

## Sensory integration research: priority scientific directions based on the analysis of Web of Science Core Collection resources

Olha Podrihalo<sup>1ABCDE</sup>, Władysław Jagiełło<sup>2ABCDE</sup>, Guo Xiaohong<sup>1,3ABCDE</sup>, Leonid Podrigalo<sup>1ABCDE</sup>, Tetiana Yermakova<sup>4ABCDE</sup>, Mirosława Cieslicka<sup>5ABCDE</sup>

<sup>1</sup> Kharkiv State Academy of Physical Culture, Kharkiv, Ukraine

<sup>2</sup> Gdansk University of Physical Education and Sports, Gdańsk, Poland

<sup>3</sup> Haikou School of Economics, Haikou, Hainan Province, China

<sup>4</sup> Kharkiv State Academy of Design and Arts, Kharkiv, Ukraine

<sup>5</sup> Collegium Medicum in Bydgoszcz, Nicolaus Copernicus University in Toruń, Bydgoszcz, Poland.

Authors' Contribution: A – Study design; B – Data collection; C – Statistical analysis; D – Manuscript Preparation; E – Funds Collection.

### Abstract

**Background and Study Aim** Monitoring the condition of athletes is one of the leading tasks in sports science. Predicting success and skill growth is an integral part of monitoring. The fulfillment of this task requires the use of modern methods and the sensory integration analysis occupies an important place. The purpose of this article is to analyze publications on sensory integration and identify priority research areas in this field.

**Material and Methods** The bibliometric database Web of Science Core Collection (WoS) was analyzed. 388 sources that met the search criteria for 2013-2023 were selected for primary analysis. Bibliometric methods were used for processing the obtained information. The program VOSviewer 1.6.18 was used for keyword analysis and direct citation analysis with the construction of bibliometric maps, visualization of cluster density, and weight – citations.

**Results** The leading publication categories in WoS were Neurosciences, Sport Sciences, Psychology, Psychology Experimental, Physiology, Rehabilitation. The distribution of publications by years was fairly evenly. Most publications were related to Germany and the USA. The most frequent institutions were German Sport University Cologne, Universidade de Sao Paulo, Shanghai University of Sport, Institute National de la Sante et de la Recherche Medicale Inserm, University of Freiburg. The most cited authors were identified. The constructed bibliometric maps allowed us to identify the leading thematic areas of research and current research directions in the field. The two most important clusters were identified. The largest cluster reflects research on balance and posture and the use of special exercises for rehabilitation in different population groups. The second cluster includes the most significant keyword in the whole map – “sensorimotor integration”. The works reflect studies of sensorimotor integration, the study of movement features, and coordination and control of movement at different levels.

**Conclusions** The conducted bibliometric analysis of publications confirms the relevance of sensorimotor integration. A stable interest in this problem has been determined. Research in this area has neurophysiological, sports-recreational, and medical-rehabilitation directions. Neurophysiological research is aimed at analyzing balance and equilibrium and the application of various tests and functional samples. The sport context studies sensory integration in different sports. Recreational publications have investigated sensory integration as a criterion of health. The therapeutic and rehabilitation focus explores the use of sensory integration as a criterion for treatment and rehabilitation. A characteristic feature is the intersection of these directions. There is a lack of studies devoted to sensory integration in sport dancing. There is a lack of studies aimed at studying the psychophysiological state. These types of research should be assessed as relevant.

**Keywords:** sensory integration, bibliometric mapping, VOSviewer.

### Introduction

One of the leading tasks in modern sports science is monitoring the functional state of athletes. Prediction of success and growth of sportsmanship is an integral part of monitoring, as it combines the following main tasks: collection and analysis of

information and development of a forecast based on the results obtained [1, 2]. The fulfillment of this task requires the use of modern methods of analysis, among which techniques aimed at sensory integration occupy an important place.

Currently, sensory integration is understood as the ability to synthesize, systematize, and process sensory information received from the body and environment. This process is based on the interaction of the brain, peripheral nervous system,

and musculoskeletal system. Sensory integration largely ensures the functional state of a person and determines the peculiarities of tiredness formation, performance, and productivity of sports activity [3, 4, 5].

Timing, integration, and coordination between sensory perception and motor skills are necessary conditions for successful planning and execution of all complex movements. This integrated approach is important for success in sport [6, 7]. However, there is relatively little research in this area. The study of the nature of the influence of training on the motor qualities of athletes is recognized as an actual direction of sports science.

Ensuring effective professional selection allows to ensure a high level of athlete success. The essence of such selection is a complex assessment of physical and psychophysiological properties with the help of a system of special tests. The main task of psychophysiological selection is to determine the state and degree of development of psychophysiological, mental, and personal qualities of the athlete. These qualities contribute to the successful mastery and effective use of professional skills [2].

The importance of psychophysiological features in optimizing the functional state of athletes is beyond doubt. The impact of certain sports on cognitive sensorimotor abilities and basic brain functions was assessed in the study [8]. The authors analyzed the features of the psychophysiological state of athletes in martial arts, rock climbing, and racket. Persons who did not engage in sports were the control group. It is shown that martial arts athletes had the best indicators of reaction time. The test performance was the most stable with the lowest number of errors. These athletes show the best motor readiness. The highest activity associated with postperceptual processing of attention was also determined in martial arts athletes. It is concluded that martial arts can provide the best functional level for athletes.

The psychophysiological features of athletes' conditions are an important component of ensuring success. Testing of coordination, reaction speed, concentration, and switching of attention and memory is used to control the state in various sports. Correlation between psychophysiological indicators and other criteria allow evaluation of training and prediction of the growth of mastery [9].

The effects of various exercises on postural balance control and the underlying physiological mechanisms have been extensively investigated. However, little is known about how the demanding conditions of exercise contribute to improved body balance and to what extent these changes can be explained by sensorimotor and/or neuromuscular adaptations [10, 11]. The aim of the review [10] was to analyze the literature investigating the

adaptation and control of posture in sport-specific training conditions and assess its correlation with sports performance indicators. The analysis made it possible to identify gaps in the existing research and offer suggestions for its optimization. The correlation between static and/or dynamic balance and sports performance criteria has been determined in archery, golf, and baseball. There is a tremendous amount of evidence to support neurophysiological adaptation to control postural balance due to exercise. However, there is insufficient research that explains balance adaptation and its effects on athletic performance. The correlation between performance and improved neuromuscular function induced by sport-specific balance exercises has not been definitively resolved. There is an opinion that this may be due to the influence of general physical exercises. It is concluded that there is a need for further research in this field.

In this context, it was of interest to conduct a bibliometric analysis of scientific publications devoted to sensory integration in journals of the international database Web of Science Core Collection.

The aim of this study was to analyze the publications devoted to sensory integration and to identify the priority scientific directions in this field.

## Methodology

### *Data sources*

Web of Science Core Collection (WoS) bibliometric database was selected as the source of the research sample as at 29.09.2023.

The main criterion for selecting databases was the quality of the information sources. 388 publications were selected (WoS). The sources met the criteria «sensory integration» + «sport». The added keywords used were «multisensory integration», «posture control», «sensorimotor integration», «sensory reweighting». The search time interval was from 2013-01-01 to 2023-09-29.

The leading WoS categories were Neurosciences with 142 publications (36.5%), Sport Sciences with 105 (27.1%), Psychology with 43 (11.1%), Psychology Experimental with 36 (9.3%), Physiology with 32 (8.2%), and Rehabilitation with 28 (7.2%).

The distribution of publications by years was fairly even. For the last 5 years of analysis, the specific weight of publications was: 2023 – 33 (8.5%), 2022 – 64 (16.5%), 2021 – 46 (11.9%), 2020 – 42 (10.8%), and 2019 – 41 (10.6%).

Analysis of document types confirmed most research articles. The number of article – 325 (83.8%), review article – 35 (9.0%), meeting abstracts – 12 (3.1%), proceedings papers – 12 (3.1%), and early access – 7 (1.8%).

Most publications were related to the following countries: Germany, 92 (23.7%); USA, 83 (21.4%);

England, 74 (19.1%); China, 36 (9.2); and France, 35 (9.0%). The analysis of affiliations allowed us to identify the most frequently occurring institutions: German Sport University Cologne – 19 (4.9%), Universidade de Sao Paulo – 19 (4.9%), Shanghai University of Sport – 17 (4.4%), Institute National de la Sante et de la Recherche Medicale Inserm – 16 (4.1%), University of Freiburg – 16 (4.1%).

#### Data analysis

Bibliometric methods [12, 13] for processing the obtained information in the context of sensory integration were used to analyse and determine the leading directions of research on the problem under study. To create and visualize bibliometric networks, we used the special program VOSviewer 1.6.18 [14]. This tool allows the analysis of keywords [12] and direct citations [13]. The calculation of the main indicators for analysing and identifying the most significant categories was performed according to the method [15]. The most cited references were used to identify promising research directions in this category. Distance-based bibliometric maps were used, in which the distance between two elements reflects the strength of the link between the elements. A smaller distance usually indicates a stronger link.

## Results

The program VOSviewer 1.6.18 created a set of bibliometric maps based on the purpose of the study. The main purpose of these maps is to identify trends in sensory integration research and highlight priority fields. The network visualization is presented in Figure 1.

The network was created based on 133 elements – keywords that had a repeatability of at least 5. They are organized into 6 clusters. The network is characterized by 2033 links, with a total strength of 3946. The size of the circles-keywords corresponds to the number of links received. The proximity of these circles on the map indicates the strength of the correlations between the elements. According to Fig. 1, the most common studies can be identified. They are centred around the keywords “sensorimotor integration”, “balance”, “performance”, “perception”, “proprioception”, “movement”.

The first cluster includes 38 keywords. This is the most significant cluster. It is marked on the map in red. The cluster is conditionally named “balance”. It is the most significant keyword. It has 122 links with other keywords in the map, and the total link strength (TLS) is 671. Next in order of decreasing number of links are: “gait” 53, (TLS 104), “reliability” 53, (TLS 106), “exercise” 51, (TLS 82), “older-adults” 50, (TLS 101), “walking” 44, (TLS 80), “adults” 41, (TLS 65), “individuals” 39, (TLS 71), “people” 39, (TLS 53), “young” 37, (TLS 59), “deficits”

35, (TLS 61), “risk” 34, (TLS 58), “recovery” 33, (TLS 45), “falls” 32, (TLS 60), “concussion” 28, (TLS 54), “physical-activity” 28, (TLS 38), “therapy” 28, (TLS 36), “injury” 27, (TLS 42), “symptoms” 24, (TLS 44), “quality-of-life” 22, (TLS 31), “risk-factors” 22, (TLS 31), “management” 22, (TLS 29), “tai chi” 22, (TLS 27), “association” 21, (TLS 27), “cognitive task” 21, (TLS 29), “error scoring system” 21, (TLS 37), “time” 21, (TLS 34), “anxiety” 20, (TLS 21), “health” 20, (TLS 22), “space” 20, (TLS 29), “synchronization” 20, (TLS 24), “prevalence” 19, (TLS 23), “epidemiology” 19, (TLS 22), “validity” 17, (TLS 29), “fatigue” 17, (TLS 20), “orientation” 16, (TLS 19), “instability” 15, (TLS 24), “traumatic brain- injury” 15, (TLS 25).

