J. Phys. Ther. Sci. 35: 714–717, 2023

The Journal of Physical Therapy Science

Original Article

Reliability and validity of impact absorption rate using accelerometers during single-leg drop-jump landings

Yasushi Kurihara, PhD[1)*], Hironori Ohsugi, PhD[1)], Hiroshi Karasuno, PhD[1)], Tadamitsu Matsuda, PhD[2)], Masashi Matsumura, PhD[3)]

[1)] *Department of Physical Therapy, Faculty of Social Work Studies, Josai International University: 1 Gumyo, Togane-shi, Chiba 283-8555, Japan*
[2)] *Department of Physical Therapy, Faculty of Health Sciences, Juntendo University, Japan*
[3)] *Department of Rehabilitation, Faculty of Health Sciences, Kyorin University, Japan*

Abstract. [Purpose] To assess the reliability and validity of accelerometer-based impact absorption rate measurements during single-leg drop-jump landings. [Participants and Methods] Study participants were healthy adult males. The task involved a single-leg drop-jump from the platform with a forward landing onto a floor reaction force plate. Accelerometers were fastened to the trunk, while foot switches were attached to the forefoot plantar surfaces. The impact absorption rate was calculated as the peak composite acceleration during the single-leg drop-jump landing divided by the duration from foot contact to the attainment of peak value. The loading rate (LR) was calculated by dividing the peak vertical force by the duration from foot contact to the attainment of peak value, leveraging the data obtained from a floor reaction force plate. Intraclass correlation coefficients (ICC) were used for intra- and inter-rater reliability analyses of 18 and 12 participants, respectively. The validity was examined through the correlation between impact absorption rate and LR in the 18 participants. [Results] The intra- (ICC (1,1)) and inter-rater (ICC (2,1)) reliabilities for the impact absorption rates were 0.89 and 0.88, respectively. A significant positive correlation was observed between impact absorption rates and LR (r=0.71). [Conclusion] The impact absorption rate may be valuable in clinical practice.

Key words: Accelerometer, Loading rate, Single-leg drop-jump landing

(This article was submitted Jun. 21, 2023, and was accepted Jul. 27, 2023)

INTRODUCTION

Ankle sprain (AS) is the most frequent sports injury with a very high recurrence rate[1)]. Recurrent AS can lead to chronic ankle instability[2)], which limits athletic performance and decreases athletic ability. Therefore, it is important to have clear criteria to guide athletes' return to sports competitions.

Currently, the Side Hop Test[3)] and the Star Excursion Balance Test[4)] are used in clinical practice to evaluate athletes' return to competition after an AS. These tests can be performed without using special equipment. However, these tests are used to determine agility and balance function based on the quality of movement during the test and indirectly evaluate the relationship between the quality of movement with AS. Evaluating the results of these tests and the mechanical load directly related to the injured movement is necessary.

To evaluate the mechanical load of the motion, Terada et al.[5)] performed a three-dimensional analysis, and Delahunt et al.[6)] performed an electromyographic analysis. Both analyzed single-leg drop jump landing (SDL) and found that the knee joint and ankle joint angles of motion decreased in those with a history of AS compared to those in the control group, while the

*Corresponding author. Yasushi Kurihara (E-mail: kurihara@jiu.ac.jp)

activity of the peroneus longus muscle was reduced. This suggests the need for evaluation of impact loading during landing maneuvers in cases of AS.

In recent years, portable accelerometers have become widely available, and efforts are underway to quantitatively evaluate impact loads during competition[7, 8]. The loading rate (LR) is an indicator for evaluating the impact load of SDL[9, 10] and is the peak value of the vertical component of the floor reaction force divided by the time from foot contact to peak value. A high value indicates poor impact attenuation and a large load over a short period. Nagano et al.[11] showed a significant positive correlation between the peak composite acceleration obtained from accelerometers attached to the trunk and lower leg during SDL and the peak vertical component of the floor reaction force. In addition, if the time to reach the peak value of the composite acceleration can be calculated, it may be possible to extract an impact absorption rate that can reflect the results of the LR using accelerometers.

