remains in good harmony with his ideas.

The diagram presented in Figure 1 needs a comment. Bernstein invented his idea while analysed the development of various living creatures in the course of evolution. However, specific nervous structures make up in living beings not a sum, but a system. It always works as a whole, and not as a sum of its parts separately. Hence, the analogous neural structures play different functions in various creatures. For instance, in humans processing of visual stimuli takes place in the brain cortex. Fishes also have eyes and use vision, though they do not have a brain cortex at all. This is why a given component may play different part in different systems.

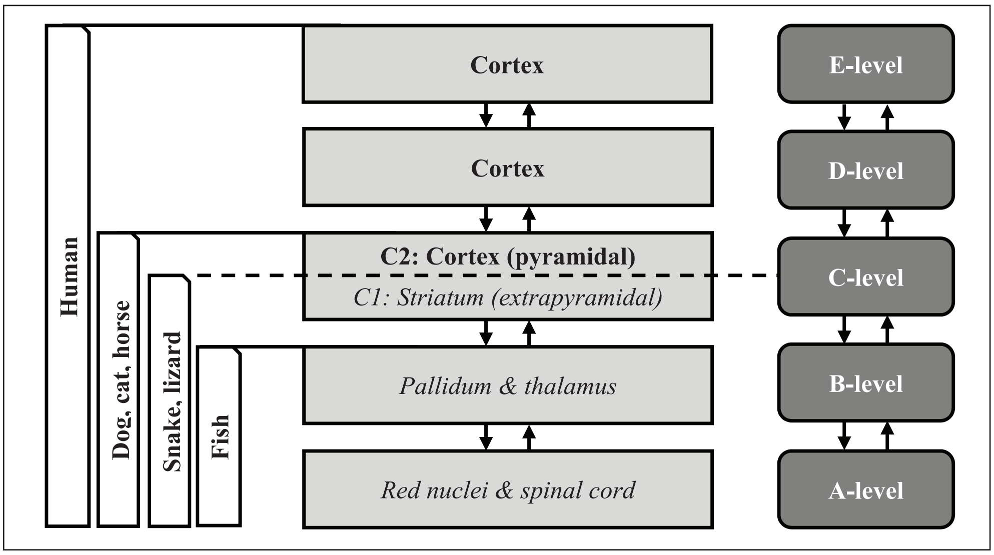

Figure 1. Bernstein's brain skyscraper, simplified diagram: the interdependence of evolutionary (left column), neurophysiological (middle column) and mental (right column) factors [21-22, 26].

The modalities' ladder

The brain skyscraper has an evolutionary and neurophysiological character, but in 'everyday use' its functional aspects are the most important. Let's make the following analogy. For a good driver, a thorough knowledge of the construction and functions of the car is not necessary. S/he just needs to make the most of the vehicle's capabilities. They result from its construction, indeed, but technological details do not come to the fore in everyday use of the car.

The functional 'equivalent' of the neurophysiological brain skyscraper is the functional modalities' ladder [21-22, 26]. Both are consistent with each other. A skyscraper can be roughly compared to the construction of a car, and a modalities' ladder – to the skills of the driver.

Like the brain skyscraper, the modalities' ladder is a hierarchical structure of information processing modalities that can be assigned to individual rungs. However, their layout is somewhat different from that of the brain skyscraper (Table 1). In a skyscraper, the brain level C is divided into two sublevels C1 and C2 (subcortical and cortical, respectively), but in the functional system it is not important. On the other hand, in the modalities' ladder the rung A is divided into two sub-rungs. A1 regulates postural maintenance (muscle tonus), crucial in vertebrates, especially bipedal, while A2 controls muscle contractions that produce strength and movement.

Table 1. General structure of the modalities' ladder.

