A comparative study of balance measurements in ice hockey players

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Abstract

Maintaining stability is a fundamental aspect of human movement, essential for executing tasks efficiently and smoothly. Stability is achieved through the generation of precise joint torques that counteract any deviations from the desired body orientation. These deviations are primarily detected by our sensory systems, which integrate information from three key sources: the somatosensory/proprioceptive system, the visual system, and the vestibular system.

Sport-related concussions are a significant concern in ice hockey, and balance assessments play a crucial role in their management. Concussions can impair various aspects of balance and postural control, and balance tests are often incorporated into concussion evaluation and return-to-play protocols. Identifying and addressing balance deficits through comprehensive assessments is vital for proper concussion management, rehabilitation, and ensuring a safe return to play for affected athletes.

This study aimed to compare the subjective Sport Concussion Assessment Tool 5 (SCAT5) and objective sway measurements in assessing balance among ice hockey players. It investigated performance differences between good and poor balance groups, determined by SCAT5 scores, across various sway protocols. Ice hockey players underwent SCAT5 balance assessment and sway measurements under different stance positions, visual conditions, and surface stability.

The study recognised that, the poor balance group, identified by higher SCAT5 scores, exhibited significantly worse performance in most protocols. However, the lack of significant differences in certain protocols suggested an oversimplification of the SCAT5 tool in comprehensively assessing balance control. Comparisons of sway length distance measurements across different stance protocols within groups revealed the critical roles of the somatosensory, visual, and vestibular systems in maintaining postural stability. As task complexity increased by altering surface compliance, visual input, or stance position, deficits in integrating sensory information became more apparent in the poor balance group.

In conclusion, this study highlights the significance of comprehensive balance assessments that include both challenging and relatively easier protocols. The double leg stance and tandem stance protocols demonstrated sensitivity in detecting balance deficits or strengths, making them valuable early indicators of overall balance abilities. These protocols offer practical applications beyond the study's participants, particularly for assessing balance in populations with varying abilities, such as the elderly. By incorporating these protocols into assessment batteries, practitioners can tailor interventions and training programs to improve postural stability and reduce the risk of falls and injuries across diverse populations.

Keywords/tags (subjects)

Balance, SCAT5, sway measurement, Ice Hockey, concussion, vestibular balance assessment.

Contents

Figures

Tables

1 Introduction

Stability in human movement is crucial for efficient and smooth execution of tasks. It is achieved through the generation of appropriate joint torques, which counteract any deviations from a desired orientation. The identification of these deviations predominantly relies on the sensory systems, encompassing the somatosensory, visual, and vestibular systems.

The somatosensory system provides information about the position and movement of the limbs and body in space, allowing to sense the changes in orientation. The visual system enables us to perceive our environment and detect any external cues that may indicate changes in orientation. Lastly, the vestibular system, senses changes in head position and movement, contributing to our overall sense of balance and orientation. The combined input from these sensory systems enables us to generate precise and timely joint torques to maintain stability, ensuring successful completion of various tasks and activities. (Peterka, 2018)

The ability to maintain proper balance is not only crucial for optimizing performance but also for minimizing the risk of injuries and is a fundamental aspect of physical performance in various sports, including ice hockey (Hrysomallis, 2011). However, evaluating and assessing balance in athletes can be a complex task, as there are different methods and measures employed to quantify balance outcomes (Johnston et al., 2016).

The assessment of balance in ice hockey players holds significant importance for several reasons. Optimal balance is essential for enhancing performance in ice hockey. The sport requires athletes to execute quick and precise movements on the ice, such as skating, changing directions, and making turns. Maintaining proper balance enables players to execute these movements effectively and efficiently, thus enhancing their overall performance. For example, a study found that ice hockey players with better balance had significantly faster skating speeds and were able to perform more complex skating manoeuvres (Behm et al., 2005).

Assessing balance can also help identify athletes who may be at a higher risk of injury. Ice hockey is a physically demanding sport characterized by high-speed collisions, body checks, and abrupt changes in direction. Consequently, injuries are prevalent among ice hockey players, with studies indicating that injury rates of 66-78.4 per 1000 player-game hours in the Finnish and Swedish ice hockey leagues (Lorentzon et al., 1988). In Finland an injury rate of 36 per 1000 player-game hours in the second highest level league (Division I) is reported. (Mölsä et al.,1997)

By evaluating balance, it becomes possible to identify athletes with compromised stability, who may be more prone to falls, collisions, and subsequent injuries. This information can be used to implement targeted preventive measures, such as balance training and specific conditioning programs, to mitigate injury risks and enhance player safety. For example, a study found that ice hockey players with poor balance were significantly more likely to sustain injuries than those with good balance (Hrysomallis, 2011).

Furthermore, assessing balance provides valuable information for injury rehabilitation and return-to-play protocols. Injured athletes often experience deficits in balance and proprioception, which can impair their ability to return to sport safely and perform at their pre-injury level. (Hrysomallis, 2011).

One commonly used method to assess balance is sway measurements. Sway measurements involve the physiological evaluation of balance by quantifying the displacement of an individual's center of gravity during a standing position (Browne and O'Hare, 2001). This method offers valuable information about an athlete's postural stability and sway patterns. It has been widely employed in various sports research studies, including those involving ice hockey players (Johnston et al., 2017).

While sway measurements offer insights into an athlete's balance abilities, recent attention has been directed towards the Sport Concussion Assessment Tool 5 (SCAT5) and its Modified Balance Error Scoring System (mBESS) testing as an alternative method for balance assessment (Echemendia et al., 2017). The SCAT5 is a comprehensive evaluation tool that encompasses various components, including the vestibular system, to provide a more holistic assessment of balance outcomes. The vestibular system is an essential part of sense of balance and spatial orientation and critical for maintaining equilibrium (Baloh & Honrubia, 1979; Nandi & Luxon, 2008).

In ice hockey, the vestibular system becomes particularly relevant due to the frequent changes in head position and movement experienced by athletes (Alpini et al., 2008). These sudden movements and shifts in head orientation can significantly affect an athlete's balance and stability. By incorporating vestibular components into the assessment process, the SCAT5 provides additional information that sway measurements alone may not capture. This information can be utilized to design more targeted training programs and rehabilitative interventions tailored to the specific balance deficits identified in ice hockey players.

By comparing balance methods and evaluating an athlete's balance progress throughout the rehabilitation process, healthcare professionals can tailor individualized interventions, monitor recovery, and ensure a safe return to sport.

Finally, a comparative study of balance assessment methods can contribute to the development of more effective evaluation tools and protocols. Sports science and medicine constantly strive to improve assessment techniques to provide more accurate, reliable, and comprehensive information about an athlete's balance capabilities. By comparing different methods, such as sway measurements and the SCAT5, Researchers and practitioners can assess the advantages and disadvantages of each approach and potentially develop integrated assessment protocols that capture multiple dimensions of balance, including both physiological and vestibular components.

2 Theoretical basis

2.1 Balance

Balance is a frequently used term in various clinical specialties, is essential for maintaining stability and controlling posture. It is considered relevant for assessing patients with neurological deficits, orthopedic deficits, and vestibular disorders. (Berg, 1989) Clearly defining clinical terms is essential for accurately assessing, documenting, and understanding patient problems. Having valid definitions of clinical terminology is fundamental for evidence-based practice and optimal patient care. However, despite its widespread use, the definition of human balance is still under debate. (Ekdahl et al., 1989)

The concept of balance or equilibrium refers to the state of an object where the combined forces or moments acting on it result in a net load of zero, in accordance with Newton's First Law (Bell, 1998). For an object to remain balanced in a static position, its centre of mass must be within its base of support. (Hall, 1991) An object remains balanced as long as its center of gravity is within its base of support. If the center of gravity moves outside the base of support, the object becomes unbalanced and will fall. (Bell, 1998).). This relationship is visually depicted in Figure 1.

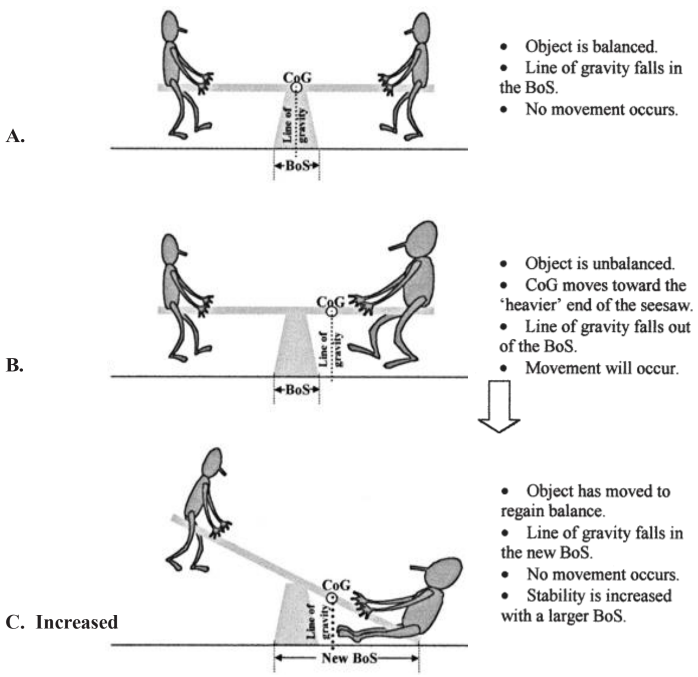

Figure 1: Relationship between base of support (BoS), line of gravity and stability. (adapted from Pollock et al., 2000, p. 403)

2.2 Stability

The level of stability of an object is directly related to the extent of displacement of its line of gravity before it becomes unbalanced. In other words, the greater the displacement that can be tolerated before losing balance, the higher the stability of the object (Jewett & Serway, 2010).

Similarly, an object's stability is also influenced by its ability to withstand external forces without becoming unbalanced. An object's stability is determined by the amount of force it can withstand before it topples over.
Stability is achieved when the object's center of gravity is within its base of support. A wider base of support, a lower center of gravity, and a more central center of gravity all increase stability. (Bell, 1998).

2.3 Balance components

Balance is the ability to maintain the body's center of gravity within the base of support area. Improving balance reduces the risk of falls and enhances physical capabilities. Assessing balance is important for evaluating functional abilities. Balance relies on the integration of visual, vestibular, and proprioceptive systems. The relative importance of these sensory systems may vary depending on the situation. In general, somatosensory and visual inputs are more important than the vestibular system for maintaining balance when both inputs are accessible. (Jacobson et al., 2019; Chittrakul et al., 2020; Duncan et al., 1990; Peterka, 2002; Shumway-Cook et al., 2023)

2.3.1 The visual system

The visual system plays a crucial role in balance and postural control. It consists of two systems: the focal system for object motion perception and the ambient system for self-motion perception. Visual cues, even in low-light conditions, improve postural stability. Peripheral vision reduces sway, particularly in the antero-posterior direction, and aids in integrating sensory inputs for balance control. Proprioceptive receptors in the extraocular muscles provide feedback on eye position, while motor commands based on visual input help maintain visual consistency (Kapoula and Lê, 2006; Guerraz & Bronstein, 2008; Berencsi et al., 2005).

Impact of visual inputs on postural stability and balance control have been the topic of different research. One study investigated the influence of visual inputs and cues on postural stability and balance control, emphasizing the significant impact of visual information on maintaining balance (Redfern et al., 2001). Another study focused specifically on community-dwelling older adults and explore the association between functional vision and balance and mobility performance. The study examines the association between functional vision and balance as well as mobility performance in older adults who live independently in the community. The study investigates how visual impairments may influence balance and mobility in this population. (Aartolahti et al., 2013)

The findings of the study revealed that individuals with low vision exhibited significantly higher levels of body sway in comparison to those with normal vision across multiple assessments, including balance on a foam surface ($p \leq 0.001$), the Unilateral Stance test for both limbs ($p \leq 0.001$), and the Tandem Walk test. These findings indicate that individuals with low vision experience greater difficulty in maintaining balance and stability in challenging conditions, such as on an unstable foam surface or during tasks that require single-leg balance or tandem walking. (Tomomitsu et al., 2013)

2.3.2 The somatosensory system

To maintain stability and perform daily activities safely, individuals rely on proprioceptive and cutaneous input in the somatosensory system. The central nervous system processes this input and coordinates muscle activity through alpha motoneurons and muscle fibers. Proprioception, mediated by muscle spindles, provides information about muscle length and contraction velocity, allowing individuals to perceive joint movement and body position. Muscle spindles also contribute to motor control by providing feedback for reflexive responses and voluntary movements. The Golgi tendon organ, located at the muscle tendon interface, relays information about tensile forces and helps regulate muscle tension through inhibitory connections with spinal cord interneurons (Shaffer & Harrison, 2007).

A systematic review which includes studies that investigate various populations with reduced somatosensation, such as individuals with peripheral neuropathy, diabetes, or sensory deficits examined the effects of reduced somatosensation on standing balance across different conditions and measures of postural control. The findings of this systematic review suggest that reduced somatosensation has a detrimental effect on standing balance. Individuals with impaired somatosensory function exhibit increased postural sway, reduced stability, and higher risk of falls compared to individuals with intact somatosensation. The review identifies specific parameters of postural control, such as sway area, sway velocity, and center of pressure excursion, that are significantly affected by reduced somatosensation. (Kars et al., 2009)

In another study, researchers investigated the influence of a firm-textured surface on postural control. The researchers conducted a focused literature review specifically examining the effects of surface characteristics on postural control. The review revealed that surface properties play a significant role in balance regulation and postural adjustments.

Findings from the review indicated that a firm-textured surface provides greater stability and enhances postural control compared to softer or unstable surfaces. The firmness of the surface contributes to the sensory feedback received through the feet, allowing individuals to make more precise adjustments and maintain balance more effectively. (Palazzo et al., 2021)

2.3.3 The vestibular system

The vestibular system stands out among other sensory systems due to its immediate engagement with multiple senses and modes. For instance, it collaborates with the proprioceptive system, aided by corollary discharge of a motor plan, enabling the brain to differentiate between actively generated and passive head movements. Moreover, the vestibular system interacts with both the visual and proprioceptive systems through the central vestibular pathways, playing a vital role in gaze and postural control.

within the brain stem, postural control and balance involve premotor neurons and second-order sensory neurons that receive afferent input and transmit it directly to motoneurons. This streamlined circuitry allows for rapid processing and response to sensory information, resulting in short latencies. Additionally, simple pathways facilitate the vestibulo-spinal reflexes, which are crucial for maintaining posture and balance by generating appropriate motor responses to counteract perturbations.

The interaction of multisensory and multimodal pathways is of utmost importance for higher-level functions, including self-motion perception and spatial orientation. These pathways allow the integration of information from multiple sensory modalities, such as vision, proprioception, and the vestibular system, to create a comprehensive understanding of one's own motion and position in space. (Angelaki & Cullen, 2008)

2.4 Biomechanics of human balance

The principles of Newtonian mechanics and the relationships between stability, base of support (BoS), line of gravity, and center of gravity (CoG) are equally relevant to both inanimate objects and human beings. The human body has a high centre of gravity and a small base of support when standing upright, making it challenging to maintain balance. (Maki & McIlroy, 1997; Winter, 1995)

In the case of inanimate objects, if the line of gravity falls outside the base of support, gravity causes objects to fall or move. However, Humans possess an innate ability to detect and respond to threats to balance, utilizing muscular activity to maintain stability (Horak, 1987). This demonstrates the unique control over balance, often referred to as balance control or more commonly, postural control, that humans possess compared to inanimate objects.

Postural control is essential for maintaining a variety of postures and engaging in different activities. Balance control is a critical component of maintaining specific postural stability, performing voluntary movements, and responding to perturbations (e.g., trips, slips, or pushes) which encompass all actions that contribute to maintaining, achieving, or restoring postural stability (Berg et al., 1989; King et al., 1994).

From a mechanical perspective, stability is the intrinsic capacity of an object to remain balanced or return to a balanced state, which is determined by physical properties such as the center of gravity's position relative to the base of support. In humans, stability refers to the inherent capacity to maintain, attain, or regain balance, considering the sensory and motor systems in addition to the physical properties of the center of gravity and base of support. (Nashner, 1982; Horak, 1987; Berg et al., 1989; King et al., 1994)

Balance control and postural control are two closely related concepts. Balance control is the ability to maintain the center of gravity within the base of support during daily activities, while postural control is the act of maintaining, attaining, or regaining a state of balance during any posture or activity (Maki & McIlroy, 1997).

2.4.1 Center of mass (COM), center of gravity (COG), and center of pressure (COP)

Center of mass (COM), center of gravity (COG), and center of pressure (COP) are all important concepts in human balance. The center of mass of an object is determined by considering the weighted average position of its entire mass distribution. It is a fixed property of an object, regardless of its orientation or the gravitational field in which it is located. The center of gravity represents the specific location within an object where the total weight of the object can be assumed to be concentrated or effectively applied. It is the same as the center of mass in a uniform gravitational field. The center of pressure refers to the precise position where the combined ground reaction force is concentrated or effectively applied. It is the location where all forces exerted on the body from the ground are in equilibrium.

