Bachelor's thesis

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Can Motion Capture Technology serve as a non-invasive monitoring tool for assessing the relationship between reduced sprinting capacity and hamstring injury risk in football

Bachelor's thesis in Human Movement Science
Supervisor: Øyvind B. Sandbakk (NTNU/BEV)
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Abstract

Background: According to the Men's European Football injury Index for the 22/23 season (1), the total number of injuries in the top 5 European leagues were 3985, with a cost estimated to 704,89 million Euros. Hamstring injuries are one of the most common in football due to the muscles' dominant role in facilitating acceleration and deceleration, which are essential components of the physiological performance aspect in football. Accuracy and efficiency of test methods and protocols are important in order to validly monitor the athlete's physical capacity and associated fatigue. This study summarises existing research on the association between reductions in acceleration and deceleration capacity and hamstring injury risk among soccer players and explains how monitoring of these components with Motion Capture Technology Systems (MOCAPs) could aid hamstring injury prevention. **Method:** PubMed was used as the primary database in this systematic review, with several other reports and databases as supportive literature. **Results:** Seven studies were included. **Conclusion:** A drop in acceleration/deceleration performance could serve as a non-invasive fatigue marker, and MOCAPs could be used as a monitoring tool. This could aid in lowering the risk of hamstring injuries.

Abstrakt

Bakgrunn: Ifølge "Men's European Football Injury Index" for 22/23 sesongen (1), var det totale skadeomfanget i Europas topp 5 ligaer 3985, med en estimert kostnad på 704,89 millioner euro. Hamstringskade er en av de mest vanlige i fotball på grunn av muskelens dominerende rolle under akselerasjon/deselerasjon, som er essensielle deler av den fysiologiske prestasjonen i fotball. Nøyaktigheten og effektiviteten til testmetoder og protokoller er viktig for å på en gyldig måte observere utøveres fysiske kapasitet og utmattelse. Dette studiet oppsummerer eksisterende forskning om forholdet mellom redusert kapasitet til å akselerere/deselerere og risiko for hamstringskader blant fotballspillere, og forklarer hvordan observasjon av disse aspektene med "Motion Capture Technology Systems" (MOCAPs) kan bistå i prevensjon av hamstring skader.
Metode: I dette litteraturstudiet ble PubMed brukt som primær database, med enkelte andre rapporter og databaser som støttelitteratur. **Resultater:** Syv studier ble inkludert. **Konklusjon:** En reduksjon i kapasiteten til å akselerere/deselerere kan observeres med MOCAPs og fungere

som et ikke-invasivt mål på utmattelse. Dette kan bidra til å redusere risikoen for hamstringskader.

Keywords: Injuries - Hamstring - Acceleration/Deceleration - football/soccer - Motion Capture

Introduction

When describing the skill requirements in football we can not isolate the physiological demands from the strategical, tactical and technical aspects of the sport, as these are closely linked together. A Team can only benefit from the speed of a fast player if he knows when and where to run. The ability to utilise speed in a football context therefore rests upon strategic and tactical decision making, not the speed in isolation. However, according to the Gatorade Sports Science Institute (2), high speed accelerations are closely linked to the important moments in a match, and that teams with a higher percentage of high-speed running performs better (2). Endurance, acceleration, deceleration, maximal sprinting and repeated sprinting ability are important capacities in soccer (3). The hamstring muscle is very important in sprint acceleration performance and maximal sprinting (4), which is expressed through the observation that as much as 57% of all hamstring strain injuries (HSI) are associated with sprinting (5), most often late in the match or training session (6-8), which suggests that neuromuscular fatigue (NMF) plays a role (9,10).

Biomechanically, the hamstring is a biarticular muscle, which crosses both the hip and the knee joints. As we sprint the hamstring lengthens in both ends across both joints to facilitate extension at the knee and flexion at the hip. Accelerations and decelerations involve rapid velocity changes with significant force, which means that the hamstring contraction must be fast. The risk of injury increases when the hamstring is not able to execute this function with the force and speed required. When a player is fatigued, force and speed decline.

General fatigue (11) and a reduction in strength (12) have been shown following competitive soccer matches. Furthermore, soccer matches are also known to elicit exercise induced muscle damage and subsequent soreness, which is thought to be due to the high magnitude eccentric muscle loading derived from training and matches (7). Due to the physically demanding nature of the sport, the cost associated with injuries in football is high. According to the Howden Men's

European football injury index the costs associated with injuries for the top 5 soccer leagues in the 22/23 season was 704.89 million Euros (1).