Rung	Function	Information processing modality	Regulation mechanism	Spatial dimensionality	Temporal dimensionality
A1	Posture maintaining	Kinesthetic	Kinaesthesia, muscle tonus	Internal, one's own body limits	Very short time axis present-near future, without scale
A2	Movement production	Proprioceptive	Reflex, motor coupling		
B	Synergies' regulation	Contactceptive	Automatism, motor template	External, two-dimensional, one's own body limits	Very short time axis, near past-near future, without scale
C	Current movements in the space	Teleceptive	Habit, motor scenario	Three-dimensional, reach of vision	Timing, short time axis past-future with scale
D	Preparation of the future motor operations	Verbal	Performance, motor programme	Three-dimensional, 'stiffly' geometrical	Full 'geometrical' time axis with 'stiff' scale
E	Fantastic representation of reality	Symbolic	No motor action, motor idea	Three-dimensional, 'plastically' topological	Full 'topological' time axis, with 'plastic' scale

The 'Temporal dimensionality' column needs a comment. Time is undoubtedly the most enigmatic and mysterious phenomenon, both in physics and psychology. The mental processing of the temporal aspects of any motor operation is very 'expensive' intellectually. Therefore, it is necessary to mentally process the concept of time as economically as possible.

At A-rung, which operates internally, only a very short timeline is needed, from 'now' to 'near future'. If there is something wrong in the 'now', it is necessary to correct it in the 'near future'. For example, when a motor command comes to the motor unit in a muscle, it contracts, because for a motor command the loosen motor unit is 'wrong'. Such unit does not have to 'remember' anything before receiving a motor command. Hence, in this situation, time processing is very 'cheap'. By the way: while seen from such perspective, the bizarre term 'muscle memory' does not make sense. In STA terms, each rung of the ladder has its own tools for information processing – emotions, intellect, etc. – which also require a specific type of memory. Hence, 'muscular memory' is simply a memory of rung A (or level A, as in a brain skyscraper), neurological, not muscular, in nature.

At B-rung, there is tactile contact with the environment, and the timeline takes the form of a very short period from the recent past to the near future. An illustrative description of such a phenomenon can be found in the book by Charles Darwin, who wrote:

> *If worms are able to judge, either before drawing or after having drawn an object close to the mouths of their burrows, how best to drag it in, they must acquire some notion of its general shape. This they probably acquire by touching it in many places with an anterior extremity of their bodies, which serves as a tactile organ [27].*

Worms do not have C-rung eyesight, hence they are undoubtedly B-rung (tactile) animals. To build any image of an object, as described by Darwin, it is necessary to distinguish between something 'before', 'now' and 'after'. Therefore, the timeline at B-rung must cover the near past, present and near future.

Neither at A-rung nor at B-rung does it seem possible to create any kind of time scale. However, at the C-rung, eyesight appears, which makes it possible to perceive movement in the environment and create the concept of time in the mind. Isaac Barrow, Isaac Newton's mentor, argued: "*Time implies motion to be measurable; without motion we could not perceive the passage of Time*" [28]. Let us emphasise: along with the perception of velocity, a specific assessment (not measurability) of the passage of time arises: shorter – at the same time – longer. This makes it possible to organise the sequence of phenomena observed outside and inside one's own body and to discover cause-and-effect chains, which constitute the germ of logic. In addition, at C-rung it forms the basis of a specific perception of the phenomenon of time, called 'timing', which Arturo Hotz defined as follows:

> ***Timing*** *is the temporal punctuality towards a spatial point, and also the functional potential to be at proper time, with optimum speed and in relevant place [29].*

It is timing that makes it possible to create agility (whole body) and dexterity (working organs), which are the most advanced motor abilities in living creatures, including humans. Nevertheless, time processing at the C-rung is quite obvious and mentally 'cheap'.

Verbal modality (D-rung) results not only from the detachment of the internal representation of a given concept from current external stimuli, but also from giving it the value of permanence. As such, it expands the timeline far into the past and future; theoretically – into infinity. The inevitable price for this is the very high mental cost of perception and processing of time notion.