In order to maintain balance, the body must keep its COM within its base of support. The base of support is the area enclosed by the feet and any other body parts that are in contact with the ground. If the COM moves outside of the base of support, the body will topple over. If the center of pressure is outside of the base of support, the body will move and fall. The body achieves balance by ensuring that the center of pressure (CoP) remains within the base of support and by utilizing muscular adjustments to move the center of mass (COM) within this base. This is accomplished through fine-tuning the body's posture and redistributing weight between the feet. (Winter, 1991; Hall, 2006; McGinnis, 2013)

The center of mass (COM) is crucial for analyzing balance and movement. It serves as a reference point, indicating shifts in balance and providing insights into coordination. Tracking the COM helps assess balance disorders, monitor interventions, and improve outcomes in various domains such as sports and ergonomics. (Erdmann, 2018)

The COG is also important for understanding human balance. If the COG is outside of the base of support, the body will lose balance. However, the COG is not as important as the COM, because it can be shifted by tilting the body. The COP is the least important of the three concepts for understanding human balance. However, it is still important to understand, because it is the point at which all the forces acting on the body from the ground are balanced. (Winter, 1991; Hall, 2006; McGinnis, 2013)

2.4.2 Postural control strategy

To investigate postural control, researchers frequently employ an inverted pendulum model to represent the human body. Postural control within this model is defined by the interaction between the center of pressure (COP) and the center of mass (COM) of the entire body (Winter, 1995). The distinction between the center of pressure (COP) and the center of mass (COM), referred to as COP-COM, has demonstrated a significant correlation with the horizontal acceleration of the overall body's COM during postural sway (Winter et al., 1996). The disparity between the center of pressure (COP) and the center of mass (COM), regarded as an "error" within the postural control system, offers valuable insights into the mechanisms of postural control. A study indicated that the root mean square (RMS) error of the COP-COM is greater in elderly individuals with neurological impairments in comparison to their healthy counterparts (Corriveau et al., 2000).

The human bipedal quiet stance can be described as a multi-joint inverted pendulum, with the ankle acting as the pivotal joint. Within this model, the center of mass is projected in front of the ankle, resulting in a dorsiflexor moment. This moment is consistently counterbalanced by the stabilizing action of tonic muscles. (Morasso et al., 2019) The oscillation observed during postural control is predominantly an automatic process, with individuals being mostly unaware of the continuous adjustments made by their postural muscles (Takakusaki, 2017). As a result, the regulation of posture mainly takes place at brainstem-spinal levels, where neural circuits are finely tuned through local loops of assistance or self-organized mechanisms. This regulation occurs in response to the predictable and undisturbed context of the postural control task. (Lajoie et al., 1993)

In contrast, during dynamic tasks, the surrounding environment undergoes constant changes, including external forces and sensory inputs. This necessitates a greater engagement of cognitive processes in postural control to achieve goal-directed movements (Takakusaki, 2017). Consequently, a supra-spinal postural strategy becomes more prominent as ongoing movement regulation is necessary to adapt to the new environment (Lajoie et al., 1993).

2.4.3 Perturbation vs. non-perturbation paradigm

The perturbation vs. non-perturbation paradigm is a research approach that is used to study how the body maintains its balance. In a perturbation paradigm, a sudden, unexpected disturbance is applied to the body, such as a push or a pull. In a non-perturbation paradigm, the body is not disturbed in any way. (Maki., 1986)

Researchers use both perturbation and non-perturbation paradigms to study postural control strategy. Perturbation paradigms are used to study how the body reacts to unexpected disturbances (Corbeil et al., 2003; Brüll et al., 2023). Non-perturbation paradigms are used to study how the body maintains its balance in a quiet, undisturbed environment (Bardy et al., 2007; Qiao et al., 2018).

One advantage of the non-perturbation paradigm is that it allows researchers to study the body's postural control strategy in a quiet, undisturbed environment. This is important because it allows researchers to isolate the body's postural control strategy from other factors that may influence postural control, such as the need to react to disturbances. (Winter, 1991; Hall, 2006; McGinnis, 2013)

2.4.4 Automatic vs. voluntary postural control process

There are two main types of postural control: automatic and voluntary. Automatic postural control is a subconscious process that is mediated by the central nervous system. It is responsible for maintaining postural stability in response to unexpected disturbances, such as a push or a pull.

Voluntary postural control refers to a conscious process employed to uphold postural stability during voluntary movements such as reaching or walking. It is also utilized to maintain postural stability in demanding environments, such as standing on uneven surfaces or when handling heavy objects.

Automatic postural control is faster and more efficient than voluntary postural control. It is also more robust to disturbances. However, voluntary postural control is more versatile and can be used to maintain postural stability in a wider range of situations.

Here are some examples of automatic postural control:

- maintaining postural stability while standing in a crowd
- reacting to a slip or a trip
- maintaining postural stability while carrying a heavy object

Here are some examples of voluntary postural control:

- balancing on a tightrope
- standing on one leg
- maintaining postural stability while reaching for an object on a high shelf

Automatic and voluntary postural control often work together to maintain postural stability. For example, when you reach for an object on a high shelf, your automatic postural control system will help you to maintain your balance while your voluntary postural control system helps you to adjust your posture to reach the object. (Winter, 1995)

2.4.5 Static balance vs. dynamic balance

Postural control or balance can be defined in two distinct ways. The first is static balance, which pertains to the capacity to sustain a stable position with minimal movement within a given base of support. The second is dynamic balance, which involves executing tasks while simultaneously maintaining stability (Shumway-Cook et al., 2023).

Balance is influenced by a multitude of factors, which encompass sensory information derived from the somatosensory, visual, and vestibular systems. Additionally, motor responses play a crucial role, affecting coordination, joint range of motion (ROM), and strength, all of which contribute to maintaining balance. (Grigg, 1994; Nashner et al., 1982; Palmieri et al., 2003)

Different sports demand varying static and dynamic balance abilities (Schmit et al., 2005). A study showed that soccer players and gymnasts showed no significant differences in terms of static and dynamic balance as measured by the BESS (Balance Error Scoring System) or SEBT (Star Excursion Balance Test). In comparison, basketball players have shown lower levels of static balance compared to gymnasts. Additionally, they also exhibit lower levels of dynamic balance when compared to soccer players. (Bressel et al., 2007)

2.5 Balance in sports

Achieving optimal postural performance, which involves minimizing postural sway, is crucial in various athletic activities and sport-specific postural control (Paillard et al., 2002). However, the relationship between balance ability and athletic performance remains somewhat unclear according to previous studies (Alderton et al., 2003; Hryssomalis et al., 2011). Multiple factors influence postural control responses, including sensory information from the somatosensory, visual, and vestibular systems, as well as motor responses that impact the quality and safety of performance in routine functional movements, athletic endeavors (Hryssomalis et al., 2011), coordination, joint range of motion (ROM), fatigue-inducing incremental exercise (Erkmen et al., 2012), and strength (Grigg, 1994). To achieve optimal balance, it is crucial for the proprioception, vision, and vestibular input, which are the three afferent systems, to provide the necessary information for successful postural performance.

Balance is of paramount importance in sports as it plays a vital role in enhancing athletic performance and reducing the risk of injuries. Maintaining balance allows athletes to efficiently control their body's center of gravity within the base of support area, enabling them to execute precise movements and maneuvers with agility and stability (Jacobson et al., 2019). In sports such as gymnastics, figure skating, and surfing, where intricate body control and coordination are essential, balance serves as a foundation for executing complex routines and maintaining control during dynamic movements (Hrysomallis., 2011). Furthermore, balance is crucial for sports that involve rapid changes in direction, sudden accelerations, and decelerations, such as basketball, soccer, and tennis. Effective balance enables athletes to quickly adjust their body position, respond to external stimuli, and maintain stability while performing explosive movements (Duncan et al., 1990).

Not only does balance contribute to performance, but it also plays a significant role in injury prevention. Athletes with good balance are better equipped to withstand external forces and maintain stability, reducing the likelihood of falls and related injuries (Hrysomallis., 2011). Furthermore, an impaired balance system can limit an athlete's ability to recover from perturbations and maintain control, increasing the risk of sprains, strains, and other musculoskeletal injuries during sports activities (Lord et al., 1991). By focusing on balance training and incorporating exercises that challenge stability, athletes can improve their proprioceptive awareness, enhance neuromuscular coordination, and reduce the risk of injury (Jacobson et al., 2019). By incorporating balance training into their regimens, athletes can enhance their overall performance, reduce the risk of injuries, and improve their quality of life on and off the field (Peterka, 2002).

2.5.1 Balance and ice hockey

Ice hockey is a dynamic sport that places unique demands on players' balance abilities. Effective balance control is crucial for ice hockey players to optimize performance and reduce the risk of injuries. The study's findings suggested that training on an unstable surface does not necessarily lead to improved balance on a stable surface, and similarly, training on a stable surface does not guarantee enhanced balance on an unstable surface. This finding highlights the importance of sport-specific training and the recognition of distinct balance characteristics that are specific to individual sports. In other words, balance training should be tailored to the specific demands and conditions of the sport to achieve optimal balance performance. (Strang et al., 2011)

Balance is among several qualities describing the efficiency of movement such as timing, anticipation, direction, accuracy, rhythm, speed, versatility, agility, and reaction time to define the level of hockey skills possessed by a player. (Pearsall et al., 2000)

In ice hockey, balance plays a significant role in several key aspects of the game. Skating, the fundamental skill in ice hockey, relies heavily on balance control. Maintaining a stable base of support and center of gravity allows players to glide smoothly, transition between different skating techniques, and generate powerful movements. Ice hockey players and other athletes who wear ice skates have unique balance characteristics that have been relatively under-researched. The design of the skate blade creates a fulcrum for rotational movement around its longitudinal axis, positioned several inches below the foot's plantar surface. This differs from most land-based sports, where the fulcrum would be the inside or outside edge of the shoe. The skate's blade, which is much narrower than the foot, serves as its base of support (see figure 2).

2.5.2 Balance demands in ice hockey

Skating involves a base of support that is narrower than the foot itself, requiring frequent postural adjustments in the mediolateral direction to counter slight lateral movements of the center of pressure. These adjustments can lead to multiple directional changes within a limited lateral range, which may result in an increased path length over time. The rhythmic side-to-side motion characteristic of skating makes it suitable for applying nonlinear analysis techniques such as sample entropy. These techniques can help capture the complexity and irregularity of the movement patterns observed during skating.

Furthermore, the low friction between skate blades and ice affects the anteroposterior (AP) balance parameters. Ice hockey players possess the ability to readily modify their anterior-posterior (AP) balance by exerting force on one skate, either positioned in front of or behind their center of pressure, while keeping it in contact with the ice. In contrast, land-based sports require shifting most of the weight to the supporting foot to reduce friction before moving the desired foot. Additionally, ice hockey players typically maintain either single-leg or double-leg support throughout the majority of their skating, unlike land-based sports that involve airborne phases during activities like sprinting. (Walsh et al., 2018)

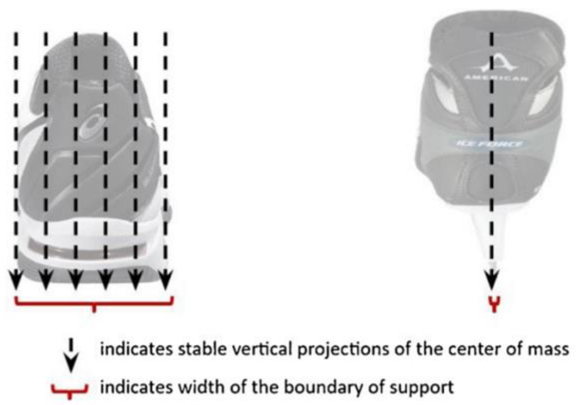

Figure 2: Graphic representing the different mechanical limits afforded by different sports footwear, a typical athletic shoe (left) and an ice hockey skate (adapted from Walsh et al., 2018, p. 279)

Considering the distinctive balance demands of ice sports, it is hypothesized that the postural sway exhibited by ice hockey players would differ from that of athletes involved in land-based sports and non-athletes, particularly when performing a one-footed stance. The specific challenges of maintaining stability on the ice, along with the need for precise control and adjustments during skating movements, may lead to unique postural characteristics in ice hockey players compared to individuals engaged in other sports or non-athletes. (Strang et al., 2011)

Postural control and balance can be used as an indirect measure to evaluate the health of the neurological system due to the complex relationship between the sensory and motor systems. The interplay between these systems allows for the body to maintain stability and adjust to changes in the environment. Therefore, deficits in postural control and balance may indicate underlying neurological issues that require further evaluation and treatment. (Murray et al., 2019)

2.6 Concussion in ice hockey

An impairment of the vestibular system, either in the peripheral or central regions, can lead to disruptions in the body's balance and equilibrium. Head trauma is an organic mechanism of vestibular dysfunction and has the potential to cause damage to both the peripheral and central vestibular structures, resulting in variety of symptoms such as vertigo, nausea and vomiting, intolerance to head motion, spontaneous nystagmus, unsteady gait, and postural instability. (Kolev & Sergeeva, 2016) Traumatic brain injury (TBI) affect millions of people worldwide each year, with over 90% classified as mild TBI (mTBI) (Gao et al., 2022). In Europe, estimates of TBI incidence vary from 95-221 per 100,000 people (Alaranta et al., 2000; Winqvist et al., 2007; Numminen, 2011).

Concussion as a subset of mild traumatic brain injury (mTBI) can affect the vestibular system and the peripheral part. (Dougherty et al., 2023; Harmon et al., 2019) Sport related concussion (SRC), which is estimated to occur annually in a range of 1.6 to 3.8 million cases, is an evolving injury in the acute phase and as the immediate and transient symptoms and least severe form of TBI induced by biomechanical forces has a frequent occurrence in contact sports, such as ice hockey and the most challenging injuries in sports medicine due to its complex nature, making it difficult to diagnose, assess, and manage effectively. The immediate and transient symptoms associated with SRC require careful evaluation and monitoring to ensure appropriate treatment and promote the long-term well-being of athletes. (McCrory et al., 2017; Zetterberg et al., 2019; Langlois et al., 2006)

2.6.1 Concussion incidence in ice hockey

In sports, the incidence of concussion varies depending on age and gender (Marar et al., 2012). A review of 13 studies across 12 sports in Europe reported an incidence of 0.23 per 1000 athlete exposures to sport (Pfster et al., 2016). However, certain sports, such as American football, rugby, ice hockey, equestrian, and cycling, have higher incidence ratios of concussion (McCrory et al., 2013; Theadom et al., 2014).

The most frequently reported symptoms of sport-related concussion (SRC) include headache, difficulty sleeping, fatigue, irritability, visual problems, and academic difficulties. Athletes who experience SRC often encounter vestibular-related symptoms as well, such as dizziness and balance problems. These symptoms can significantly impact an athlete's daily life and may require specialized assessment and management strategies to address the specific challenges associated with SRC. Proper recognition and management of these symptoms are crucial for the well-being and safe return-to-play of athletes who have experienced a concussion. (Christy et al., 2019) Damage or injury to the vestibular system, the CNS processing centers, or both can result in vestibular (Strupp & Arbusow, 2001).

Ice hockey carries a higher risk of concussion compared to other sports. When considering 15 different collegiate sports, the total rate of concussions was estimated to be 0.28 per 1000 athletic exposures. However, in male ice hockey, the rate was found to be 0.41, indicating a higher incidence of concussions in this sport. (Daneshvar et al., 2011; Hootman et al., 2007) A study of all the International Ice Hockey Federation (IIHF) World Championships and Olympic Winter Games between 2006 and 2015 found an average injury rate of 1.1 concussions per 1000 ice hockey player-games (Tuominen et al., 2017). A longitudinal cohort study conducted on a high-level professional ice hockey team from 1984 to 2013 revealed a significant rise in the incidence rate of concussions over this period. Moreover, there was a noticeable trend towards longer rehabilitation periods associated with concussions during the same timeframe. (Pauelsen et al., 2017).

The concussion injury rate among male ice hockey players is among highest at around 0.41 per 1000 athletic exposure while the total rate of concussions among 15 different collegiate sports was estimated at 0.28 (Daneshvar et al., 2011). Sports-related concussions are caused by biomechanical forces and can result from a direct blow to the head, face, neck, or other parts of the body. They typically cause a brief impairment of neurological function that resolves on its own, although in some cases, symptoms may develop gradually over time. While concussions can cause changes in the brain, these changes are generally functional rather than structural, and cannot be detected using standard neuroimaging techniques. The symptoms of a concussion can differ among individuals and in certain cases, symptoms may persist for an extended duration. Generally, these symptoms follow a sequential pattern and gradually improve over time. It's important to note that the symptoms cannot be attributed to drug or alcohol use, medication, or other injuries or medical conditions. (McCrory et al., 2017)

Dizziness is a common symptom reported in sports-related concussions, with an incidence ranging from 35 to 80%, according to studies. This suggests that disruptions in the processing of vestibular and/or visual signals along their pathways are frequently observed, making it the second most commonly reported symptom after headache. (Feddermann-Demont et al., 2017)

The first prospective epidemiologic study of ice hockey injuries in Finland, Seven Finnish national league ice hockey teams were observed during the 1988 to 1989 season and the highest rate of injury was 18 % from a total of 189 injuries and it was to the head or face. (Mölsä et al., 1997)

Functional performance tests, when used as part of a comprehensive concussion assessment, may improve the ability of health clinicians to predict the course of recovery (Alkathiry et al, 2022).

2.7 Balance assessment

Balance is a complex physiological process that is critical for maintaining postural stability and movement control. In bipedal quiet stance, humans are constantly making small adjustments to maintain alignment with gravitational forces. These adjustments are mediated by the motor control system, which receives information from the sensory systems about the body's orientation, position, and motion. The integration of sensory information and motor coordination is essential for the effective execution of postural control.

Disruptions to this delicate balance can result in muscular maladjustments and inconsistent sway patterns. Following a concussion, balance assessment is a critical component of evaluating the effects of the injury on the motor control system. In particular, the identification of abnormal sway patterns can provide important information about the extent of the injury and guide clinical decisions regarding return to activity. (Reed-Jones et al., 2014) Therefore, a comprehensive understanding of the role of balance in concussion evaluation is essential for effective treatment and management of this common injury. Numerous clinical assessments are available to evaluate human balance, each providing information on different aspects of postural control. While each of these clinical tests is a valid assessment of balance, they target different facets of postural control. (Pollock et al., 2000)

When assessing balance, there are various components that need to be considered. These include motor systems, anticipatory postural control, dynamic stability, static stability, sensory integration, functional stability limits, reactive postural control, cognitive influences, and verticality. However, in a scoping review, it was found that out of thirty-four measures, only three or fewer components of balance were evaluated. Interestingly, the Balance Evaluation Systems Test was the only measure identified that evaluated all components of balance. This highlights the need for comprehensive assessment tools that encompass all aspects of balance to provide a more holistic understanding of an individual's balance capabilities. (Sibely et al., 2015)

2.8 The importance of balance assessment

Assessing the postural control system is valuable for determining decisions regarding return-to-play and return-to-learn after a concussion. The sport-related concussion consensus statement recommends the ongoing use of balance testing, including postural control and gait assessments, to enhance the clinical utility of the Sport Concussion Assessment Tool 5th edition (SCAT5). (McCrory et al., 2017) However, the clinical effectiveness of postural control assessments varies depending on the specific method employed (Murray et al., 2014). Nevertheless, clinicians recognize the importance of utilizing postural control assessments as essential tools when making informed decisions about return-to-play and return-to-learn protocols (McCrory et al., 2017). The assessment of balance in concussion evaluations remains of utmost significance (Reed-Jones et al., 2014).

