Chapter 4

Wearable Technology Usage in Race Walking

Yeliz Ay Yıldız[1]

Abstract

The use of temporal sensor data related to human activity has greatly increased in recent years thanks to smart technology has become widespread and even ubiquitous in our daily lives. Today wearable technology has many roles in our daily life. Wearable technological products allow us to easily obtain a lot of data in the field of sport and health. This data can make it possible to monitor physical condition, athletic performance, training load and can even be used to prevent injury mechanisms or to analyze rehabilitation. Athletics is one of the sports in which performance is tracked metrically and chronometrically. The only exception is race walking which based on subjective observation of the judges in this sport. There is a need for the development and use of wearable technological devices that can support referee judgment in walking and can be used for fair decisions in disqualification and penalty time applications during the competition.

INTRODUCTION

It is very important to analyze the role of wearable technology in daily life and why there is such a need for that devices, it is known that there is a need for this technology from different groups. Wearable technologies are innovative products which created with the help of technology and can be considered as one of the most important technological elements of the 21st century. Today, there are products which are sometimes integrated into clothing or accessories and at the same time have information and communication technology. These products can store data or transmit the data to smart devices via the smart sensors in their systems. Wearable technology products and the markets of it's are developing together with many disciplines and connected with needs. In addition to important areas such as health, education, production and security, wearable technological products are also used to follow the activities of everday life (Çakır et al.

1 Email: yelizayyildiz1977@gmail.com, ORCID: 0000-0002-2002-0389

https://doi.org/10.58830/ozgur.pub315.c1479

2018). The first examples of wearable technological products emerged in 1884. The first products of wearable technolgy were created by adding led lamps to ballerina tutus which called Electric Girls are considered to be the pioneers of wearable technology. Not every product used in today is considered as have wearable technology features. Trackers of wearable technologies can help motivate you during workouts. Together with your smartphone they can track and inform you about your daily routine or fitness, without requiring potentially annoying manual calculations or recordings(Kaewkannate & Kim 2016). In order for a product to be a wearable technology, it must transfer the data collected for a specific purpose through smart sensors through an integrated system to the technological product developed by bluetooth or any wireless means (Çakır et al. 2018) Wearable technology products specialized electronic tracking which are designed as devices synchronized with a computer or smartphone to provide long-term data tracking, in most cases wirelessly., Smart sports products such as Rings, smart glasses, smart watches, wristbands or bracelets, smart helmets, smart t-shirts, smart gloves, smart socks, smart shoes and many more collect information during the athlete's training activities and store or transmit this information internally. These products are state-of-the-art mini computers that can be worn and integrated into various parts of objects in different ways (Kaewkannate & Kim, 2016). Smart sports equipment generally consists of a wrist-worn device and sensors that store the user's activities on mobile devices. With sports specialized smart products, the user measures some values such as temperature, muscle activity, sweating amount, body fat ratios thanks to the sensors inside and reports the result to the user. One of the biggest benefits of these products is what they provide the user with very detailed information about the sport. They monitor, record and regularly track all types of actions, from musculoskeletal system actions, as blood pressure and heart rhythm values (Kaewkannate & Kim, 2016), (Çakır et al. 2018).

With the appearance of wearable devices such as phones and tablets, the accessibility of temporal sensor data related to human activity has greatly increased. Therefore, the fields of human activity recognition (HAR), intelligent monitoring, human-computer interaction and video capturing based on wearable devices have also attracted more attention (Wang et al., 2023). In many sports, team sports, water sports, snow sports and of course individual sports such as running, cycling, triathlon, etc., wearable technological devices have become one of the safest ways to monitor the trainings (Chambers et al., 2015). Motion capture is used in sports performance to analyze physical condition, athletic performance, technical expertise and injury prevention mechanism or rehabilitation. Inertial measurement unit (IMU) and Global Positioning System (GPS) sensors are mostly found in wearable sports devices, but other features can be programmed for different needs (Adesida et al., 2019). The general demand from users is for a combination of wearable technology and aesthetics; products that are sleek, modern and lightweight, with unobtrusive designs, waterproof and with versatile functionality, and multiple options for charging the battery are the most preferred. High accuracy in tracking the physical parameters of these technological products for simple activities such as climbing or descending stairs and healthy monitoring of vital parameters (heart rate, pulse rate, body temperature, respiration or others) are the main features expected in a smart device (Kaewkannate & Kim 2016).