The keywords in this cluster reflect the focus of research on balance and posture and the use of special exercises for rehabilitation in different population groups. The maximum total link strength of the keywords “balance”, “gait” and “reliability” confirms this assumption. The analysis of key words allows us to assess the peculiarities of the research design, focus on studying the peculiarities of the human condition, and the prevalence of injuries and diseases that lead to balance disorders.

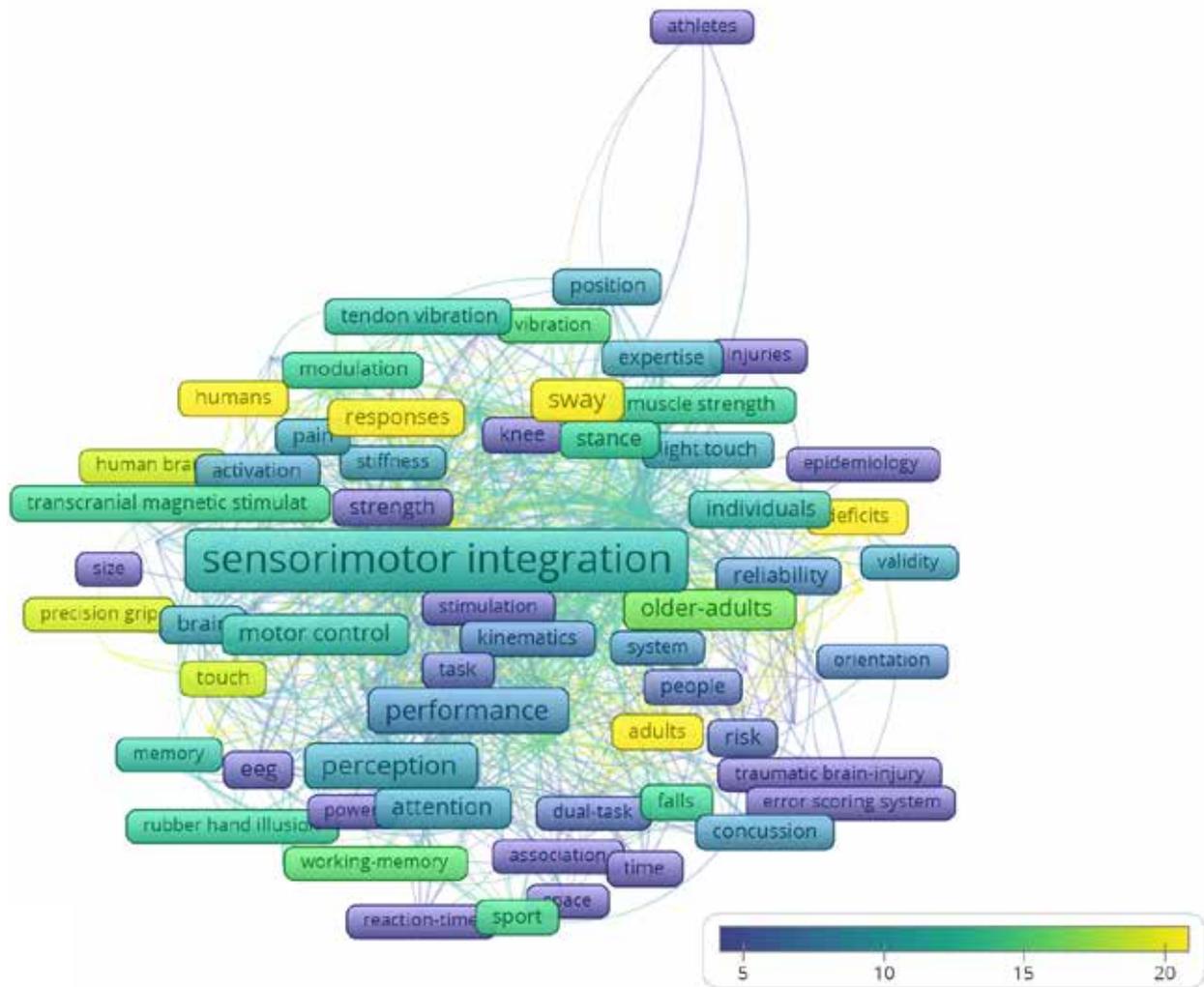
The second cluster includes 37 keywords. It is marked on the map in green. The cluster is tentatively named “sensorimotor integration”. It is the most significant keyword in the entire map. It has 128 links with other keywords in the map (TLS 782). Next, in order of decreasing number of links are as follows: “movement” 82, (TLS 193), “coordination” 47, (TLS 92), “motor control” 45, (TLS 78), “dynamics” 41, (TLS 80), “brain” 41, (TLS 65), “mechanisms” 41, (TLS 56), “humans” 40, (TLS 69), “model” 35, (TLS 55), “pain” 32, (TLS 38), “transcranial magnetic stimulation” 32, (TLS 51), “activation” 31, (TLS 42), “cortex” 31, (TLS 41), “visual feedback” 30, (TLS 35), “touch” 29, (TLS 50), “inhibition” 28, (TLS 39), “motor imagery” 26, (TLS 30), “stiffness” 25, (TLS 32), “healthy” 24, (TLS 30), “plasticity” 23, (TLS 32), “body” 22, (TLS 29), “discrimination” 21, (TLS 25), “hand” 21, (TLS 28), “position sense” 21, (TLS 29), “cognition” 20, (TLS 25), “knee osteoarthritis” 20, (TLS 27), “representation” 19, (TLS 26), “sensory feedback” 18, (TLS 21), “sensorimotor control” 17, (TLS 25), “motor cortex” 17, (TLS 25), “size” 15, (TLS 16), “embodiment” 15, (TLS 20), “functional magnetic resonance imaging” 13, (TLS 16), “precision grip” 13, (TLS 16), “human brain” 12, (TLS 13), “internal models” 11, (TLS 15), “rubber hand illusion” 11, (TLS 17).

This cluster illustrates the focus of research specifically on sensorimotor integration, the study of movement patterns, and coordination and control of movement at different levels. Most of the keywords in this cluster reflect neurological approaches to research in both healthy and sick people.

The third cluster includes 28 keywords. It is indicated in blue on the map. The cluster is conditionally named “performance”. This is the







**Figure 3.** Average number of keyword citations in publications on sensor integration and overlay visualization. Source: authors' own research based on data retrieved from WoS and analyzed with VOSviewer (29.09.2023).

“health”. This reflects the changing focus of research. This trend illustrates the correlation between sensory integration and various qualities, psychophysiological features, health, and quality of life. This suggests the need to study sensory integration in people with different levels of health. Sensory integration is used to monitor the condition of healthy people and to rehabilitate the sick.

Density visualization analysis by citation density of the authors revealed that the most cited authors are Asslander L [16, 17] with 264 citations and Han J [18] with 118 citations. This allows us to consider these authors to be the most authoritative in this field. They determine in many respects the direction of scientific research.

The overlay visualization network based on the number of citations is shown in Fig. 3. Keywords are analyzed by average citation frequency and are distinguished by color. Blue color corresponds to the lowest average number of citations, while the yellow color corresponds to the highest. In the first cluster, this index is the highest for “adults” – 38.45 and “instability” – 32.60, in the second cluster –

for “healthy” – 32.20, “model” – 30.27, in the third cluster – for “working-memory” – 15.00, “sport” – 13.82, in the fourth cluster for “adaptation” – 20.67, “motor learning” – 17.17, in the fifth cluster for “responses” – 22.35, “strategies” – 20.40, in the sixth cluster for “sway” – 19.91, “stroke” – 10.40.

### Discussion

The need for analytical reviews of the scientific literature is undeniable. This type of analysis allows assessment of the state of the problem, highlighting the most relevant problems, outlining ways to solve them, and identifying priority areas of research within the framework of the problem under study. Therefore, the purpose of this study should be evaluated as important for developing sports science.

The analytical review [10] pursued a similar goal. The authors conducted a literature search in Scopus, Web of Science, MEDLINE, and Cochrane Library databases on materials from Elsevier, SpringerLink, and Google Scholar publishers without date restrictions.

The bibliometric program VOSviewer is widely used in sports science. Its application allowed us to analyze publications devoted to the rehabilitation of patients with Alzheimer's disease with physical culture [19]. With the help of this program, an analytical analysis of Web of Science publications devoted to sport dancing was conducted, and the main directions of research in this area were established [1].

The analysis of the constructed bibliometric maps allowed us to identify the main directions of scientific research on this problem. They are defined as neurophysiological (the study of sensorintegration to control posture and balance, the use of tests and functional samples to analyze sensorintegration), sports and recreational (the use of sensorintegration in sports and recreational physical culture), and rehabilitation and therapeutic (sensorintegration as part of rehabilitation and treatment).

*Sensory integration study for posture and balance control*

Learning new movement patterns is a normal part of daily life, but of critical importance in both sport and rehabilitation. A major question is how different sensory signals are integrated together to give rise to motor adaptation and learning [20].

Multisensory integration is necessary for maintaining motor and cognitive abilities. It ensures normal functioning. Balance control is compromised during aging or movement disorders, increasing the likelihood of injuries and falls [4].

Human sensorimotor control involves inter-segmental coordination to cope with the complexity of a multi-segment system. The combined activation of hip and ankle muscles during upright stance represents the hip-ankle coordination. The study [21] postulates that the coordination emerges from interactions on the sensory levels in the feedback control. Seven subjects were standing with eyes closed on an anterior-posterior tilting motion platform. Postural responses in terms of angular excursions of trunk and legs with respect to vertical were measured and characterized using spectral analysis. The presented control model consists of separate feedback modules for the hip and ankle joints, which exchange sensory information with each other. The findings show that the hip-ankle coordination can be explained by interactions between the feedback control modules of the hip and ankle joints.

Sensorimotor integration processes play an important role in everyday life. Their implementation requires the analysis of different sources of information - information related to the object under the control of the indicator agent and information about the goal of the action [22]. The use of EEG has confirmed that complex sensorimotor

integration is realized through a cascade of theta- and beta-band activity in the ventral-flow-parietal-frontal network.

