

Original Research

The Validity and Reliability of a Smartphone Application for Break-Point Angle Measurement during Nordic Hamstring Exercise

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Background

A recently developed smartphone application (Nordic Angle) allows the automatic calculation of the break-point angle (BPA) during Nordic hamstring exercise (NHE) without transferring the collected data to a computer. The BPA is the point at which the hamstrings are unable to withstand force. However, the validity of the BPA values obtained by this method has not been examined.

Hypothesis/Purpose

This study aimed to evaluate the validity and reliability of the Nordic Angle by comparing the BPA values of the Nordic Angle with those of two-dimensional motion analysis software that can calculate the angles and angular velocities of various joints.

Study Design

Cohort assessing Validity and Reliability

Methods

The validity of the Nordic Angle BPA data was verified by Spearman's correlation test for consistency with the movement analysis data, and the magnitude of the correlation was indicated by r_s . The agreement between these measurements was examined using the Bland-Altman analysis. The reliability of the Nordic Angle and motion analysis was examined using the intraclass correlation coefficient (ICC) (1,k) based on data from repeated trials within a day.

Results

Although the spearman correlation between the Nordic angle and the angle determined using motion analysis did not reach statistical significance ($p = 0.052$), a very large correlation was present ($r_s = 0.75$). The difference between the mean values of the Nordic Angle and motion analysis was $0.4 \pm 2.1^\circ$, and the limits of agreement ranged from -3.9° to 4.6° . In two BPA measurements, the Nordic Angle showed perfect reliability (ICC = 1.00, $p < 0.001$), while motion analysis showed nearly perfect reliability (ICC = 0.97, $p < 0.001$).

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Nordic Angle is a smartphone application developed in collaboration with S-CADE. Co., Ltd. and Athletic Training Laboratory at Waseda University (instructed by Professor Norikazu Hirose). The first author of the article collected and analyzed the data. However, the authors of the current study assert no conflicts as they do not receive any fees from S-CADE. Co., Ltd. for developing the Nordic Angle, and the installation of the Nordic Angle app is free.

Conclusion

The Nordic Angle, which has both validity and reliability, may be appropriate for field measurement because it allows immediate feedback of BPA and the measurement of many athletes.

Level of evidence

3b

BACKGROUND

Hamstring strain injury (HSI) occurs in many sports activities.¹ For example, HSI reportedly accounted for 12% of all injuries in football,² with recurrence rates exceeding 50%.³ It is important to prevent the initial occurrence and recurrence of HSI to maintain and improve the performance of athletes.

The risk factors for HSI include eccentric knee flexion strength,^{4,5} fascicle length of the biceps femoris long head,⁵ and a history of HSI.⁶ Isokinetic eccentric knee flexion strength assessment is a popular screening tool for identifying athletes who are at risk of future HSI.⁴ However, the use of isokinetic equipment is limited by various factors, including time, cost, and poor portability.⁷ Although eccentric knee flexion strength is a kinetic variable, the Nordic break-point test of the Chinese University of Hong Kong uses a kinematic variable and has recently been reported as a unique method for predicting eccentric knee flexion strength.⁸ As a feature of the Nordic hamstring exercise (NHE), further forward leaning of the upper trunk is associated with longer moment arm from the knee joint to the center of mass, which increases the knee flexion moment.⁹ The point at which the hamstring force can no longer tolerate this increased eccentric load and the upper body begins to accelerate toward the ground is known as the break point. A very large correlation has been observed between eccentric knee flexion strength and knee flexion angle at the break point measured by smartphone application (SensorLog) ($r = 0.88$, $p < 0.001$).⁸ Although the break-point angle (BPA) during NHE does not directly measure eccentric knee flexion strength, the regular measurement of the BPA might indicate whether there is increased HSI risk. However, there is a disadvantage in measuring BPA by using smartphone applications, namely, the need to transfer the data to a personal computer for analysis.⁸ Therefore, providing immediate feedback and measuring a large number of athletes are expectedly difficult.⁸

A very recent development of a smartphone application (Nordic Angle) allowed automatic calculation of BPA without transferring the collected data to a personal computer. However, the validity of the BPA values obtained by this method has not been examined. Therefore, this study aimed to examine the validity and reliability of the Nordic Angle by comparing the BPA values of the Nordic Angle with those of two-dimensional motion analysis software.

DESCRIPTION

STUDY DESIGN

After the warm-up, the participants performed 12 NHE repetitions while being recorded with an iPhone 12 high-speed camera. Based on the same movie data recorded with an iPhone camera, BPA during NHE was calculated using two-dimensional motion analysis software and the Nordic Angle (Figure 1). The validity of the Nordic Angle data was examined using the Spearman's correlation test for consistency with motion analysis data, and the agreement between these measurements was examined using the Bland-Altman analysis. The reliability of Nordic Angle and motion analysis was examined using the intraclass correlation coefficient (ICC) (1,k) based on data from repeated trials within a day.

