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Validity and Reliability of the Accelerometer for Assessing Jump Performance Variables: Review Study

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ABSTRACT

Aims: Since physical performance is one of the important parts of health, proper evaluation of people's performance is so much important, as it helps rehabilitation team to choose the best methods to improve performance. Involving all the muscles and joints, jumping is an activity used to evaluate performance. The accelerometer is an instrument that has recently been considered in the field of performance evaluation for some reasons like being economical, accessible, and the ability to replace expensive tools in the health system. This article reviews some studies that use accelerometer to evaluate performance of the neuromuscular system.

Method and Materials: Keywords were searched in PubMed, Scopus, and Google Scholar databases to find studies on the reliability and validity of accelerometers in jump performance from 2010 to January 2024.

Findings: In calculating most variables including jump height, flight time, contact time, stiffness, force, power, and reactive strength index of countermovement, squat, and drop jumps, studies have revealed high validity and reliability for this device. In calculating peak power and peak velocity, accelerometer has low validity and reliability, though.

Conclusion: Under the ground of the fact that accelerometer is a valid and reliable instrument in evaluating most jump performance variables, it may be counted as a useful instrument. Rehabilitation team, physical medicine, and sports medicine specialists would use this device to evaluate musculoskeletal system performance; Therefore, they will be able to adjust, modify, and finally improve the rehabilitation program for patients or athletes and thus promote health in society.

Keywords: : Wearable Devices, Smartphone, Sport, Athletic Performance, Telerehabilitation

Introduction

The physical performance of people in activities such as walking, running and jumping, in which the whole musculoskeletal system is involved, determines the physical health of people. Proper evaluation of the neuromuscular system is very important in rehabilitation [1], because paying attention to the correct assessment, will lead to the selection of appropriate rehabilitation treatments [2-4].

In a functional activity, all the muscles and joints act in coordination [5]. Jumping, running, and walking are examples of functional performance, as they involve a large number of joints and muscles in the body, particularly in the lower limbs [6]. Jumping is a multi-joint functional activity affecting the muscles of the lower limbs and the biomechanics of the center of gravity [7, 8]. Therefore, performing a jump test is a proper technique to assess functional variables such as force, power, rate of force development, that would finally make a depiction of the overall performance of the body, in athletes and non-athletes [7, 9]. On the other hand, jumping is used as an advantageous exercise to improve people's performance in clinic and sport fields [7, 9]. Different individuals might use jumping as a way to prepare themselves before starting a specific exercise [7]. Jumping is also used to analyze ordinary people's performance in the society in addition to athletes' performance analysis [7].

So far, individuals' Performance been recorded using a variety of technologies [10]. To test performance in the laboratory, technologies such as motion analysis system and force plate are utilized [2, 7]. These tools are expensive [5, 9, 10], and there are just a few of them in Iran; Furthermore, motion analysis system and force plate use is restricted to research and academic laboratories [9], so for most clinicians using these instruments is challenging and inaccessible [5, 9, 11]. Not only is the cost of maintenance for these tools considerably high, but it is also impossible to repair or change their parts due to sanctions; moreover, evaluating individuals' performance in the laboratory environment is different from the real environment outside [12], that is, any of the physical challenges that people or athletes confront in the street, gym or at home may not exist in the lab; therefore, different individuals' performance evaluations in a laboratory environment may differ from their work environment, and might not represent a real reflection of their actual performance [12].