Another system that is needed especially in professional sports is motion analysis systems, particularly in the last 30 years, with the development of cameras, computer science and image processing technology, these systems have started to become widely used in sports. Especially in sports, wearable sensors with different nature have a variety of uses, which are useful in many ways. The function of wearable technological devices in our lives is increasing day by day, and by integrating technology into sports, users have the opportunity to collect more data about their technique and performance. Feedback on an athlete's performance plays a huge role in success. Today, the field of wearable technology is very wide and each of them is thought to have its own role to play in different sports and industries (Adesida et al., 2019). Wearable technological devices have many uses in the field of sports performance; motion capture is used to analyze athletes' physical condition, performance, technique and the underlying causes of injuries. At the same time, technological devices are used to monitor and record human movements in order to analyze rehabilitation as well as injury prevention (Ortega & Olmedo 2017). Microtechnology has allowed sports scientists to understand locomotor demands in various sports. While wearable global positioning technology (GPS) is widely used to measure the movement-related demands of activities in line with the needs of the respective sport, sometimes microsensors integrated into the units (i.e. accelerometers, gyroscopes and magnetometers) are also capable of detecting sport-specific movements (Chambers et al., 2015).

Sports research often requires capturing human movement of an athlete. Human motion capture is the process of recording human movement; the system mostly focuses on recording the global position of (segments of) an athlete's body (Van der Kruk & Reijne 2018). Both coaches and athletes can benefit from performance monitoring and objective feedback using technological devices as a method to monitor and improve their athletic performance, while minimizing the possibility of injury. The traditional observation technique and approach used by the coaches is based on their expertise, experience and background. Growing interest in technology and research is pushing this subjectivity further into the background; for example, video analytics, where videos can be annotated to measure angles, allows performance to be measured objectively rather than depending on the critical eye of coaches. However, such approaches provide objectivity and allow athletes to provide real-time feedback (Adesida et al., 2019). However, such approaches provide objectivity and allow athletes to provide real-time feedback (Adesida et al., 2019). The human body has reference systems; reference systems allow body segments to be positioned relative to each other and to the body in its environment. They facilitate the description and study of movement (Balthazard et al., 2015).

The study of movement, which is the nature of sport, has of great importance in each branch for the development of performance. Athletics is undoubtedly one of the most popular Olympic sports. Athletics is a main sports branch that consists of many sub-branches and always aims to renew records with the principle of faster, higher, stronger. Athletics is by its very nature based on objective data, and since its measurements are metric and chronometric, there is no room for doubt in the process of determining the champion. The only exception of athletics which has subjectively evaluated is walking. Race walking is an Olympic competition discipline considered to be the fastest expression of walking (Paveyi et al., 2012). A lot of work has been done since the 1980s for the kinematic analysis of race walking. Nowadays, technology in sport plays an important role in assisting training and evaluation processes .There is a need for technological equipments to support referee judgment in race walking competitions. Many studies in recent years have proposed the use of a wearable inertial system to derive new biomechanical indices for the assessment of performance and violations in race walking (Caporaso 2020).This study was conducted to inform the reader about the wearable technological products that are used and planned to be used in the race walking branch of Athletics, both for performance monitoring and to objectify the adequacy of the technique and to form the basis for the decisions of the referees during the competitions.