Movement planning is determined by factors such as accuracy and effort. Improving the quality and efficiency of movement is associated with minimizing force and increasing accuracy. Optimal movement is characterized by feedback control, which allows for prompt correction of errors. However, the quality of sensory feedback during motion can be significantly affected by the motion generated [23]. The results show that trajectory planning is sensitive to motor input and takes sensory input into account. This is an argument in favor of optimal motion control.

Body sensing involves the integration of different sensory cues according to their contextual relevance (i.e., multisensory integration). Most studies of multisensory integration and body ownership have examined the influence of vision, touch, and proprioception. The role of the vestibular system and interoception remains poorly understood. A previous study [5] confirmed that the vestibular system influences multisensory integration. A possible pathway of influence was to reevaluate the multifaceted connections between proprioception, vision, and affective touch.

The ability to assess visual and proprioceptive information is crucial for maintaining postural stability in a dynamic environment [17]. Healthy people control the balance of their standing posture with the help of active feedback. This communication is based on a combination of motion and orientation signals from the visual, vestibular, and proprioceptive systems. The contribution of each of these sensory systems varies depending on the perturbations occurring during stance and the environmental conditions [16]. The process of adjusting the sensory contribution to balance control is called sensory reweighting. In a study involving healthy young adults, the responses to changes in a swinging platform combined with different visual stimuli were examined. The different contribution of extrinsic and intrinsic factors to posture control and balance maintenance was confirmed.

In the study [24], how the nervous system manages muscle forces and controls upright posture and locomotion in varying gravity is reviewed. The main aspects of posture and gait control for short- and long-term adaptation are presented. These include sensory feedback integration and biomechanical outcomes that determine the quality of motor skills.

Removing or adding sensory cues from one sensory system during standing balance changes the contribution of the remaining sensory systems, a process referred to as sensory reweighting [16]. Changes in sensory conditions were achieved by adding or removing visual (light on/off) or

proprioceptive cues (surface sway). A dependence of steady-state responses on upcoming transitions was observed, suggesting that knowledge of impending changes can influence sensory weighting.

The vestibular system contributes to multisensory integration by balancing conflictual sensory information [25]. It was shown that vestibular signals modulate the weight of each sensory modality according to the context in which they are perceived and that such modulation extends to different aspects of tactile stimulation: felt and seen touch are differentially balanced in multisensory integration according to their epistemic relevance.

The use of virtual reality (VR) is another way to explore balance control, a tool for gait rehabilitation. VR offers the possibility of decoupling the visual from the somatosensory and vestibular systems. This means that it enables training under conflicting sensorimotor stimulation that creates additional demands on sensory reweighting and balance control. The results of the study [26] allow us to recommend the use of VR to assess adaptation to balance changes.

A promising method for studying sensory integration is the use of fractal analysis. Multifractal analysis is used to study balance. This allows us to understand the patterns of movement of the centre of pressure at different spatial scales [27]. In this paper [27], this method was used to compare balance in obese and normal weight children. It was confirmed that balance disorders in obese children may be the result of reduced proprioceptive abilities.

A similar aim was found in another work [28]. The effect of physical activity level on postural control in obese and overweight Spanish adult males was studied. The anthropometric parameters, body composition, and physical activity variables were evaluated. Postural control was assessed using the sensory organization test. It was concluded that altered integration of somatosensory signals affects balance in sedentary men with a high percentage of total fat masses.

The purpose of another study [29] was to compare the postural control of young and elderly people. Older people had worse sensory and motor characteristics and greater amplitude of body sway while standing. A stronger correlation between body sway and movement in a moving room was observed in the elderly. It was confirmed that increasing the complexity of motor task impairs posture control in elderly individuals.

In another study [30], the effects of distance and optical flow structure on visual information and body jiggle interaction in children and young adults were studied. The effect of distance and visual flow structure on the transmission of visual information and body sway is dependent on age. The effect is more pronounced in children. The authors

attribute this to the immaturity of the coordination mechanisms.

Another study [31] evaluated the dynamics of pose parameters when subjects switched from a habitual passive pose to an actively corrected pose. We confirmed that changes in sagittal postural parameters can be used for diagnostic purposes in postural disorders and regulation.

#### *Tests and functional tests used to analyse sensory integration*

At present, a large number of functional tests and trials are used to study the peculiarities of sensory integration. The purpose of this study [32] was to determine the sensitivity of the instrumental-modified clinical sensory integration test for balance assessment. The test consisted of opening and closing the eyes while on a hard and frothy surface. A special sensor was used to detect deviation. The time of the stable position was also determined. The effectiveness of the test used to assess central sensory integration deficits was confirmed.

The use of computer programs for testing has several advantages in monitoring the functional state. This variant of testing is characterized by promptness, mobility, accessibility, and informativeness. Approbation of the complex confirmed the possibility of assessing the peculiarities of athletes' condition, confirming the specificity of the influence of sports, and allowing the identification of predictors of success in various martial arts [2, 33, 34].

A set of psychophysiological tests was used in study [33] to assess the sensory systems of the body of taekwondo athletes. A special computer program for devices with iOS operating system was used. The device used was an Apple tablet computer (iPad, 4th generation) with a screen diagonal of 9.7 inches. Reaction choice or complex visual-motor reaction evaluated the reaction time to a stimulus with certain qualitative characteristics. The reaction to a moving object consisted of stopping the object at a given location at a given speed of the moving object. The size test consisted of fixing the moment when the size of a gradually increasing circle coincided with the size of the template.

Another methodological technique used to investigate sensory integration is the use of Achilles tendon stimulation. This approach was used in the study [35]. Bilateral Achilles tendon vibration was used to disrupt the accuracy of proprioceptive information. Participants were in a standing position and performed two tasks: maintaining a standing posture and waiting for virtual objects. It was concluded that there is an age dependence of the ability to maintain posture. It was suggested that the results could be used to prevent fall-related injuries in the elderly.

A study [36] used muscle electromyography

under different conditions to compare the postural control of young and elderly people. Participants were placed on a fixed platform (baseline: 2 minutes), followed by 3 min on a platform with sway control (adaptation) and a final 3 min again on a fixed platform (reintegration). Older adults exhibited greater joint contraction of lower limb muscles under conditions of increased postural instability. This response reflects a compensatory postural strategy.

In another study [37], a comparative evaluation of tests that are used to assess sensory dependence was conducted. The sensory organization test (SOT) is a standard for quantifying sensory dependence via sway-referenced conditions (sway-referenced support and sway-referenced vision (SRV). However, the SOT is limited to expensive equipment. Thus, a practical version of the SOT is more commonly employed—the clinical test for sensory integration in balance; however, it fails to induce postural instability to the level of SRV. It was indicating that stroboscopic vision could be a portable and relatively inexpensive alternative for the assessment of sensory dependence and reweighting.

The design of the study [38] involved assessing postural balance while standing blindfolded on a fixed platform, then on a fixed platform, and then again on a fixed platform. The sway-oriented platform was more malleable for young adults and elicited similar levels of sway in both age groups. Participants were asked to press a button whenever they felt the platform stopped moving. It was confirmed that older people took longer than younger people to feel the platform stabilize. It was concluded that sensory integration is less effective in the elderly.

In another study [39], participants performed a temporal rhythm reproduction task. The experiment included auditory (beeps), visual (flashing dots), and audiovisual conditions (beeps and dots simultaneously). The results showed higher accuracy and less variability in the auditory condition than in the visual condition. It is concluded that the auditory modality dominated the multimodal perception in the task. The visual modality was ignored and did not enhance the playback performance.

A mediated reality device called MIRAGE was used in the study [40]. The purpose of this study was to examine how the brain evaluates visual and proprioceptive information during a hand place task. Children aged 4–11 years estimated the position of their index finger after viewing visual and proprioceptive information about hand position. It was confirmed that the way visual and proprioceptive information is integrated is optimized throughout development. It was found that the propensity for visual information increases with age.

An integrated approach in the evaluation of

sensor integration contributes to the effectiveness of the study. In this study [7], a set of specific tests was used for comparative assessment of sensory integration. These include T-test agility, stork static balance test, and Y-balance test. Significant differences in the performance of these functional tests in athletes with different postures were confirmed.

A rather large battery of tests was used in the study[41]. It was including the modified Balance Error Scoring System (mBESS), concussion balance test (COBALT), and sensory organization test (SOT) in healthy young adults. The mBESS conditions included double limb stance, single limb stance, and tandem stance. The COBALT was comprised of yaw plane head shake (HS) and vestibular ocular reflex cancellation conditions performed on firm and foam surfaces. The representativeness and informativeness of the tests used and the presence of correlation between the results were confirmed.

The analysis of correlations between neurocognitive data, performance, and balance was performed in the study [9]. The sensory organization test (SOT) was used in college athletes. The test's scoring criterion is composite and includes three measures of sensory relations: vestibular (VEST), visual (VIS), and somatosensory (SOM). Their use describes the overall sensory organization of athletes and their ability to use signals from each sensory system to maintain balance.

Functional ankle instability in soccer players is an important risk factor for athletic performance [42]. The aim of this study was to evaluate the effectiveness of tai-chi exercises together with joint taping for the rehabilitation of soccer athletes. A set of sensor integration tests was used as an assessment tool. These include the Star Excursion Balance Test (SEBT), UniPedal Stance Test (UST), and toe touch test (TTT).

Agility and the ability to maintain balance are important qualities for success in sport and physical education. Determining informative and adequate tests for their evaluation is an important task in sports science [43]. In this study, we studied the correlation between agility and dynamic balance in elementary school children. The modified Star Excursion Balance Test (SEBT) and shuttle run (4 10 m) were used to assess dynamic balance and agility. The presence of correlations between the test results was confirmed.

SEBT was used to assess the motor skills of golfers [44]. Differences in postural control were observed in golfers with chronic low back pain. This group had more pronounced balance deficits than those without pain. The informative and accessible nature of the SEBT allows it to be recommended for skill assessment of elite golfers.

The Y-Balance-Test is a functional test that assesses balance features. It was proposed to use this

test to assess the preservation of balance in soccer players with different game roles and different skill levels [45]. The determined differences show how these factors influence the development of asymmetry. They should be considered in the development of preventive and health improvement programs.

Analysing balance and equilibrium requires developed benchmarks and normative indicators. This was the purpose of this study [46]. The battery of tests used included the Counter Movement Jump (bipodal jump), 5-m Shuttle Run Sprint Test (speed/agility), Barrow Test (agility), Y Balance Test (posture control), Single Hop Test, and Triple Hop Test (unipodal jump). Approbation was carried out with the participation of 42 professional soccer players who were functionally assessed during two seasons (2012/13 and 2013/14) at three different times: pre-season, midpoint of the season, and end of the season. The paper contributes reference values that can be used to determine the sports performance or quantify the degree of functional recovery of a professional injured soccer player during his recovery.