This study aimed to verify the reliability and validity of the SDL impact absorption rate calculated using accelerometers and to clarify whether this score is an indicator of the LR.

PARTICIPANTS AND METHODS

Eighteen healthy adult males (height: 171.3 ± 5.6 cm, weight: 64.1 ± 10.8 kg, age: 19.9 ± 0.9 years) were included in the reliability and validity analyses. The inter-rater reliability analysis between the two testers was conducted with 12 participants, with six participants dropping out. The participants were informed orally and in writing concerning the purpose and methods of the study. Then, their consent was obtained. This study was approved by the ethics committee of Josai International University (No. 23M220005). This study was conducted in accordance with the tenets of the Declaration of Helsinki.

An accelerometer (AMWS020 1000 Hz, ATR-promotions, Kyoto, Japan) was attached to the second thoracic vertebra (trunk) of each participant. In addition, a foot switch (Flexi Force A201-100; Nitta Corp., Osaka, Japan) was attached to the plantar surface (forefoot) on the landing side. In this study, the contact pattern of the participants was forefoot contact in all cases. The participant was instructed to assume a single-leg standing posture with arms crossed on a 30-cm platform and to land with a single leg on a floor reaction force plate (TF-4060 1000 Hz, Toshiba Tec. Corp., Tokyo, Japan,) 20 cm forward from the platform, with the leg that did not kick the ball being considered the axis leg. After landing, they were asked to remain still for 3 s, and this was repeated until three successful attempts were made.

The composite acceleration ($=\sqrt{(x^2+y^2+z^2)}$) was calculated from the accelerometer's component accelerations, and the composite acceleration's peak value after landing was extracted. The time taken to reach the peak value of the composite acceleration was calculated using a footswitch synchronized with an accelerometer, and the peak value of the composite acceleration divided by this time (impact absorption rate) was extracted. The LR of SDL was calculated as the peak value of the vertical component of the floor reaction force divided by the time from foot contact to the peak value of the floor reaction force[9, 10]. The measurement was conducted by two testers, both of whom were experienced in the measurement method. The measurements of the two testers (Tester A, Tester B) were performed on different days, and the participants were rested sufficiently between measurements.

The intra-class correlation coefficient (ICC) (1,1) and (1,3) were calculated for three measurements of the impact absorption rates performed by Tester A, and intra-rater reliability was examined. The ICC (2,1) and (2,3) were calculated for three measurements of the impact absorption rates performed by two testers to verify inter-rater reliability. The correlation between the impact absorption rates and LR was validated by calculating Pearson's correlation coefficient using the measured data of Tester A. IBM SPSS Statistics 27 (IBM Corp., Armonk, NY, USA) was used for the statistical analysis, with a significance level of $p<0.05$.

RESULTS

Table 1 lists the fundamental characteristics of each analysis. Table 2 presents the ICC for impact absorption rates. The intra-rater reliability ICC (1,1) and ICC (1,3) for the impact absorption rates were 0.89 (95% confidence interval [CI]: 0.75–0.96) and 0.96 (95% CI: 0.90–0.99), respectively. The inter-rater reliability ICC (2,1) and ICC (2,3) for the impact absorption rates were 0.88 (95% CI: 0.64–0.97) and 0.94 (95% CI: 0.78–0.98), respectively. Table 3 shows the correlation coefficients between the impact absorption rate and the LR. The impact absorption rate was strongly positively correlated with the LR ($r=0.71$, $p<0.01$).

DISCUSSION

This study verified the reliability and validity of the impact absorption rate calculated using accelerometers as an indicator of the LR. The results showed that the impact absorption rate had high intra-rater and inter-rater reliabilities. Furthermore, a strong correlation was obtained between the LR and impact absorption rate in the validity investigation of the shock buffer score.