Assessing the balance abilities of hockey players, both in static and dynamic conditions, can be valuable in evaluating their competitive performance levels. Players who have well-developed postural control strategies demonstrate superior capabilities in compensating for unexpected postural disturbances and collisions, providing them with a significant competitive advantage. Therefore, conducting tests to evaluate the balance abilities of hockey players can offer insights into their overall competitive potential. (Ondra & Svoboda, 2021)

2.9 Vestibular assessment of balance

The vestibular system plays a crucial role in maintaining balance and postural control. It provides the brain with information about the body's position, motion, and orientation in space, and helps to coordinate motor responses to maintain balance. Sport-related concussions can lead to vestibular and balance issues in athletes. Objective assessments such as the Balance Error Scoring System (BESS) and computerized dynamic posturography (CDP) can help evaluate vestibular and balance impairments. (Valovich McLeod & Hale 2015)

The human vestibular system serves two main functions. Firstly, it helps to stabilize the eyes on a fixed target when the head and body are in motion. Secondly, it contributes to maintaining balance by integrating information from visual and somatosensory inputs. The semicircular canals in the vestibular system detect the head's angular acceleration, converting it into velocity information. This information is then transmitted through the vestibulo-ocular reflex (VOR) pathways to the eye muscles, allowing for stable vision during movement.

Furthermore, the vestibular system integrates angular data derived from the semicircular canals, as well as linear acceleration information, including the effects of gravity, obtained from the utricles and saccules located within the inner ear. This information is transmitted through the vestibulospinal spinal tract (VST) to the muscles in the spinal cord and lower extremities, assisting in maintaining balance. While visual and somatosensory inputs are typically sufficient for normal balance, individuals with known vestibular deficits rely on the inner ear's sense of balance when visual and somatosensory information is disrupted or conflicting. (Guskiewicz, 2001)

One commonly used vestibular assessment tool is the vestibular ocular reflex (VOR) test, which evaluates the ability of the vestibular system to stabilize gaze during head movements. The VOR test involves the patient wearing a pair of goggles with cameras that record eye movements while the patient's head is moved in various directions. The recorded eye movements are then analyzed to determine the integrity of the VOR. (Herdman, 2013)

Another commonly used vestibular assessment tool is the vestibular evoked myogenic potential (VEMP) test, which evaluates the function of the otolithic organs in the inner ear. The VEMP test involves the placement of surface electrodes on the neck and forehead, and the delivery of brief auditory stimuli to elicit a muscle response in the neck. The recorded muscle response is then analyzed to determine the integrity of the otolithic organs. (Colebatch & Halmagyi, 1992)

In addition to the VOR and VEMP tests, other vestibular assessment tools include the head impulse test, dynamic visual acuity test, and balance platform systems. These tests can help to identify deficits in vestibular function that may contribute to balance disorders in patients with concussion.

2.10 Quantitative balance assessment

Accurately evaluating an individual's balance abilities is essential for diagnosing impairments, assessing fall risk, planning treatments, and monitoring progress over time. However, the assessment of balance can be challenging due to its complex and multifactorial nature, as well as the wide range of psychometrically valid and standardized measures available. Clinicians must navigate through these complexities to select appropriate assessment tools and ensure comprehensive evaluation of an individual's balance function. (Woollacott & Tang, 1997; Orr et al., 2008)

A The study utilized a mobile technology approach to quantify the Balance Error Scoring System (BESS). Participants were recruited and instructed to perform the BESS test, which assesses postural stability and balance. Movements during the test were recorded using a smartphone's built-in accelerometer. The recorded data were processed and analyzed to automatically calculate the BESS scores. To determine the feasibility and reliability of the smartphone-based approach, the scores obtained from the mobile technology were compared to the manual scoring done by trained clinicians. Statistical analyses were performed to assess the agreement and consistency between the smartphone-based scores and the manual scores. The study employed a cross-sectional design and included a sufficient number of participants to ensure robust findings. The methodology aimed to explore the potential of mobile technology in quantifying the BESS scores accurately and efficiently. (Alberts et al., 2015)

In clinical settings, identifying balance and gait abnormalities that increase the risk of falling relies on examiner expertise, often utilizing subjective rating scales. While performance-based clinical tests exist for balance and gait assessment, they may have limitations for highly functional individuals like athletes, as they require specialized expertise for accurate interpretation and administration. (Studenski et al., 2003; Verghese et al., 2009; Godi et al., 2013)

It is crucial to use quantitative measures for assessing balance in athletes who have experienced sport-related concussions (SRC). These measures provide a more objective and accurate assessment of balance compared to clinical observation and subjective measures. A systematic review study examined studies that have utilized quantitative measures such as the Balance Error Scoring System (BESS) and the NeuroCom Sensory Organization Test (SOT) to evaluate balance in athletes with SRC and determine their readiness to return to sport. The authors suggested that using quantitative measures to assess balance can help identify athletes who may be at a higher risk of re-injury and assist in making informed decisions about their return to sport. (Kerr et al., 2022) Furthermore, quantitative measures are more sensitive than subjective measures in detecting changes in balance and gait over time.

2.11 Balance assessment in concussion

2.11.1 The Romberg test

The Romberg test is a common component of concussion assessment, to assess somatosensory perception component of balance, proprioception, which involves standing as still as possible without deviation under various visual sensory conditions, such as eyes open or closed (Forbes et al., 2023). Impaired proprioception can have multiple causes, including sensory peripheral neuropathies, aging, and spinal cord injuries. Other than neurological conditions, other factors such as changes in body position, injuries to muscle, tendon and ligaments, fatigue and poor footwear can affect proprioception. (yahya et al., 2019; Henry & Baudry, 2019)

The Romberg sign, a binary test, can yield a positive result indicating loss of proprioception in patients with myelopathies and sensory neuropathies, or uncompensated unilateral or bilateral vestibular dysfunction. (Lanska & Goetz, 2000)

Romberg's quotient (RQ) is a measure of the influence of vision on balance (Dornan et al., 1978; Morioka et al., 2000; Lê & Kapoula, 2008). Traditional Romberg tests use a stopwatch and error grading, while computerized balance tests use the same test positions (feet together, tandem, one-leg, and double-leg stance) for more precise and objective measurement of performance (De Kegel et al., 2011).

RQ has been used to detect falls in the elderly (Howcroft et al., 2017) and balance disturbances in multiple sclerosis (Kalron, 2017). It has also shown promising results in measuring concussions sustained during sports (Vartiainen et al., 2017).

Although computerized balance boards provide more accurate measurements, comparing results across studies that use different devices can be challenging. Therefore, common measures such as RQ are necessary for comparison purposes.

The use of certain standardized balance measures might offer incomplete insights into postural control and fail to capture crucial aspects of balance that are essential for preventing falls. Consequently, the selection of these measures could constrain the comprehensive assessment of an individual's balance capabilities. As a matter of fact, in a scoping review of 66 studies only one study measured evaluated all 9 components of balance (Balance Evaluation Systems Test [BESTest] (Sibely et al., 2015).

2.11.2 SCAT5

The Standardized Concussion Assessment Tool 5 (SCAT5) is a widely used assessment tool for evaluating and managing concussions in various sports, including ice hockey. In the context of ice hockey, one crucial aspect of balance assessment within SCAT5 is the evaluation of vestibular balance. (Appendix 1)

The vestibular system, located in the inner ear, plays a significant role in maintaining balance and spatial orientation. In ice hockey, the vestibular system is particularly important due to the dynamic and fast-paced nature of the game, which involves rapid changes in direction, accelerations, and decelerations. Vestibular balance assessments included in SCAT5 aim to evaluate the functioning of this system following a concussion (Echemendia et al., 2017). Specific vestibular balance assessments may be incorporated into SCAT5 for ice hockey players. These assessments can include tests that evaluate the player's ability to maintain balance during head movements, such as the head impulse test or the dynamic visual acuity test. These tests assess the vestibulo-ocular reflex, which allows for stable vision during head movements.

Research has highlighted the importance of assessing vestibular balance in ice hockey players after a concussion. Studies have shown that vestibular dysfunction is a common finding in individuals with concussions, and it can contribute to balance impairments and postural instability (Mucha et al., 2014). Identifying and addressing vestibular deficits through SCAT5 assessments and appropriate rehabilitation can be crucial for optimizing the recovery and safe return to play of ice hockey players.

2.11.3 Ainone

The evaluation system developed by Ainone, employs the Movesense Sensor and the Ainone Balance application to assess sway. The assessment is via an inertial measurement unit (IMU), which is a commonly used wearable device that incorporates multiple sensors, including accelerometers, gyroscopes, and magnetometers (Ma et al., 2016). IMUs are used to capture and measure various aspects of motion and orientation in three-dimensional space and serve as valuable tools for assessing balance-related variables and enhance the quantification of standard clinical scales in fall risk assessment and prediction. (Sample et al., 2017)

By attaching IMUs to body segments or wearable devices, researchers can collect data on body movements, orientations, and accelerations during balance tasks or activities. This data provides insights into an individual's postural control, stability, and sway characteristics, allowing for the identification of balance deficits and the evaluation of interventions. (Ahmad et al., 2013) By utilizing various tests and adjustable testing parameters, the system enables the evaluation of sway, yielding measurable, consistent, and cost-effective outcomes (Sjöman et al., 2018).

3 Purpose

The purpose of this master's thesis study was to find out if the balance outcomes from SCAT5 in ice hockey players are different than those from sway measurements. There is only one pilot study to compare the baseline performance of athletes in terms of SCAT5/BESS error calculation with the effects of various visual and somatosensory conditions during balance testing in similar postures measured. (Marsat, 2022)

The main research question in this thesis was:

1: How do SCAT5 measurements compare to sway measurements in assessing balance outcomes in ice hockey players?

Null Hypothesis (H0): There is no significant difference between SCAT5 and sway measurements in assessing balance outcomes. (H0: $\mu1 \leq \mu2$)

Alternative Hypothesis (H1 or Ha): SCAT5 measurements and sway measurements yield different outcomes in assessing balance, indicating the need for complementary or alternative assessment methods. (H1: $\mu1 > \mu2$)

According to the data collection another question was:

2: How do testing different protocols affect sway measurements?

Null hypothesis (H0): There is no significant effect of testing different protocols on sway measurements. (H0: $\mu1 \leq \mu2$)

Alternative hypothesis (Ha): Testing different protocols has a significant effect on sway measurements. (H1: $\mu1 > \mu2$)

4 Material & Methods

4.1 Study design

This study employs an observational design to assess the sway measurements and balance profiles of ice hockey players across different protocols, while considering the sensory integration components of visual, somatosensory, and vestibular inputs. The study involves observing and collecting data on ice hockey players' balance performance without directly manipulating variables.

4.2 Data collection insturmentation

For this study, two main instruments were utilized for data collection. First, the Ainone Balance which is a medical device classified as Class I under MDD 93/42/EEC (ISO 13485) regulations. application was employed to capture sway measurements and balance data of ice hockey players in a more objective and precise measurements.

To obtain a comprehensive assessment of postural control, it is important to consider the involvement of various systems, including visual, somatosensory, and vestibular. A set of 16 different protocols have been identified and utilized to gather data and evaluate postural control.

These protocols are carefully designed to challenge the individual's ability to maintain balance and stability while incorporating different sensory inputs. By systematically varying protocols and sensory conditions, practitioners can gain insights into the functioning of the visual, somatosensory, and vestibular systems and their contributions to postural control.

The 16 protocols encompass a wide range of postural challenges, such as standing on both legs, one leg, and tandem position, with eyes open and closed, and standing on a soft foam and hard floor. These protocols are selected to isolate and manipulate specific sensory inputs, allowing researchers to assess the relative importance of each system in maintaining postural stability. The evaluation conducted using Ainone Balance enables targeted testing, encompassing various stances such as feet together, one leg, tandem, etc. Additionally, the evaluation allows for testing modifications, including variations in visual input (eyes open/closed) and surface conditions (soft/hard surface).

This mobile application, embedded in a tablet, utilizes a compact wireless inertial measurement unit (IMU) sensor that was securely strapped to the subject' chest height with a velcro band to monitor balance as a physiological signal, specifically the amount of sway. The sensor collects sway data of centre of mass during the assessment process to assess postural stability and provides quantitative measures of sway.
The data collected from the Ainone Balance include sway path length and its velocity standard deviation, the area enclosed by the path of movement and Romberg quotient.

Second, In the SCAT5, balance vestibular data is gathered through a combination of subjective reports and objective assessments. Participants are asked to self-report any symptoms of dizziness, unsteadiness, or balance problems they may be experiencing. These subjective reports provide valuable information about their vestibular function.

Additionally, objective assessments of vestibular function are conducted as part of the SCAT5 evaluation Modified Balance Error Scoring System (mBESS) testing. These assessments typically include testing eye movements, assessing postural stability during different conditions (e.g., standing on a firm or foam surface), and evaluating coordination and balance control in different standing positions (double legs, single leg, and tandem stance). The results from these objective assessments contribute to the overall assessment of vestibular function and balance as part of the SCAT5 protocol.

4.3 Data sharing agreement

A written agreement was established between the student and the host company regarding the usage of the numeric data. The agreement explicitly stated that the data would be utilized in an anonymous form and solely for the purpose of conducting the master's thesis research. The utmost importance was placed on safeguarding the anonymity and privacy of the study participants throughout all stages of data utilization and result interpretation.

As per the agreement, it was strictly prohibited to copy or disclose the data to any third parties. Furthermore, the student was responsible for ensuring the secure storage of the data and committed to deleting it from all secured storage devices upon the completion of the analysis.

This agreement was established to ensure the ethical and responsible handling of the data, in adherence to the principles of good scientific practice and the protection of participants' confidentiality.

4.4 Data collection procedure

4.4.1 Participant recruitment

The study included a total of 123 participants, utilizing a convenience sampling approach, whereby participants were selected from a specific ice hockey team. The selection criteria included athletes who were actively engaged in training during the designated data collection period and the eligibility criteria for participant selection were healthy male ice hockey players aged 12-33 years old. The data collection took place over the course of 5 days in June 2021.

4.4.2 Ethical consideration

All players were notified about the commencement of the study. Additionally, parents or guardians of participants under the age of 18 were also informed. To maintain confidentiality and protect participant privacy, all personal identifying information was anonymized or pseudonymized. Ethical considerations and research guidelines were followed throughout the study. (Appendix 2)

4.4.3 Data collection

The assessment was conducted on 122 male ice hockey players from a specific Finnish ice hockey club, aged 12 to 33 years gave consent to participate in the study. The study aimed to evaluate the athletes' balance and postural stability. SCAT5 data collection and sway measurements occurred in two different rooms.

In SCAT5 measurements, office, or off-field part of SCAT5 was administered to each participant individually in a quiet and distraction-free environment. The toll consisted of several sections, including athletic background symptom evaluation, cognitive screening, and neurological screening. In the neurological screening section of SCAT5, using a Modified Balanced Error Scoring System (mBESS) testing, the non-dominant foot was tested. The dominant foot was determined by asking the participants which leg they would use to shoot a ball shoot a ball on a target (Van Melick et al., 2017).

Then the participants were asked to stand on feet together and both hands on the iliac crest with eyes open and closed, on a hard floor and soft floor. A soft block of 45 X 45 foam was used as the soft floor. The participant should not be having any taping on ankle or wearing shoes. Each test was administered for 10 seconds. In static conditions, it is important to allow sufficient time for the posture signal to reach a steady state through adjustment, which usually takes a few seconds (Eysel-Gosepath et al., 2016).

The errors were lifting hands off iliac crest (Figure 1), opening eyes (when the test is with eyes open), stepping, stumbling or falling, moving hip into more than 30-degree abduction (Figure 2), lifting forefoot or heel, and remaining out of testing positions for more than 5 seconds.

Figure 3: The error of lifting hands off iliac crest

Figure 4: The error of hip abduction more then 30-degree

The testing positions were on single leg stance, double leg stance and tandem stance (non-dominant foot at the back) and the errors were counted out of 10 and the total score of three positions was accumulated, the higher the total score, the poorer the balance.

In sway measurements, the assessment included a series of balance tests, including the Romberg position (standing with feet together), tandem stance (non-dominant foot in back), and single leg standing with hands on iliac crest. All tests were done with both eyes open and closed, and both on soft floor and hard floor without shoes or taping on ankle, creating 16 different protocols. The same soft foam, used in SCAT5 assessment, was used as the soft floor.

The data were collected by the wireless sensor attached securely to the athletes' chest using a velcro band. Sway data was recorded for a duration of 10 seconds during each testing position and was captured on a tablet device. The gathered data were sway path length and its velocity standard deviation, the area enclosed by the path of movement and Romberg quotient. There were 5 seconds rest between each test.

Efforts were made to ensure that the data collection process was standardized and consistent across all participants to minimize potential biases and confounding factors. Clear instructions were provided to participants regarding the study procedures, and any questions or concerns they had been addressed.

5 Statistics

This study aims to investigate how SCAT5 measurements compare to sway measurements in assessing balance outcomes in ice hockey players. The research questions address the comparison between these two assessment methods and the potential effects of testing different conditions on sway measurements.