Wearable sensors are other instruments that have recently been utilized to analyze performance [2, 10]. Inertial measurement unit (IMU) is a wearable sensor that includes an accelerometer, a magnetometer and a gyroscope [12, 13]. Until recently, these instruments have been used in a variety of rehabilitation fields including assessing elderly functions [14, 15], postural correction [16, 17], neurological [18, 19] and cardiopulmonary patient condition [20]. One of these small-sized and user-friendly tools is sufficient for evaluating the aforementioned variables [21]. Being categorized as a wearable sensor, the accelerometer is used as a portable and wearable instrument [9, 22]. They are also are economical and do not require any specific maintenance or repair [10]. Furthermore, because of their portability, these instruments can be used in a variety of environments without being limited to the laboratory e.g. routine, sports, and clinical environments [2, 21, 23]. Recent researches have demonstrated that the accelerometer could be used not only to calculate the performance of the body, but also to indirectly calculate the forces and torques of the muscles [24]. Therefore, since the accelerometer is economical and at the same time practical, it can replace expensive laboratory devices to evaluate people's performance as a new technology in the health system.

Smartphones also have accelerometer [1, 25]. They are relatively inexpensive, in comparison to other biomechanical device, and also affordable to the public [25]. If therapists do not have access to IMU, they only analyze patients and athletes' functional activity using a smartphone [1, 25]. Furthermore, people, both healthy ones and patients, may use the smartphone to assess and improve their performance under the supervision of the rehabilitation team [25]. Assessing the performance by using more available tools will assist therapists in easier performance evaluations and thus selecting the best performance improvement methods [25-28]. Therefore, even with a smartphone, it is possible to monitor the physical health status of all the people in the society under the supervision of the rehabilitation and medical team, and finally to fix their functional defects and improve their health.

In conclusion, the usage of accelerometers, both in the forms of IMU and smartphones, has made a significant development in the methods of assessing and improving individuals' performance [4, 10]. Because of the importance and advantages of using accelerometers and smartphones in performance evaluation, one of the first questions is whether this instrument is reliable and valid. The accelerometer's validity and reliability in jumping is questionable as multifunctional activity, though. Two standard instruments in performance evaluation are the force plate device and motion analysis system. As a result, the goal of this study is to compose a list of studies that have investigated the validity and reliability of accelerometers in assessing athletes and non-athletes' performance in comparison to standard devices.

Method and Materials

The keywords "performance, accelerometer, smartphone, jump, reliability, and validity" were searched in recent studies from 2010 to January 2024 in the PubMed, Google Scholar, and Scopus databases. In this search 56 articles were found by keywords. Among these studies, 23 studies that examined the functional variables of jumping including jump height, force, Reactive Strength Index (RSI), power, flight time, peak velocity, contact time, leg stiffness, and take off velocity through an accelerometer were selected for summarization.

Findings

According to a general overview and classification of these investigations, accelerometers have been utilized for almost everyone, including healthy and patient, athletes, and non-athletes. The overall goal was to obtain a final conclusion about the validity and reliability of the accelerometer to evaluate the jump performance. Therefore, studies that investigated accelerometer reliability and validity in jumping activity were chosen. In jump performance, there are several variables that may be calculated. Each variable can represent a different aspect of the performance of the body, and as follows, we examined the validity and reliability of accelerometers in calculating each of the jump variables separately.

Jump height

Jump height reveals a person's maximal effort to use body muscles [29, 30]. Upper limbs are positioned on the waist or chest in all types of jumps in this review study to make lower limbs muscles more active, which indicates the overall activity of the musculoskeletal system [9, 31]. Twelve studies found that using accelerometer is a valid and reliable method to calculate jump height [1, 9, 11, 12, 21, 22, 32-37]. Four studies have measured jump in athletes [12, 21, 32, 37], the explanations of which are described below.

In two studies, an accelerometer was attached to the ankle to investigate the drop jump (DJ) [21, 37]. Comparison of data with force plate demonstrated that the accelerometer and the force plate data are 95% correlated with each other in both studies; therefore, based on these two studies, using accelerometer appears to be a valid method to determine drop jump height. The other two studies [12, 32] also examined the performance of squat (SJ), countermovement (CMJ), and spike jumps in athletes. The reliability of the accelerometer was determined to be about 0.99 in one of these studies [32] when the accelerometer was mounted on the ankle. In another study [12], the accelerometer was placed on the back of the body and the result also confirmed the reliability of the accelerometer (ICC=0.87 in CMJ and ICC=0.81 in SJ).