Hargrave et al.[9] calculated the LR during SDL in healthy adults and reported a result of 0.06 ± 0.02 (N/w/ms). Although the reference value was unclear in the previous study, the results showed an average of 0.05 ± 0.01 (N/w/ms), supporting these reports.

Table 1. Fundamental characteristics

	Tester A (n=18)	Tester B (n=12)
Height (cm)	171.3 ± 5.6	170.9 ± 5.0
Weight (kg)	64.1 ± 10.8	62.8 ± 7.1
BMI (kg/m^2)	21.7 ± 2.7	21.5 ± 1.9
Age (years)	19.9 ± 0.9	19.9 ± 0.9
LR (N/w/ms)	0.05 ± 0.01	
Impact absorption rate (mG/w/ms)	753.2 ± 424.2	745.7 ± 340.1

The values are presented as means ± standard deviation.
BMI: body mass index; Impact absorption rate, Peak composite acceleration component (mG) after SDL divided by the time (ms) taken from foot contact to peak composite acceleration value; LR: loading rate; peak value of the vertical component of the floor reaction force divided by the time from foot contact to the peak value. SDL: single-leg drop jump landing; Trunk, the second thoracic vertebra.
Tester B: Measurements were performed on a different day from Tester A to verify inter-rater reliability, and six out of 18 participants dropped out.

Table 2. Intraclass correlation coefficient for the impact absorption rates

Impact absorption rate	Value	95% CI
ICC (1, 1)	0.89	0.75–0.96
ICC (1, 3)	0.96	0.90–0.99
ICC (2, 1)	0.88	0.64–0.97
ICC (2, 3)	0.94	0.78–0.98

Impact absorption rate, peak composite acceleration component (mG) after SDL divided by the time (ms) taken from foot contact to peak composite acceleration value; Trunk, the second thoracic vertebra. 95% CI: 95% confidence interval; ICC: intraclass correlation coefficient. SDL: single-leg drop jump landing.

Table 3. Correlation coefficient between impact absorption rate and LR (r)

	Trunk acceleration	
	Impact absorption rate	p-value
LR	0.71	<0.01

Impact absorption rate, Peak composite acceleration component (mG) after SDL divided by the time (ms) taken from foot contact to peak composite acceleration value. LR: Loading rate; SDL: single-leg drop jump landing; trunk: the second thoracic vertebra.

Regarding reliability, Landis et al.[12] classified the criteria for ICC into five levels. In general, an ICC of ≥0.7 is considered a high level of agreement. In this study, both ICC were ≥0.7, and the criterion for the judgment was almost perfect. Therefore, the impact absorption rate is considered an index that can be evaluated based on its high inter-rater and intra-rater reliability. The values of ICC (1,3) and ICC (2,3) were higher than both ICC (1,1) and ICC (2,1), suggesting that the average of three measurements is more reliable. A strong positive correlation was found between the impact absorption rate and the LR. Nagano et al.[11] reported a strong positive correlation between the peak value of the vertical component of the floor reaction force after SDL and the composite acceleration obtained from accelerometers attached to the trunk and knees on the landing side. The results of the present study partially support this finding. The impact of the knee joint flexion angle of the landing leg is considered to affect the magnitude of acceleration during SDL. Previous reports have shown that changing the knee flexion angle can lead to variations in the peak impact force and peak acceleration at landing[13, 14], which is expected to influence the results of the impact absorption rate used in this study. However, no specific instructions regarding SDL were provided. Nevertheless, high intra-rater and inter-rater reliabilities were achieved, suggesting that measurements tailored to the participants' functions were possible. Additionally, by attaching the accelerometers to the second thoracic vertebra (trunk) as the attachment site, there is less equipment displacement compared to that obtained when the accelerometers are attached to the landing leg, potentially increasing the reliability of the repeated data. The impact absorption rate is an index that includes the time required to reach the peak value of composite acceleration. In this study, it was impossible to determine

the time's accuracy using the footswitch as the trigger signal. However, the impact absorption rate was validated in relation to the LR. These results suggest that the impact absorption rate can be used as an index to reflect the LR and applied in clinical practice.