Wearable Technology in Sports

Wearable Technological Products Which Used in Athletics

The most commonly used wearable devices for walking and running in athletics: Nike, Polar, Suunto, Fitbit, Garmin, Apple, Misfit, Samsung Gear, TomTom and Lumo and many other brands are also been used. With these devices, often data such as heart rate, step count, running-walking speed, exercise distance, energy consumption, metabolic analysis, sleep duration and sleep quality can be monitored. (Bunn et al., 2018). While there are many devices for tracking and sharing running and walking-based exercise routines, unfortunately these devices offer limited functionality for strength trainings. There are also some products that automatically track repetitive exercises such as weight training and calisthenics through an inertial sensor which worn on the arm (Morris et al., 2014). In sports, some applications of wearable technologies are useful tools to measure the athlete's performance in outdoor conditions and can therefore play an important role to support training. Moreover, because they can provide accurate and reliable data from athletes, they can also be used for the development of tools that can support judgments (Caporaso & Grazioso 2020). Some of these wearable products aim to monitor and record athletes' movements in real time (Pueo & Jimenez 2017). Nowadays 3D kinematics is a basic input data for many fields such as motor control, biomechanics or animation. However, the most popular opto-electronic systems using active or passive markers are based on fixed cameras and can only acquire a limited volume of data with this method. Human movement can be studied during several cycles (Begon et al. 2019). Motion capture systems have the capability to analyze many functional movements and sporting tasks from a biomechanical point of view. Optical systems consist of cameras and branch-specific systems to track passive or active markers placed on anatomical landmarks for full body capture. It has been reported that these systems are widely used in a series of different sports, from track and field to boxing, modern pentathlon, tennis, swimming and taekwondo (Krüger & Edelmann 2009). However, due to the required camera setup these systems often have quite limited capture volumes in to the laboratory environment. Furthermore, the large number of markers that were often needed had negative effects on timing. This may hinder a clear understanding of the performance of the tasks under investigation, and even conversely, the complexity of sporting tasks can often lead to confusion due to the markers and a blocking of the analysis process. Wearable technology is an alternative approach that has the potential to overcome these limitations. There are a number of different types of sensors, including Inertial Measurement Units (IMUs), which include a combination of magnetometers, accelerometers and gyroscopes, and Microelectromechanical sensors (MEMS). In addition, there are flexible sensors, such as those manufactured by Spectra Symbol (Salt Lake City, UT, USA), which can track joint motion through changes in resistance when a force is applied to the sensor (Adesida et al., 2019).

By processing and analyzing sensor data collected with HARs, it is possible to automatically detect activity types. The monitoring system has utilized HAR in many applications, including activity analysis, gesture recognition and user health monitoring. The development of smart devices has provided good opportunities for HAR based on wearable devices. Compared with computer vision-based recognition, HAR based on wearable devices has provided significant advantages such as low budget, high performance, and portability while avoiding the impact of video blind spots and insufficient illumination (Wang et al., 2023).

Another important advantage of these wearable systems is the ability to monitor athletes in a real sports environment to provide real-time feedback, a feature not provided by video analytics. It is also designed as a small, lightweight, wireless and inconspicuous device to allow for all movements during participation in a sport. This makes it possible to observe athletes outside the laboratory environment and in natural training areas. The sensors can be used in many sports such as swimming, mountain biking, skiing and snowboarding that take place in the extreme conditions and have additional features like being waterproof or able to withstand very cold weather and quite high temperatures while recording data (Adesida et al., 2019) However, along with the advantages of being wireless, it can sometimes be said to create some limitations: ferromagnetic objects in the environment can degrade the data quality and measurement values from inertial-based systems. Besides data accuracy, accurate positioning can also introduce errors when trying to estimate data input, acceleration measurements and positional data (Alonge et al., 2014). Furthermore, selecting a wireless method for data transmission may create the possibility of signal loss during recording or interference from cell phones or other devices which may be on the same transmission frequency (Reenalda et al., 2016).

Recent developments in wearable and wireless sensor technology allow for a complete ongoing 3D motion analysis outside the lab. Inertial sensors, also named inertial measurement units (IMUs) or inertial magnetic measurement units (IMMUs, devices that also include a magnetometer), have been successfully used for 3D walking analysis (i.e. walking) and have shown considerably better accuracy compared to optical motion analysis systems (Dejnabadi et al., 2006.; Roetenberg et al., 2007). Various inertial sensors are also used in sports science to consistently analyze the motion.

The process of capturing motion with wearable sensors can be a highly tedious and intensive process, and it can sometimes be challenging to obtain information about the accuracy and practicality of the measurement systems.