PARTICIPANTS

The sample size was calculated a priori based on Pearson correlation coefficient analysis (G*Power version 3.1, Heinrich Heine Universität Düsseldorf, Germany). Its input parameters (correlation ρ H1 = 0.9, $\alpha = 0.05$, power = 0.8) were set with reference to the effect size of a previous study.¹⁰ This setting resulted in a sample size of five. Therefore, seven male volunteers (age, 23.9 ± 2.0 years; height, 174.3 ± 5.4 cm; and body mass, 67.3 ± 7.9 kg; all measured in mean $\pm$ standard deviation [SD]) participated in this study. The inclusion criterion was healthy males between the ages of 18 and 35 who participates in sports activities and can perform exercises without musculoskeletal pain. The exclusion criterion was participants who could not perform NHE because of a current injury to the lower extremities. The experimental protocol was approved by the institutional review board of Waseda University's ethical committee (approval number: 2022-345), and all procedures in this study were performed in accordance with the Declaration of Helsinki. All participants were informed of the purpose and procedure of the study, and informed consent was obtained from all participants.

PROCEDURES

Before the experiment, participants initially performed a warm-up consisting of light aerobic activity (2 minutes of alternating stepping on a 15-cm high box), a 15-second static hamstring stretch (standing hamstring stretch on one leg), and one set of 10 repetitions of dynamic hamstring stretching (forward leg swing). Hamstring stretching was performed on both legs. Thereafter, participants were given two repetitions to gain familiarity with the movement be-

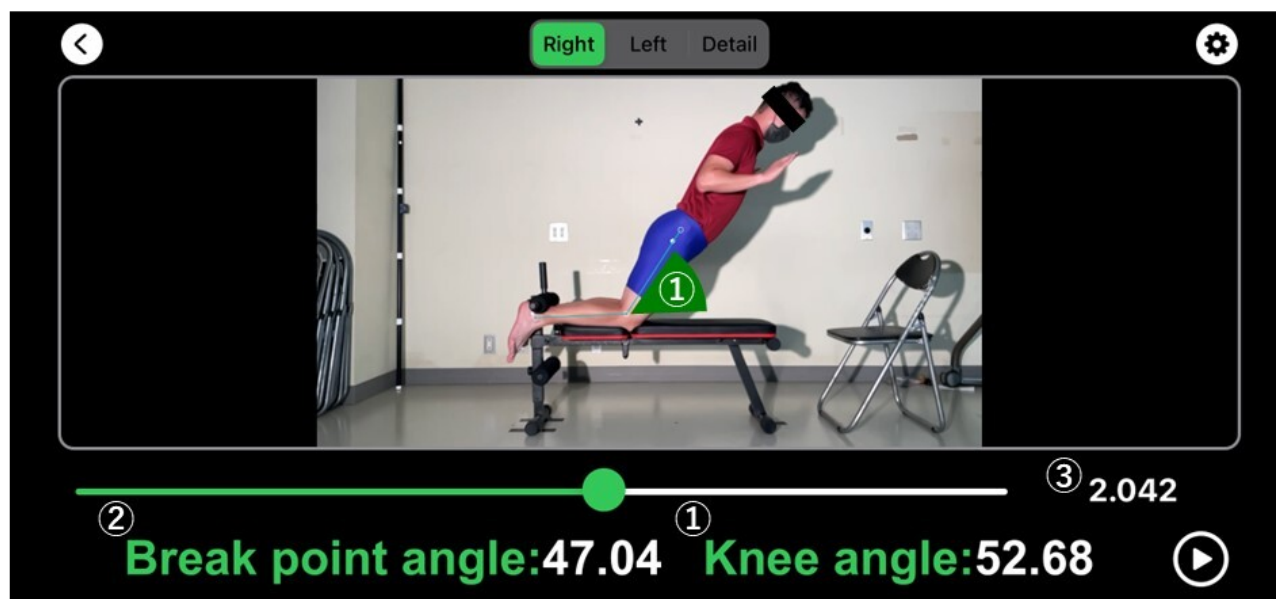


Figure 1. Nordic Angle screen information during the Nordic hamstring exercise.

1: Knee flexion angle (0° indicates the fully extended position of the knee.); 2: Break-point angle determined by Nordic Angle; 3: Current time from movie data start.

ing assessed, and then performed 12 repetitions of NHE for data collection. There was at least one minute of rest between each repetition. The experiment was conducted under the supervision of an examiner, who was qualified as a National Strength and Conditioning Association Certified Strength and Conditioning Specialist.