The limitations of this study are as follows: the participant that performed SDL was instructed to ensure forward landing to avoid flying upward from the platform. Therefore, it is conceivable that the SDL would happen at forefoot contact. The foot contact of the participants in this study was forefoot contact in all the cases. However, if there had been participants with full plantar contact or heel contact, this would have affected the time variable obtained from the footswitch. In the future, it will be necessary to consider these contact patterns and examine the locations where footswitches should be affixed.

Conflict of interest

The authors declared no conflict of interest.

REFERENCES

1) Attenborough AS, Hiller CE, Smith RM, et al.: Chronic ankle instability in sporting populations. Sports Med, 2014, 44: 1545–1556. [Medline] [CrossRef]
2) Anandacoomarasamy A, Barnsley L: Long term outcomes of inversion ankle injuries. Br J Sports Med, 2005, 39: e14, discussion e14. [Medline] [CrossRef]
3) Caffrey E, Docherty CL, Schrader J, et al.: The ability of 4 single-limb hopping tests to detect functional performance deficits in individuals with functional ankle instability. J Orthop Sports Phys Ther, 2009, 39: 799–806. [Medline] [CrossRef]
4) Hertel J, Braham RA, Hale SA, et al.: Simplifying the star excursion balance test: analyses of subjects with and without chronic ankle instability. J Orthop Sports Phys Ther, 2006, 36: 131–137. [Medline] [CrossRef]
5) Terada M, Pietrosimone B, Gribble PA: Individuals with chronic ankle instability exhibit altered landing knee kinematics: potential link with the mechanism of loading for the anterior cruciate ligament. Clin Biomech (Bristol, Avon), 2014, 29: 1125–1130. [Medline] [CrossRef]
6) Delahunt E, Monaghan K, Caulfield B: Changes in lower limb kinematics, kinetics, and muscle activity in subjects with functional instability of the ankle joint during a single leg drop jump. J Orthop Res, 2006, 24: 1991–2000. [Medline] [CrossRef]
7) Luteberget LS, Spencer M: High-intensity events in international women's team handball matches. Int J Sports Physiol Perform, 2017, 12: 56–61. [Medline] [CrossRef]
8) Dalen T, Ingebrigtsen J, Ettema G, et al.: Player Load, acceleration, and deceleration during forty-five competitive matches of elite soccer. J Strength Cond Res, 2016, 30: 351–359. [Medline] [CrossRef]
9) Hargrave MD, Carcia CR, Gansneder BM, et al.: Subtalar pronation does not influence impact forces or rate of loading during a single-leg landing. J Athl Train, 2003, 38: 18–23. [Medline]
10) Ithurburn MP, Paterno MV, Ford KR, et al.: Young athletes with quadriceps femoris strength asymmetry at return to sport after anterior cruciate ligament reconstruction demonstrate asymmetric single-leg drop-landing mechanics. Am J Sports Med, 2015, 43: 2727–2737. [Medline] [CrossRef]
11) Nagano Y, Sasaki S, Higashihara A: Relationships between trunk and knee acceleration and the ground reaction force during single limb landing. ISBS Conference Proceedings Archive, 2016, 34: 875–878.
12) Landis JR, Koch GG: The measurement of observer agreement for categorical data. Biometrics, 1977, 33: 159–174. [Medline] [CrossRef]
13) Derrick TR: The effects of knee contact angle on impact forces and accelerations. Med Sci Sports Exerc, 2004, 36: 832–837. [Medline] [CrossRef]
14) Gerritsen KG, van den Bogert AJ, Nigg BM: Direct dynamics simulation of the impact phase in heel-toe running. J Biomech, 1995, 28: 661–668. [Medline] [CrossRef]