The psychological costs of time perception and processing at E-rung are even higher. The concepts of D-rung are geometrically anchored in the 'hard' reality, whereas the E-rung concepts are freely immersed in the topologically deformable temporal-spatial realm of pure, enigmatic and elusive abstraction. The price of unlimited freedom is the absence of any hard points of reference. Therefore, Albert Einstein needed five or six weeks to create a specific theory of relativity [30] and about eight years to create a general theory of relativity [31]. The former, although highly abstract, is nevertheless significantly closer to the 'hard reality' than the latter.

Let us compare the process of forming the modalities' ladder to Thomas Kuhn's series of scientific revolutions [32]. Such revolutions can be placed on the borders between different levels. Here we can imagine phenomena analogous to mathematical catastrophes, as in René Thom's theory [33]. In the modalities' ladder, the small development of the sense organ causes the emergence of new ways of processing information and a huge leap (analogous to Thom's catastrophe) in cognitive abilities. Such a leap can be identified with a specific, cognitive system effect – unpredictable, qualitatively new and not resulting from the properties of the components of the system.

The boundary between rungs A1 and A2 is purely hypothetical. According to Tibor Gánti, even the simplest living structure – chemoton – has a chemical system with a boundary surface that provides the B-rung contact with the environment [11].

The B-rung contactceptive information processing modality is rather primitive, yet in some living organisms such a modality may produce astonishing results. Ian Stewart describes slime moulds (*Physarum polycephalum*), which may form vast nets displaying nearly engineer logic in search for food [34].

A single contactceptive being can only identify a two-dimensional surface limited by the reach of its own body. Nevertheless, some B-rung animals (e.g. snails) have developed a certain sensitivity to light. However, their visual abilities are poor and cannot significantly affect cognitive abilities.

The appearance of well-developed eyes (C-rung) caused a specific system effect and a great leap in the cognitive abilities of living beings. They gained the ability to perceive a three-dimensional part of space much larger than the size of their own bodies. In addition, vision makes it possible to perceive movement in environment.

This brought on a cognitive revolution. For beings with sight, the movement is easily observable. It has such a rich cognitive content that it provides an excellent starting point for a more abstract areas of thinking. It is no accident that this is a movement that the brilliant Nikolai Bernstein chose as a 'keyhole' for understanding the functions of the brain and, indirectly, the workings of human mind.

A very important consequence of distinguishing movement is the perception and evaluation of time. It was not an ordinary leap, but a real revolution in the cognitive abilities of living beings. This made it possible to create cause-and-effect chains in the mind, as well as the temporal organization of motor operations. In this way, it laid the foundations for the development of logic, which is the 'glue' of the whole intellect – instinct, intuition and intelligence.

Incidentally. Logic itself is just a 'raw tool' for creating mental structures with intellect – instinct, intuition, and intelligence. Very symptomatic are the words of Niels Bohr to Albert Einstein: "*You are not thinking. You are merely being logical*."

The development of teleceptors significantly accelerated the process, which Peter Gärdenfors described as follows:

> *The activities of the brain have become detached from the direct control from the senses. Thought can lift and fly its own way [35].*

However, vision, although it is simply a miraculous sensory organ, also has some disadvantages. First, it needs light. Secondly, it can receive stimuli only from a limited sector of space called the field of view. Therefore, the early germs of the next cognitive leap can be traced in another sensory modality: hearing. Unlike the eye, the ear can pick up sounds from all directions. Moreover, vision creates images that truly and clearly represent reality. The interpretation is therefore quite limited. Auditory representations, on the other hand, consist entirely of mental, abstract interpretations of the sounds perceived by the hearing person. This is s/he who gives specific meanings to the configuration of sounds, regardless of environmental stimuli. In humans, the production of sounds (and words) is therefore very important; Nikolai Bernstein devoted much attention to the movements of tongue [1, 2, 3, 4]. Much of the human cerebral cortex is designed to control these movements. No other animal needs to emit such a variety of sounds – the language – as a human. That is why, in compliance with the principle of parsimony, no other animal needs such sophisticated neurophysiological 'equipment'.