Another study [47] examined gender differences in postural balance, physical activity, BMI, and body composition in athletes with visual impairment. The Clinical Sensory Integration and Balance Test was used to assess postural balance. The test was performed in four standing positions: with eyes open on a hard surface, with eyes closed on a hard surface, with eyes open on a pliable surface, and with eyes closed on a pliable surface. Depending on the athletes' levels of fitness, differences in postural maintenance have been found.

The aim of this study [48] was to study the possibility of improving functional status in patients with Down syndrome who practiced taekwondo. The evaluation of exercise performance included a balance study. A battery of tests included the modified clinical sensory integration and balance test (mCTSIB) with eyes open and closed. Dynamic balance was measured using the limits of stability (LOS) test.

The aim of this study [6] was to investigate the effect of synchronized training using a metronome on sensorimotor synchronization in elite and semi-elite female soccer players. Timing accuracy was assessed by synchronizing hand and foot movements with a rhythmic sound. The results show that the training variant used can positively affect attention and working memory functioning. This leads to better movement planning and improved performance and accuracy of movements. It was confirmed that an increase in speed is positively correlated with accuracy and duration of movement execution.

Another study [49] examined the effects of karate-do classes on improving the motor skills

of adolescents with developmental coordination disorder. A short form of the Bruininks-Oseretsky test was used as the instrument. This test assesses the accuracy and integration of fine motor skills, upper extremity dexterity and coordination, bilateral coordination, balance, strength, speed, agility, and overall motor skill level of the participants.

Another study investigated the effect of calf muscle taping on postural stability [50]. A battery of tests was used, namely a balance test, a surface sensory function test, and a combined cortical sensation test. The adequacy of the tests used for solving the task was confirmed.

A computer complex of 10 psychophysiological tests was used for comparative analysis of the psychophysiological features of athletes in different types of wrestling [2]. The applied battery of tests allows us to estimate the speed of the reaction to various signals, coordination, concentration, and sense of space. A different magnitude of the contribution of the studied indicators to the formation of the functional system of wrestlers was established. In judoka and sambo wrestlers, these are the tapping test, the number of touches in simple motor skills, and the form matching test. The applied tests are informative for the assessment of athletes' functional states.

#### *Use of sensory integration in sports and recreational physical culture*

Visual skills in sport are considered relevant variables of athletic performance. However, data on the specific contribution of stereopsis - as the ability to perceive depth - in sport performance are still scarce and scattered in the literature. The aim of review [51] is therefore to take stock of the effects of stereopsis on the athletic performance, also looking at the training tools to improve visual abilities and potential differences in the visuomotor integration processes of professional and non-professional athletes. Dynamic stereopsis is mainly involved in catching or interceptive actions of ball sports, whereas strategic sports use different visual skills (peripheral and spatial vision) due to the sport-specific requirements. As expected, professional athletes show better visual skills as compared to non-professionals. However, both non-professional and professional athletes should train their visual skills by using sensory stations and light boards systems. Non-professional athletes use the visual inputs as the main method for programming motor gestures. In contrast, professional athletes integrate visual information with sport expertise, thus, they encode the match (or the athletic performance) through a more complex visuomotor integration system.

Sensorimotor stimulation during the sensitive period is crucial for proper brain development. Sports training stimulates these sensorimotor

functions. The aim of this study [52] was to investigate the effect of such stimulation on specific sensorimotor characteristics of adolescents. A comparative analysis of stability limits in the athletes and control group was carried out. It was found that training in martial arts improves balance control and proprioceptive integration.

Improving balance control is one of the most important tasks in sports and physical education. Improved balance is positively associated with improved athletic performance and negatively associated with lower extremity sports injuries. Proprioception is critical to balance control, and ankle proprioception is perhaps the most important. An article [18] reviewed ankle proprioception and investigated its interaction with balance control, which is particularly important in a sporting context.

A previous study [53] investigated the integration of visual and auditory cues to control interceptive movements. A baseball launch was evaluated as a model. Human observers estimated its trajectory. It was shown that auditory and visual cues integrate. This integration process should occur as early as possible.

Vision is the dominant sensory system in sports, but many sports require multisensory integration to perform tasks effectively. Accelerating the processing of auditory information contributes to improved reaction speed, considering the audiovisual characteristics of the signals. In the study [54], the response speed of elite badminton athletes to sport-specific monosensory (visual and auditory) and multisensory (audiovisual) stimulation was studied. The results emphasize the importance of auditory information in accelerating reaction times in sport-specific multisensory situations. The results can be used to optimize training in racket sports.

Stimulus identification and understanding of action results are crucial for fast and accurate reaction selection in racket sports. The article [55] investigated the neurodynamics of visual anticipation in tennis by manipulating the postural and kinematic information associated with the body of opponents with a spatial occlusion protocol. Experienced athletes were characterized by better resource allocation, reaction speed, and sensorimotor representation.

A previously cited study [9] examined the correlation between neurocognitive data, performance, and balance in college athletes. Reaction time and executive function were significantly correlated with balance characteristics. These processes may affect athletes' ability to organize and process information and generate appropriate responses to changes in the environment.

The study of the dynamics of psychophysiological indicators of 15-16 years old ice hockey players was the aim of this study [56]. The battery of tests

included the speed and accuracy of visual-motor reactions, the level of sensorimotor and arbitrary coordination of movements, and the functional state of the central nervous system. The mental state was determined using the Lusher test. Interference resistance of hockey players increases at the end of the competitive period because of the improvement in arousal concentration. Sensorimotor and arbitrary coordination of movements changes only in the static form of muscle contractions. The mental status of hockey players varies from conditional norm to stressful, which requires individualized corrective measures.

The relative contribution of sensory signals to balance control in the standing position is dynamically regulated. These processes are influenced by age and athletic ability. This is especially characteristic of sports in which balance and balance maintenance are important, for example, in artistic gymnastics. The aim of study [57] was to investigate sensory reweighting processes to adjust standing posture in children and adults with different gymnastic expertise (gymnasts, G, and non-gymnasts, NG). Sensory integration was assessed by standing on a balancing platform with the eyes open and closed. Gymnast children required less time to regain balance and performed fewer movements than non-gymnast children. Maintaining balance was more effective with the eyes open. It is concluded that age may have a positive effect on balance recovery processes and that gymnastic experience may contribute to better postural control.

Exercise, particularly gymnastics, contributes to balance improvement. The aim of this study [11] was to evaluate balance control and adjustment in children and adults with different gymnastic experiences. The characteristics of sensorimotor control in children with no gymnastic experience differed significantly from those of gymnast children. Gymnast children were characterized by better coordination and posture control than adults.

Another study [58] investigated the effect of sports experience on the sensory control of posture. The participants were experienced soccer players, ballet dancers, and non-sports individuals. Soccer athletes were more field dependent than were non athletes. They are performed (a) a Rod and Frame test and (b) a 100-s bipedal stance task during which vision and proprioception were successively or concurrently disrupted in 20-s blocks. During standing, dancers were more destabilized by vibration and required more time to reweigh sensory information compared with the other 2 groups. These findings reveal a sport skill-specific bias in the reweighing of sensory inputs for spatial orientation and postural control.

Balance control in sports is essential for success. In the study [59], a comparative analysis of such

control in kung fu athletes and swimmers was conducted. The aim of this study was to determine which activities are more effective in developing the ability to maintain balance. The deviation of the center of gravity while standing on two and one leg on a stabilometric force platform under open-eye and closed-eye conditions was used as the main evaluation criterion. Unicyclists were characterized by better control in the one-legged stand. Swimmers were confirmed to have better control in the two-legged stand. It is concluded that both types of exercise positively affect the ability to maintain balance.

A comparative analysis of the psychophysiological features of taekwondo athletes of different ages was carried out in the study [33]. The change in reaction speed to different stimuli was confirmed. An increase in age and years of training leads to an improvement in reaction speed indicators. The established correlations between the tests used also reflect the improvement in the psychophysiological state of athletes as age increases.

The effect of Tai Chi exercise on cognitive processes was investigated in the study [60]. The authors compared elderly people with a long history of tai chi with those with a long history of walking. The results showed that the accuracy of the Tai Chi group was higher than that of the control group because of increased perceptual sensitivity. It is concluded that prolonged Tai Chi exercise improves multisensory integration in the elderly.

The review [61] evaluated the effectiveness of Tai Chi exercise in improving walking and posture control in older adults. This meta-analysis confirmed that Tai Chi can be an excellent exercise strategy for improving walking function and posture control in older adults with knee osteoarthritis. Tai Chi exercises are quite effective and safe. It is recommended that they be used as a supportive and reliable physical training strategy to improve walking function and balance control.

Another study [62] presented a developed neuromuscular model that describes jumping movements. The model evaluates the effects of the proprioceptive length (LFB), velocity (VFB), and force feedback (FFB) pathways of the leg extensor muscle on the stability, performance, and efficiency of jumping. The model predicted that different reflex pathway compositions selectively optimize specific hopping characteristics (e.g., performance and efficiency). Both FFB and LFB were pathways that enable hopping. FFB resulted in the largest hopping heights, LFB enhanced hopping efficiency and VFB had the ability to disable hopping. Results indicate that different feedback pathway compositions may serve different functional roles.

Sensory integration is very important in sports such as badminton [63]. The “rubber hand illusion” was used to assess the athlete’s hand representation.

A negative correlation was found between the playing experience and the magnitude of the illusion. This finding suggests that tool embodiment obtained by the prolonged use of the badminton racket is less likely to be disturbed when holding the racket.

The dependence of sensory integration on age was studied in a previous study [64]. The ability of young and old people to maintain their posture under normal conditions and under the influence of destabilizing factors was studied. It was confirmed that elderly people have less ability to reduce the destabilizing effects of multisensory perturbations on posture.

In other article [65] investigated the effects of bimodal integration in a sport-specific task. Beach volleyball players were required to make a tactical decision, responding either verbally or via a motor response, after being presented with visual, auditory, or both kinds of stimuli in a beach volleyball scenario. In Experiment 1, players made the correct decision in a game situation more often when visual and auditory information were congruent than in trials in which they experienced only one of the modalities or incongruent information. Decision-making accuracy was greater when motor, rather than verbal, responses were given. It is concluded that the integration of visual and auditory information leads to more accurate decision making in sports than unimodal information.

The study [66] confirmed that auditory cues influence motor behavior and emotional valence. It is shown that sounds that do not match the movement being performed are processed at a lower rate of information processing. The results obtained are important for the use of auditory cues in sport competitions, given their influence on motor behavior.