SPSS Statistics 29.0.0.0 (IBM Corp, Armonk, NY) was used to conduct the statistical analysis in the study. Descriptive statistics, including mean, median, and standard deviation, were calculated for the SCAT5 balance examination total error and sway path distance data obtained from the Ainone Balance tool. Median values were used for comparisons between the groups (Figure 5). The significance of group differences in these baseline measurements was evaluated using independent samples t-tests, with a significance level (α) set at 0.05.

6 Results

Following the assessment of the SCAT5 balance examination total error, the participants were divided into two groups based on their performance: a poor group (n=54) and a good group (n=68). The reference error point for the good group was set at 4 errors or less in the Balance Error Scoring System (BESS), while the poor group had a reference point set at 5 errors or more (total errors higher than total group medium score + 1SD).
The results were interpreted from two different aspects:

1. Comparison of SCAT5 and sway measurements between groups:

The statistical analysis will determine whether there is a significant difference between SCAT5 and sway measurements in assessing balance outcomes. The results will support either the null hypothesis (H0) or the alternative hypothesis (H1), providing insights into the comparability of these assessment methods.

2. Effect of testing different protocols on sway measurements within groups:

The statistical analysis will assess the impact of testing different conditions on sway measurements. The results will either support the null hypothesis (H0) or the alternative hypothesis (Ha), indicating the presence of a significant effect.

The analysis will be presented through distinct tables based on the type of stance and different protocols. Each stance type follows a protocol that includes variations of eyes open or closed, as well as different floor conditions, such as soft or hard.

6.1 Comparison of SCAT5 and sway measurements between groups:

According to the data presented in Table 1, notable disparities can be observed between the poor and good groups across all protocols of standing on both feet, except for standing on both feet on a hard floor with eyes open, with t (1.70) and p (0.09).

Table 1: Comparison of SCAT5 and sway measurements in standing on both feet protocols

	Median			Mean			Standard deviation			Comparison	
Protocols	**Total**	**Good**	**Poor**	**Total**	**Good**	**Poor**	**Total**	**Good**	**Poor**	**t(120)**	**p-value**
Standing on both feet, hard floor, eyes closed	0,32	0,31	0,35	0,35	0,32	0,38	0,13	0,12	0,14	2,36	0,02
Standing on both feet, hard floor, eyes open	0,30	0,28	0,33	0,33	0,32	0,36	0,13	0,12	0,14	1,70	0.09
Standing on both feet, soft floor, eyes closed	0,43	0,39	0,47	0,43	0,40	0,48	0,13	0,11	0,14	3,37	0.00
Standing on both feet, soft floor, eyes open	0,34	0,31	0,38	0,36	0,33	0,40	0,13	0,11	0,15	3,22	0.00

Table 2 presents data, comparing sway measurements and SCAT5 scores in tandem stance protocols. The result indicates differences between protocols involving eyes closed versus eyes open, as well as between protocols on soft floor versus hard floor, when comparing the good and poor groups in tandem stance. However, in the case of the hard floor with eyes closed protocol, the difference between the good group and poor group is not statistically significant, as indicated by a p (0.07) and t (1.82)

Table 2: Comparison of SCAT5 and sway measurements in tandem stance protocols

	Median			Mean			Standard deviation			Comparison	
Protocols	**Total**	**Good**	**Poor**	**Total**	**Good**	**Poor**	**Total**	**Good**	**Poor**	**t(120)**	**p-value**
Tandem stance, hard floor, eyes closed	0,49	0,46	0,53	0,56	0,52	0,60	0,25	0,25	0,26	1,82	0.07
Tandem stance, hard floor, eyes open	0,38	0,37	0,43	0,41	0,38	0,45	0,15	0,13	0,15	2,83	0.00
Tandem stance, soft floor, eyes closed	0,84	0,75	1,13	1,09	0,88	1,35	0,74	0,52	0,89	3,59	0.00
Tandem stance, soft floor, eyes open	0,50	0,48	0,57	0,53	0,49	0,58	0,20	0,18	0,22	2,36	0.02

Table 3 displays result indicating a significant difference in sway measurements between the good and poor groups during the standing on one-foot protocols.

Table 3: Comparison of SCAT5 and sway measurements in standing on one foot protocols

	Median			Mean			Standard deviation			Comparison	
Protocols	**Total**	**Good**	**Poor**	**Total**	**Good**	**Poor**	**Total**	**Good**	**Poor**	**t(120)**	**p-value**
Standing on left foot, hard floor, eyes closed	0,82	0,70	0,89	0,91	0,81	1,03	0,44	0,38	0,48	2,75	0.01
Standing on right foot, hard floor, eyes closed	0,84	0,76	0,98	0,97	0,88	1,08	0,43	0,39	0,46	2,61	0.01
Standing on left foot, hard floor, eyes open	0,52	0,47	0,57	0,53	0,50	0,58	0,18	0,15	0,21	2,76	0.01
Standing on right foot, hard floor, eyes open	0,53	0,50	0,60	0,57	0,53	0,63	0,19	0,17	0,21	2,86	0.01
Standing on left foot, soft floor, eyes closed	1,78	1,50	2,22	2,15	1,79	2,61	1,32	1,01	1,52	3,57	0.00
Standing on right foot, soft floor, eyes closed	1,95	1,59	2,58	2,11	1,76	2,54	1,10	1,01	1,05	4,15	0.00
Standing on left foot, soft floor, eyes open	0,66	0,62	0,74	0,69	0,64	0,76	0,24	0,20	0,26	3,03	0.00
Standing on right foot, soft floor, eyes open	0,66	0,60	0,73	0,72	0,66	0,80	0,33	0,32	0,33	2,33	0.02

In summary the analysis of the total balance scores for the sixteen different protocols revealed that there is a statistically significant difference between the total balance scores of the good and poor groups for 14 of the protocols. This suggests that the poor group has poorer balance than the good group for most of the positions studied.

Figure 5, 6, and 7 show median, mean, and standard deviation of comparison of sway length distance and SCAT5, respectively. According to Figure 7, the standard deviation of the total balance scores was higher for the poor group than for the good group for all 16 positions. This suggests that there is more variability in the performance of the poor group, with some members performing very poorly and some performing less poorly. The good group, on the other hand, has less variability in their performance.

Table 4: List of abbreviations

SFFHFEC	standing feet together on hard floor with closed eyes	SLFSFEC	standing on left foot on soft floor with closed eyes
SFFHFEO	standing feet together on hard floor with open eyes	SRFSFEC	standing on right foot on soft floor with closed eyes
SFFSFEC	standing feet together on soft floor with closed eyes	SLFSFEO	standing on left foot on soft floor with open eyes
SFFSFEO	standing feet together on soft floor with open eyes	SRFSFEO	standing on right foot on soft floor with open eyes
SLFHFEC	standing on left foot on hard floor with closed eyes	TDHFEC	Tandem standing, dominant foot in front on hard floor with closed eyes
SRFHFEC	standing on right foot on hard floor with closed eyes	TDHFEO	Tandem standing, dominant foot in front on hard floor with open eyes
SLFHFEO	standing on left foot on hard floor with open eyes	TDSFEC	Tandem standing, dominant foot in front on soft floor with closed eyes
SRFHFEO	standing on right foot on hard floor with open eyes	TDSFEO	Tandem standing, dominant foot in front, on soft floor with open eyes

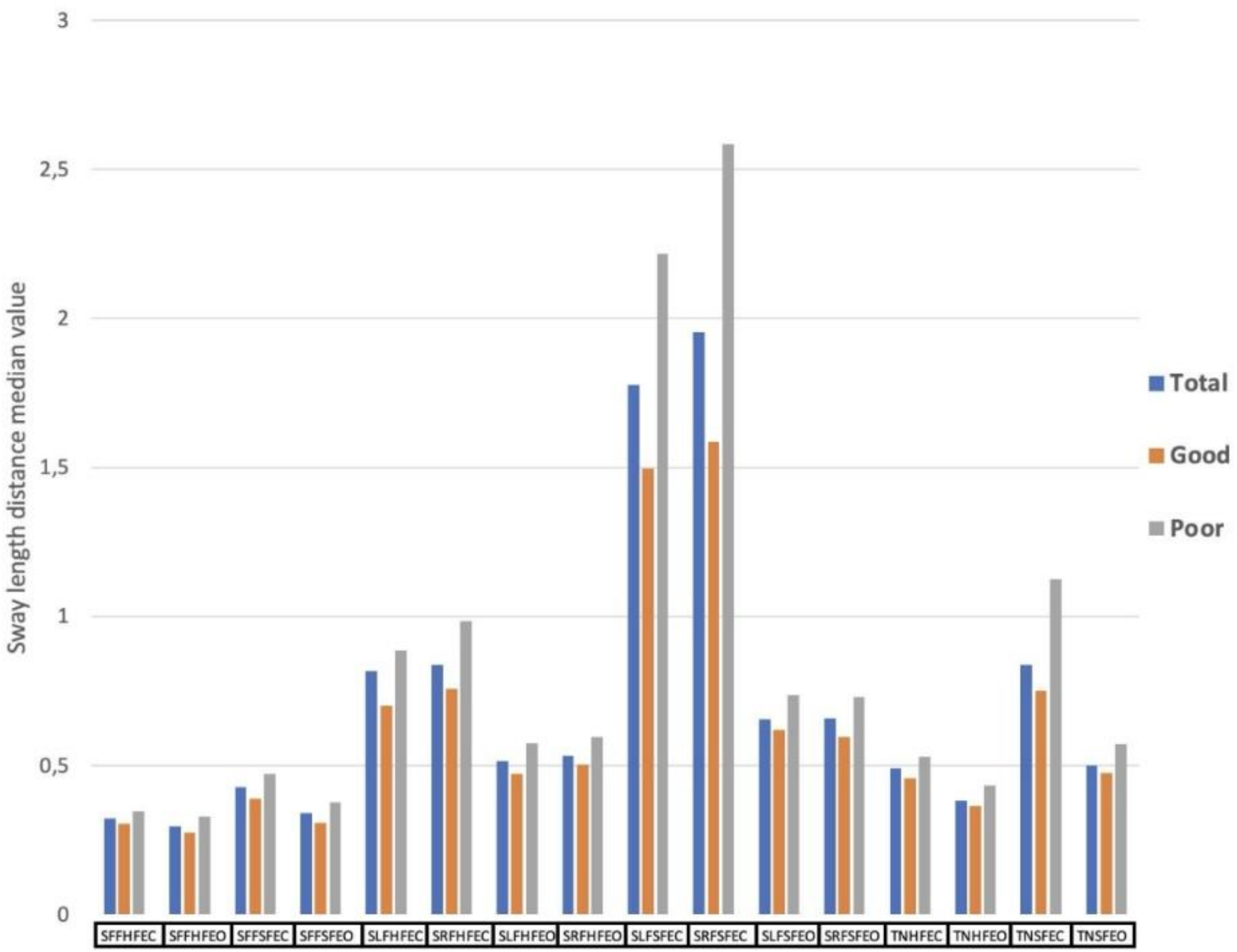

Figure 5: Comparison of sway length distance median among protocols

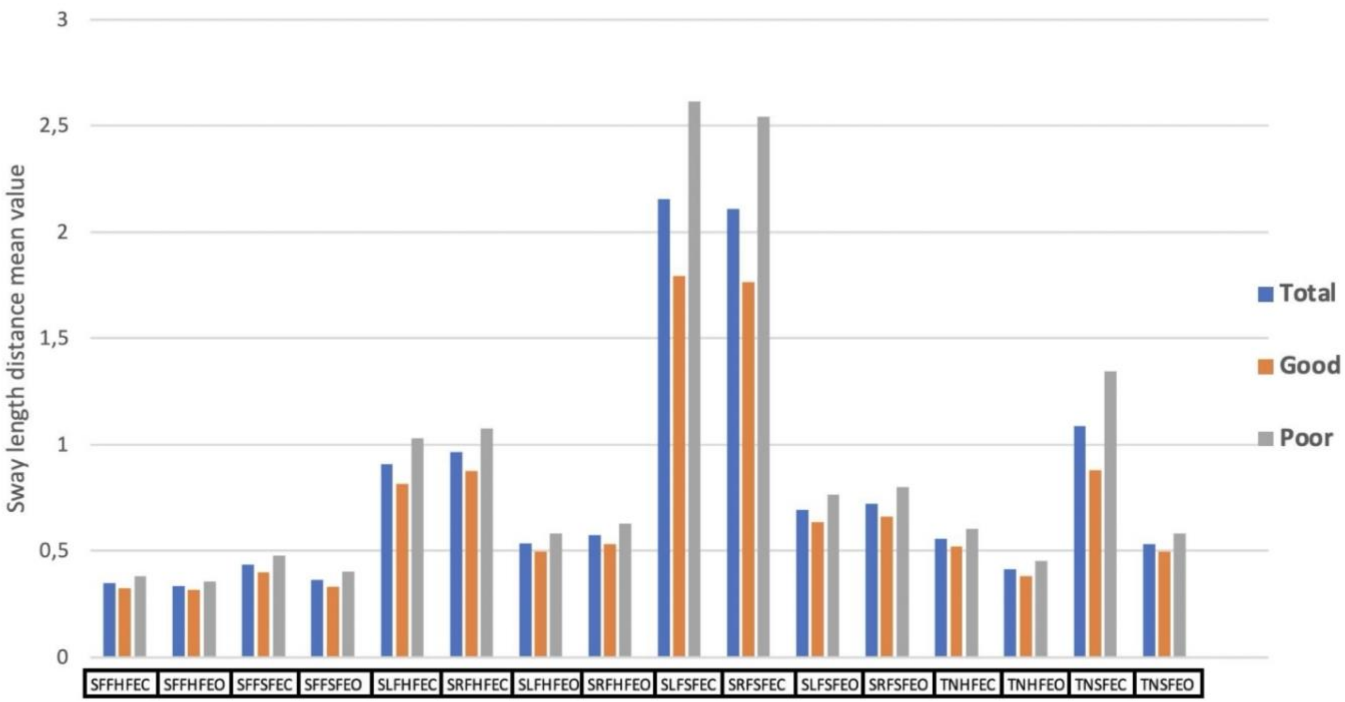

Figure 6: Comparison of sway length distance mean among protocols

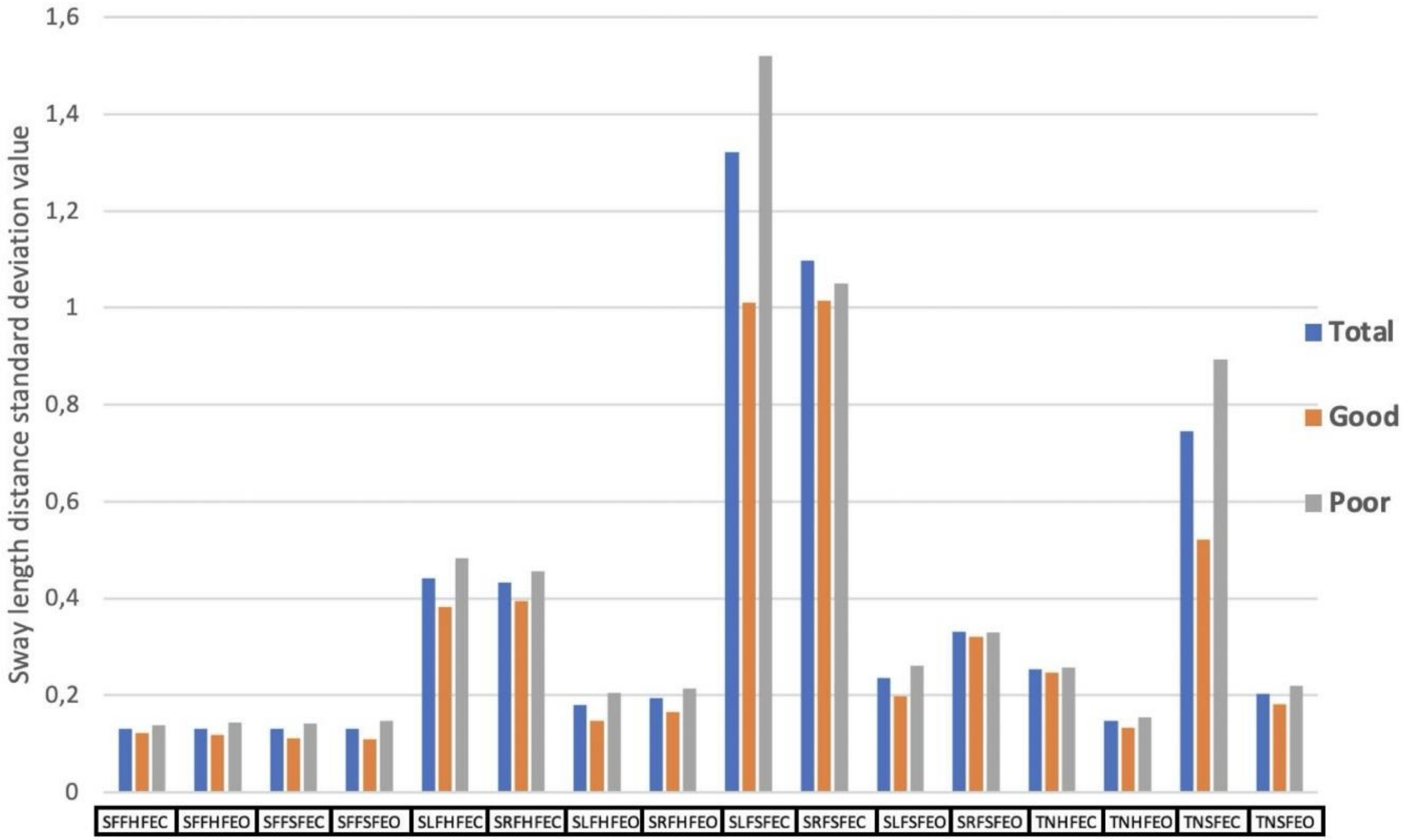

Figure 7: Comparison of sway length distance standard deviations among protocols

The sway length increase from eyes open to eyes closed protocol was largest in the poor group, on soft foam, from standing on right foot, with eyes open, with sway length median=0,73 (SD=0.33) to eyes closed, with sway length median=2.58 (SD=1.05) with p-value=0 and t (-8.63). On the other hand, the sway length increase from eyes open to close was smallest in the poor group on hard floor, while standing on both feet, with sway length median=0.33 (SD=0.14) to sway length median=0.35 (SD=0.14), p (0.39), and t (0.87).