According to Karl Bühler, John Lyons and Michael Halliday, in the sphere of the mind, communication is inextricably linked to the independent mental representation of verbally transmitted knowledge [36]. This creates the basis for another astonishing effect of the system: the ability to truly, 'geometrically' represent reality beyond the temporal constraints of timing. This extends the timeline far into the past and the future, which represents the biggest cognitive leap at the D rung of the modalities' ladder. This makes it possible to consolidate the knowledge not only accumulated by a single person, but also by other people. That is why I am able to learn the philosophy of Plato or Aristotle, even though they lived more than two thousand years ago. Therefore, the formation of a 'full-scale' culture is possible only in humans.

According to the principle of parsimony, nature does not equip us with abilities that we are not able to use. Nonetheless, the fantastic E-rung cannot control any actual motor operation. Here the question arises: what is the purpose of this mental capacity?

This is the seat of both madness and genius. Here is placed an arsenal of the most powerful mental tools not only for sheer representation, but also for independent shaping of reality. Only on E-rung was it possible to create a curved space-time continuum by Albert Einstein. This is the 'unrealistic' E-rung, which makes it possible to create Great Science and Great Art. But at the same time, this also includes the danger of deviating towards great madness.

In short, the modalities' ladder can be considered a kind of 'gearbox' enabling the selection of the cheapest – in mental terms – way of performing a given motor operation. Therefore, the driver, who must immediately press the brake pedal, does not have to process the necessary information in a slow verbal modality.

The brain skyscraper and the modalities' ladder – mutual relations

The roots of the modalities' ladder, consisting of a hierarchy of individual rungs, are firmly anchored in the structure of the brain skyscraper, built of individual levels. Their relationship to each other is shown in Table 2 [21-22; modified].

Table 2. General characteristics and interrelations between the brain skyscraper and the modalities' ladder [21-22; modified].

Brain skyscraper level	**Modalities' ladder rung**	**Motor operation class**	**Control mechanism floor**	**Physical description layer**
A-level Rubro-spinal; Posture maintaining, strength and movement production	**A1-subrung** Interoceptive modality; Kinesthesis	**A1-class** Muscle tonus	**A1-subfloor** Posture maintaining	**A1-sublayer** Statics
	A2-subrung Proprioceptive modality; Motor coupling	**A2-class** Motor reflex	**A2-subfloor** Strength control	**A2-sublayer** Dynamics
B-level Thalamo-pallidal; Muscle synergies	**B-rung** Contact modality; Motor template	**B-class** Motor automatism	**B-floor** Technique	**B-layer** Kinetics

C2-sublevel Cortical; Dexterity	**C-rung** Teleceptive modality; Motor scenario	**C-class** Motor habit	**C-floor** Tactics	**C-layer** Kinematics
C1-sublevel Stratial; Agility				
D-level Cortical; Adroitness	**D-rung** Verbal modality; Motor programme	**D-class** Motor performance	**D-floor** Strategy	**D-layer** Geometry
E-level Cortical; Fantasy	**E-rung** Symbolic modality; Idea	**E-class** No motor operation	**E- floor** Politics	**E-layer** Topology

The prematurely born full-term baby and the recapitulation principle

Nikolai Bernstein called the new-born baby '*a premature born full-term baby'* [2-3]. A very young child is not able to live independently and requires careful care for a long time. Let us try, then, to apply Ernst Haeckel's principle of recapitulation [37-38] to the period after birth, until full maturity. The course of ontogeny (and of phylogeny as well) can be represented as a series of biological milestones – e.g. the emergence of eyesight – similar to catastrophes in the mathematical sense. Each of them brought about a huge, unpredictable leap in cognitive abilities, being *de facto* a system effect in the history of life on Earth (Table 3).

Table 3. The series of biological 'catastrophes' in the development of 'prematurely born full-time baby' into matured human being.