The features reported by the manufacturers are sometimes determined in different conditions and set-up conditions than the field and competition conditions in which the sports research is carried out; therefore, the sports research is carried out depending on four important characteristics of the field. First of them is; sport research is mostly conducted in non-laboratory settings, on the training field, track or arena where athletes play sports. Measuring in a space outside of controlled laboratory environments presents several challenges, such as the different locations of the indoor and outdoor environment, weather conditions, temperature, humidity, light differences, measurement interferences such as noise, scattering, magnetic disturbances, and obstacles that cause obstructions in the space (Van der Kruk & Reijne 2018). Second, the area and capture volume set for making measurements is usually large. Accuracy is therefore often inversely proportional to the coverage of a positioning system. That means the larger the measurement coverage, the wider the area, the lower the accuracy, which is often one of the main factors limiting the researcher in the choice of a measurement system. When participants' displacement increases during training or competition, ergometers are sometimes used to obtain a large number of movement cycles (Begon et al., 2009). (Van der Kruk & Reijne 2018) Third, research for sports analysis often deals with a wide range of sporting movements, from static or slow movements (e.g. walking analysis) to highly dynamic movements that are much more difficult to capture. For importantly, the requirement of high sample frequencies poses a technical challenge. Typical sample frequencies for sports applications are between 50 and 250 Hz. There is a preference to avoid the use of very high sampling frequencies to avoid excessive amounts of data and high frequency noise. Only in certain situations very high frequencies are required, for example to detect impact (such as during a jump) or to examine very high speed movements (>1000 Hz) such as a serve in volleyball, a shot in soccer or a baseball throw. Moreover, the system has to deal with motion dynamics, which poses some problems, for example, in inertial measurement units (IMUs), where linear accelerations can spoil the sensor position estimation of sensor fusion algorithms (Van der Kruk & Reijne 2018). Fourth, when a measurement system demands sensors, markers, transponders or tags to be placed directly on an athlete, the size and weight of the sensors are critical to ensure that movement can be performed with true speed and technique. Especially in high performance and high dynamic conditions, an athlete's freedom of movement should not be inhibited or minimally restricted (Van der Kruk, Reijne 2018).

Race walking from past to present

Race walking is a long-distance competition discipline that has been part of the Athletics competition program since the 1908 Olympics. These locomotor limitations have forced athletes to develop a characteristic pattern commonly known as the 'race walking style' (Pavei 2014), (Brisswalter 1998). The rules for this walking technique are clearly stated in the World Atheltcis Rule Book (Rule 230). Due to the high technical demands of the walking event, race walkers are under constant monitoring by referees during the races to ensure they comply with the rules (Harisson 2018). 'Race Walking is a progression of steps so taken that the walker makes contact with the ground, so that no visible (to the human eye) loss of contact occurs. The advancing leg must be straightened (i.e. not bent at the knee) from the moment of first contact with the ground until the vertical upright position' (IAAF 2016). Race walkers use a unique walking technique to optimize speed while following the rules.(Harisson 2018) Unlike other disciplines in athletics, race walking is the only discipline in all athletics disciplines where the human factor and subjective decisions are involved. Failure to comply with the rule that the athlete must not lose contact with the ground (a visible loss of contact) is a common rule violation in this sport discipline, especially at the elite level. It is called loss of ground contact (LOGC Loss of Ground Contatct). LOGC is defined as the time when the toe of the rear foot loses contact with the ground and the heel of the front foot touches the ground.

There should be no visible interruption between two temporal walking events. The movement must continue in a series of steps as shown in Figure 1.

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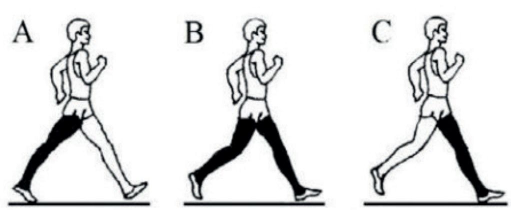

Fig. 1 –Temporal gait events: A) the toe-off and C) the heel-strike; B) shows a LOGC

Figure 1) Steps of the race walk A) Foot off the ground B) Loss of contact C) Heel contact with the ground

In image B, the athlete's rear toe and the heel of the front foot are not in contact, showing illegal technique.