NORDIC HAMSTRING EXERCISE

Participants were instructed to start in a kneeling position on a bench of application of approximately 50 cm with elbows bent and hands open in front of them (Figure 1). The examiner instructed participants to keep their posture straight from the knee to the head and to lean forward “as slowly as possible”. A certified examiner confirmed that the participant performed the NHE correctly.

TWO-DIMENSIONAL MOTION ANALYSIS

The speed of the camera was set to 240 frames per second (fps), and the height was approximately 0.8 m, while the camera was positioned application approximately 3 m from the right side of the participants. After the recorded movie was transported to a personal computer, two-dimensional motion analysis was performed on the obtained movie data using the Frame-DIAS V software (DKH Inc., Tokyo, Japan). Reflective markers were attached to the greater trochanter and the lateral malleolus. The knee flexion angle was calculated by digitizing the greater trochanter, center of knee joint, and lateral malleolus. The digitization of the center of the knee joint was performed visually by the examiner. The line connecting the greater trochanter with the center of the knee joint and the line connecting the center of the knee joint with the lateral malleolus created an angle that

was defined as the knee flexion angle. The knee flexion angle was calculated using the following formula:

$$\theta = \frac{a_1 b_1 + a_2 b_2}{\sqrt{a_1^2 + a_2^2} \sqrt{b_1^2 + b_2^2}},$$

where θ is the knee flexion angle, a_1 and a_2 are the points of the line connecting the greater trochanter with the center of the knee joint, and b_1 and b_2 are the points of the line connecting the center of the knee joint with the lateral malleolus.

The knee extension angular velocity was calculated using the following formula:

$$\text{deg/s} = \frac{\theta_{t+1} - \theta_{t-1}}{2\Delta t},$$

where θ is the knee flexion angle, and t is the time.

BPA was defined as the angle at which the knee extension angular velocity exceeded 30°/s. The kinematic data were smoothed with a Butterworth filter for two-dimensional motion analysis. The order of the Butterworth filter was as follows: (1) the characteristic was low-pass, (2) the cutoff frequency was 6 Hz, and (3) the number of extended data for the correction of both ends was 20.

STATISTICAL ANALYSIS

Values were expressed as mean $\pm$ SD. The average BPA values from motion analysis and the Nordic Angle were calculated from the BPA values of the 12 NHE repetitions performed by each participant. The Shapiro-Wilk test was performed for the analysis of the normal distribution of the BPA data of motion analysis and the Nordic Angle. As a result, there was no confirmed normal distribution in the BPA of the Nordic Angle. Because BPA data were not normally distributed, the validity of the Nordic Angle

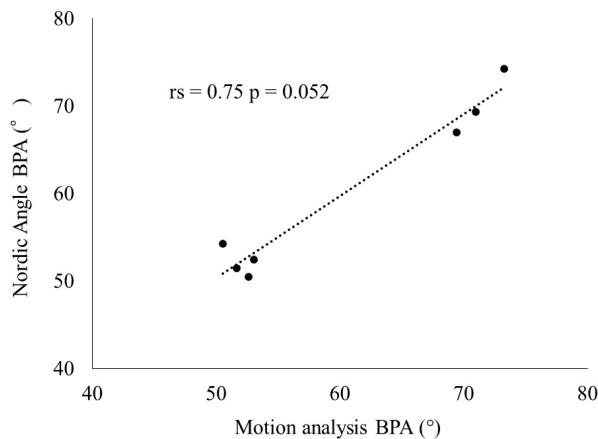


Figure 2. The correlation between break-point angle of the Nordic Angle and that of motion analysis.

data was examined using the Spearman's correlation test for consistency with the motion analysis data. Although normality was not confirmed in the BPA data, the agreement between these measurements was examined using the Bland-Altman analysis. The Wilcoxon signed-rank test was performed to confirm the difference in BPA between the Nordic Angle and motion analysis data. The limits of agreement in the Bland-Altman analysis were calculated by multiplying SD by ± 1.96 .¹⁰ The reliability of the Nordic Angle and motion analysis was examined using ICC (1,k). Correlation is indicated as r_s for Spearman's correlation test, and its magnitude of the correlation was established based on the following criteria: $r_s = 1$, perfect correlation; $1 \geq r_s \geq 0.9$, nearly perfect; $0.9 \geq r_s \geq 0.7$, very large; $0.7 \geq r_s \geq 0.5$, large; $0.5 \geq r_s \geq 0.3$, moderate; $0.3 \geq r_s \geq 0.1$, small; and $0.1 \leq r_s$, trivial). Statistical analyses were performed using SPSS version 27 (IBM SPSS, Armonk, NY, USA). The significance level was set at $p < 0.05$.

OUTCOMES

THE VALIDITY OF THE NORDIC ANGLE

Figure 2 showed the correlation between the BPA of Nordic Angle and that of motion analysis. Although the spearman correlation between the Nordic angle and the angle determined using Motion analysis did not reach statistical significance ($p = 0.052$), it represents a very large correlation ($r_s = 0.75$).