The athletes who had higher scores in SCAT5 also had increased sway length in sway length measurements. The sway length appears to be the highest in standing on right foot on soft floor with eyes closed in the poor group, with sway length Median 2.58 (SD=1.05). The second highest sway length was in the poor group, in the same protocol but on left foot, with sway length Median 2.22 (SD=1.52) in the poor group. The highest sway length in good group was in the same protocol as poor group, standing on right foot on soft floor with eyes closed, with sway length Median 1.58 (SD=1.01), following by same protocol but on left foot, with sway length Median=1.50 (SD=1.01). The lowest sway was in standing on both feet and hard floor with eyes open, with sway length Median=0.28 (SD=0.12) and t (1.70), in the good group.

6.2 Comparison of balance across different stances

As presented in Table 5, The sway parameters exhibited variations in response to changes in somatosensory conditions resulted from different stance conditions. There were significant differences in sway changes between double leg stance and single leg stance on both hard and soft floors, with eyes open or closed, within groups. Similarly, there were significant differences in sway changes between tandem stances and single leg stance on both hard and soft floors.

Table 5: Comparison of Sway Length Distance Measurements across different stance protoclos within groups

Protocols	Poor		Good		Total	
	p-value	t-value	p-value	t-value	p-value	t-value
Hard floor, eyes closed, Standing on both feet vs. left foot	0,00	-9,50	0,00	-10,08	0,00	-13,45
Hard floor, eyes closed, Standing on both feet vs. right foot	0,00	-10,76	0,00	-11,02	0,00	-15,05
Hard floor, eyes closed, standing on both feet vs. tandem	0,00	-5,65	0,00	-5,89	0,00	-8,07
Hard floor, eyes open, standing on both feet vs. left foot	0,00	-6,05	0,00	-7,37	0,00	-9,18
Hard floor, eyes open, standing on both feet vs. right foot	0,00	-7,21	0,00	-8,27	0,00	-10,63
Hard floor, eyes open, standing on both feet vs. tandem	0,01	-2,61	0,01	-2,55	0,00	-3,56
Soft floor, eyes closed, standing on both feet vs. left foot	0,00	-10,75	0,00	-11,88	0,00	-15,03
Soft floor, eyes closed, standing on both feet vs. right foot	0,00	-15,00	0,00	-11,62	0,00	-17,58
Soft floor, eyes closed, standing on both feet vs. tandem	0,00	-7,85	0,00	-8,54	0,00	-10,77
Soft floor, eyes open, standing on both feet vs. left foot	0,00	-9,55	0,00	-11,05	0,00	-14,06
Soft floor, eyes open, standing on both feet vs. right foot	0,00	-8,63	0,00	-8,09	0,00	-11,59
Soft floor, eyes open, standing on both feet vs. tandem	0,00	-5,67	0,00	-6,41	0,00	-8,37
Hard floor with eyes closed, tandem stance vs. standing on left foot	0.00	-5.71	0.00	-5.33	0.00	-7.64
Hard floor with eyes closed, tandem stance vs. standing on rightt foot	0.00	-6.65	0.00	-6.31	0.00	-8.98
Hard floor with eyes open, tandem stance vs. standing on left foot	0.00	-3.72	0.00	-4.81	0.00	-5.80
Hard floor with eyes open, tandem stance vs. standing on right foot	0.00	-4.91	0.00	-5.88	0.00	-7.37
Soft floor with eyes closed, tandem stance vs. standing on left foot	0.00	-5.29	0.00	-6.61	0.00	-7.79
Soft floor with eyes closed, tandem stance vs. standing on right foot	0.00	-6.39	0.00	-6.39	0.00	-8.53
Soft floor with eyes open, tandem stance vs. standing on left foot	0.00	-3.94	0.00	-4.37	0.00	-5.70
Soft floor with eyes open, tandem stance vs. standing on right foot	0.00	-4.07	0.00	-3.74	0.00	-5.42

The findings suggest that alterations in somatosensory conditions have a notable impact on sway parameters, reflecting postural control and stability. When individuals transitioned from a stable double leg stance to a more challenging single leg stance, whether on a hard or soft floor and with eyes open or closed, significant differences in sway patterns were observed. The greatest absolute t-value belongs to standing on both feet, on soft floor with eyes closed protocol compared to standing on right foot in the poor group with p (0.00) and, t (-15.00).

6.3 Comparison of balance with eyes open vs. eyes closed (visual condition)

As presented in Table 5, all sway parameters varied with the changes in visual conditions.
The analysis of sway changes from eyes open to eyes closed, while standing on both feet on a soft or hard floor, reveals no significant differences within groups.

On the other hand, significant differences were observed within the groups when comparing the sway changes from eyes open to eyes closed during tandem stance on a soft floor. The corresponding negative t-values indicate that the performance of participants in tandem stance with eyes closed was significantly worse compared to their performance with eyes open in this comparison.

These findings suggest that the level of difficulty involved in maintaining a tandem stance on a soft floor and transitioning from eyes open to eyes closed has a significant impact on sway changes. It is evident that postural control and stability vary notably within groups under this specific condition. The results highlight the importance of sensory input and balance strategies in maintaining stability during challenging postural tasks.

Table 6: Comparison of sway measurements across different protocols of eyes open and closed

Protocols	Poor		Good		Total	
	p-value	t-value	p-value	t-value	p-value	t-value
Standing on both feet, hard floor, eyes open vs. closed	0,39	0,87	0,68	0,41	0,37	0,90
Standing on both feet, soft floor, eyes open vs. closed	0,39	-0,87	0,80	-0,25	0,43	-0,79
Standing on left foot, hard floor, eyes open vs. closed	0,00	-6,05	0,00	-7,37	0,00	-9,18
Standing on right foot, hard floor, eyes open vs. closed	0,00	-7,21	0,00	-8,27	0,00	-10,63
Standing on left foot, soft floor, eyes open vs. closed	0,00	-9,55	0,00	-11,05	0,00	-14,06
Standing on right foot, soft floor, eyes open vs. closed	0,00	-8,63	0,00	-8,09	0,00	-11,59
Tandem stance, hard floor, eyes open vs. closed	0,01	-2,61	0,01	-2,55	0,00	-3,56
Tandem stance, soft floor, eyes open vs. closed	0,00	-7,85	0,00	-8,54	0,00	-10,77

According to Table 6, comparison showed that there are no significant differences in performance between eyes closed and eyes open protocols in the double stance condition, on either soft floor with p (0.39), and t (- 0.87) in the poor group and p (0.80), and t (- 0.25) in the good group, or hard floor with p (0.39), t (0.87) in the poor group, and p (0.68), and t (0.41) in the good group.

However, significant differences are observed in the tandem stance protocols on both hard floor with p (0,01), and t (- 2.61) in the poor group, and p (0.01), and t (- 2.55) in the good group, and on soft floor with p (0.00), and t (- 7.85) in the poor group and p (0.00), t (- 8.54) in the good group. This suggests that the difficulty level and balance demand of the two stances might influence the impact of closing the eyes on postural control.

The findings of sway changes from eyes open to eyes closed, while standing on one foot on soft or hard floor, either on left or right foot, showed that closing the eyes during one-foot stance on a soft floor has a significant impact on postural control and stability. The sensory input deprivation caused by closing the eyes likely increases the difficulty of maintaining balance, leading to noticeable changes in sway. The results hold true for both the individual groups and the overall analysis, indicating a consistent effect across the entire sample.

These findings emphasize the importance of visual feedback in maintaining balance during challenging postural tasks, particularly when standing on one foot on an unstable surface like a soft floor.

6.4 Comparison of balance between floor conditions (somatosensory condition)

As presented in Table 7 there are no significant differences in sway changes when comparing the performance of individuals in double stance with eyes open on a hard floor versus a soft floor within the poor group with p (0.39), and t (- 0.87), and good group with p (0.80), and t (- 0.25), and in total, with p (0.43), and t (- 0.79). In contrast to the results for double stance, significant differences are observed in sway changes between tandem stance on a hard floor and tandem stance on a soft floor with eyes open within the poor group with p (0.01), and t (- 2.61), and in good group with p (0.01), and t (- 2.55), and in total with p (0.00), and t (- 3.56).

Table 7: Comparison of sway measurements across different protocols of hard floor vs. soft

Protocols	Poor		Good		Total	
	p-value	t-value	p-value	t-value	p-value	t-value
Standing on both feet, eyes closed, hard floor vs. soft	0,00	-3,62	0,00	-3,77	0,00	-5,07
Standing on both feet, eyes open, hard floor vs. soft	0,39	-0,87	0,80	-0,25	0,43	-0,79
Standing on left foot, eyes closed, hard floor vs. soft	0,00	-10,75	0,00	-11,88	0,00	-15,03
Standing on right foot, eyes closed, hard floor vs. soft	0,00	-15,00	0,00	-11,62	0,00	-17,58
Standing on left foot, eyes open, hard floor vs. soft	0,00	-9,55	0,00	-11,05	0,00	-14,06
Standing on right foot, eyes open, hard floor vs. soft	0,00	-8,63	0,00	-8,09	0,00	-11,59
Tandem stance, eyes closed, hard floor vs. soft	0,00	-7,85	0,00	-8,54	0,00	-10,77
Tandem stance, eyes open, hard floor vs. soft	0,01	-2,61	0,01	-2,55	0,00	-3,56

The analysis of sway changes from a hard floor to a soft floor, while standing on one foot (either left or right) with eyes closed or open, reveals statistically significant differences in poor, good and in total, with p (0.00), and t (- 10.75) in the poor group, p (0,00), and t (- 11.88) within the good group, both on left foot and with eyes closed. The observed differences in sway changes highlight the influence of the floor surface on the proprioceptive and sensory feedback received by the individual.

The findings indicate that individuals in all groups (poor, good, and in total) experience difficulties in maintaining balance and stability when standing on both feet with eyes closed on a soft floor compared to a hard floor, with p (0.00), and t (- 3.62) in double stance protocol in the poor group, and p (0.00), and t (- 3.77) in the good group. The reduced sensory input and increased instability of the soft floor likely contribute to the observed differences in sway changes. The same results were seen in the

The analysis of sway changes from a hard floor to a soft floor, while standing on tandem stance with eyes closed, also revealed statistically significant differences in poor group with p (0.00), and t (- 2.61) in the poor group, and p (0.00), and t (- 8.54) in the good group. These results highlight the significant impact of floor surface on postural control and stability during both tandem stance with eyes closed. The transition from a hard floor to a soft floor introduces a more challenging and unstable surface, which leads to noticeable changes in sway.

Furthermore, a correlation analysis was conducted to examine the relationship between more challenging and relatively less challenging protocols in both groups. Specifically, the correlation focused on the comparison of the tandem stance on a soft floor with eyes closed (considered an easier position) with the standing on one leg protocols (both right and left) on either floor with eyes closed, which are considered more challenging.

Additionally, another correlation analysis was performed between the less challenging protocol of standing on both feet with eyes closed on a soft floor and the same protocols as previously mentioned. The objective of these correlations was to identify a seemingly less challenging protocol that could still elicit balance errors, allowing for the generalization of findings to groups other than athletes.

Among all the correlations examined, only two of them, which displayed a relatively mild positive linear relationship, are reported in this section, and are depicted in Figure 8 & 9 & 10 &11. Figure 8 illustrates mild positive linear relationship between two variables: standing on one foot on a hard floor with eyes closed and standing on both feet on a soft floor with eyes closed in the poor group with r (0.46), p (0.00), and t (9.23).

Moving on to Figure 10, in poor group it demonstrates a similar mild positive linear relationship between standing on one foot on a soft floor with eyes closed and standing in a tandem position on the same soft floor with eyes closed with r (0.48), p (0.00), and t (-6.35). The correlation heat maps of these are shown in Figure 9 and 11, respectively.

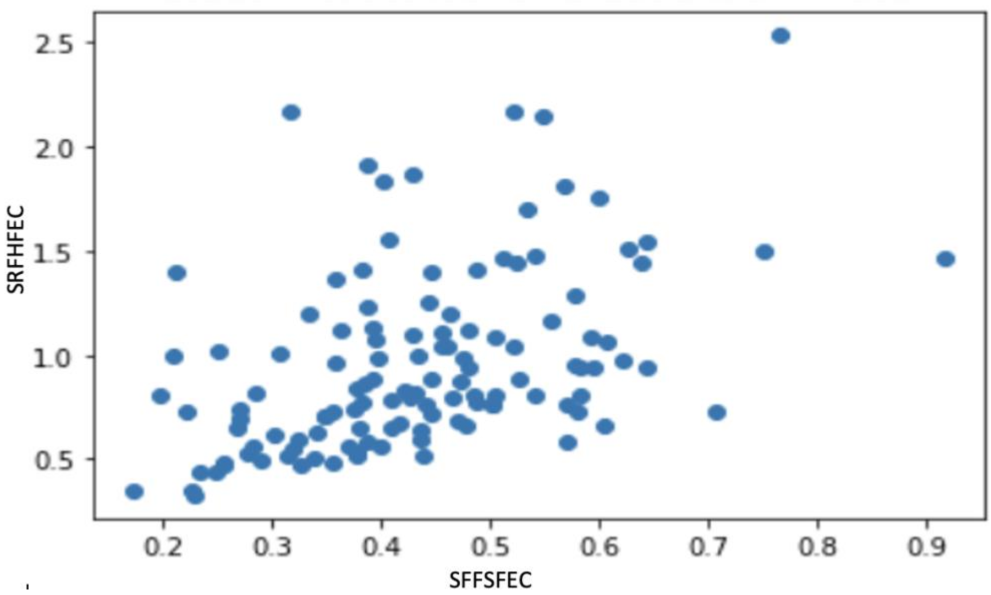

Figure 8: Scatter plot between protocols 'standing on both feet on soft floor with eyes closed' and 'standing on right foot on hard floor with eyes closed'

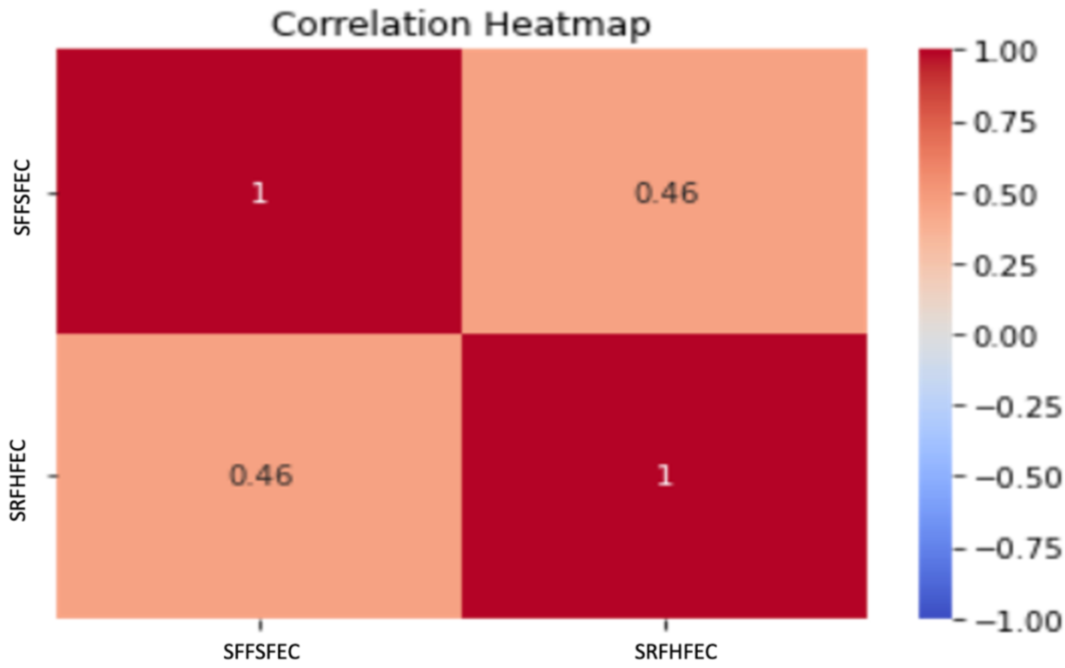

Figure 9: Correlation Heatmap between protocols ‘standing on both feet on soft floor with eyes closed’ and ‘standing on right foot on hard floor with eyes closed’ in poor group