In the context of race walking, the main users can be considered in three contexts: athletes, the leading actors of the race; coaches, the "chief technical officers" of the athletes' team, responsible for the adequacy of performance and technique; and referees, the guarantors of the orderliness and fairness of the race. All these stakeholders are always interested in new tools to monitor sports technique in training and competition scenarios. Athletes are interested in receiving objective feedback about their performance and technique. Coaches are interested in having basic indicators of athletes' performance and violations, which are very useful for optimizing training and competitions, but also for developing new customized strategies. Referees are interested in useful tools to help evaluate violations during competitions (Caporaso & Grazioso 2020). For this reason, coaches focus highly on development, especially training aimed at developing specific motor behaviors. All this makes race walking a very technical discipline (Girnomio et al. 2016). Even a minor violation of this rule on the track can lead to the athlete being disqualified. The most common rule violation is the loss of ground contact (i.e. the flight phase). Race walking is an Olympic event in which athletes are not allowed any noticeable loss of contact and where competitors try to minimize their flight time as a result (Hanley 2019). Two main defects can be found in the visible observations of walking contest judges. First, the human eye can maintain an image gradation at 16 Hz. Therefore, a flight phase lasting less than 0.06 seconds cannot be detected by any judge. In addition, athletes usually compete in groups, it makes extremely difficult to track a single athlete during the race, also known as the theory of change blindness (Harisson et al. 2018). Secondly, the judges are located at different points of the race track and can therefore evaluate each athlete for limited periods of time. The direct consequence of these flaws is the presence of cases of missed violations or wrong disqualifications during each official competition. As a result, the credibility of this Olympic sport is gradually diminishing and its future inclusion in the Olympic Games is being questioned (Harisson et al. 2018).

Examples of Wearable Technology needs and Applications in race walking

In a field study evaluating race walking (Loss of Ground Contatct) in terms of LOGC (Loss of Ground Contact), it was observed that the results obtained were in line with the values obtained in laboratory tests. Both studies consider the acceleration system to be a useful as a tool for judges to use in their measurement and decision-making process for loss of contact decisions during a race walking competition. In specific, the proposed data analysis protocol in combination with the inertial sensor is a valuable tool for identifying strides during a low-speed walking training session (it can be said that illegal strides are not very common in terms of the assessment of contact loss during the speeds obtained in slow-paced training). However, in cases where athletes reach high speeds in the competition pace, many contact losses occur, therefore, illegal steps were detected in the questions reached in the races. It is thought that this system will help coaches in training and referees in the process of evaluating athletes during the competition. Every athlete wants to win the race. It is much more difficult for race walkers to pick up the pace in the last few minutes of a race in major organizations where race walkers typically win with a negative pacing strategy and faster second-half times than first-half times. This challenge comes from the fact that athletes and coaches need to be careful with the important effects of technical limitations, since they have to follow the technical rules that regulate this discipline (Vernillo et al., 2012; Gironimo et al., 2016). In major walking events such as the 2011 IAAF World Athletics Championships and the 2012 London Olympic Games, 12% of race walkers were disqualified due to loss of primary ground contact or knee bending (Lee et al., 2013). In a study which conducted by Hanley, biomechanical analyses were performed on the flight time of athletes who ranked in their categories at the 2012 World Walking Championships. In this study, it was determined that each athlete has a flight phase that can be measured with milliseconds, although it is invisible to the human eye as the rule states. As a result of the biomechanical analysis, it is reported that athletes with longer step lengths have longer flight times and this creates a risk for disqualification (Hanley 2013).

Table 1: Table of flight times and cautions received by medalists in the 2012 Race Walking World Cup (Hanley 2013).

	Contact time (sec)	Flight time (sec)	Contact time (%)	Red cards (~)
20km Senior Women	0.26 (± .00)	0.03 (± .01)	88.7 (± 3.6)	0
20km Senior Men	0.26 (± .02)	0.05 (± .01)	84.7 (± 4.1)	2
50km Senior Men	0.26 (± .00)	0.04 (± .00)	86.7 (± 0.0)	0
10km Junior Women	0.25 (± .01)	0.04 (± .00)	86.3 (± 0.5)	3
10km Junior Men	0.26 (± .02)	0.04 (± .00)	86.6 (± 0.9)	1

It is important to note that loss of contact lasts for a tiny fraction of a second, so it is quite difficult to assess (reliably) using only human eyes, as is often the case in current practice. The importance of this necessity is also underlined by the international federation (World Athletics 2023), which is interested in the conception of a new competition system (World Athletics 2023) capable of assessing contact loss, reducing judgmental problems and thus increasing the external trustworthiness of the race walk (Caporaso & Grazioso 2020).