On average, a professional football team made up of 25 players experiences 50 injuries over a season, so each player can get injured twice a year (8). In football HSI constitutes 12 - 16% of all injuries associated with the sport and more than a third of all time lost with regards to injuries (6,8,13,14). It is now obvious that injuries are a huge concern with economic, performance and health implications in professional football.

There are different tools to help with injury prevention, this literate study will focus on hamstring injuries. In previous studies, various measurements of complete rehabilitation after a HSI such as leg strength, hamstring flexibility (15), and sprinting speed have been used (16). However, there is to date no gold standard, and the recurrence rate of HSI is reported to be as high as 33% (16). Since the most commonly cited risk factor for a future HSI is a previous HSI (13,14), sufficient rehabilitation is crucial (17).

Although multiple biochemical and physiological markers of post-match play fatigue exist, Creatine Kinase (CK) is the most widely used marker of fatigue status in an applied setting (10,11). However this method is time consuming and somewhat invasive as a blood test is required. There is a need for a low cost, time efficient and non-invasive way to measure fatigue. The work requirements of the sport, the muscle induced fatigue that is associated with it and the high prevalence of hamstring injuries suggests that a change in the capacity to perform sprints, accelerations and decelerations may serve as a marker especially associated with injury risks.

The assessment of physical capacity is a central component in sports. Testing physical capacity can be low cost, time efficient and is usually non-invasive. MOCAPs enable us to capture different movement variables and to assess physical capacity. We can observe changes in speed and analyse movements based on the video captured by the motion capture camera. There are a wide range of MOCAPs on the market, created for different purposes. The relevant technologies will be highlighted in this literate search.

Procedures and methods of sprint timing can result in trivial-to-very large differences in sprint time (18). Fully automatic timing systems used in international athletics have been considered the 'gold standard' for accurately and reliably quantifying straight-line, still-start sprint performance (19). Fully automatic timing systems include silent gun, photo-finish camera and pressure-sensitive start blocks to detect false starts. High-resolution photo-finish cameras capture thousands of frames per second, enabling the timing officials to estimate time with less than 10.0005 s resolution (19). However this setup is very clinical and not ideal for most clubs and athletes due to cost and lack of simplicity. To make the technology more cost- and user-friendly, some MOCAPs use estimations of athletes' center of mass (CoM) as reference point.

Arguably, the current gold standard in determining the athlete's CoM location during sprinting is through the use of marker-based motion capture (20). However, such methods are often limited to laboratory environments with small capture volumes and highly controlled lighting conditions (20). Furthermore, the placement of markers is time consuming and may alter technique (21), and we regard the placement of markers as invasive. To address these problems and allow for field-based collection of CoM displacement and velocity information, a range of technologies have emerged including manually annotated video analysis (23), laser distance measurement (24) and global or local positioning systems (GPS and LPS) technology (18). Laser data should not be used during the first 5 metres of a sprint, and are likely of limited use for assessing within-subject variation in performance during a single session (24).

The aim of this study is twofold: 1) to summarise existing research focusing on the association between decrements in the capacity to accelerate and decelerate and hamstring injury risk among professional football players, and 2) provide insight into how MOCAPs can assist as non-invasive monitoring tools.