The review [67] discusses the possible difference between effort and tension and the implications of such differences for understanding the role of representations in pace control during exercise. Estimates of perceived exertion and effort are considered extremely important for intensity regulation during physical activity at an individualized pace.

Qualitative sensory perception is related to success factors in sports. In the study [68], stereognosis, self-body perception, and kinesthesia were compared in karate athletes and individuals who did not practice sports. The athletes had significantly better perception and accuracy in performing fast dynamic movements compared with the controls.

The review [69] evaluated the possibility of using dance to improve the health of healthy individuals and Parkinson’s disease patients. Dance as a sensorimotor activity stimulates the nervous system. It improves structures involved

in movement planning and execution, sensory integration, and cognitive processing. Dance interventions in healthy older adults were associated with increased activation of the prefrontal cortex and improved functional connectivity between the basal ganglia, cerebellum, and prefrontal cortex. Overall, the data suggest that dance interventions can induce neuroplastic changes in healthy elderly participants. This leads to improvements in both motor and cognitive functions.

A comparative analysis of balance control in athletes of different sports was conducted in the study [70]. The study involved judo athletes, equestrian sport athletes, and non-athletes. The influence of sports experience on postural control was confirmed. The severity of the influence depends on the sport. Equestrian athletes had a greater dependence on vision than non-athletes. This confirms the different contributions of sensory components to balance control in different sports.

The analysis of sensory integration in athletes requires the use of standardized tools and the development of specific norms. This was the aim of this study [71]. The modified clinical test of sensory interaction and balance (m-CTSIB) was used as the instrument. Analyzing the results of the athletes confirmed the differences by gender. Norms for the test results were developed for the entire sample and by gender. It has been suggested that norms can be used to assess the effects of sports injuries.

In another study [72], posture control and vestibularocular apparatus of pistol shooters were evaluated. The posture of athletes is characterized by a significant shift of the center of gravity in the anteroposterior and medial-lateral directions. This causes significant changes in posture control.

Habitual posture is important for ensuring sensory integration in sports. In the study [7], a comparative analysis of sensorimotor integration of athletes with different head postures was performed. Athletes with a forward head tilt were characterized by impaired sensorimotor processing and decreased fitness compared with those with a normal sagittal head posture.

Golf is a sport in which the result mostly depends on correct body position and control. Blind trainings are practiced in this sport to improve sensation [73]. Beginning golfers performed strokes with and without visual control. The results suggest that the body position task provides adequate sensory cues for successful execution.

The possibility of using visual information for prediction in tennis was analyzed in the study [74]. Video recordings of matches in the Australian Open Tennis Championship were used as material. Experienced tennis players predicted where the ball would land on the opponent's half of the field. It is shown that the louder the sound of racket contact with the ball, the longer the participants predicted

the trajectory of the ball. It is concluded that action-related auditory cues can significantly influence the prediction of stroke outcomes in tennis.

The effect of multi-ball table tennis training on balance performance in males and females was investigated in another study [75]. Compared with male table tennis athletes, females showed worse dynamic posture control. The results obtained should be considered in the training of athletes.

Anticipation of ground reaction force (GRF) in depth jumping requires multisensory integration of exteroceptive, vestibular, and proprioceptive inputs. Vision contributes to the anticipation of GRF in drop landings and may influence depth jump performance when disrupted. The purpose of this investigation [76] was to evaluate the effects of stroboscopic vision on depth jump performance. Stroboscopic vision could be used to modify the intensity of depth jumping and should be considered for inclusion into plyometric training.

Physical inactivity and sensory integration dysfunction are public health problems in preschool children in China [77]. To optimize the situation, a functional training program was developed for healthy children aged 5 to 6 years. The purpose of this study [77] was to evaluate the effectiveness of this program. It was concluded that a 12-week functional training program improved large motor skills, physical fitness, and sensory integration in healthy Chinese children aged 5-6 years.

The importance of sensory integration in cyber sports is discussed in the study [78]. It should be noted that there are still insufficient criteria to differentiate elite athletes in this sport. Using the example of first person shooter games, a comparative analysis of the state of cyber athletes of different levels and the control group was carried out. The position and speed of cursor movements for target acquisition were evaluated. Higher-level gamers demonstrate superior motor planning and sensorimotor integration. These qualities can be improved with training.

Success in soccer depends on proposing and implementing unpredictable, sudden, and yet creative ideas in situations with large time constraints. Accordingly, the performance of creative tasks in soccer should be primarily driven using fast and automatic cognitive processes. In the study [79], we investigated whether functional patterns of brain activation during the observation of real soccer game situations can predict the performance of creative soccer tasks. Machine learning, which is based on multidimensional pattern recognition, was used as a tool. The study was conducted with experienced soccer players. The results showed that brain activation while watching soccer scenes significantly predicted the performance of creative tasks.

Proper posture is a predictor of success in

archery. Posture control can improve performance, prevent injury, and maintain optimal performance. The main parameters of posture and movements of experienced archers were analyzed in the study [80]. The angles of the main joints are important for quality shooting. An algorithm for automating the evaluation of the biomechanical features of archery was proposed.

Sports equipment is one of the factors affecting postural balance. Possible differences in stability between standing conditions in ski boots and barefoot were analyzed in the study [81]. The authors evaluated the influence of surface type on stability and determined the differences in stability levels between different planes. Restriction of ankle joint mobility due to wearing ski boots resulted in decreased stability of participants, especially in the sagittal plane. The differences found were due to difficulties reorganizing muscle coordination at the hip joints. The use of mechanical ski boot support was effective in reducing lower limb muscle tone. The use of a soft surface improved the subjects' stability in the frontal plane but did not change the stability in the sagittal plane. The soft surface may have helped to reduce excessive corrective movements, thereby improving the participants' postural stability.

Another study [82] analyzed the peculiarities of postural maintenance in volleyball players compared with non-athletes. Athletes showed a different pattern of sensory integration of postural stability than the control group. Large deviations of the center of gravity reflect these differences. Increasing levels of athletic skill contribute to better postural control. It is proposed to use this protocol to evaluate the effectiveness of training programs, select elite players, and determine playing roles.

A similar design was used in the study [83]. The aim of this study was to compare the postural control of players of the Polish women's national volleyball team with a control group of women. Participants stood on a force plate with their eyes open. The center of gravity signals were recorded in the medial-lateral and anteroposterior planes. It was confirmed that the high demands of volleyball movements resulted in the formation of unique postural control abilities in female volleyball players. On the court, athletes optimally distribute their sensory resources between balance control and game actions. There are no well-defined criteria for an optimal postural strategy for elite athletes. These criteria may be sport-specific.

The effects of core training using slings and Togus on the improvement of posture control in Taekwondo club students, that is, balance ability, were investigated [84]. The result suggests that active core exercise using Slings and Togus can be applied as a very effective exercise program for enhancing balance, which is an important physical factor for

Taekwondo club students.

Another study [85] determined the effect of proprioceptive training on balance, strength, agility, and ball handling in adolescent soccer players. Specific exercises were used to improve balance, stability, and strength with and without a ball. Pre- and post-tests included the static balance (Balance Error Scoring System (BESS)), vertical, horizontal, and lateral jumping, and the completion of agility ("arrowhead") and dribbling ("short dribbling") tests. The results of the study revealed that sports training on the foam surfaces determined a superior progress of the development of proprioception compared to the increased training on the firm surfaces.

Interest in the study of short-term memory of athletes is due to the integral nature of this criterion and its correlation with indicators important for assessing the state. The design of the study [86] was to simultaneously record psychophysiological (short-term memory) and physiological (HR) parameters. The importance of short-term memory for success in martial arts has been confirmed. Athletes need not only fast reaction but also accuracy of work, which is evaluated by this parameter. Comparative analysis of the results confirmed the dependence on the level of athletic skill.

#### *Sensory integration as a part of rehabilitation and treatment*

Multisensory integration is currently defined as the ability to effectively combine information received from different senses. This process is quite variable and depends on the aging process. The main factors that impair processing is age, balance disorders, and cognitive impairment. The aim of the review [87] was to evaluate the evidence for the feasibility of multisensory perception training. It was confirmed that training with feedback during task performance using standardized protocols resulted in improved task performance. The training results indicate that physical activity protocols require further investigation as a means of improving multisensory integration.

Balance disorders are a frequent complication of brain injury and can be quite long lasting. The sensorimotor responses of healthy individuals and individuals with balance disorders due to brain injury were compared in the study [88]. The consequences of the injuries led to longer time delays in performing special tests and significantly reduced motor activation compared with controls. The results indicate that the effectiveness of rehabilitation is enhanced when interventions aimed at correcting balance disorders are implemented.

Another study [69] evaluated the possibility of using dance to improve the condition of patients with Parkinson's disease. The results showed an improvement in the quality of life and mobility of

patients. It has been confirmed that dance therapy is a popular additional method of treatment of this pathology in addition to pharmacological therapies.

The significant prevalence of knee joint injuries in athletes indicates the use of sensory integration indicators as a criterion for the effectiveness of treatment and rehabilitation. These include indicators of sensory integration that ensure the maintenance of balance [89]. The use of stabilometric analysis confirmed the restoration of balance. It is proposed to use sensorimotor integration as a screening test for the primary and secondary prevention of anterior cruciate ligament injuries.

It has been proposed that balance indices should be used as criteria for the effectiveness of rehabilitation of soccer players after concussion [90]. Static balance in the anteroposterior and medial-lateral directions was assessed in a quiet stance with eyes open and closed. Participants with concussion were characterized by deficits in balance control, particularly pronounced in the anteroposterior direction.

A similar design was used in the study [91]. The effects of concussions in former rugby players were assessed. Susceptibility to sound illusion was selected as a criterion for assessing the effects of injury. Diagnostic value of a multisensory integration study in athletes with outcomes of a concussion was confirmed.

The state of sensory integration is used in sports as a criterion for the effectiveness of recovery and rehabilitation after injuries. The dynamics of auditory perception in young athletes after concussion was used in the study [92] for this purpose. The usefulness of the test for assessing auditory perception and motor skills was confirmed.

A consequence of concussion in athletes is deficit in neuromuscular control. The long-term persistence of this deficit significantly affects athletic performance. Therefore, studying the correlations between brain activity and motor control is important for evaluating the effectiveness of rehabilitation. In the study [93], brain activity and leg press performance by female athletes who had a concussion were compared with those who did not have such injuries. The experimental group had less neural activity in certain brain regions than the control group. We conclude that changes in neural activity in brain regions important for sensorimotor integration and motor attention reflect compensatory neural mechanisms. These mechanisms may underlie the persistent deficits in neuromuscular control associated with concussion.