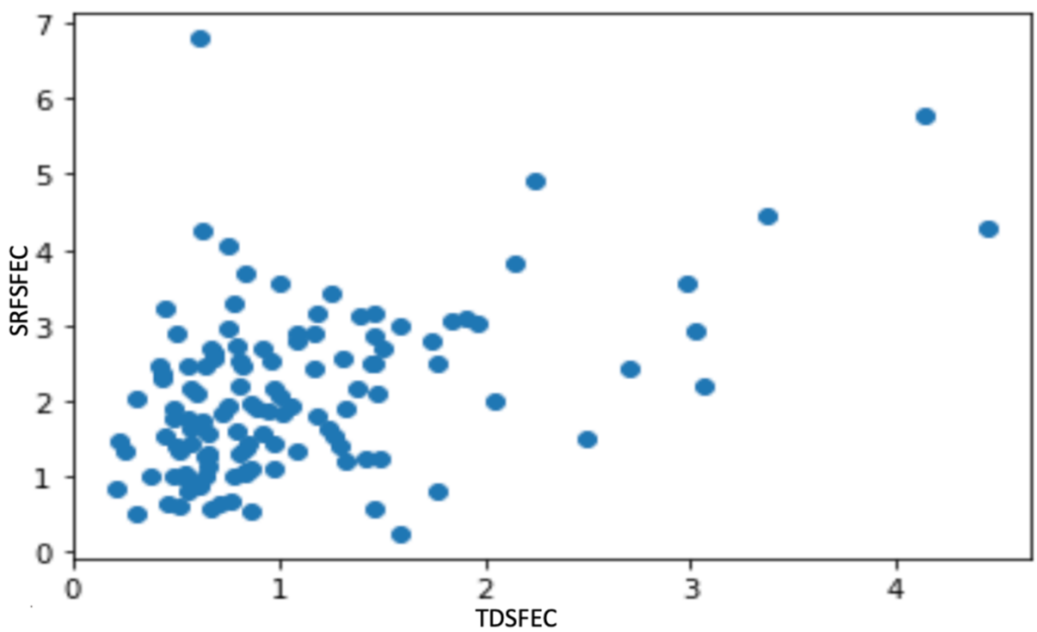

Figure 10: Scatter plot between protocols ‘tandem stance on soft floor with eyes closed’ and ‘standing on right foot on soft floor with eyes closed’ in poor group

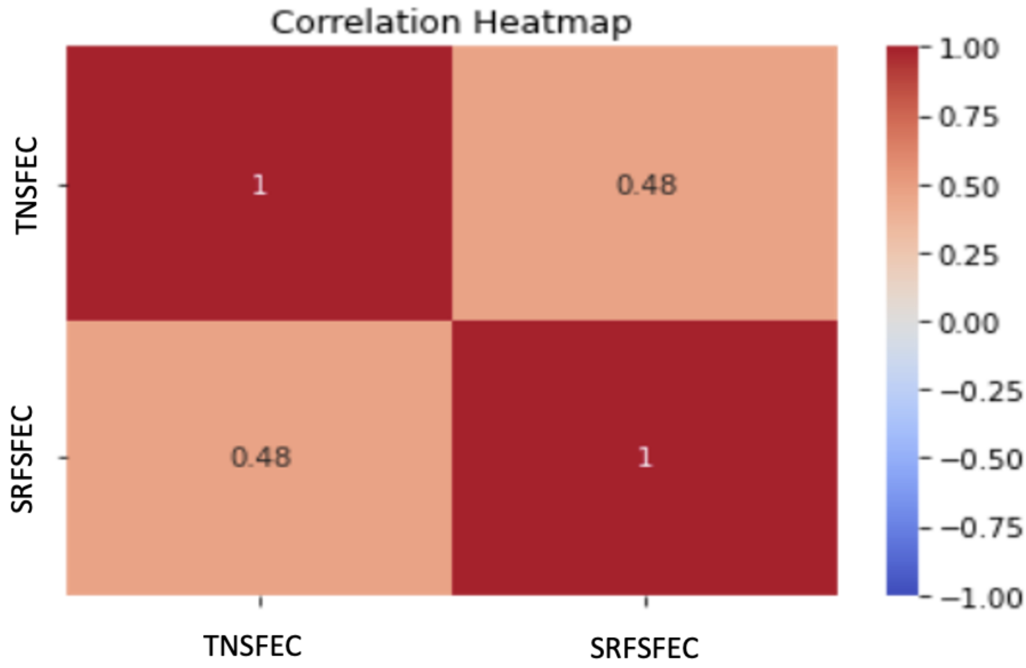

Figure 11: Correlation Heatmap between protocols 'tandem stance on soft floor with eyes closed' and 'standing on right foot on soft floor with eyes closed' in poor group

7 Discussion

The primary objective of this study was to compare balance measurements using SCAT5 and sway measurements in assessing balance outcomes in ice hockey players. Additionally, the study aimed to investigate different protocols sway measurements between two groups (good and poor) based on SCAT5 outcomes. The key findings revealed significant differences between the poor balance and good balance groups across various protocols.

Consistent with previous research, the results demonstrated that the poor balance group exhibited significantly worse balance performance compared to the good balance group in most of the assessed protocols except for, standing on both feet on the hard floor with eyes open and tandem stance on hard floor with eyes closed, which there was no significant difference between poor and good group (Mancini et al., 2012; Alberts et al., 2015). The SCAT5 provided a broad categorization of participants into distinct groups based on the overall assessment. However, when evaluated using the more nuanced and multi-faceted sway measurement method, targeting different aspects of the construct being measured, the groups did not exhibit significant differences in certain protocols in aforementioned protocols. This finding suggests that the SCAT5 balance assessment may have oversimplified the assessment or failed to capture the granular differences between the groups across specific sub-components.

This also suggests that athletes with poorer balance are at a higher risk of experiencing balance-related issues during ice hockey activities, including reduced stability and increased susceptibility to injuries (Behm et al., 2005). These findings underscore the importance of balance assessment as a valuable tool for identifying athletes at risk and implementing targeted interventions to improve their balance capabilities (Hrysomallis, 2011).

The comparison between subjective measurements using SCAT5 and objective sway measurements provided valuable insights into the relationship between self-report measures and objective balance impairments. Interestingly, athletes with higher SCAT5 scores also exhibited increased sway length measurements. This finding suggests that subjective measures may reflect objective balance deficits in ice hockey players. Similar observations have been reported in other sports contexts, highlighting the potential utility of subjective measures in detecting balance impairments (Echemendia et al., 2017). However, further research is needed to explore the specific relationship between SCAT5 scores and sway measurements in the context of ice hockey.

Regarding the effect of different testing conditions on sway measurements, the results indicated variations in balance performance across different positions. Specifically, the sway length was found to be larger in the eyes closed condition compared to the eyes open condition, indicating the reliance on visual cues for balance control. This aligns with previous research demonstrating the crucial role of visual information in maintaining balance during dynamic tasks (Lee & Scudds, 2003; Paillard, 2017). Additionally, the sway length was greater when standing on a soft foam surface compared to a hard surface, suggesting the influence of surface stability on balance maintenance during specific ice hockey movements. These findings are consistent with studies highlighting the impact of surface properties on postural stability and sway patterns (Browne & O'Hare, 2001).

The higher standard deviation in the total balance scores of the poor group indicates greater variability in performance within this group. This suggests that some individuals in the poor group may have more severe balance impairments compared to others. Understanding this variability is crucial for tailoring interventions to meet individual needs and providing targeted support to those with more pronounced balance difficulties.

The findings also suggests that alterations in somatosensory conditions have a notable impact on sway parameters, reflecting postural control and stability. Transitioning from a stable double leg stance to a more challenging single leg stance elicited significant differences in sway patterns, regardless of the floor surface and visual condition. These results underline the importance of considering the influence of somatosensory inputs on balance performance during different stance conditions. These findings suggest that alterations in somatosensory conditions have a notable impact on sway parameters, reflecting postural control and stability. (Kars et al., 2009)

In line with the previous research outcomes, these findings of analysis of sway changes from eyes open to eyes closed in tandem stance on a soft floor suggest that the level of difficulty involved in maintaining a tandem stance on a soft floor and transitioning from eyes open to eyes closed has a significant impact on sway changes. The impaired visual input caused by closing the eyes during tandem stance on a soft floor led to significantly worse performance compared to the eyes-open condition (Tomomitsu et al., 2013). This highlights the importance of visual feedback in maintaining balance during challenging postural tasks, particularly on unstable surfaces.

Furthermore, the results indicated that while there were no significant differences in performance between eyes closed and eyes open methods in the double stance condition, significant differences were observed in the tandem stance condition. This suggests that the difficulty level and balance demand of the tandem stances might influence the impact of closing the eyes on postural control. It implies that when individuals are required to maintain balance in a more challenging stance condition, such as tandem stance, closing the eyes may have a greater effect on postural control compared to the relatively stable double stance condition.

Similar results were observed in the analysis of sway changes between different floor conditions (Palazzo et al., 2021). Specifically, significant differences in sway parameters were observed when comparing tandem stance on a hard floor versus a soft floor with eyes open. However, no significant differences were found when comparing double stance with eyes open on different floor surfaces within the poor, good, and total groups. This indicates that especially less demanding protocols were not sensitive enough to detect potential vestibular deficits or impairments. Similarly, it was only in tandem stance that significant differences in sway parameters were observed when comparing eyes open tandem stance on a hard floor versus a soft floor within the poor, good, and total groups, while the was no significant differences in double stance sway changes.

The t-test results not reaching statistical significance for two positions (standing on both feet on hard floor with eyes open and in tandem stance on hard floor with eyes closed) may indicate a smaller or non-existent difference in balance performance between the good and poor groups. However, it is important to acknowledge that the available data may have limited sensitivity to detect subtle differences. Future research with larger sample sizes or different measurement techniques could provide further insights into the balance performance of individuals in these positions.

Similarly, the statistically significant differences result of the analysis of sway changes from a hard floor to a soft floor while standing on both feet with eyes closed highlight the significant impact of the floor surface on postural control and stability during both double stance and tandem stance with eyes closed (Palazzo et al., 2021). The transition from a hard floor to a soft floor introduces a more challenging and unstable surface, leading to noticeable changes in sway.

These findings highlight the nuanced relationship between visual conditions, stance difficulty, and postural control. They suggest that the interplay between visual inputs and balance demands is context-dependent, with the impact of closing the eyes on postural control being more pronounced in demanding stance conditions. These findings highlight the importance of considering both the stance type and floor surface when assessing postural control.

Overall, these findings indicate that individuals in all groups (poor, good, and total) experience difficulties in maintaining balance and stability when standing on both feet with eyes closed on a soft floor compared to a hard floor. The reduced sensory input and increased instability of the soft floor likely contribute to the observed differences in sway changes.

These results underscore the significant impact of different stances, visual conditions, and floor surfaces on balance control and stability. The findings highlight the complex interplay between sensory inputs, including vision and somatosensation, and the challenges posed by specific postural tasks and environmental conditions. Understanding these relationships is essential for developing targeted interventions and strategies to improve balance and reduce the risk of falls in various populations.

In addition to the overall differences in balance performance between individuals with poor and good balance, it is noteworthy that the study identified specific balance tasks in which the two groups exhibited statistically meaningful differences. Particularly, the findings revealed that individuals with poor balance struggled significantly more than those with good balance in relatively easier yet still demanding positions, such as in tandem positions or double leg stance on soft floor with eyes closed. It has been stated that postural stability during single-leg stance may indeed have implications for lower extremity injury risk (Dingenen et al., 2016; Lehmann et al., 2017). This indicates that individuals with poor balance may have difficulty maintaining stability in less challenging balance conditions, where sensory inputs and proprioceptive cues are relatively more accessible.

This correlation draws the following conclusions:

- Sensitivity of relatively easier protocols:
  The relatively easier protocols, despite being less challenging than the harder ones, are still sensitive enough to detect and reflect the underlying abilities or deficits that are more prominently exposed in the harder protocols. This suggests that even the relatively easier protocols are tapping into the same underlying constructs or mechanisms being assessed by the more difficult tasks.
- Early Indicators of Performance:
  The performance on the relatively easier protocols could potentially serve as an early indicator or predictor of an individual's performance on the harder protocols. These protocols may provide valuable insights into an individual's capabilities or limitations, even before administering the more challenging assessments.
- Efficiency and Practicality:
  Given the correlation between the relatively easier protocols and harder ones, it may be

possible to streamline the assessment process by prioritizing the relatively easier protocols as an initial screening tool. This could improve the efficiency and practicality of the assessment, particularly in situations where time or resources are limited, without compromising the ability to identify individuals who may require further evaluation with the harder tasks.

- Targeted Interventions:
  By identifying individuals who struggle with the relatively easier protocols, which are correlated with the harder tasks, targeted interventions or training programs can be designed to address the underlying deficits or weaknesses. This proactive approach can potentially improve overall performance across the entire spectrum of tasks, from relatively easier protocols to more challenging.
- Progression and Monitoring:
  The relatively easier protocols could serve as a baseline or benchmark for monitoring an individual's progress over time or in response to interventions. As the relatively easier protocols are correlated with the harder tasks, improvements in the former may indicate potential improvements in the latter, allowing for more effective tracking and adjustment of training programs.

The importance of these two protocols, namely the double leg stance and tandem stance, goes beyond their relevance in the context of the study's participants. These protocols have implications for generalizing the findings to other populations, particularly the elderly population. For many elderly individuals, balance tasks that require standing on a single leg can be quite challenging due to factors such as decreased muscle strength, reduced joint stability, and impaired sensory perception. As a result, utilizing single-leg balance protocols in this population might not accurately reflect their balance abilities or provide meaningful insights into their postural stability. In contrast, the double leg stance and tandem stance protocols offer a less demanding yet still challenging alternative for assessing balance in the elderly population. These protocols require individuals to maintain stability while standing on both feet or in a tandem position, respectively. These positions allow for a wider base of support and potentially easier maintenance of balance compared to single-leg stances.

By demonstrating statistically meaningful differences between individuals with poor and good balance in these relatively easier yet demanding positions, the study highlights the potential relevance of these protocols in assessing and improving balance in populations such as the elderly. Understanding how individuals with poor balance struggle in these less challenging conditions can provide valuable insights for designing targeted interventions and exercise programs to enhance balance and reduce the risk of falls in these populations.

Given that these positions demonstrated statistically meaningful differences between the "good" and "poor" balance groups, focusing on these specific tasks could provide valuable insights into an individual's balance capabilities. Moreover, including only these two positions in the assessment may offer a more efficient and streamlined approach without compromising the assessment's effectiveness.

Furthermore, the study highlighted a significant disparity between the two groups when it came to standing on one leg on a soft floor with eyes closed. This task, which demands greater reliance on proprioception and vestibular inputs, proved to be particularly challenging for individuals with poor balance. The results suggest that these individuals may have compromised proprioceptive and vestibular mechanisms, leading to difficulties in maintaining postural stability without visual cues.

8 Conclusion

In conclusion, this comparative study of balance measurements in ice hockey players highlights the significance of balance assessment for performance optimization and injury prevention. By integrating objective measurements with subjective self-report measures, a comprehensive evaluation of balance capabilities in ice hockey players can be achieved. The findings underscore the importance of considering specific protocols when assessing balance control in the context of ice hockey.

These insights have important implications for reliable balance performance assessment and designing targeted interventions and training programs to enhance balance capabilities and reduce the risk of injuries in ice hockey players. By identifying athletes with poor balance, tailored interventions can be implemented to address specific sensory deficits and challenges in different stance conditions. Furthermore, incorporating exercises that target proprioception and postural control in unstable surface conditions can improve balance and reduce injury risks.

The findings of this study underscore the importance of a comprehensive and multi-faceted approach to assessing balance capabilities. While more challenging protocols, such as single-leg stances, provide valuable insights into an individual's balance performance under demanding conditions, the significance of relatively easier protocols should not be overlooked. The double leg stance and tandem stance protocols on soft floor with eyes closed, despite being less complex comparing to single leg stance protocols, demonstrated sensitivity in detecting underlying balance deficits or strengths. This sensitivity highlights the potential of these protocols to serve as early indicators of an individual's overall balance abilities, even before progressing to more challenging assessments. By prioritizing these relatively easier protocols, practitioners can streamline the assessment process, improve efficiency, and identify individuals who may require targeted interventions or further evaluation.

Moreover, the relevance of the double leg stance and tandem on soft floor with eyes closed, stance protocols extend beyond the study's participants, offering valuable applications for assessing balance in populations with varying abilities, such as the elderly. For many older adults, single-leg balance tasks may be too demanding, potentially leading to inaccurate assessments or increased risk of falls. In contrast, the double leg stance and tandem stance protocols provide a more accessible yet still challenging alternative, allowing for a more accurate evaluation of balance capabilities in this population. By incorporating these protocols into assessment batteries, practitioners can tailor interventions and training programs to address specific deficits, ultimately improving postural stability and reducing the risk of falls and injuries. The findings of this study emphasize the importance of a comprehensive and multi-dimensional approach to balance assessment, recognizing the value of both challenging and relatively easier protocols in identifying and addressing balance-related limitations across diverse populations.

In clinical practice and rehabilitation, these findings can guide the design of tailored balance training programs. By addressing the identified balance deficits and providing appropriate challenges, healthcare professionals can enhance proprioception, postural control, and overall balance performance.

Moreover, the study highlights the importance of environmental modifications to enhance balance and safety. Providing interventions to improve balance adaptation and stability on soft or uneven surfaces can reduce the risk of falls, particularly in outdoor settings or certain workplaces.

Overall, this study contributes to our understanding of balance mechanisms and provides valuable insights into the factors influencing postural control and stability. By improving our knowledge of balance assessment and addressing specific balance deficits, interventions can be developed to enhance balance capabilities, optimize performance, and reduce the risk of injuries in various populations, including ice hockey players.

8.1 Limitation of the study

It is important to acknowledge the limitations of this study. The sample size and specific characteristics of the participants may limit the generalizability of the findings. Additionally, the study focused on a specific set of balance measurements, and other factors such as muscle strength and coordination were not included in the analysis. Future research could explore a broader range of balance assessment methods, such as the Sensory Organization Test (SOT) or the Functional Gait Assessment (FGA), which may provide a more comprehensive evaluation of balance abilities in ice hockey players. Incorporating assessments of lower limb strength, proprioception, and dynamic stability could offer valuable insights into the interplay between these factors and balance performance, as these elements are crucial for the demanding movements and situations encountered on the ice.

Existing assessment methods primarily focus on evaluating single tasks within static environments, which fails to adequately capture the demands of postural control in real-life situations characterized by dynamic and changing environments, person-environment interactions, and multitasking. Future research should explore more ecologically valid and sport-specific balance assessment protocols, such as evaluating balance while wearing hockey equipment, simulating game-like conditions with stick handling, or shooting drills, or assessing balance on actual ice surfaces.