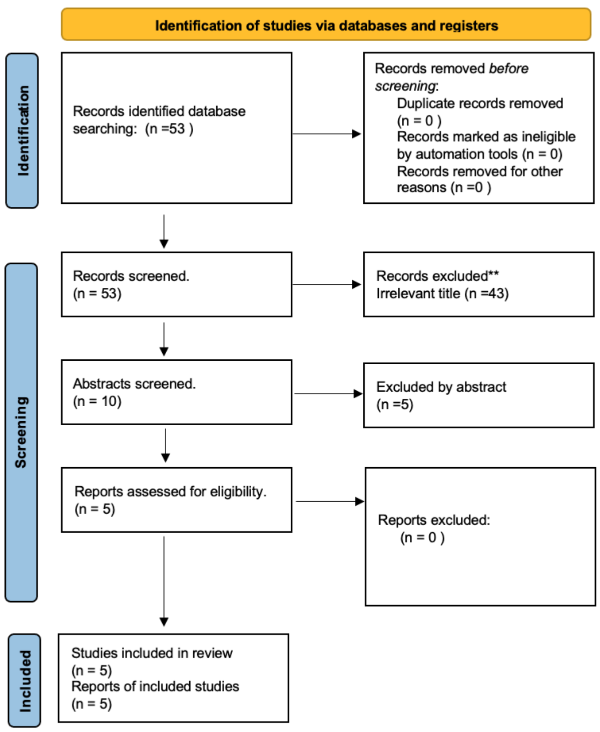
Method

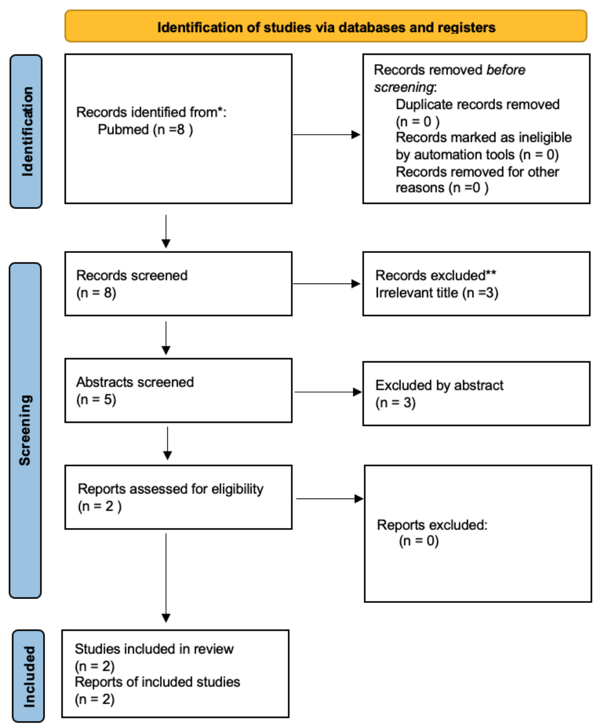
This literary search used PubMed as a database, other miscellaneous sources were used as advocacy to this study. To gather and sort literature, Zotero was used as software. We did two main searches, one for each research aim, research aim two consisted of two searches. The first search was conducted on 16.01.24, on our first research aim, the following keywords were used:

Sprinting, capacity, and, fatigue, in, soccer. The second search was conducted on 08.02.24, researching our second aim, it consisted of the following keywords; Sprinting motion capture markerless. And these keywords; automatic, timing, system, sprint.The results were sorted and screened for eligibility as portrayed in the Prisma flow-diagram (Table 1 and 2).

Prisma Flow-diagram

Research aim one **(Table 1)** and research aim two **(Table 2)**, screened and sorted for eligibility.





Inclusion Criterias

Table 3 Inclusion and exclusion criteria for this literate search.

Peer reviewed articles
English and Norwegian
2010 and newer

Results

Seven studies (5,17,18,20,28,29) were included, with the number of participants ranging from n = 10 to 198. Five out of seven studies used amateur to professional football players. Two studies did not use football players, and out of these studies, one used athletes from a winter sport called skeleton, and the other is a literate study on assessment of sprinting performance. All the studies focused on male participants except for two, Needham et al. (20) had a mix of both genders, and Haugen and Buchheit (18) wrote a systematic review focusing on guidelines and technology related to sprinting assessment.

The results (Table 4 and Table 5) shows a correlation between fatigue and physical capacity, several studies specifically mentioning decrements in the capacity to accelerate and decelerate. The systematic review (18) thoroughly describes different aspects to assessing sprinting performance (Table 5). The review includes important considerations like timing technology (Manual timing, floor pods, photocell etc.), procedures, environmental factors, clothing and equipment, running surface and how to monitor the changes in sprinting performance (Integrating data across technology). This systematic review has no applicable results regarding our first aim, but a large amount related to aim two. It is therefore presented in its own table (Table 5).

Table 4 Main findings related to our research aims, each row represents one study and how it relates to our aims.

Study	Aim	Method	Research aim one	Research aim two
Observational study (25)	To determine the association between commonly recorded match activity variables during elite competitive matches and measures of fatigue and neuromuscular performance capacity immediately, 40 and 64 h post-match (25).	Two competitive football matches, measuring activity variables and subsequent measures of fatigue and neuromuscular performance (25). Baseline measures of fatigue and neuromuscular performance capacity were assessed following three days of rest (25).	A positive correlation between fatigue (CK) and decrements in the capacity to accelerate and decelerate, and the number of sprints (25).	Sprint distance, total distance, the number of accelerations and decelerations and the number of sprints (26) were assessed using Prozone Matchviewer (Prozone® Sports Ltd, Leeds, United Kingdom). Prozone Matchviewer had been previously shown to be a valid and reliable (27) measure of performance characteristics.
Observational study (5)	Football-specific fatigue on sprinting kinematics, sprint performance, hamstring maximal voluntary torque	Measurements were taken before and after every 15 minutes of play (5).	Hamstring MVT and sprint performance were significantly reduced by 7.5% and 14.3% at the end of the football match simulation (5).	This study used a wearable inertial-based motion analysis system (MPU-9150, Invensense San Jose, CA). It can help assess fatigue-induced changes on sprinting kinematics (5).