Chronic ankle instability in athletes is responsible for pain, decreased postural control, and decreased balance stability that affect athletic performance. The use of special aids to improve stability is an effective means of rehabilitation. In the study [94], a

medial wedge at an angle of 4 degrees was used for this purpose. The wedge was applied to the insole of the hind foot. The use of a medial wedge improved static and dynamic balance in athletes with ankle instability. The use of foot insoles to correct balance deficits in athletes has been suggested.

The high prevalence of head injuries in ice hockey players significantly affects their performance in this sport. The study [95] used resting-state functional magnetic resonance imaging to evaluate changes in the functional connectivity of the frontoparietal brain network responsible for executive functions. This study was conducted with the participation of university doubleheader hockey players in the dynamics of one season. An increase in functional connectivity between the areas involved in sensory integration was observed. More pronounced changes in connectivity were observed in those who had more head hits. It has been hypothesized that these results reflect the effects of head injuries.

In the study already cited [49], karate-do classes were used as an alternative to rehabilitation programs for developing motor skills. A special training program was conducted in adolescents with different socioeconomic statuses for 8 consecutive weeks (3 sessions per week, each session lasted 75 minutes). The state of motor skills after completion of the program confirmed its effectiveness.

Intensive loads in gymnastics lead to injuries and pain in the lower back. This necessitates the search for effective and informative rehabilitation criteria. A comparative analysis of the musculoskeletal apparatus in rhythmic gymnastics athletes with and without low back pain was performed in the study [96]. It was suggested that anthropometric parameters be used to monitor the musculoskeletal system in this group. The spinal curvature in the sagittal plane was recorded using a pantograph. Torso flexor and extensor muscle tone was monitored using a myotonometer. The difference in body height in the supine and standing positions was calculated to illustrate the elasticity of the spine. The presence of imbalance in the tone of the trunk flexor and extensor muscles, unsatisfactory posture control, predominance of lumbar lordosis, and decreased spine elasticity in gymnasts with low back pain was confirmed.

## Conclusions

The conducted bibliometric analysis of publications confirms the relevance of sensory integration. Stable interest in this problem has been determined. The studies in this area have neurophysiological, sports-recreational, and medical-rehabilitation directions. Neurophysiological studies are aimed at analyzing balance and equilibrium and the application of various tests and functional samples. The sport

context studies sensory integration in different sports. Recreational publications have investigated sensory integration as a criterion of health. The therapeutic and rehabilitation focus explores the use of sensory integration as a criterion for treatment and rehabilitation. A characteristic

feature is the intersection of these directions. There is a lack of studies devoted to sensory integration in sport dancing and aimed at studying the psychophysiological state. These types of studies should be assessed as relevant.

## References

- Podrihalo O, Xiaohong G, Mulyk V, Podrigalo L, Galashko M, Sokol K, Jagiello W. Priority scientific areas in sports dances research: the analysis of the scientific resources of Web of Science Core Collection. *Physical Education of Students*. 2022;26(5):207-223. <https://doi.org/10.15561/20755279.2022.0501>
- Podrigalo L, Iermakov S, Romanenko V, Rovnaya O, Tropin Y, Goloha V. Psychophysiological features of athletes practicing different styles of martial arts - the comparative analysis. *International Journal of Applied Exercise Physiology*. 2019;8(1):84-91. <https://doi.org/10.30472/ijaep.v8i1.299>
- Venhorst A, Micklewright DP, Noakes TD. The Psychophysiological Determinants of Pacing Behaviour and Performance During Prolonged Endurance Exercise: A Performance Level and Competition Outcome Comparison. *Sports Medicine*. 2018;48(10):2387-2400. <https://doi.org/10.1007/s40279-018-0893-5>
- White O, Babic J, Trenado CI, Johannsen L, Goswami N. The Promise of Stochastic Resonance in Falls Prevention. *Frontiers in Physiology*. 2019; 9: 1865. <https://doi.org/10.3389/fphys.2018.01865>
- Ponzo S, Kirsch LP, Fotopoulou A, Jenkinson PM. Balancing body ownership: Visual capture of proprioception and affectivity during vestibular stimulation. *Neuropsychologia*. 2018;117:311-321. <https://doi.org/10.1016/j.neuropsychologia.2018.06.020>
- Ronnqvist L, McDonald R, Sommer M. Influences of Synchronized Metronome Training on Soccer Players' Timing Ability, Performance Accuracy, and Lower-Limb Kinematics. *Frontiers in Psychology*. 2018;9:2469. <https://doi.org/10.3389/fpsyg.2018.02469>
- Moustafa I, Kim M, Harrison DE. Comparison of Sensorimotor Integration and Skill-Related Physical Fitness Components Between College Athletes With and Without Forward Head Posture. *Journal of Sport Rehabilitation*. 2023;32(1):53-62. <https://doi.org/10.1123/jsr.2022-0094>
- Quinzi F, Modica M, Berchicci M, Bianco V, Perri RL, Di Russo F. Does sport type matter? The effect of sport discipline on cognitive control strategies in preadolescents. *International Journal of Psychophysiology*. 2022;177:230-239. <https://doi.org/10.1016/j.ijpsycho.2022.05.016>
- Vander Vegt CB, Register-Mihalik JK, Ford CB, Rodrigo CJ, Guskiewicz KM, Mihalik JP. Baseline Concussion Clinical Measures Are Related to Sensory Organization and Balance. *Medicine & Science in Sports & Exercise*. 2019;51(2):264-270. <https://doi.org/10.1249/MSS.0000000000001789>
- Zemkova E, Kovacikova Z. Sport-specific training induced adaptations in postural control and their relationship with athletic performance. *Frontiers in Human Neuroscience*. 2023;16: 1007804. <https://doi.org/10.3389/fnhum.2022.1007804>
- Busquets A, Ferrer-Uris B, Angulo-Barroso RM, Federolf P. Gymnastics Experience Enhances the Development of Bipedal-Stance Multi-Segmental Coordination and Control During Proprioceptive Reweighting. *Frontiers in Psychology*. 2021; 12: 661312. <https://doi.org/10.3389/fpsyg.2021.661312>
- He Q. Knowledge discovery through co-word analysis. *Libr Trends*. 1999;48:133-59.
- Smith LC. Citation analysis. *Libr Trends*. 1981;30:83-106.
- VOSviewer version 1.6.17. [Internet]. VOSviewer, 2021. [updated 2021 July 22; cited 2021 Sep 11]. Available from: <https://www.vosviewer.com/>
- Van Eck NJ, Waltman L. Software survey: VOSviewer, a computer program for bibliometric mapping. *Scientometrics*. 2010;84(2):523-538.
- Asslander L, Peterka RJ. Sensory reweighting dynamics following removal and addition of visual and proprioceptive cues. *Journal of Neurophysiology*. 2016;116(2):272-285. <https://doi.org/10.1152/jn.01145.2015>
- Asslander L, Peterka RJ. Sensory reweighting dynamics in human postural control. *Journal of Neurophysiology*. 2014;111(9):1852-1864. <https://doi.org/10.1152/jn.00669.2013>
- Han J, Anson J, Waddington G, Adams R, Liu Y. The Role of Ankle Proprioception for Balance Control in relation to Sports Performance and Injury. *BioMed Research International*. 2015; 2015:842804. <https://doi.org/10.1155/2015/842804>
- Iermakov S, Podrigalo L, Podrigalo O et al. Means and methods of physical activity in the context of prevention and treatment of Alzheimer's disease (analysis of Russian-language scientific resources) and the perspective of implementing the unique achievements of the "Polish School of Safe Falling". *Arch Budo* 2022; 18: 121-143
- Izadi M, Franklin S, Bellafiore M, Franklin DW. Motor Learning in Response to Different Experimental Pain Models Among Healthy Individuals: A Systematic Review. *Frontiers in Human Neuroscience*. 2022; 16: 863741. <https://doi.org/10.3389/fnhum.2022.863741>
- Hettich G, Asslander L, Gollhofer A, Mergner T. Human hip-ankle coordination emerging from