Rung	Biological "catastrophe"	Results	System effect in humans
A1	Kinesthetical modality creation	Posture maintaining	Building of 'background of all backgrounds' for purposeful motor operations.
A2	Proprioceptive modality creation	Strength and movement production	Building of 'raw movement's material' for purposeful motor operations.
B	Contactceptive modality creation	Tactile contact with environment; perception of tactile stimuli	Primary cognition of the ambient world. Two-dimensional, confined to dimensions of one's own body
C	Teleceptive modality creation	Teleceptive contact with environment; perception of visual and auditory stimuli	Vision: Three dimensional image of the ambient world, far greater space than dimensions of one's body. Movement and time perception. Basis for timing. Hearing: Construction of abstract representation of the world. Basis for language.
	Verbal modality creation	Verbal communication and representation of the ambient world	Breaking off direct connection of sensory experiences and temporal order. Immersing the world representation in the sphere of verbal fiction. Geometric representation of ambient world – common sense. Ability to creation of a new fiction.
	Symbolic modality creation	Symbolic communication and representation of the ambient world	Breaking off direct connections with real world representation. Free immersion in the sphere of fiction – dreams, poetry, madness, genius and Great Science.

This is coherent with Jean Piaget's and Bärbel Inhelder's views [39], as well as – roughly – with Nikolai Bernstein's brain skyscraper [2]. The development of intellectual and motor abilities in ontogeny of human is shown in Tab. 4.

Table 4. Development of intellectual and motor ability in ontogeny of a human [2, 21, 39].

Approx. age	Piaget's stage	Most advanced Bernstein's level	Main development factors
6 months		A	Child gains ability to make one's muscles stiff enough to be able to develop goal-aimed movements.
2 years	Sensori-motor	B	Child uses his/her sensory and motor capabilities to examine the environment.
2-7 years	Pre-operational	C	Child begins to use symbols. S/he reacts only to specific objects and phenomena, as well as their mental representations.
7-11 years	Specific operations	D	Child begins to think logically (cause-effect relations, temporal sequence).
Over 11	Formal operations	E	Child begins to think about thinking.

The family tree of science in a system-theoretical approach

The role of the senses in building human knowledge was expressed by Aristotle in his peripatetic axiom, which reads: "*there is nothing in the mind that is not first in the senses*" *(nihil est in intellectu quod non fuerit in sensu*) [40]. The 'raw' product of senses is referred to as '*quale*' (plural: *qualia*). In itself, it does not matter and makes up what is termed 'reception'. Only if joined with a specific meaning, retrieved in the process of perception from one's own memory, it gains some 'mental life' and the ability to be processed mentally, independent of environmental stimuli.

A very important phenomenon is the 'object permanence'. This means that the recipient of qualia retains some awareness of the item being the origin of sensory experiences even in the absence of stimuli. To achieve this, it is necessary to give the quale a certain mental meaning, that is, to separate mental representation from physiological sensations; this is called perception. The processing of these meanings then becomes possible even in the absence of stimuli. Therefore, two thousand years after Aristotle, Gottfried Leibniz completed the peripatetic axiom with the words: "... *except the mind itself*" (... *excipe: nisi ipse intellectus*) [41].

The object permanence gives rise to two other breakthrough phenomena: the sense number [42] and the perception of motion and time [28]. The former can be called "*protomathematics*", the latter – "*protophysics*". Together, they form what might be called "*protologic*." Unfortunately, it is made of extremely elusive concepts. Only the creation of a word that is resistant to the passage of time made it possible for protologic to mature and transform it into a 'full-size' logic. The latter is the 'binding agent' for two methods of mental order creating: philosophy (along with poetry) and protoscience, which later develops into full-fledged science. In a STA, particular branches of science are based – roughly – on mathematics (inanimate world), systems theory (animate world) and specific verbal logic (humanities, social sciences). Therefore, the general, simplified family tree of science based on STA can be shown as in Figure 2 [21].