	(MVT), and hamstring rate of torque development during a simulated running based football match (5).			
Cross-sectional design (17) 2017	Physical capacities of football players with (previous two years) and without a prior hamstring injury (17).	They filled out a questionnaire and did the following physical capacity tests; 40m maximal sprint, repeated sprint test, counter movement jump, Vo2 max test, leg strength and hamstring flexibility test (17). 16% of the participants had a prior hamstring injury (17).	The study found only a difference in performance on the repeated sprint test for players with a reported prior hamstring injury (17). This difference was shown as a drop in speed on the two last runs. P = 0.007 (17).	Times were recorded using Brower equipment (Wireless Sprint System, USA, accuracy of 0.01 s) (17).
Observational study	Analysed and quantified the acute	Testing sprint, kicking and jump capacity before,	The study observed a significant decline in	Using a single beam photocell system (DSD Laser System, Leo

/w cross sectional design ([28](#)) 2020	effects of playing a soccer match on essential explosive movements occurring during a match for players in different playing positions (28).	halfway and right after the match (28). The tests included a 40 metres sprint, counter movement jumps (CMJ) and kicking the ball for measuring velocity (28).	performance in all tests for all positions, except for the CMJ test for defenders (28).	´n, Spain). Two photocells were sited at the start, another two at 30 m and two at 40 m (28). Players started the sprint test half a meter behind the first two photocells (28).
Observational study (29) 2022	Analyses associations between soccer match related internal and external loads, neuromuscular performance decrease and intermittent-running endurance capacity decrement. immediately post-match (29).	Countermovement jump, straight-line sprinting (10- and 20-m sprint), change of direction ability (T-test) and intermittent running endurance capacity (YO-YO intermittent recovery level 2) were measured one day before and immediately after a friendly match (29). During the match, players' internal and external loads were also	The relationships between match activity variables and fatigue status show that the quantification of Δ of match external-load metrics, particularly accelerations and decelerations, provide a useful non-invasive predictor of subsequent NMF status in soccer players immediately post-match (29). However, only internal load metrics present practical	Three pairs of photoelectric cells (Microgate Racetime2, Microgate®, Bolzano, Italy) placed 0.4 m above the ground were used to evaluate the straight-line sprinting performance (29). The players started when they were ready from a standing position of 0.5 m away from the first photocell gate and sprinted to the finish line (20-m) where the last photocell had been located (finish time) (29).

		monitored, including heart rate-derived indices, total distance at various speed thresholds, average running velocity, maximal running velocity, number of sprints and number of accelerations and decelerations at various intensity thresholds (29).	applications for predicting intermittent-running endurance capacity impairment (29).	
Comparative/experimental study (20)	Examines a method for non-invasively measuring mass centre velocities using markerless human pose estimation and Kalman smoothing (20).	Two testing sessions, one outdoor push track and a second indoor sprints track (20). During both pushing and sprinting trials, motion data were captured concurrently using marker-based and markerless motion capture systems (20).	Not applicable	Both the motion capture systems demonstrated high reconstruction accuracy (mean < 1 mm) and acceptable marker derived CoM accuracy (20). Both horizontal and vertical CoM velocity differences were high for unfiltered OpenPose data but greatly improved in

			performance under low-pass filtering and Kalman smoothing (20).

Table 5 An overview of Haugen and Buchheit's (18) methodological guidelines to MOCAPs, and possible confounding factors.