The performance of non-athletes has been studied in 8 studies [1, 9, 11, 22, 33-36]. Three of these studies that place the accelerometer on the back [22, 33, 34], considering accelerometer to be a reliable and valid tool, that is explained, hereafter. In the first study [22], the correlation of CMJ data with stereo photogrammetry, which is the gold standard of the study, is 0.87 and the reliability is 0.83-0.89. In the second study [33], the validity of the height of CMJ and SJ was 0.79-0.86 and 0.71-0.79, and their reliability was 0.80-0.89 and 0.82-0.84, respectively, in comparison with the force plate device. In the third study [34], the jump height values were not significantly different from the values obtained from the force plate and also the reliability of the data for all three CMJ, SJ and DJ was 0.98.

Unlike the aforementioned studies, which examined both validity and reliability of the accelerometer, two studies [1, 9] examined only the validity of the accelerometer in non-athletes. In these studies, the accelerometer was mounted on the waist and near to the center of gravity, and the validity of the data, compared to the camera and force plate, was reported to be 0.92 and 0.93 respectively.

Three other studies [11, 35, 36] have found that using an accelerometer to determine the height of a CMJ has a high degree of reliability. The accelerometer was placed at the waist in two studies and the reliability values were found to be about 0.91-0.95 [36] and 0.86 [11], respectively. A smartphone was positioned near the hip joint in another study [35], the reliability of accelerometer data in this way is around 0.88.

As a result, most studies indicate that the accelerometer is a valid and reliable tool to calculate jump height. Contrary to the above studies, one study [7] found that the results of accelerometer data compared to video may have systematic errors. The accelerometer was compared with Vertec tool, a contact mat, and a camera, which is the gold standard of this study. The height calculated by the accelerometer, on average, is 11.7 cm less than the height calculated by the camera. It appears that each instrument has a different method for calculating jump height, which has resulted in a systemic error.

Also despite having high reliability in some cases, the accelerometer may not be valid enough to calculate the jump height, that has been reported by two studies [12, 35]. In the first study [12], by using accelerometer attached to the waist, force plate and optojump tools, SJ and CMJ were recorded in female athletes. In comparison with the other two instruments, the accelerometer did not gain enough validity to evaluate the jump height. In the second study [35], non-athletes performance was evaluated by CMJ. This study used a smartphone accelerometer and revealed that it does not have enough validity in this study to determine jump height, contrary to the fact that the phone accelerometer is a reliable tool.

Force

The amount of force could be obtained by applying calculations to acceleration data [7]. Other variables could be influenced by the amount of force in different phases of the jump [38]. Therefore, the force, like the jump height, would indicate the performance of the body [9, 38]. The validity and reliability of the forces estimated from acceleration data have been investigated in different studies.

Accelerometers were used in five studies to calculate the force in various types of jumps [2, 13]. The accelerometer has been shown to be reliable in determining peak eccentric and concentric force in two studies [2, 13]. In these studies, the accelerometer was used to assess countermovement jump and drop jump in physically active individuals and male athletes. This tool was attached around the waist and the hip joint. This tool has an acceptable reliability in calculating the peak concentric and eccentric force in the CMJ, according to the ICC reported for that variable, which was 0.93 for peak eccentric force and 0.80 for peak concentric force. In other study [13], the ICC reported for peak concentric force is about 0.89. Therefore, it appears that the accelerometer have sufficient reliability to calculate the peak concentric and eccentric force.

Another study [11] found that an accelerometer may be used to evaluate the force variable, regardless of its being eccentric or concentric. In this study the accelerometer was attached to the non-athlete men's lower trunk. The ICC of the accelerometer in force calculation is 0.86; therefore, according to the findings of this study, the accelerometer can be used to calculate the force in CMJ.