- multisensory feedback control. *Human Movement Science*. 2014;37:123-146. <https://doi.org/10.1016/j.humov.2014.07.004>
22. Bottcher A, Wilken S, Adelhöfer N, Raab M, Hoffmann S, Beste C. A dissociable functional relevance of theta- and beta-band activities during complex sensorimotor integration. *Cerebral Cortex*. 2023; 33(14): 9154–9164. <https://doi.org/10.1093/cercor/bhad191>
  23. Yeo SH, Franklin DW, Wolpert DM. When Optimal Feedback Control Is Not Enough: Feedforward Strategies Are Required for Optimal Control with Active Sensing. *Plos Computational Biology*. 2016;12(12): e1005190. <https://doi.org/10.1371/journal.pcbi.1005190>
  24. Ritzmann R, Gollhofer A, Freyler K. Posture and Locomotion. *Sensory Motor and Behavioral Research in Space*. 2017: 1-35. [https://doi.org/10.1007/978-3-319-68201-3\\_1](https://doi.org/10.1007/978-3-319-68201-3_1)
  25. Ponzo S, Kirsch LP, Jenkinson PM et al. Vestibular modulation of multisensory integration during actual and vicarious tactile stimulation. *Psychophysiology*. 2019;56(10). <https://doi.org/10.1111/psyp.13430>
  26. Ketterer J, Ringhof S, Gollhofer A et al. Sinusoidal Optic Flow Perturbations Reduce Transient but Not Continuous Postural Stability: A Virtual Reality-Based Study. *Frontiers in Physiology*. 2022;13:803185. <https://doi.org/10.3389/fphys.2022.803185>
  27. Fink PW, Shultz SP, D'Hondt E, Lenoir M, Hills AP. Multifractal Analysis Differentiates Postural Sway in Obese and Nonobese Children. *Motor Control*. 2019;23(2):262-271. <https://doi.org/10.1123/mc.2016-0085>
  28. Delfa-de la Morena JM, Castro EA, Rojo-Tirado MÁ, Bores-Garcia D. Relation of Physical Activity Level to Postural Balance in Obese and Overweight Spanish Adult Males: A Cross-Sectional Study. *Int. J. Environ. Res. Public Health*. 2021;18(16):8282. <https://doi.org/10.3390/ijerph18168282>
  29. Toledo DR, Barela JA. Age-related differences in postural control: effects of the complexity of visual manipulation and sensorimotor contribution to postural performance. *Experimental Brain Research*. 2014;232(2):493-502. <https://doi.org/10.1007/s00221-013-3756-1>
  30. Godoi D, Barela JA. Optical Flow Structure Effects in Children's Postural Control. *PLOS ONE*. 2016;11(6). <https://doi.org/10.1371/journal.pone.0158416>
  31. Ludwig O, Mazet C, Mazet D, Hammes A, Schmitt E. Changes in Habitual and Active Sagittal Posture in Children and Adolescents with and without Visual Input - Implications for Diagnostic Analysis of Posture. *Journal of Clinical and Diagnostic Research*. 2016;10(2):SC14-SC17. <https://doi.org/10.7860/JCDR/2016/16647.7283>
  32. Martini DN, Gera G, Brumbach BH, Campbell KR, Parrington L, Chesnutt J, et al. Symptoms and Central Sensory Integration in People With Chronic mTBI: Clinical Implications. *Military Medicine*, 2023;188(11–12): 3553–3560. <https://doi.org/10.1093/milmed/usac157>
  33. Podrigalo L, Romanenko V, Podrihalo O, Iermakov S, Huba A, Perevoznyk V, Podavalenko O. Comparative analysis of psychophysiological features of taekwondo athletes of different age groups. *Pedagogy of Physical Culture and Sports*. 2023;27(1):38-44. <https://doi.org/10.15561/26649837.2023.0105>
  34. Podrihalo O, Iermakov S, Podrigalo L, Perevoznyk V, Paievskiy V, Deineko A, Oleinichuk V. Methods of predictive selection in wrestling compared with martial arts. *Arch Budo Sci Martial Art Extreme Sport*. 2022;18:117-124.
  35. Eikema DJA, Hatzitaki V, Konstadakos S, Papaxanthis C. Elderly adults delay proprioceptive reweighting during the anticipation of collision avoidance when standing. *Neuroscience*. 2013; 234:22-30. <https://doi.org/10.1016/j.neuroscience.2012.12.053>
  36. Craig CE, Calvert GHM, Doumas M. Effects of the availability of accurate proprioceptive information on older adults' postural sway and muscle co-contraction. *European Journal of Neuroscience*. 2017;46(10):2548-2556. <https://doi.org/10.1111/ejn.13703>
  37. Kim KM, Kim JS, Oh J, Grooms DR. Stroboscopic Vision as a Dynamic Sensory Reweighting Alternative to the Sensory Organization Test. *Journal of Sport Rehabilitation*. 2021;30(1):166-172. <https://doi.org/10.1123/jsr.2019-0466>
  38. Craig CE, Doumas M. Slowed sensory reweighting and postural illusions in older adults: the moving platform illusion. *Journal of Neurophysiology*. 2019;121(2):690-700. <https://doi.org/10.1152/jn.00389.2018>
  39. Hildebrandt A, Griefsbach E, Cañal-Bruland R. Auditory perception dominates in motor rhythm reproduction. *Perception*. 2022;51(6):403-416. <https://doi.org/10.1177/03010066221093604>
  40. Ratcliffe N, Greenfield K, Ropar D, Howard E, Newport R. The Relative Contributions of Visual and Proprioceptive Inputs on Hand Localization in Early Childhood. *Frontiers in Human Neuroscience*. 2021;15:702519. <https://doi.org/10.3389/fnhum.2021.702519>
  41. DeFeo C, Heebner N, Baker C, Hoch M, Morelli N. The Relationship Between Measures of Postural Control in Concussion Assessment. *Journal of Sport Rehabilitation*. 2022;31(4):452-456. <https://doi.org/10.1123/jsr.2021-0291>
  42. Li YH, Liu XY, Luo X, Guo CJ. Effect of Tai Chi combined with Kinesio taping on posture control of football players with FAI: protocol for a randomized controlled trial. *Trials*. 2022;23 (1): 162. <https://doi.org/10.1186/s13063-022-06083-5>
  43. Calatayud J, Martin F, Flandez J. Relationship between the modified star excursion balance test and the 4x10 m shuttle run test in children. *Cultura Ciencia y Deporte*. 2017;12(35):111-116.
  44. Peng YC, Hsu CY, Tang WT. Deficits in the Star Excursion Balance Test and Golf Performance

- in Elite Golfers with Chronic Low Back Pain. *Journal of Sports Science and Medicine*. 2021;20(2):229-236. <https://doi.org/10.52082/jssm.2021.229>
45. Prieto MF, Morales SB, Fernandez FTG. Y-balance-test in soccer players according to the competition level. *Retos-Nuevas Tendencias en Educacion Fisica Deporte y Recreacion*. 2020;37:333-338.
  46. Piqueras PG, Gonzalez-Villora S, de Baranda PS. The functional assessment as a key element in the recovery of football players after an injury. *SPORT TK-Revista Euroamericana de Ciencias del Deporte*. 2020;9(1):15-25.
  47. Esatbeyoglu F, Kin-Isler A. Gender differences in postural balance, physical activity level, BMI, and body composition in athletes with visual impairment. *British Journal of Visual Impairment*. 2022;40(3):530-544. <https://doi.org/10.1177/026461962111009921>
  48. Carter K, Horvat M. Effect of Taekwondo Training on Lower Body Strength and Balance in Young Adults with Down Syndrome. *Journal of Policy and Practice in Intellectual Disabilities*. 2016;13(2):65-172. <https://doi.org/10.1111/jppi.12164>
  49. Ghadiri F, O'Brien W, Soltani S, Faraji M, Bahmani M. The effect of karate interventions on the motor proficiency of female adolescents with developmental coordination disorder (DCD) from high and low socio-economic status. *BMC Sports Science, Medicine and Rehabilitation*. 2022; 14(1):121. <https://doi.org/10.1186/s13102-022-00501-6>
  50. Hung MH, Chen HY, Chang YC, Chiu CW, Chang HY. Effects of the direction of Kinesio taping on sensation and postural control before and after muscle fatigue in healthy athletes. *Scientific Reports*. 2023;13(1):1282. <https://doi.org/10.1038/s41598-023-27801-2>
  51. Presta V, Vitale C, Ambrosini L, Gobbi G. Stereopsis in Sports: Visual Skills and Visuomotor Integration Models in Professional and Non-Professional Athletes. *Int. J. Environ. Res. Public Health*. 2021;18(21):11281. <https://doi.org/10.3390/ijerph182111281>
  52. Blanchet M, Prince F. Mediolateral Postural Control Mechanisms and Proprioception Improve With Kicking Sports Training During Adolescence. *Pediatric Exercise Science*. 2023;35(3):118-126. <https://doi.org/10.1123/pes.2020-0204>
  53. Kreyenmeier P, Schroeger A, Cañal-Bruland R, Raab M, Spering M. Rapid Audiovisual Integration Guides Predictive Actions. *ENEURO*. 2023;10(8). <https://doi.org/10.1523/ENEURO.0134-23.2023>
  54. Huelsduenker T, Riedel D, Kaesbauer H, Ruhnnow D, Mierau A. Auditory Information Accelerates the Visuomotor Reaction Speed of Elite Badminton Players in Multisensory Environments. *Frontiers in Human Neuroscience*. 2021;15:779343. <https://doi.org/10.3389/fnhum.2021.779343>
  55. Costa S, Berchicci M, Bianco V, Croce P, Di Russo F, Quinzi F et al. Brain dynamics of visual anticipation during spatial occlusion tasks in expert tennis players. *Psychology of Sport and Exercise*. 2023;65:102335. <https://doi.org/10.1016/j.psychsport.2022.102335>
  56. Fedorovna SME, Viktorovich EV, Andreevna MK. Psychophysiological features of hockey players aged 15-16 years in the annual training macrocycle. *4th International Conference on Innovations in Sports, Tourism and Instructional Science (ICISTIS)*. 2019;17:262-265.
  57. Busquets A, Aranda-Garcia S, Ferrer-Uris B, Marina M, Angulo-Barroso R. Age and gymnastic experience effects on sensory reweighting processes during quiet stand. *Gait & Posture*, 2018;63: 177–183. <https://doi.org/10.1016/j.gaitpost.2018.05.009>
  58. Thalassinos M, Fotiadis G, Arabatzi F, Isableu B, Hatzitaki V. Sport Skill-Specific Expertise Biases Sensory Integration for Spatial Referencing and Postural Control. *Journal of Motor Behavior*. 2018;50(4):426-435. <https://doi.org/10.1080/0022895.2017.1363704>
  59. Baccouch R, Rebai H, Sahli S. Kung-fu versus swimming training and the effects on balance abilities in young adolescents. *Physical Therapy in Sport*. 2015;16(4):349-354. <https://doi.org/10.1016/j.ptsp.2015.01.004>
  60. Wang AJ, Wang TT, Yue C, Zhang M. Long-term Tai Chi training reduces the fusion illusion in older adults. *Experimental Brain Research*. 2023;241(2):517-526. <https://doi.org/10.1007/s00221-023-06544-6>
  61. You YW, Liu JX, Tang MMA, Wang D, Ma XD. Effects of Tai Chi exercise on improving walking function and posture control in elderly patients with knee osteoarthritis A systematic review and meta-analysis. *Medicine*. 2021;100(16): e25655. <https://doi.org/10.1097/MD.00000000000025655>
  62. Schumacher C, Seyfarth A. Sensor-Motor Maps for Describing Linear Reflex Composition in Hopping. *Frontiers in Computational Neuroscience*. 2017; 11. <https://doi.org/10.3389/fncom.2017.00108>
  63. Sakamoto M, Ifuku, H. Experience-Dependent Modulation of Rubber Hand Illusion in Badminton Players. *Journal of Sport & Exercise Psychology*. 2022;44(1):14-22. <https://doi.org/10.1123/jsep.2020-0178>
  64. Eikema DJA, Hatzitaki V, Konstadakos S, Papaxanthis C. Application of intermittent galvanic vestibular stimulation reveals age-related constraints in the multisensory reweighting of posture. *Neuroscience Letters*. 2014; 561:112-117. <https://doi.org/10.1016/j.neulet.2013.12.048>
  65. Klatt S, Smeeton NJ. Visual and Auditory Information During Decision Making in Sport. *Journal of Sport & Exercise Psychology*. 2020;42(1):15-25. <https://doi.org/10.1123/jsep.2019-0107>
  66. Stanton TR, Spence C. The Influence of Auditory Cues on Bodily and Movement Perception. *Frontiers in Psychology*. 2020;10:3001. <https://doi.org/10.3389/fpsyg.2019.03001>
  67. Abbiss CR, Peiffer JJ, Meeusen R, Skorski S. Role of Ratings of Perceived Exertion during Self-Paced Exercise: What are We Actually Measuring? *Sports Medicine*. 2015;45(9):1235-1243. <https://doi.org/10.1007/s40279-015-0344-5>