Although loss of contact (or "time of flight") can solely be assessed visually during competition, research has been conducted on this topic using several different methodologies. The purpose of these studies is to support athletes during training and to provide quantitative measurements for referee training. These include work with standard video cameras, high-speed videography optoelectronic systems, power plates and an inertial sensor. Considering the importance of flight time measurements for race walkers and coaches (e.g. when comparing flight time between different periods of the training season), using a trustworthy system is essential in determining the actual duration of flight time (Hanley 2019).

In track conditions, four technologies are potentially available for the estimation of contact loss: high-speed camera, optical measurement systems, base pressure and wearable inertial systems. Video analysis using a high-speed camera provides a reliable assessment of sports kinematic parameters; indeed, some authors (Padulo 2015) have used this technology for the assessment of contact loss. However, video analysis requires intensive post-processing and is therefore difficult to use in real conditions (training and competition scenarios) where a continuous and real-time assessment is required. In summary, the main limitations of video analysis are that it is a time-consuming process and does not allow for continuous analysis of athletes, especially when athletes are in groups. More recently, optical measurement systems (i.e. the OptoJump Next system) have been used for race walking analysis, demonstrating how this system can be used to provide highly reliable values for the evaluation of contact loss timing in elite race walkers and in on-ground and treadmill testing (Hanley 2019). This technology allows for faster assessment of contact loss compared to video analysis. However, even this technology is difficult to use in real training and competition scenarios as it requires the athlete to walk alone and only allows analyzing a few steps. Many researchers have proposed different systems for automatic detection of illegal steps in walking competitions. The first use of inertial sensors in race walking can be traced back to the work proposed by Lee et al. In this study, Lee et al. estimated the flight time with a formula derived from the analysis of the vertical acceleration curve and reported that only one linear accelerometer placed on the S1 vertebra was successful in detecting contact loss errors with a sensitivity of up to 88%. Santoso and Setyanto conducted a study by placing a piezoelectric transducer they developed in their research on the shoes of hikers. In this study, they enabled real-time detection of contact loss depending on the on / off processes of the piezoelectric transducer(Di Gironimo et al., 2016; Di Gironimo et al., 2017). They developed a sensor that detects contact loss defects with a sensitivity equal to 82% by means of a two-way classifier. The use of a sole pressure system Amigo (by World Athletics) is currently under trial. The system consists of piezoelectric sole pressure sensors (less than 1 mm thick) that collect contact loss data, which is subsequently transmitted to a control unit by R-FID (radio frequency identification). The insoles system allows direct measurement of contact loss, but from the athlete's point of view it can be invasive and can be said to be uncomfortable enough to affect the outcome of the race. Indeed, direct contact with the foot can lead to problems (e.g. blisters, nail damage), especially for long-distance competitions specific to race walking. The use of wearable inertial systems, even if they do not offer a direct assessment of race walking temporal events, could potentially reduce the discomfort of sole pressure systems and be more user-friendly in real training and competition scenarios. Taborri et al. used a single inertial sensor (with a sampling frequency of 1 Hz) placed on the S100 vertebra to relate acceleration patterns to temporal events of walking for the assessment of contact loss. In an experimental verification study involving seven Australian race walkers, in which more than 80 steps were collected, the accuracy of inertial-based detection of loss-of-contact events was equal to 91% of the values obtained from video analysis (Taborri et al., 2019). Another study presented a method based on machine learning algorithms for the identification of race walking violations (loss of contact and knee bending). They started testing a system of seven inertial sensors (with a sampling frequency of 60 Hz) and included eight elite Italian race walkers in this study. A total of 972 steps (i.e. 1944 steps) were collected from the walkers. Based on the data collected by four different body segments, three different signal combinations for each body segment were elaborated using nine different machine learning algorithms (108 classifications in total). The validation of the classifications was carried out using a coach's judgmental evaluation as a criterion in this study, where they reported that the classification based on a second-order support vector machine fed by shaft linear acceleration gave the best performance with an overall accuracy value equal to 93% according to a subjective evaluation of a coach (Caporaso and Grazioso 2020).

Conclusion

As a result, various protocols and sensors for loss of contact and knee bending violations have been studied for many years in order to make objective evaluations in addition to the monitoring of the walking competition in the Olympics since the 1908 Olympics and the observation of the referees. It can be said that with the use of wearable technology in the race walking branch during the competitions in the future, it can be said that the new era is rapidly approaching in the evaluation of this branch by providing objective and evidence-based refereeing.

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