Another study [33], similar to the one mentioned above, considers the accelerometer as a valid tool for evaluating force. In this study, CMJ and SJ data of healthy non-athlete men were collected using an accelerometer attached to the lower back. The amount of force obtained did not differ significantly from the amount obtained with the force plate. In CMJ and SJ, the validity of the force variable is 0.79-0.68 and 0.78-0.63, respectively, indicating that the accelerometer is a valid tool for force evaluation. The reliability of the force in CMJ and SJ, is 0.79-0.66 and 0.92-0.85, respectively. Thus, the accelerometer data has a high validity and reliability to calculate the force.

Only one study reported different results [9], in which there are no results indicating the validity or reliability of the accelerometer in calculating the force. In this study, the peak force in countermovement jump of non-athletes has been investigated. Despite the fact that the accelerometer is mounted in the correct location and close to the center of mass of the body, the accelerometer data is not valid enough to determine the peak force in CMJ of non-athletes when compared to the force plate device and the optical timing system.

Reactive strength index

Reactive strength index is obtained by dividing the jump height by the contact time [4]. This variable indicates how the muscles work in the stretch-shortening cycle [4]. When increased jump height increases and contact time decreases, the amount of this variable increases [39]. Given that the jump height is related to the overall performance of the body, this variable would also reflect whole body performance [9].

Several researches have used accelerometers to evaluate reactive strength index to obtain its validity and reliability for calculating this variable. Two studies [4, 34] have proven the validity and reliability of the accelerometer in measuring the reactive strength index. In this regard, SJ, CMJ, and DJ were performed in these studies, which were conducted on active and non-active adults. In these studies, in which the accelerometers were placed on the ankle and the back of the body, validity and ICC values obtained for this variable were 0.98 and 0.96, respectively and indicating high values.

In addition to the accelerometer reliability mentioned in two recent studies, the accelerometer is a valid instrument for calculating the reactive strength index. Athletes were evaluated in two studies [21, 37] using the drop jump. In these studies, the accelerometer was able to appropriately represent 95% correlation in comparison to the force plate. Some studies, examining functional variables, suggested that accelerometer should be attached near the body center of mass. In these two studies, the accelerometer was mounted on the ankle and showed a high correlation with the force plate, though.

In another study [34], the calculation of reactive strength index has been evaluated in CMJ and SJ, in addition to drop jump, with one accelerometer placed on the back of the body, and the participants were non-athletes performing all three types of SJ, CMJ and DJ. Finally, the results revealed that the accelerometer data were not significantly different from the data collected by the other instruments i.e., the accelerometer would have a high validity in calculating the reactive strength index.

Flight time

Flight time is another important and functional variable in jumping [40]. By using a series of formulas, the jump height would be calculated by the flight time [40, 41]. Changes in this variable would affect the height of the jump and thereby the body performance [40]. Hence evaluating the validity and reliability of the accelerometer in measuring this variable seems to be important.

An accelerometer has been used to calculate the flight time of individuals in five studies. In three studies [5, 6, 8], researchers found that accelerometers would have a high level of validity when measuring flight time, which will be described below.

In the first study [5], athletes volunteered to do several CMJ. The accelerometer was placed around the lumbar vertebrae, and the data was compared to the force plate and optojump. The flight time calculated by the accelerometer was highly correlated with the values calculated by the gold standard devices ($r = 0.89$).

Not only could accelerometers be used in healthy people, but also, they could be used in people suffering from tendon injuries. In the second study [8], healthy individuals, with a history of Achilles tendon surgery, conducted CMJ and SJ, with the accelerometer attached on the ankle. The data collected from the accelerometer in this study were highly correlated with the data obtained from the force plate (Spearman's coefficient>0.95), indicating the validity of this tool in evaluating the flight time.

Another study [6] that investigated the validity of the accelerometer concluded that the accelerometer, if mounted correctly, has a high validity for measuring flight time. This study placed two accelerometers on the lower back and the hip area. According to this study, the flight time in SJ would be valid only when the accelerometer is placed on the waist ($r = 0.82$).