Furthermore, instead of considering a single factor sway measurements interpretation, further research could utilize a ratio of multiple variables, such as the distance-time ratio, which may provide a more comprehensive understanding of balance performance. By considering a combination of factors, including sway measurements, muscle strength, coordination, and environmental demands, future studies can better elucidate the specific balance requirements and deficits in ice hockey players.

Longitudinal studies tracking balance changes throughout a season or following injuries could also shed light on the recovery patterns and potential long-term effects on balance abilities. Such research could inform the development of targeted rehabilitation protocols and return-to-play guidelines for ice hockey players recovering from injuries or concussions.

By addressing these limitations and exploring more comprehensive and ecologically valid balance assessment methods, future research can provide a deeper understanding of the balance demands in ice hockey, ultimately guiding the development of targeted training, rehabilitation, and injury prevention strategies to optimize performance and reduce injury risk.

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Appendices

Appendix 1: SPORT CONCUSSION ASSESSMENT TOOL – 5TH EDITION

BJSM Online First, published on April 26, 2017 as 10.1136/bjsports-2017-097506SCAT5
To download a clean version of the SCAT tools please visit the journal online (http://dx.doi.org/10.1136/bjsports-2017-097506SCAT5)

SCAT5©

SPORT CONCUSSION ASSESSMENT TOOL — 5TH EDITION
DEVELOPED BY THE CONCUSSION IN SPORT GROUP
FOR USE BY MEDICAL PROFESSIONALS ONLY

supported by

FIFA® FEI

Patient details

Name: ______________________________

DOB: ______________________________

Address: ______________________________

ID number: ______________________________

Examiner: ______________________________

Date of Injury: ____________________ Time: ____________________

WHAT IS THE SCAT5?

The SCAT5 is a standardized tool for evaluating concussions designed for use by physicians and licensed healthcare professionals[1]. The SCAT5 cannot be performed correctly in less than 10 minutes.

If you are not a physician or licensed healthcare professional, please use the Concussion Recognition Tool 5 (CRT5). The SCAT5 is to be used for evaluating athletes aged 13 years and older. For children aged 12 years or younger, please use the Child SCAT5.

Preseason SCAT5 baseline testing can be useful for interpreting post-injury test scores, but is not required for that purpose.Detailed instructions for use of the SCAT5 are provided on page 7. Please read through these instructions carefully before testing the athlete. Brief verbal instructions for each test are given in italics. The only equipment required for the tester is a watch or timer.

This tool may be freely copied in its current form for distribution to individuals, teams, groups and organizations. It should not be altered in any way, re-branded or sold for commercial gain. Any revision, translation or reproduction in a digital form requires specific approval by the Concussion in Sport Group.

Recognise and Remove

A head impact by either a direct blow or indirect transmission of force can be associated with a serious and potentially fatal brain injury. If there are significant concerns, including any of the red flags listed in Box 1, then activation of emergency procedures and urgent transport to the nearest hospital should be arranged.

Key points

- Any athlete with suspected concussion should be REMOVED FROM PLAY, medically assessed and monitored for deterioration. No athlete diagnosed with concussion should be returned to play on the day of injury.
- If an athlete is suspected of having a concussion and medical personnel are not immediately available, the athlete should be referred to a medical facility for urgent assessment.
- Athletes with suspected concussion should not drink alcohol, use recreational drugs and should not drive a motor vehicle until cleared to do so by a medical professional.
- Concussion signs and symptoms evolve over time and it is important to consider repeat evaluation in the assessment of concussion.
- The diagnosis of a concussion is a clinical judgment, made by a medical professional. The SCAT5 should NOT be used by itself to make, or exclude, the diagnosis of concussion. An athlete may have a concussion even if their SCAT5 is "normal".

Remember:

- The basic principles of first aid (danger, response, airway, breathing, circulation) should be followed.
- Do not attempt to move the athlete (other than that required for airway management) unless trained to do so.
- Assessment for a spinal cord injury is a critical part of the initial on-field assessment.
- Do not remove a helmet or any other equipment unless trained to do so safely.

1

IMMEDIATE OR ON-FIELD ASSESSMENT

The following elements should be assessed for all athletes who are suspected of having a concussion prior to proceeding to the neurocognitive assessment and ideally should be done on-field after the first first aid / emergency care priorities are completed.

If any of the "Red Flags" or observable signs are noted after a direct or indirect blow to the head, the athlete should be immediately and safely removed from participation and evaluated by a physician or licensed healthcare professional.

Consideration of transportation to a medical facility should be at the discretion of the physician or licensed healthcare professional.

The GCS is important as a standard measure for all patients and can be done serially if necessary in the event of deterioration in conscious state. The Maddocks questions and cervical spine exam are critical steps of the immediate assessment; however, these do not need to be done serially.

STEP 1: RED FLAGS

RED FLAGS:

- Neck pain or tenderness
- Double vision
- Weakness or tingling/ burning in arms or legs
- Severe or increasing headache
- Seizure or convulsion
- Loss of consciousness
- Deteriorating conscious state
- Vomiting
- Increasingly restless, agitated or combative

STEP 2: OBSERVABLE SIGNS

Witnessed ☐ Observed on Video ☐

Lying motionless on the playing surface	Y	N
Balance / gait difficulties / motor incoordination: stumbling, slow / laboured movements	Y	N
Disorientation or confusion, or an inability to respond appropriately to questions	Y	N
Blank or vacant look	Y	N
Facial injury after head trauma	Y	N

STEP 3: MEMORY ASSESSMENT MADDOCKS QUESTIONS[2]

"I am going to ask you a few questions, please listen carefully and give your best effort. First, tell me what happened?"

____

____

Mark Y for correct answer / N for incorrect

What venue are we at today?	Y	N
Which half is it now?	Y	N
Who scored last in this match?	Y	N
What team did you play last week / game?	Y	N
Did your team win the last game?	Y	N

Note: Appropriate sport-specific questions may be substituted.

Name: ______________________________

DOB: ______________________________

Address: ______________________________

ID number: ______________________________

Examiner: ______________________________

Date: ______________________________

STEP 4: EXAMINATION GLASGOW COMA SCALE (GCS)[3]

Time of assessment			
Date of assessment			
Best eye response (E)			
No eye opening	1	1	1
Eye opening in response to pain	2	2	2
Eye opening to speech	3	3	3
Eyes opening spontaneously	4	4	4
Best verbal response (V)			
No verbal response	1	1	1
Incomprehensible sounds	2	2	2
Inappropriate words	3	3	3
Confused	4	4	4
Oriented	5	5	5
Best motor response (M)			
No motor response	1	1	1
Extension to pain	2	2	2
Abnormal flexion to pain	3	3	3
Flexion / Withdrawal to pain	4	4	4
Localizes to pain	5	5	5
Obeys commands	6	6	6
Glasgow Coma score (E + V + M)			

CERVICAL SPINE ASSESSMENT

Does the athlete report that their neck is pain free at rest?	Y	N
If there is NO neck pain at rest, does the athlete have a full range of ACTIVE pain free movement?	Y	N
Is the limb strength and sensation normal?	Y	N

In a patient who is not lucid or fully conscious, a cervical spine injury should be assumed until proven otherwise.

OFFICE OR OFF-FIELD ASSESSMENT

Please note that the neurocognitive assessment should be done in a distraction-free environment with the athlete in a resting state.

STEP 1: ATHLETE BACKGROUND

Sport / team / school: ______

Date / time of injury: ______

Years of education completed: ______

Age: ______

Gender: M / F / Other

Dominant hand: left / neither / right

How many diagnosed concussions has the athlete had in the past?: ______

When was the most recent concussion?: ______

How long was the recovery (time to being cleared to play) from the most recent concussion?: ______ (days)

Has the athlete ever been:

Hospitalized for a head injury?	Yes	No
Diagnosed / treated for headache disorder or migraines?	Yes	No
Diagnosed with a learning disability / dyslexia?	Yes	No
Diagnosed with ADD / ADHD?	Yes	No
Diagnosed with depression, anxiety or other psychiatric disorder?	Yes	No

Current medications? If yes, please list:

______

______

______

______

______

______

Name: ______

DOB: ______

Address: ______

ID number: ______

Examiner: ______

Date: ______

2

STEP 2: SYMPTOM EVALUATION

The athlete should be given the symptom form and asked to read this instruction paragraph out loud then complete the symptom scale. For the baseline assessment, the athlete should rate his/her symptoms based on how he/she typically feels and for the post injury assessment the athlete should rate their symptoms at this point in time.

Please Check: ☐ **Baseline** ☐ **Post-Injury**

Please hand the form to the athlete

	none	mild		moderate		severe	
Headache	0	1	2	3	4	5	6
"Pressure in head"	0	1	2	3	4	5	6
Neck Pain	0	1	2	3	4	5	6
Nausea or vomiting	0	1	2	3	4	5	6
Dizziness	0	1	2	3	4	5	6
Blurred vision	0	1	2	3	4	5	6
Balance problems	0	1	2	3	4	5	6
Sensitivity to light	0	1	2	3	4	5	6
Sensitivity to noise	0	1	2	3	4	5	6
Feeling slowed down	0	1	2	3	4	5	6
Feeling like "in a fog"	0	1	2	3	4	5	6
"Don't feel right"	0	1	2	3	4	5	6
Difficulty concentrating	0	1	2	3	4	5	6
Difficulty remembering	0	1	2	3	4	5	6
Fatigue or low energy	0	1	2	3	4	5	6
Confusion	0	1	2	3	4	5	6
Drowsiness	0	1	2	3	4	5	6
More emotional	0	1	2	3	4	5	6
Irritability	0	1	2	3	4	5	6
Sadness	0	1	2	3	4	5	6
Nervous or Anxious	0	1	2	3	4	5	6
Trouble falling asleep (if applicable)	0	1	2	3	4	5	6

Total number of symptoms:	of 22
Symptom severity score:	of 132
Do your symptoms get worse with physical activity?	Y N
Do your symptoms get worse with mental activity?	Y N
If 100% is feeling perfectly normal, what percent of normal do you feel?	

If not 100%, why?

______

______

______

Please hand form back to examiner

3

STEP 3: COGNITIVE SCREENING

Standardised Assessment of Concussion (SAC)[4]

ORIENTATION

What month is it?	0	1
What is the date today?	0	1
What is the day of the week?	0	1
What year is it?	0	1
What time is it right now? (within 1 hour)	0	1
Orientation score		of 5

IMMEDIATE MEMORY

The Immediate Memory component can be completed using the traditional 5-word per trial list or optionally using 10-words per trial to minimise any ceiling effect. All 3 trials must be administered irrespective of the number correct on the first trial. Administer at the rate of one word per second.

Please choose EITHER the 5 or 10 word list groups and circle the specific word list chosen for this test.

I am going to test your memory. I will read you a list of words and when I am done, repeat back as many words as you can remember, in any order. For Trials 2 & 3: I am going to repeat the same list again. Repeat back as many words as you can remember in any order, even if you said the word before.

List	Alternate 5 word lists					Score (of 5) Trial 1	Trial 2	Trial 3
A	Finger	Penny	Blanket	Lemon	Insect			
B	Candle	Paper	Sugar	Sandwich	Wagon			
C	Baby	Monkey	Perfume	Sunset	Iron			
D	Elbow	Apple	Carpet	Saddle	Bubble			
E	Jacket	Arrow	Pepper	Cotton	Movie			
F	Dollar	Honey	Mirror	Saddle	Anchor			
				Immediate Memory Score				of 15
				Time that last trial was completed				

List	Alternate 10 word lists					Score (of 10) Trial 1	Trial 2	Trial 3
G	Finger	Penny	Blanket	Lemon	Insect			
	Candle	Paper	Sugar	Sandwich	Wagon			
H	Baby	Monkey	Perfume	Sunset	Iron			
	Elbow	Apple	Carpet	Saddle	Bubble			
I	Jacket	Arrow	Pepper	Cotton	Movie			
	Dollar	Honey	Mirror	Saddle	Anchor			
				Immediate Memory Score				of 30
				Time that last trial was completed				

Name: ________________

DOB: ________________

Address: ________________

ID number: ________________

Examiner: ________________

Date: ________________

CONCENTRATION

DIGITS BACKWARDS

Please circle the Digit list chosen (A, B, C, D, E, F). Administer at the rate of one digit per second reading DOWN the selected column.

I am going to read a string of numbers and when I am done, you repeat them back to me in reverse order of how I read them to you. For example, if I say 7-1-9, you would say 9-1-7.

Concentration Number Lists (circle one)					
List A	List B	List C			
4-9-3	5-2-6	1-4-2	Y	N	0
6-2-9	4-1-5	6-5-8	Y	N	1
3-8-1-4	1-7-9-5	6-8-3-1	Y	N	0
3-2-7-9	4-9-6-8	3-4-8-1	Y	N	1
6-2-9-7-1	4-8-5-2-7	4-9-1-5-3	Y	N	0
1-5-2-8-6	6-1-8-4-3	6-8-2-5-1	Y	N	1
7-1-8-4-6-2	8-3-1-9-6-4	3-7-6-5-1-9	Y	N	0
5-3-9-1-4-8	7-2-4-8-5-6	9-2-6-5-1-4	Y	N	1
List D	List E	List F			
7-8-2	3-8-2	2-7-1	Y	N	0
9-2-6	5-1-8	4-7-9	Y	N	1
4-1-8-3	2-7-9-3	1-6-8-3	Y	N	0
9-7-2-3	2-1-6-9	3-9-2-4	Y	N	1
1-7-9-2-6	4-1-8-6-9	2-4-7-5-8	Y	N	0
4-1-7-5-2	9-4-1-7-5	8-3-9-6-4	Y	N	1
2-6-4-8-1-7	6-9-7-3-8-2	5-8-6-2-4-9	Y	N	0
8-4-1-9-3-5	4-2-7-9-3-8	3-1-7-8-2-6	Y	N	1
		Digits Score:			of 4

MONTHS IN REVERSE ORDER

Now tell me the months of the year in reverse order. Start with the last month and go backward. So you'll say December, November. Go ahead.

Dec - Nov - Oct - Sept - Aug - Jul - Jun - May - Apr - Mar - Feb - Jan	0 1
Months Score	of 1
Concentration Total Score (Digits + Months)	of 5

4

STEP 4: NEUROLOGICAL SCREEN

See the instruction sheet (page 7) for details of test administration and scoring of the tests.

Can the patient read aloud (e.g. symptom check-list) and follow instructions without difficulty?	Y	N
Does the patient have a full range of pain-free PASSIVE cervical spine movement?	Y	N
Without moving their head or neck, can the patient look side-to-side and up-and-down without double vision?	Y	N
Can the patient perform the finger nose coordination test normally?	Y	N
Can the patient perform tandem gait normally?	Y	N

BALANCE EXAMINATION

Modified Balance Error Scoring System (mBESS) testing[5]

Which foot was tested (i.e. which is the non-dominant foot) ☐ Left ☐ Right

Testing surface (hard floor, field, etc.) ______

Footwear (shoes, barefoot, braces, tape, etc.) ______

Condition	Errors
Double leg stance	of 10
Single leg stance (non-dominant foot)	of 10
Tandem stance (non-dominant foot at the back)	of 10
Total Errors	of 30

Name: ______

DOB: ______

Address: ______

ID number: ______

Examiner: ______

Date: ______

5

STEP 5: DELAYED RECALL:

The delayed recall should be performed after 5 minutes have elapsed since the end of the Immediate Recall section. Score 1 pt. for each correct response.

Do you remember that list of words I read a few times earlier? Tell me as many words from the list as you can remember in any order.

Time Started ______

Please record each word correctly recalled. Total score equals number of words recalled.

______

______

______

Total number of words recalled accurately: of 5 or of 10

6

STEP 6: DECISION

Domain	Date & time of assessment:		
Symptom number (of 22)			
Symptom severity score (of 132)			
Orientation (of 5)			
Immediate memory	of 15 of 30	of 15 of 30	of 15 of 30
Concentration (of 5)			
Neuro exam	Normal Abnormal	Normal Abnormal	Normal Abnormal
Balance errors (of 30)			
Delayed Recall	of 5 of 10	of 5 of 10	of 5 of 10

Date and time of injury: ______

If the athlete is known to you prior to their injury, are they different from their usual self?
☐ **Yes** ☐ **No** ☐ **Unsure** ☐ **Not Applicable**
(If different, describe why in the clinical notes section)

Concussion Diagnosed?
☐ **Yes** ☐ **No** ☐ **Unsure** ☐ **Not Applicable**

If re-testing, has the athlete improved?
☐ **Yes** ☐ **No** ☐ **Unsure** ☐ **Not Applicable**

I am a physician or licensed healthcare professional and I have personally administered or supervised the administration of this SCAT5.

Signature: ______

Name: ______

Title: ______

Registration number (if applicable): ______

Date: ______

SCORING ON THE SCAT5 SHOULD NOT BE USED AS A STAND-ALONE METHOD TO DIAGNOSE CONCUSSION, MEASURE RECOVERY OR MAKE DECISIONS ABOUT AN ATHLETE'S READINESS TO RETURN TO COMPETITION AFTER CONCUSSION.

CLINICAL NOTES:

Name: ____________________
DOB: ____________________
Address: ____________________
ID number: ____________________
Examiner: ____________________
Date: ____________________

CONCUSSION INJURY ADVICE

(To be given to the person monitoring the concussed athlete)

This patient has received an injury to the head. A careful medical examination has been carried out and no sign of any serious complications has been found. Recovery time is variable across individuals and the patient will need monitoring for a further period by a responsible adult. Your treating physician will provide guidance as to this timeframe.

If you notice any change in behaviour, vomiting, worsening headache, double vision or excessive drowsiness, please telephone your doctor or the nearest hospital emergency department immediately.

Other important points:

Initial rest: Limit physical activity to routine daily activities (avoid exercise, training, sports) and limit activities such as school, work, and screen time to a level that does not worsen symptoms.