According to the logic underlying the diagram shown in Figure 2, the considerations presented in this article should be placed in the block "*Inventiveness, mental order: protoscience, philosophy*". The latter is often rejected by 'genuine scientists' who worship the commonly accepted methodologies and model of the scientific article '*experimental material – research – discussion – conclusions*'. In their community, the term '*philosopher'* has a distinctly pejorative tinge. However, Mihai Nadin noted that "*philosophy remains the science of the sciences*" [43].

A similar idea was expressed by Albert Einstein, who stated:

> *Philosophy is like a mother who gave birth to and endowed all the other sciences. Therefore, one should not scorn her in her nakedness and poverty, but should hope, rather, that part of her Don Quixote ideal will live on in her children so that they do not sink into philistinism [44].*

Consequently, philosophy does not provide new, original experimental data and concrete, easily applicable solutions to the problems, so highly valued in the modern scientific 'vanity fair.' However, it provides a compass in navigating on the endless Ocean of the Unknown, searching for the enigmatic but powerful 'mind of God'. Only bold and good navigators will dare to venture into this vast, mysterious and full of traps space.

Incidentally: Albert Einstein stated: "*I want to know the thoughts of God; The rest is the details*." [30, 45]. However, the term 'mind of God' was coined by another atheist, Stephen Hawking [46].

Symptomatically, 'genuine scientists' are unable to discern a glimpse of mind of God, because it requires genius – and sometimes a drop of madness – not just 'commonly accepted methodologies.'