In addition to validity, the accelerometer has enough reliability for the flight time variable. The accelerometer was mounted on the waist in one study [3], and then athletes performed a CMJ. The accelerometer obtained enough validity compared to the camera and the force plate ($r = 0.98$). This instrument also had high reliability for calculating flight time (ICC = 0.93).

In another study [42], similar results were reported. Athletes in this study conducted CMJ, SJ, and DJ, after the accelerometer was placed on their lower back. The validity of flight time in CMJ and SJ appeared to be sufficient (r = 0.95 and 0.93, respectively), moreover; the reported ICC for CMJ and SJ were 0.97 and 0.96, respectively. After classifying and evaluating the studies, it appears that using an accelerometer for flight time calculation shows acceptable validity and reliability, and this calculation has low errors.

Power

In the power definition, the total power of the body and the power of the lower limbs have the same meaning and represent the whole performance of the body [43, 44]. The overall power of the body would increase as the velocity and amount of force produced by the muscles increases [33]. Thus, power indicates the velocity and force combination and is related to the performance of the body [9, 44].

One study [33] evaluated the validity and reliability of accelerometers in SJ and CMJ power of non-athlete men. In this study, the accelerometer was located on the middle of the lower back. The validity of the accelerometer in power calculation in CMJ and SJ, were 0.46-0.19 and 0.31-0.18, respectively. As a result, the validity of accelerometer in evaluating power appeared to be weak. Also, the calculated reliability for the power in CMJ and SJ were about 0.45-0.29 and 0.83-0.74, respectively. According to the findings, the accelerometer was reliable only in the assessment of the power in SJ.

However, unlike the previous study, another study [11] found that the accelerometer had a high level of reliability in evaluating CMJ power. The accelerometer was utilized in this study to evaluate the power in countermovement jumps after it was attached on the lower trunk. Men who were healthy and non-athletes took part in this study. The results suggested that the accelerometer had a good level of reliability in these individuals, and that it might be used to measure general power (ICC = 0.86).

Although the accelerometer has a high degree of reliability in measuring power, it does not have enough reliability to evaluate the peak power. The accelerometer has been used in two studies [9, 13] to calculate peak power.

In one study [9], non-athletes' peak power in the CMJ, was calculated using an accelerometer attached to their waist and close to the center of mass. This variable did not demonstrate enough reliability in this study.

In addition in another study [13], an accelerometer was placed near the hip joint, evaluating CMJ in male athletes, and the results revealed low to medium reliability (ICC 0.72-0.69). So, the studies show that this instrument could not be reliable for measuring peak power, and it is recommended that this variable be evaluated by using other tools.

Peak velocity

High velocity in the eccentric and concentric phases of the jump is required to achieve optimal performance [21]. Thus, two studies have been conducted to determine the peak velocity.

The accelerometer was situated on the center of mass in one study [9]. Non-athletes took part in the study, and performed countermovement jumps. The results revealed that the accelerometer data differed significantly from the force plate data; indicating that the accelerometer is not valid to evaluate peak velocity.

In another study [13], the reliability of the accelerometer in calculating peak velocity in eccentric and concentric phases was discussed. The accelerometer was attached at the neck of the femur and near the hip joint. Accelerometer reliability for measuring peak velocity in eccentric and concentric phases of the jump, was 0.61 and 0.68, respectively. Therefore, the accelerometer does not show enough validity in examining the peak velocity, like its low to medium level of reliability. Thus, it is preferable to evaluate this variable with other tools.

Contact time

Contact time indicates the change of phase of individuals from the eccentric phase to the concentric phase of the jump [45]. Individuals that have a lower value of contact time can perform the stretch-shortening cycle more effectively [45]. Therefore, this variable is associated with body performance.

In two studies, the validity and reliability of this variable have been investigated [34, 37]. In the first study [34], the accelerometer was located in the lower back. CMJ, SJ and DJ were performed by healthy non-athletes. There was no significant difference in contact time between accelerometer, motion analysis system, and force plate devices. As a result, the accelerometer may be valid enough to calculate this variable. The accelerometer is also a reliable device for measuring contact time, according to the reliability test (ICC = 0.97).