1) Avoid alcohol

2) Avoid prescription or non-prescription drugs without medical supervision. Specifically:

   a) Avoid sleeping tablets

   b) Do not use aspirin, anti-inflammatory medication or stronger pain medications such as narcotics

3) Do not drive until cleared by a healthcare professional.

4) Return to play/sport requires clearance by a healthcare professional.

Clinic phone number: ____________________

Patient's name: ____________________

Date / time of injury: ____________________

Date / time of medical review: ____________________

Healthcare Provider: ____________________

Contact details or stamp

INSTRUCTIONS

Words in *Italics* throughout the SCAT5 are the instructions given to the athlete by the clinician

Symptom Scale

The time frame for symptoms should be based on the type of test being administered. At baseline it is advantageous to assess how an athlete "typically" feels whereas during the acute/post-acute stage it is best to ask how the athlete feels at the time of testing.

The symptom scale should be completed by the athlete, not by the examiner. In situations where the symptom scale is being completed after exercise, it should be done in a resting state, generally by approximating his/her resting heart rate.

For total number of symptoms, maximum possible is 22 except immediately post injury, if sleep item is omitted, which then creates a maximum of 21.

For Symptom severity score, add all scores in table, maximum possible is 22 x 6 = 132, except immediately post injury if sleep item is omitted, which then creates a maximum of 21x6=126.

Immediate Memory

The Immediate Memory component can be completed using the traditional 5-word per trial list or, optionally, using 10-words per trial. The literature suggests that the Immediate Memory has a notable ceiling effect when a 5-word list is used. In settings where this ceiling is prominent, the examiner may wish to make the task more difficult by incorporating two 5–word groups for a total of 10 words per trial. In this case, the maximum score per trial is 10 with a total trial maximum of 30.

Choose one of the word lists (either 5 or 10). Then perform 3 trials of immediate memory using this list.

Complete all 3 trials regardless of score on previous trials.

"I am going to test your memory. I will read you a list of words and when I am done, repeat back as many words as you can remember, in any order." The words must be read at a rate of one word per second.

Trials 2 & 3 MUST be completed regardless of score on trial 1 & 2.

Trials 2 & 3:

"I am going to repeat the same list again. Repeat back as many words as you can remember in any order, even if you said the word before."

Score 1 pt. for each correct response. Total score equals sum across all 3 trials. Do NOT inform the athlete that delayed recall will be tested.

Concentration

Digits backward

Choose one column of digits from lists A, B, C, D, E or F and administer those digits as follows:

Say: *"I am going to read a string of numbers and when I am done, you repeat them back to me in reverse order of how I read them to you. For example, if I say 7-1-9, you would say 9-1-7."*

Begin with first 3 digit string.

If correct, circle "Y" for correct and go to next string length. If incorrect, circle "N" for the first string length and read trial 2 in the same string length. One point possible for each string length. Stop after incorrect on both trials (2 N's) in a string length. The digits should be read at the rate of one per second.

Months in reverse order

"Now tell me the months of the year in reverse order. Start with the last month and go backward. So you'll say December, November ... Go ahead"

1 pt. for entire sequence correct

Delayed Recall

The delayed recall should be performed after 5 minutes have elapsed since the end of the Immediate Recall section.

"Do you remember that list of words I read a few times earlier? Tell me as many words from the list as you can remember in any order."

Score 1 pt. for each correct response

Modified Balance Error Scoring System (mBESS)[5] testing

This balance testing is based on a modified version of the Balance Error Scoring System (BESS)[5]. A timing device is required for this testing.

Each of 20-second trial/stance is scored by counting the number of errors. The examiner will begin counting errors only after the athlete has assumed the proper start position. The modified BESS is calculated by adding one error point for each error during the three 20-second tests. The maximum number of errors for any single condition is 10. If the athlete commits multiple errors simultaneously, only one error is recorded but the athlete should quickly return to the testing position, and counting should resume once the athlete is set. Athletes that are unable to maintain the testing procedure for a minimum of five seconds at the start are assigned the highest possible score, ten, for that testing condition.

OPTION: For further assessment, the same 3 stances can be performed on a surface of medium density foam (e.g., approximately 50cm x 40cm x 6cm).

Balance testing – types of errors

1. Hands lifted off iliac crest	3. Step, stumble, or fall	5. Lifting forefoot or heel
2. Opening eyes	4. Moving hip into > 30 degrees abduction	6. Remaining out of test position > 5 sec

"I am now going to test your balance. Please take your shoes off (if applicable), roll up your pant legs above ankle (if applicable), and remove any ankle taping (if applicable). This test will consist of three twenty second tests with different stances."

(a) Double leg stance:

"The first stance is standing with your feet together with your hands on your hips and with your eyes closed. You should try to maintain stability in that position for 20 seconds. I will be counting the number of times you move out of this position. I will start timing when you are set and have closed your eyes."

(b) Single leg stance:

"If you were to kick a ball, which foot would you use? [This will be the dominant foot] *Now stand on your non-dominant foot. The dominant leg should be held in approximately 30 degrees of hip flexion and 45 degrees of knee flexion. Again, you should try to maintain stability for 20 seconds with your hands on your hips and your eyes closed. I will be counting the number of times you move out of this position. If you stumble out of this position, open your eyes and return to the start position and continue balancing. I will start timing when you are set and have closed your eyes."*

(c) Tandem stance:

"Now stand heel-to-toe with your non-dominant foot in back. Your weight should be evenly distributed across both feet. Again, you should try to maintain stability for 20 seconds with your hands on your hips and your eyes closed. I will be counting the number of times you move out of this position. If you stumble out of this position, open your eyes and return to the start position and continue balancing. I will start timing when you are set and have closed your eyes."

Tandem Gait

Participants are instructed to stand with their feet together behind a starting line (the test is best done with footwear removed). Then, they walk in a forward direction as quickly and as accurately as possible along a 38mm wide (sports tape), 3 metre line with an alternate foot heel-to-toe gait ensuring that they approximate their heel and toe on each step. Once they cross the end of the 3m line, they turn 180 degrees and return to the starting point using the same gait. Athletes fail the test if they step off the line, have a separation between their heel and toe, or if they touch or grab the examiner or an object.

Finger to Nose

"I am going to test your coordination now. Please sit comfortably on the chair with your eyes open and your arm (either right or left) outstretched (shoulder flexed to 90 degrees and elbow and fingers extended), pointing in front of you. When I give a start signal, I would like you to perform five successive finger to nose repetitions using your index finger to touch the tip of the nose, and then return to the starting position, as quickly and as accurately as possible."

References

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3. Jennett, B., Bond, M. Assessment of outcome after severe brain damage: a practical scale. Lancet 1975; i: 480-484
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5. Guskiewicz KM. Assessment of postural stability following sport-related concussion. Current Sports Medicine Reports. 2003; 2: 24-30

CONCUSSION INFORMATION

Any athlete suspected of having a concussion should be removed from play and seek medical evaluation.

Signs to watch for

Problems could arise over the first 24-48 hours. The athlete should not be left alone and must go to a hospital at once if they experience:

- Worsening headache
- Drowsiness or inability to be awakened
- Inability to recognize people or places
- Repeated vomiting
- Unusual behaviour or confusion or irritable
- Seizures (arms and legs jerk uncontrollably)
- Weakness or numbness in arms or legs
- Unsteadiness on their feet.
- Slurred speech

Consult your physician or licensed healthcare professional after a suspected concussion. Remember, it is better to be safe.

Rest & Rehabilitation

After a concussion, the athlete should have physical rest and relative cognitive rest for a few days to allow their symptoms to improve. In most cases, after no more than a few days of rest, the athlete should gradually increase their daily activity level as long as their symptoms do not worsen. Once the athlete is able to complete their usual daily activities without concussion-related symptoms, the second step of the return to play/sport progression can be started. The athlete should not return to play/sport until their concussion-related symptoms have resolved and the athlete has successfully returned to full school/learning activities.

When returning to play/sport, the athlete should follow a stepwise, **medically managed exercise progression, with increasing amounts of exercise.** For example:

Graduated Return to Sport Strategy

Exercise step	Functional exercise at each step	Goal of each step
1. Symptom-limited activity	Daily activities that do not provoke symptoms.	Gradual reintroduction of work/school activities.
2. Light aerobic exercise	Walking or stationary cycling at slow to medium pace. No resistance training.	Increase heart rate.
3. Sport-specific exercise	Running or skating drills. No head impact activities.	Add movement.
4. Non-contact training drills	Harder training drills, e.g., passing drills. May start progressive resistance training.	Exercise, coordination, and increased thinking.
5. Full contact practice	Following medical clearance, participate in normal training activities.	Restore confidence and assess functional skills by coaching staff.
6. Return to play/sport	Normal game play.	

In this example, it would be typical to have 24 hours (or longer) for each step of the progression. If any symptoms worsen while exercising, the athlete should go back to the previous step. Resistance training should be added only in the later stages (Stage 3 or 4 at the earliest).

Written clearance should be provided by a healthcare professional before return to play/sport as directed by local laws and regulations.

Graduated Return to School Strategy

Concussion may affect the ability to learn at school. The athlete may need to miss a few days of school after a concussion. When going back to school, some athletes may need to go back gradually and may need to have some changes made to their schedule so that concussion symptoms do not get worse. If a particular activity makes symptoms worse, then the athlete should stop that activity and rest until symptoms get better. To make sure that the athlete can get back to school without problems, it is important that the healthcare provider, parents, caregivers and teachers talk to each other so that everyone knows what the plan is for the athlete to go back to school.

Note: If mental activity does not cause any symptoms, the athlete may be able to skip step 2 and return to school part-time before doing school activities at home first.

Mental Activity	Activity at each step	Goal of each step
1. Daily activities that do not give the athlete symptoms	Typical activities that the athlete does during the day as long as they do not increase symptoms (e.g. reading, texting, screen time). Start with 5-15 minutes at a time and gradually build up.	Gradual return to typical activities.
2. School activities	Homework, reading or other cognitive activities outside of the classroom.	Increase tolerance to cognitive work.
3. Return to school part-time	Gradual introduction of schoolwork. May need to start with a partial school day or with increased breaks during the day.	Increase academic activities.
4. Return to school full-time	Gradually progress school activities until a full day can be tolerated.	Return to full academic activities and catch up on missed work.

If the athlete continues to have symptoms with mental activity, some other accomodations that can help with return to school may include:

- Starting school later, only going for half days, or going only to certain classes
- More time to finish assignments/tests
- Quiet room to finish assignments/tests
- Not going to noisy areas like the cafeteria, assembly halls, sporting events, music class, shop class, etc.
- Taking lots of breaks during class, homework, tests
- No more than one exam/day
- Shorter assignments
- Repetition/memory cues
- Use of a student helper/tutor
- Reassurance from teachers that the child will be supported while getting better

The athlete should not go back to sports until they are back to school/learning, without symptoms getting significantly worse and no longer needing any changes to their schedule.

Appendix 2: Data management plan

Plan Overview

A Data Management Plan created using DMPTuuli

Title: A Comparative Study of Balance Measurements in Ice hockey Players

Creator: Marjan Kiani

Principal Investigator: Marjan Kiani

Data Manager: Marjan Kiani

Project Administrator: Marjan Kiani

Contributor: Matti Vartiainen

Affiliation: Jamk University of Applied Sciences

Template: Data management plan for theses at Jamk University of Applied Sciences

Project abstract:

In this research project, we will conduct a comprehensive investigation on the efficacy of theSport Concussion Assessment Tool 5 (SCAT5) in comparison with sway measurements for evaluating vestibular control and balance outcomes in ice hockey players aged between 14 and 29 years old. Our study aims to determine which of these two assessment methods provides a more accurate and reliable measure of balance function in this specific population. By analyzing the performance of participants on both tests and examining the relationship between these scores and their overall vestibular function, we seek to establish a better understanding of the most effective approach to assess and monitor balance outcomes in ice hockey players, ultimately contributing to improved injury prevention and rehabilitation strategies within the sport.

ID: 22141

Start date: 01-05-2021

End date: 31-01-2024

Last modified: 28-12-2023

A Comparative Study of Balance Measurements in Ice hockey Players

1. General description of data

Describe, what kinds of data is your research based on? What data will be collected, produced, or reused? What file formats will the data be in?

collected data:
1: SCAT 5 tool: The data from this tool which was collected using pen and paper extracting the data to an excel sheet (.xlsx) include:

- **Symptom Evaluation**: This involves a self-reported checklist of 22 common concussion symptoms (e.g., headache, dizziness, and fatigue) that the athlete rates on a scale of 0 (none) to 6 (severe). The data type collected is ordinal.
- **Cognitive Assessment**: This includes the Standardized Assessment of Concussion (SAC) which assesses orientation,immediate memory, concentration, and delayed recall. The data type collected is typically numerical, as the athlete receives a score for each subcomponent.
- **Balance Assessment**: The Modified Balance Error Scoring System (mBESS) is used to evaluate an athlete's postural stability. It consists of three stances (double-leg, single-leg, and tandem stance) performed on a firm surface with eyes closed. The data type collected is numerical, as the athlete accumulates error points for each stance based on specific criteria.
- **Coordination Examination**: The Finger-to-Nose (FTN) test is used to assess coordination. The athlete is asked to touch their nose with the index finger of their dominant hand, alternating between outstretched arm position and nose-touching. The data type collected is categorical, as the performance is rated as normal or abnormal.
- **Neck Examination**: This component is performed to check for potential cervical spine injuries and includes a range of motion assessment and palpation for tenderness. The data type collected is categorical, as the findings are recorded as either normal or abnormal.
- **Glasgow Coma Scale (GCS)**: This is a neurological scale that evaluates the athlete's level of consciousness based on eye, verbal, and motor responses. The data type collected is numerical, as the athlete is given a score ranging from 3 (deeply unconscious) to 15 (fully conscious).
- **Athlete Background Information**: This includes details on the athlete's concussion history, medications, and other relevant information. The data type collected is a combination of numerical (e.g., number of previous concussions) and categorical (e.g., presence or absence of pre-existing conditions).

2: Tandem walk test: quantitative data in the form of completion time, which is measured in seconds, and will be extracted to .xlsl format for further analysis.
3: sway length measurements using Ainone Balance® mobile application.
besides that, other data can be gathered from Ainone Balance®:

- **Balance score**: This score is based on the sway length measurements, which represent the participant's postural sway during the Romberg test (both eyes open and eyes closed conditions).
- **Romberg's Quotient (RQ) score**: This score is calculated as the relative difference between the balance scores obtained during the eyes open and eyes closed tests. It helps assess the influence of vision on an individual's postural stability and identify potential balance impairments.

How will the consistency and quality of data be controlled?

To ensure that no data is accidentally changed and that the original data content is secured over its entire life cycle, these practices will be followed:

1. **Create backups**: Always maintaining multiple copies of original data in different locations. This can help recover the original data in case of accidental changes or loss.
2. **Use version control**: Implementing a version control system to track changes in the data and documents. This allows us to revert to previous versions if needed and helps maintain a clear history of changes made.
3. **Implement access control**: Restricting access to the data to authorized personnel only. Implement user permissions and access levels to prevent unauthorized changes.
4. **Check data integrity**: Calculating checksums or using data validation methods to ensure data integrity during transfer, conversion, or storage.
5. **Maintain data documentation**: Keeping detailed documentation of the data collection process, data structure, and any transformations or analyses applied to the data. This helps to ensure transparency and reproducibility.
6. **Use standardized data formats**: Choosing widely recognized and nonproprietary file formats for storing and exchanging data. This helps to ensure compatibility and reduces the risk of data corruption during conversion.
7. **Develop data quality assurance procedures**: Establishing procedures to check data quality at different stages of the data life cycle, such as data entry, data cleaning, and data analysis.
8. **Test data conversion processes**: Before converting or transferring data, testing the process on a small subset of the data to ensure that no information is lost or altered during the conversion.
9. **Keep logs of data changes**: Maintaining a log of any changes made to the data, including the reason for the change, the person responsible for the change, and the date of the change.
10. **Regularly review and update data**: Periodically reviewing the data and update it as necessary to maintain its accuracy and relevance.

2. Ethical and Legal Compliance

What ethical and legal issues are related to your data management, for example, the Data Protection Act and other legislation related to the processing of the data? Do you process personal data (yes/no)?

With anonymization or de-identification we protect the privacy and confidentiality of research participants by ensuring that their personal information is not directly linked to the collected data. Hence, there is no ethical and legal issues related to data management.

Data access rights? Is the data confidential?

access to the data is limited for the commissioner and the student for use of the thesis and future publication of the thesis.

3. Documentation and metadata

How do you document and describe your data

according to the data collection description, two sets of data were stored; one digital from Ainone Balance® and one paper-format (SCAT 5). All data is extracted to .xlsx sheet and all properties of a single file is be described by:

- name of the file
- file location (file path)
- file size
- file format
- software used to create the file
- date of creation
- file creator
- file version

Besides, the following information is documented on variables for a quantitative dataset:

- number of variables and units of observation
- list of variables with the name and label of each variable as well as its location in the file and its values and value labels
- frequency distribution of each variable
- information on the classifications used
- meanings of abbreviations used
- codings for missing data
- information on constructed variables
- recoding and standardizing of variables
- data protection measures taken

4. Storage and backup during the thesis project

Where will your data be stored, and how will it be backed up?

The thesis draft and data documents are available and stored on OneDrive for Business (OneDrive – Jamk)

Who will be responsible for controlling access to your data, and how will secured access be controlled?

Marjan Kiani (student), Matti Vartiainen (commisioner)
by using Jamk data storage service, secure access is controlled.

5. Archiving and opening, destroying or storing the data after the thesis project

Can some of the data be made openly available and published? Where will the data be published?

In a possible future publication of the thesis, some of the data might be published.

Where will data be stored, and for how long? How is the data destroyed?

The data will be stored for at least 2 years on Jamk storage service and afterward will be deleted systematically.

6. Data management responsibilities and resources

Who will be responsible for specific tasks of data management during the life cycle of the research project? Estimate the resources.

Marjan Kiani, Matti Vartiainen