68. Tapajcikova T, Liska D, Batalik L, Tucker CP, Kobesova A. Levels of Gnostic Functions in Top Karate Athletes-A Pilot Study. *Motor Control*. 2022;26(2):258-277. <https://doi.org/10.1123/mc.2021-0127>
69. Meulenberg CJW, Rehfeld K, Jovanović S, Marusic U. Unleashing the potential of dance: a neuroplasticity-based approach bridging from older adults to Parkinson's disease patients. *Frontiers in Aging Neuroscience*. 2023; 15: 1188855. <https://doi.org/10.3389/fnagi.2023.1188855>
70. Viseu JP, Yiou E, Morin P-O, Olivier A. Sport dependent effects on the sensory control of balance during upright posture: a comparison between professional horseback riders, judokas and non-athletes. *Frontiers in Human Neuroscience*. 2023; 17: 1213385. <https://doi.org/10.3389/fnhum.2023.1213385>
71. Moran RN, Meek J, Allen J, Robinson J. Sex differences and normative data for the m-CTSIB and sensory integration on baseline concussion assessment in collegiate athletes. *Brain Injury*. 2020;34(1):20-25. <https://doi.org/10.1080/02699052.2019.1669824>
72. Lourenco CP, Silva ALD. Posture control and vestibular oculomotor system in pistol sport shooters. *Revista Brasileira de Medicina do Esporte*. 2013;19(5):313-316. <https://doi.org/10.1590/S1517-86922013000500002>
73. Fisher KM, Fairbrother JT. Seeing is Believing: Blind Putting Drills Confer No Advantage to the Novice Golfer. *Research Quarterly for Exercise and Sport*. 2020;91(2):335-345. <https://doi.org/10.1080/02701367.2019.1674443>
74. Canal-Bruland R, Muller F, Lach B, Spence C. Auditory contributions to visual anticipation in tennis. *Psychology of Sport and Exercise*. 2018;36:100-103. <https://doi.org/10.1016/j.psychsport.2018.02.001>
75. Gu YD, Yu CX, Shao S, Baker JS. Effects of table tennis multi-ball training on dynamic posture control. *PEERJ*. 2019;6:e6262. <https://doi.org/10.7717/peerj.6262>
76. Kroll M, Preuss J, Ness BM, Dolny M, Louder T. Effect of stroboscopic vision on depth jump performance in female NCAA Division I volleyball athletes. *Sports Biomechanics*. 2023;22(8):1016-1026. <https://doi.org/10.1080/14763141.2020.1773917>
77. Fu T, Zhang DR, Wang W, Geng H, Lv Y, Shen R, Bu T. Functional Training Focused on Motor Development Enhances Gross Motor, Physical Fitness, and Sensory Integration in 5-6-Year-Old Healthy Chinese Children. *Frontiers in Pediatrics*. 2022; 10: 936799. <https://doi.org/10.3389/fped.2022.936799>
78. Toth AJ, Hojaji F, Campbell MJ. Exploring the mechanisms of target acquisition performance in esports: The role of component kinematic phases on a first person shooter motor skill. *Computers in Human Behavior*. 2023;139:107554. <https://doi.org/10.1016/j.chb.2022.107554>
79. Rominger C, Koschutnig K, Memmert D, Papousek I, Perchtold-Stefan CM, Benedek M et al. Brain activation during the observation of real soccer game situations predicts creative goal scoring. *Social Cognitive and Affective Neuroscience*. 2021;16(7):707-715. <https://doi.org/10.1093/scan/nsab035>
80. Phang JTS, Lim KH, Chiam DH. Deep Learning Pose Estimation for Kinematics Measurement in Archery. *International Conference on Green Energy, Computing and Sustainable Technology (GECOST)*. 2022: 298-302.
81. Tchoorzewski D, Bujas P, Jankowicz-Szymanska A. Body Posture Stability in Ski Boots Under Conditions of Unstable Supporting Surface. *Journal of Human Kinetics*. 2013;38:33-44. <https://doi.org/10.2478/hukin-2013-0043>
82. Agostini V, Chiaramello E, Canavese L, Bredariol C, Knaflitz M. Postural sway in volleyball players. *Human Movement Science*. 2013;32(3):445-456. <https://doi.org/10.1016/j.humov.2013.01.002>
83. Borzucka D, Krecisz K, Rektor Z, Kuczynski M. Postural control in top-level female volleyball players. *BMC Sports Science Medicine and Rehabilitation*. 2020;12(1):65. <https://doi.org/10.1186/s13102-020-00213-9>
84. Yoon SD, Sung DH, Park GD. The effect of active core exercise on fitness and foot pressure in Taekwondo club students. *Journal of Physical Therapy Science*. 2015;27(2):509-511. <https://doi.org/10.1589/jpts.27.509>
85. Gidu DV, Badau D, Stoica M, Aron A, Focan G, Monea D et al. The Effects of Proprioceptive Training on Balance, Strength, Agility and Dribbling in Adolescent Male Soccer Players. *International Journal of Environmental Research and Public Health*. 2022;19(4):2028. <https://doi.org/10.3390/ijerph19042028>
86. Romanenko V, Podrigalo L, Cynarski WJ, Rovnaya O, Korobeynikova L, Goloha V, Robak I. A comparative analysis of the short-term memory of martial arts' athletes of different level of sportsmanship. *Ido Movement For Culture. Journal of Martial Arts Anthropology*. 2020;20(3):18-24. <https://doi.org/10.14589/ido.20.3.3>
87. O'Brien J, Mason A, Chan J, Setti A. Can We Train Multisensory Integration in Adults? A Systematic Review. *Multisensory Research*. 2023;36(2):111-180. <https://doi.org/10.1163/22134808-bja10090>
88. Campbell KR, King LA, Parrington L, Fino PC, Antonellis P, Peterka RJ. Central sensorimotor integration assessment reveals deficits in standing balance control in people with chronic mild traumatic brain injury. *Frontiers in Neurology*. 2022; 13: 897454. <https://doi.org/10.3389/fneur.2022.897454>
89. Gandolfi M, Ricci M, Sambugaro E, Valè N, Dimitrova E, Meschieri A et al. Changes in the sensorimotor system and semitendinosus muscle morphometry after arthroscopic anterior cruciate ligament reconstruction: a prospective cohort study with 1-year follow-up. *Knee Surgery, Sports Traumatology, Arthroscopy*. 2018;26(12):3770-3779.

- <https://doi.org/10.1007/s00167-018-5020-5>
90. Powers KC, Kalmar JM, Cinelli ME. Recovery of static stability following a concussion. *Gait & Posture*. 2014;39(1):611-614. <https://doi.org/10.1016/j.gaitpost.2013.05.026>
91. Cunningham J, O'Dowd A, Broglio SP, Newell FN, Kelly Á, Joyce O et al. Multisensory perception is not influenced by previous concussion history in retired rugby union players. *Brain Injury*. 2022;36(9):1123-1132. <https://doi.org/10.1080/02699052.2022.2109732>
92. Bialunska A, Salvatore AP. The auditory comprehension changes over time after sport-related concussion can indicate multisensory processing dysfunctions. *Brain and Behavior*. 2017;7(12):e00874. <https://doi.org/10.1002/brb3.874>
93. Zuleger TM, Slutsky-Ganesh AB, Anand M, Kim HW, Warren SM, Grooms DR et al. The effects of sports-related concussion history on female adolescent brain activity and connectivity for bilateral lower extremity knee motor control. *Kpsychophysiology*. 2023;60(9):e14314. <https://doi.org/10.1111/psyp.14314>
94. Chang HY, Chang YC, Cheng SC, Wang CH. The effectiveness of rearfoot medial wedge intervention on balance for athletes with chronic ankle instability. *Medicine*. 2019;98(26):e16217. <https://doi.org/10.1097/MD.00000000000016217>
95. DiFabio MS, Smith DR, Breedlove KM, Pohlig RT, Buckley TA, Johnson CL. Altered brain functional connectivity in the frontoparietal network following an ice hockey season. *European Journal of Sport Science*. 2023;23(5):684-692. <https://doi.org/10.1080/017461391.2022.2069512>
96. Kums T, Erelina J, Veldre G, Gapeyeva H, Pääsuke M, Vain A. Markers for monitoring adaptive peculiarity of the musculoskeletal system in rhythmic gymnasts with non-specific low back pain. *Gazzetta Medica Italiana Archivio per le Scienze Mediche*. 2017;176(5):237-246. <https://doi.org/10.23736/S0393-3660.16.03358-1>

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#### Information about the authors:

**Olha Podrihalo**; <https://orcid.org/0000-0003-1519-5632>; [rovnayaolga77@ukr.net](mailto:rovnayaolga77@ukr.net); Department of Biological Discipline, Kharkiv State Academy of Physical Culture; Klochkovskaya str. 99, Kharkiv, 61022, Ukraine.

**Wladyslaw Jagiello**; <https://orcid.org/0000-0001-7417-4749>; [wjagiello1@wp.pl](mailto:wjagiello1@wp.pl); Department of Sport, Gdansk University of Physical Education and Sport; Gdansk, Poland.

Guo Xiaohong; <https://orcid.org/0000-0002-9409-5113>; [1142207650@qq.com](mailto:1142207650@qq.com); Kharkiv State Academy of Physical Culture (Kharkiv, Ukraine); Haikou School of Economics (Haikou, Hainan Province, China).

**Leonid Podrigalo**; (Corresponding author); <https://orcid.org/0000-0002-7893-524X>; [leonid.podrigalo@gmail.com](mailto:leonid.podrigalo@gmail.com); Department of Medical Discipline, Kharkiv State Academy of Physical Culture; Klochkovskaya str. 99, Kharkiv, 61022, Ukraine.

**Tetiana Yermakova**; <https://orcid.org/0000-0002-3081-0229>; [yermakova2015@gmail.com](mailto:yermakova2015@gmail.com); Department of Pedagogy, Kharkiv State Academy of Design and Arts; Kharkiv, Ukraine.

**Mirosława Cieslicka**; <https://orcid.org/0000-0002-0407-2592>; [cudaki@op.pl](mailto:cudaki@op.pl); Department of Physiology, Collegium Medicum in Bydgoszcz, Nicolaus Copernicus University in Toruń; M. Skłodowskiej-Curie 9, 85-094, Bydgoszcz, Poland.

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Cite this article as:

Podrihalo O, Jagiełło W, Xiaohong G, Podrigalo L, Yermakova T, Cieslicka M. Sensory integration research: priority scientific directions based on the analysis of Web of Science Core Collection resources. *Physical Education of Students*, 2023;27(6):358–377.

<https://doi.org/10.15561/20755279.2023.0608>

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**Received:** 10.11.2023

**Accepted:** 19.12.2023; **Published:** 30.12.2023