The second study [37] investigated the contact time in drop jump. Participants were selected from athletes, and the accelerometer was attached on the ankle. The accelerometer data was found to be 95% correlated with the force plate. So, the accelerometer is most likely valid for evaluating the contact time.

Leg stiffness

The general stiffness of the body measures the resistance of the body's soft tissue to change in length, and is determined by using the force divided by the length change formula [33]. Leg stiffness is associated with many other variables [46, 47]. This variable could indicate the efficiency of the stretch-shortening cycle [46]. Moreover, the storage and release of elastic force are related to stiffness [46, 48]. As a result, this variable reflects how muscles and other body parts store and release elastic energy, and it may be related to body performance.

Only one study used an accelerometer to evaluate stiffness [33]. In this study, the accelerometer was located in the middle of the lower back. To compare the data with the force plate, healthy non-athlete men performed CMJ and SJ. The accelerometer validity for measuring this variable is about 0.87-0.76, which is a relatively high value. Also, the ICC reported for this variable is 0.86-0.92. Therefore, the accelerometer has high validity and reliability to evaluate the stiffness of the body.

Takeoff velocity

The take-off velocity indicates the body's velocity just before the jump's flight phase [3]. Using the takeoff velocity variable is one of the known methods for estimating jump height [6]. As a result, the takeoff velocity variable, which is one of the key factors influencing the body's total performance, directly correlates with the height of the jump. Additionally, since body movement during flight has no effect on takeoff velocity, and therefore its calculation can play an effective role in the correct estimation of the jump height [3]. The validity and reliability of the accelerometer in two studies that evaluated the takeoff velocity are explained in the sections that follow.

The first study examined the takeoff velocity in countermovement jumps made by male soccer players using a force plate, camera, and linear position transducer [3]. Additionally, an accelerometer is placed on the fifth lumbar vertebra. In comparison to other tools, it appears that the accelerometer has enough reliability and validity to assess the take-off velocity because the value of r is equal to 0.89 and the value of ICC is reported to be between 0.92 and 0.97.

The second study also examined the takeoff velocity of healthy men's squat jump [6]. In addition to determining the takeoff velocity, this study placed two accelerometers in the hip and back regions and looked at how the location of the accelerometers affected kinetic and kinematic factors. According to the findings, none of the accelerometers linked to the hip and fifth lumbar vertebra could compute the takeoff velocity with acceptable reliability and validity. This study has suggested that one of the causes of the accelerometer's low reliability and validity is its being disconnected or located far from the center of mass. It's also possible that the algorithm used to extract the takeoff velocity from the accelerometer data was faulty.

The results of the two aforementioned studies demonstrate that the accelerometer would be a valid and reliable tool for determining the takeoff velocity and, consequently, effective in determining the overall performance of the body, provided it is placed in a position that is closest to the center of mass and correct calculations are used.

Discussion

The purpose of this study was to evaluate the validity and reliability of the accelerometer in assessing jump performance variables. By summarizing the studies discussed in the present review, it appears that the accelerometer has acceptable validity and reliability in most studies and for evaluating most jump variables [2, 4, 21]. Therefore, this tool assesses the overall performance of the body, which includes the musculoskeletal system performance [5, 9, 11, 49].

Although the accelerometer has been considered a valid and reliable tool to assess the overall performance of the body in most studies, it has not been able to obtain high validity and reliability in a number of the investigations. Some of the possible reasons for this issue have been extracted from the studies, which will be discussed below.