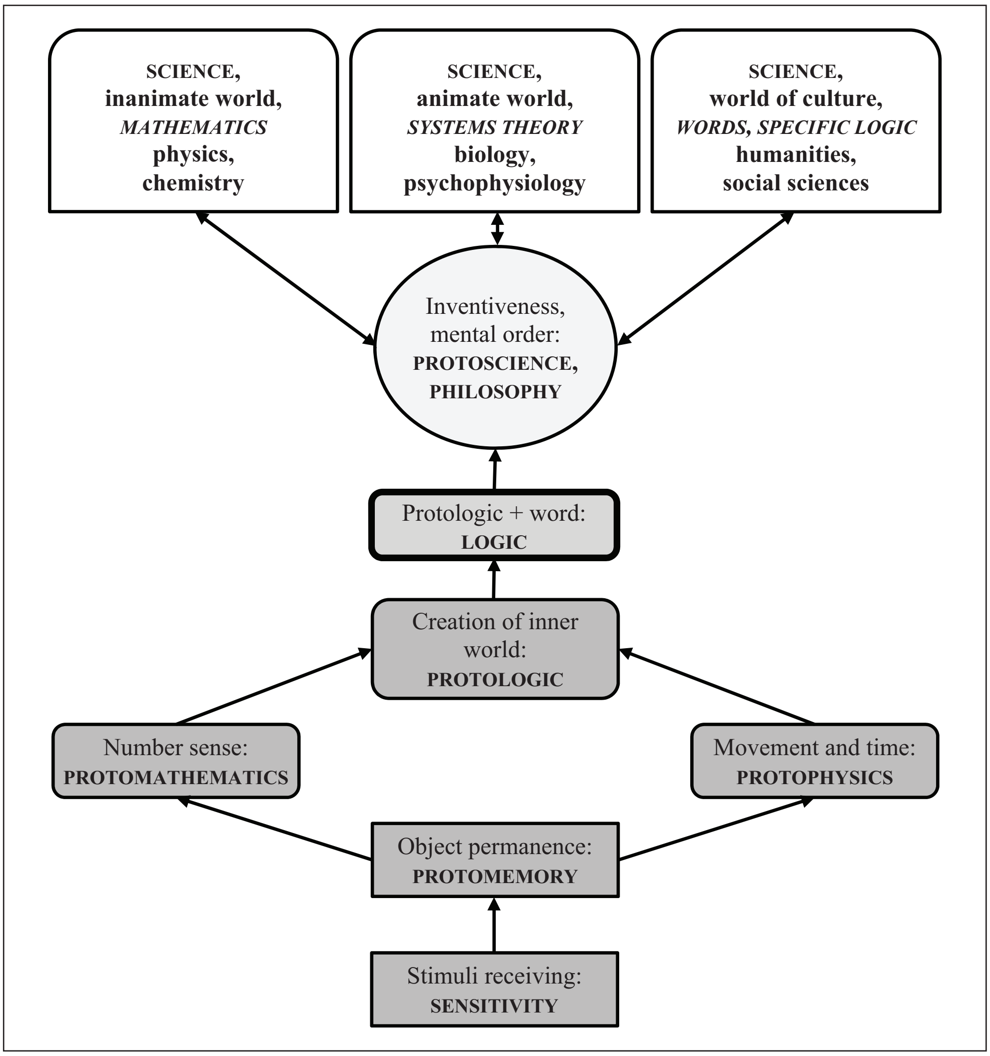

Figure 2. Simplified family tree of science in a system-theoretical approach [21; modified].

It would not be reasonable to expect such mental boldness and genius from every scientist. Therefore, science needs ‘dreamers’ who try to grasp the mind of God in the space of the Unknown. However, ‘genuine scientists’ are also necessary to methodologically bring order – but nothing more – to the region that the ‘dreamers’ transformed from the Unknown into the Known.

Final remarks

The idea of a systemic ordering of the structures of the central nervous system in the context of the motor abilities of living beings was borrowed by Nikolai Bernstein from John Hughlings Jackson [47]. The theoretical skyscraper-like construction – the triune brain – was independently developed in the period from the sixties to the eighties of the twentieth century by Paul MacLean [48-49]. Another similar concept was presented in 2003 by Jürgen Konczak [50].

A way of thinking similar to that underlying the modalities’ ladder, psychological and functional in nature, can be found in the works of William Carpenter [51] or Stanisław Gerstmann [52, 21].

In his book “Gödel, Escher, Bach” Douglas Hofstadter presented the search for the roots of human genius; the title characters were undoubtedly mental giants. The cover depicts a wooden block of a certain shape (Hofstadter carved it with his own hands) located in front of three perpendicular planes, as in the corner of the room. On one plane it casts a shadow in the shape of the letter ‘G’, on the second – in the shape of the letter ‘B’, and on the third – in the shape of the letter ‘E’. All shadows come from the same block. Neither is more or less true than any other. Nevertheless, they are clearly different from each other [53].

In science, any theory is inevitably a simplification. Biologist Jack Cohen and mathematician Ian Stewart noted, "*A Theory of Everything would have the whole universe wrapped up. And that's precisely what would make it useless*" [7]. Mathematician John Barrow also argued that "*Yet, paradoxically, science is only possible because some things are impossible*" [54]. The block sculpted by Hofstadter can thus symbolize science as a whole, and shadows – individual theories or even branches of science. Only such simplifications enable a scientist to build any understanding of the surrounding world.

In this perspective, scientists – including the author of the article – resemble slaves in Plato's cave, who from the shadows visible on the cave wall had to deduce what was happening in the world. But the scientist can either methodically study every shape on the wall, as 'genuine scientists' do, or imagine the nature of the object from which the shadow comes; the latter is the domain of dreamers and philosophers. I hope that the STA presented in the article will contribute to the explanation of at least some aspects of one of the shadows of anthropokinetics, which I consider to be the greatest intellectual challenge for all modern science.

Against this background highly instructive may sound the following anecdote:

> *During his Zurich stay the woman doctor, Paulette Brubacher, asked the whereabouts of his [Einstein's] laboratory. With a smile he took a fountain pen out of his breast pocket and said: 'here' [55].*

One cannot help feeling that modern science needs Einstein's fountain pen – filled, at least in part, with Aristotelian tincture of madness – far more than laboratories and computers. Especially in anthropokinetics.

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