Study	**Aim**	**Method**
Systematic review (18)	Provide guidelines to accurately monitor and interpret sprint performance changes, based on established magnitude thresholds and practices to decrease typical errors with trial repetitions (18).	Describes different aspects to monitoring sprint performance in regards to different equipment, technology and various possible confounding factors. PubMed and SPORTdiscus as databases (18).
	Findings relevant to research aim two: **Timing Technology**	
Gold Standard	Fully automatic timing systems employing silent gun, photo-finish camera and pressure-sensitive start blocks to detect false starts (19). High-resolution photo-finish cameras capture thousands of frames per second, enabling the timing officials to estimate time with less than 10.0005 s resolution (19).	
Manual	Usually a correction factor of 0.2s faster times with hand-held timing has been used to compensate for the timekeeper's reaction time (18).	
Photocell	Based on (single or dual) infrared beam transmitted to a reflector directly opposite of the transmitter, then reflected back to the transmitter. Timing is triggered when movement is breaking the beam. Inspections of reliability data	

	across short-sprint studies reveal 0.03s standard error of measurement (SEM) and ~ 2% coefficient variation (CV) for single-beamed timing (18).
Floor pods	Pods with pressure sensors that triggers starting time when pressure on the pods is released. Pods are made for hands or feets, but the principle of pressure release is the same for both (18). Devices are made by different manufacturers that may require different calibrations and have different thresholds for time offset (18). Since the back foot leaves the ground before the front foot in a correctly performed start, triggering will occur at an earlier stage, with less forward motion prior to time initiation (18). A small to no difference in timing (18).
Audio and visual start sensors	Audio sensors set off the timer when it captures certain sound intensities (18). An audio device is placed close to the sound source for short distance sound travelling and clear sound capture (18). In athletics audio sensors are often paired with photocells for accurate finish time (18). No studies have investigated how different countdown procedures prior to start affect monitored reaction time (18). Visual signals have been used for time triggering on some occasions, but reliability data have not been reported (18).
Video	High-Speed cameras are used in pair with another time starter device, for example floor pods or audio sensors, to capture athletes sprinting time by analysing the data captured by the camera with computer software (18). Video-based timing is highly reliable in sprint performance monitoring (18). However, a practical disadvantage is that sprint time is not presented immediately, since recordings must usually be transferred to dedicated software before they can be analysed (18).
Laser and radar devices	Laser based time capture is based on continuous measuring of velocity and time between the laser device and the athletes who are sprinting away from the device (18).

	Typically a laser gun aims the beam at the athlete and capture velocity and time data at a rate of 100 Hz (18). A new combination of two synchronised devices has recently been shown to allow the precise monitoring of change of speed and direction (18). Hader et. al. (30) reported acceptable levels of validity and reliability (e.g. moderate CV for peak deceleration and acceleration).
GPS	The great advantage of GPS technology is that it allows assessment in the field of many players simultaneously (18). Some authors have concluded that GPS shows acceptable accuracy for sprint velocity when compared with timing lights or radar guns (32-35). However, typical errors in the range 3-15% or correlation coefficients in the range 0.93-0.96 do not necessarily indicate acceptable validity (33-35). In line with these different limitations, today's GPS technology may not be a highly valid tool for accurate acceleration performance assessment (18). However, it is important to keep in mind that the validity and reliability of GPS will probably be improved with the development of the technology (18).
	Procedures
Start positions and signals	The impact of different starting positions on monitored sprint performance must be seen in relation to the hardware device used (18). The starting method and timing system used can combine to generate up to very large differences in sprint time. Silent guns are advised, but expensive (18).
Flying start	Photocell timing demands a flying start from the athlete to eliminate premature triggering (18).
	Environmental Factors

The influence of wind is most pronounced in sprint performance assessment (18). The use of multiple wind gauges positioned alongside the entire lanes on both sides would certainly strengthen the validity of wind measurements (18). 100-m sprint times may vary up to 0.1s across the combination of varying air temperatures (15-35°), humidity levels (0-100%) and atmospheric pressures (85-105 kPa) (35).

Clothing and equipment

Two studies have reported no significant benefit of wearing compression clothing on sprint performance (18).
It is possible to reduce the wind resistance of a runner by 6%, but such a wind resistance reduction provides practically no effect over short sprints (18). Research regarding the impact of footwear on sprint performance is limited (18). Stephanyshyn and Fusco (36) reported 0.7% mean performance improvement in the 20-40m interval of 40m sprints after increasing the bending stiffness of sprint shoes (18).

Running surface

Some studies found no significant difference in sprinting performance times. Another study found 2-3% faster time on an athletic rubberised track compared with natural grass (18).

Monitoring changes in performance

The study offers a table with the mean difference of all the different methodological variables (18). Practitioners wishing to optimally assess their athletes sprinting performance would need to consider 1) the actual change in performance (the signal, 2) the typical errors of measurement (the noise, representing the uncertainty in the particular measure) and 3) the smallest practical or meaningful change (18).