The difference in the method of calculating the variables compared to the gold standard could be one of the factors that contributes to the accelerometers being invalid. In one study [7], the accelerometer was compared with three tools of contact mat, camera and vertec device. The results revealed that the jump height measured by the accelerometer is 11.7 cm lower than the value measured by the camera. Accelerometers and contact mats use a different way of assessing jump height than camera and vertec devices. The criterion for the start and end of the jump in the two tools of the contact mat and the accelerometer is different from the two tools of the vertec and the camera. This may be related to the low jump height of the contact mat and accelerometer tools in comparison with the camera and the vertec devices. Therefore, a difference in the algorithm for determining the variables could be the cause of the difference in the results, but this does not necessarily indicate the invalidity of the accelerometer in estimating the jump height.

Some studies may have made a mistake in choosing their gold standard tool. Force plates and motion analysis system are the gold standard tools that often used for evaluating accelerometer data. In one investigation [7], only one camera was used instead of a multi-camera motion system. The jump height, according to the accelerometer, is around 11 cm lower than the height measured by the camera, using only one camera could lead to an error or insufficient accuracy, though.

Another important factor in determining the validity and reliability of accelerometer is how it is fixed [12, 35]. The accelerometer is placed on the body with a belt. One of the most typical errors when utilizing an accelerometer is that it is not firmly attached to the user's body. It is required to pay more attention to the belt's fixation to prevent further oscillations and movements of the accelerometer in performance evaluation. Additional fluctuations in the acceleration data, cause the jump height to be calculated incorrectly [35]. Also, it is recommended that the belt material be less elastic to make the strong fixation. Another way to limit the rate of error when attaching the accelerometer belt is to avoid using the accelerometer with other tools at the same time. For example vertec device is a simple tool to calculation of the jump height [7]. The participants' jump height determines how far they can reach for the vertec when jumping compared to a regular standing position. In one study, that vertec and accelerometer were used at the same time, the belt of accelerometer may be loosed when the upper limb is raised to contact the vertec, and data record may be altered [7].

The other essential factor is attaching the accelerometer to the correct location [13]. Accelerometers have been attached to many parts of the body in the previous studies, including the ankles [4], hips [6], upper and lower back [10], and chest [50]. According to most researches, it is better to place the accelerometer at or near the center of mass of the body [2, 23, 24]. One reason for this is that force plates examine the body's performance variables at the center of mass of the body [2, 23]. Furthermore, there is more subcutaneous fat in most areas of the body, such as the thoracic region, which prevents the belt from attaching tightly, and the belt may become loose easily during physical activity. The lumbar region is a suitable place to connect the accelerometer, because of its proximity to the body's center of mass and lack of subcutaneous fat. The inappropriate location of the accelerometer has caused errors in the calculation of variables in several studies so far [6]. Furthermore, it should be noted that when jumping, it is better to place the hands crosswise on the chest to avoid the influence of upper limb muscle torque and to avoid hitting the belt with the hands.

In general, the accelerometer is a valid and reliable tool for measuring various jump performance variables. In cases where the accelerometer does not have enough validity and reliability, problems such as loose belt, attaching the accelerometer in the inappropriate location and in areas with high subcutaneous fat, or differences in the method of calculating variables are often the cause of this problem. Thus, it is recommended to solve the aforementioned problems as much as possible in order to use the accelerometer. If the problems persist, the accelerometer data should be analyzed using a Low Pass Filter [2].

According the studied researches, the validity and reliability of the accelerometer have been verified when recording most of the jumping variables. However, it appears that these parameters have not been verified when calculating the peak acceleration variable, which is considered as one of the important variables. For this reason, this variable is not mentioned in the results section of the current study. The peak acceleration variable indicates the maximum acceleration of the body during activities, and it appears to be crucial for physical activity. For example, a study that compared the Ground Reaction Force (GRF) derived from the force plate with the peak acceleration in continuous hopping and rebound jumps, has revealed a strong correlation between the two [10]. It appears that the accelerometer can measure the peak acceleration and then use that information to estimate the impact loading. Additionally, another study directly correlated high peak acceleration to a higher risk of injury [50]. In general, it is advised that future studies look at the validity and reliability of the accelerometer in calculating the peak acceleration variable because it may be useful to predict performance and risk of injury.

The accelerometer is available as a IMU and also on a smartphone. All the benefits of using an accelerometer, including being portable [9], cheaper and more accessible than other tools, are also achieved by using a smartphone accelerometer [9, 10]. Using a smartphone may even have more benefits than wearable sensors [25, 27]. Since the smartphone is available to everyone in the community today, it is user-friendly and less expensive than wearable sensors [25, 27]. Smartphones can be used in all environments and on all groups of people, including healthy people and patients, athletes and non-athletes [26, 27]. In recent years, many accelerometer applications have been introduced. These apps are accessible for all Android and IOS systems and may be downloaded for free. These applications provide raw data as a text file in addition to recording acceleration. Physiotherapists, physical medicine specialists, sports therapists, and coaches, can use smartphones to quickly and easily evaluate patients, healthy people, and athletes. Even ordinary individuals in the community could use the smartphone to analyze and improve their performance under the supervision of the rehabilitation team.

A wearable sensor has components other than an accelerometer, such as a gyroscope, which is one of the differences between a wearable sensor and a smartphone accelerometer [12, 13]. The gyroscope shows the movement's orientation, since smartphones do not show the direction of movement due to the lack of a gyroscope, when using a smartphone accelerometer, it should be placed vertically, though [34]. Bony locations, such as the greater trochanter of the femur, are usually a better choice for vertical smartphone placement, since vertical fixation is better there and the phone is less likely to deviate from the vertical position.

In general, accelerometer is a valid and reliable tool for evaluating the overall performance of the body [5, 6, 33]. Because of the numerous advantages of this instrument, it has been widely used in the fields of rehabilitation and sports. The accelerometer is available to everyone because it is also available in smartphones in addition to wearable sensors [26]. By attaching an accelerometer to the bodies of different people, including athletes, healthy people, and patients, their overall body function can be assessed and ultimately helped to improve performance in them [5, 21]

Conclusion

The accelerometer appears to be a relatively new, valid, and reliable tool for assessing most jump performance variables. It should be noted that to get enough validity and reliability for an accelerometer, the rehabilitation team need to use the proper techniques when using this device. The accelerometer is attached to the body via a belt, which must be perfectly firm and inelastic to prevent additional oscillations in the accelerometer. It should also be noted that as the accelerometer's connection affects its validity and reliability, it's preferable to place the accelerometer near the body's center of mass to record overall performance. Accelerometers may now be found on both IMU and smartphones. Nowadays, everyone has access to smartphones as user-friendly instruments containing accelerometers. Before using smartphones, we should pay attention to the correct connection of them. Because most smartphones lack a gyroscope, they should be attached to the body vertically in order to collect data accurately. In general, accelerometers are used in different research fields such as in the field of feedback, training process, and training therapy. This tool is also an aid for medical staff including rehabilitation, physical medicine, and sports medicine. In addition, if we have access to simple accelerometer applications in smartphones, coaches, athletes and even the ordinary people can benefit from their use. Accelerometers may be utilized in clinics as well. Most assessments in clinical environments were done qualitatively so far; however, the introduction of accelerometers in clinical environments helps us to quantify performance evaluation. As a result, introducing the accelerometer into the therapeutic environment will improve evaluation and therapy processes. Finally, the results of the present study can be a background for future studies to use more convenient and accessible methods to evaluate the performance of the entire musculoskeletal system. Rehabilitation, physiotherapy and sports medicine teams in all environments, including laboratory, clinical and routine environments, and even in the form of an application, can evaluate the performance of all people, including healthy people, patients, athletes and the elderly, and create a plan to improve health. Through the use of accelerometer, it is possible to create positive effects on the health of all the society, even without being limited to the clinical or laboratory environment.

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Authors' Contributions

All authors contributed equally to the manuscript and all authors read and approved the final version of the manuscript.

Conflicts of Interest

The authors certify that there is no conflict of interest with any financial organization regarding the material discussed in the manuscript.

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