Conclusion

Procedures and methods of sprint timing can result in trivial-to-very large differences in sprint time. In most cases, their relative impact on sprint performance increase with shorter sprint distances (18). At the extreme, the combination of starting procedure and triggering devices used can cause many times greater sprint time difference than what is typically associated with several years of conditioning (18). Time differences over short sprint distances caused by air resistance, clothing, footwear and running surface are either trivial or small. However, in combination, these variables can cause moderate and even large time differences (18).

Discussion

The two aims of the current study were: 1) to summarise existing research focusing on the association between decrements in the capacity to accelerate, decelerate and hamstring injury risk among professional football players, and 2) to provide insight into how MOCAPs can assist as a non-invasive monitoring tool, by doing a literature review.

The following main findings related to aim one were observed: A positive correlation between fatigue and decrements in the capacity to accelerate and decelerate. Two studies did not investigate this relationship. The main finding related to aim two, was that a gold standard for monitoring sprinting was discovered by (18) (Table 5). They also discovered that procedures and methods of sprint timing can result in trivial-to-very large differences in sprint time (18). In most cases, their relative impact on sprint performance increase with shorter sprint distances (18) At the extreme, the combination of starting procedure and triggering devices used can cause many times greater sprint time difference than what is typically associated with several years of conditioning (18). Another study comparing markerbased and markeless MOCAPs discovered the following: Both the motion capture systems demonstrated high reconstruction accuracy (mean < 1 mm) and acceptable marker derived CoM accuracy (20).

In the current study we observed that there is a positive correlation between fatigue and decrements in the capacity to accelerate and decelerate, and the number of sprints. This is supported by findings in all of the five studies related to this aim. One study only found this correlation for athletes with a prior HSI, and this was only evident on the two last sprints on one of the tests (Table 4). This may suggest that the athletes with a prior hamstring injury may have an earlier onset of fatigue when sprinting and/or a decrease in repeated maximal sprinting performance. Despite all the knowledge, research and available information which confirms the extent of hamstring injuries and fatigue associated with playing soccer matches, there is still a large incidence of injuries. Future research could benefit from investigating the relationship between existing statistics and current injury prevention strategies. Overall, the current and previous findings demonstrate that there is a correlation with reduced capacity to accelerate and decelerate, and fatigue, and therefore elevated hamstring injury-risk.

In the current study we found that it is possible to accurately monitor sprint performance using MOCAPs. This is supported by both the studies included, however, MOCAPs is an umbrella term covering a wide spectrum of technologies, suitable for different purposes. In these studies, the accuracy of the technology was only tested on velocity changes during linear sprints, with one exception where (29) a T-test was included. A technology suited for capturing linear sprints, may not be sufficient if the purpose is to capture dynamic and rapid movements in different directions. Such movements are typically displayed by a tennis player or a soccer player, dynamic movement patterns demand more powerful sensors in the technology in order to capture and interpret movement data. A recreational sprinter could do just fine with a handheld stopwatch for monitoring sprinting time. Professionals looking for small changes in performance to give an injury risk assessment need a more advanced setup able to capture nuances. Some technologies interpret the data for the user, however relevant knowledge regarding sprinting biomechanics and injury prevention would aid in the application of the data. As shown by Haugen and Buchheit (18), for more precise results, it is advisable to combine different types of technology, and control as many variables as possible. Overall there is no one-technology that fits all scenarios, however, the literature presented in this study demonstrated that MOCAPs can assist as an accurate non-invasive monitoring tool in the assessment of sprint performance.

Methodological consideration, expanding the search to other databases and other languages could alter our findings. As with all research in medicine and sports, there are confounding factors like genetics, previous injuries (although one study researched this specifically), and different types of research-biases. Further research by different researchers may strengthen these findings. Although our findings consist mainly of male participants, the underlying anatomy and physiological factors affecting the hamstring muscle are very much alike for both sexes, and we would therefore expect similar results.

Conclusion

In conclusion a drop in acceleration/deceleration performance could serve as a non-invasive fatigue marker, and MOCAPs could be used as a monitoring tool. This could aid players and coaches in lowering the risk of hamstring injuries, and provide an otherwise useful fatigue overview. The study observed that it is possible to accurately monitor sprint performance using

MOCAPs. However, different set ups, equipment, test protocols and user knowledge have an influence on the accuracy. Therefore, knowledge about MOCAP technologies is a prerequisite for implementing MOCAPs in assessing sprint performance. For the highest accuracy it is advisable to use the golden standard, however, this may not be suitable for everyone due to a higher cost and complexity.

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