Figure 3 shows the agreement between the BPA of Nordic Angle and that of motion analysis. The BPAs of Nordic Angle and motion analysis were $60.2 \pm 10.4^\circ$ and $59.9 \pm 9.9^\circ$, respectively, and there was no significant difference between the Nordic Angle and motion analysis data ($p = 0.50$). The difference between the mean values of the Nordic Angle and motion analysis was $0.4 \pm 2.1^\circ$, and the limits of agreement ranged from -3.9° to 4.6° .

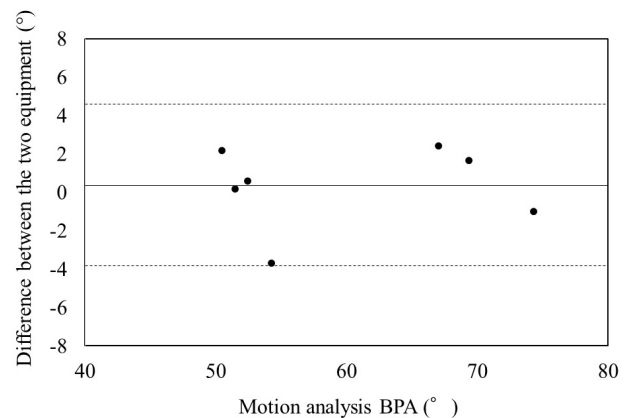


Figure 3. The agreement between break-point angle of Nordic Angle and that of motion analysis, and the limits of agreement.

The solid line showed the difference between the mean values of Nordic Angle and motion analysis and the dotted line showed the mean values in motion analysis.

THE RELIABILITY OF NORDIC ANGLE AND MOTION ANALYSIS

In two BPA measurements, the Nordic Angle showed perfect reliability ($ICC = 1.00$, $p < 0.001$), while motion analysis showed nearly perfect reliability ($ICC = 0.97$, $p < 0.001$).

DISCUSSION

This study aimed to examine the validity and reliability of the Nordic Angle by comparing the BPA values of the Nordic Angle with those of two-dimensional motion analysis software. The main outcomes of this study are as follows: (a) Although the spearman correlation between the Nordic angle and the angle determined using Motion analysis did not reach statistical significance ($p = 0.052$), it represents a very large correlation ($r_s = 0.75$); (b) the mean difference between BPA data from the Nordic Angle and motion analysis was $0.4 \pm 2.1^\circ$, with no significant difference; (c) the limits of agreement ranged from -3.9° to 4.6° ; and (d) the Nordic Angle showed perfect reliability ($ICC = 1.00$, $p < 0.001$).

The results of this study indicated a non-significant, yet very large correlation between Nordic Angle and motion analysis (Figure 1). In addition, no significant difference was observed between the BPA value of the Nordic Angle and that of the motion analysis (Figure 2), suggesting that BPA calculation by the Nordic Angle was valid. As previously reported, HSI risk might be predicted by eccentric knee flexion strength during isokinetic dynamometry.¹¹ A very large correlation was observed between eccentric knee flexion strength during isokinetic dynamometry and BPA during NHE. If there is also a strong association between BPA measured by the Nordic Angle and eccentric knee flexion strength, regular BPA measurements using the Nordic Angle may provide insights into the potential increase or decrease in HSI risk.

This study also assessed the limits of agreement between measures (Figure 3). Delahunt et al. investigated the changes in eccentric knee flexion strength during isokinetic dynamometry and BPA during NHE after a 6-week NHE training in recreationally active men.¹² Their results showed that eccentric knee flexion strength increased by 15%, and BPA changed by only -5.6° . In the current study, the limits of agreement of BPA ranged from -3.9° to 4.6° , which may either overestimate or underestimate eccentric knee flexion strength. Therefore, measuring BPA by the Nordic Angle with three to five trials and using average of these trials for BPA calculation might be recommended.

In this study, the Nordic Angle demonstrated perfect reliability ($ICC = 1.00$, $p < 0.001$). On the other hand, while the motion analysis also showed nearly perfect reliability ($ICC = 0.97$, $p < 0.001$), there was a slight difference between the first and second analysis. Thus, the Nordic Angle, which demonstrates acceptable validity and reliability, may be appropriate for field measurement because it allows immediate feedback of BPA and measurement in many athletes.

It is important to note that this study did not examine the relationship between BPA using the Nordic Angle and eccentric knee flexion strength during isokinetic dynamometry. Therefore, it remains unclear whether BPA calculated using the Nordic Angle reflects eccentric knee flexion strength. Since eccentric knee flexion strength during isokinetic dynamometry at $60^\circ/s$ is an HSI risk factor, the relationship between BPA calculated by the Nordic Angle and eccentric knee flexion strength at $60^\circ/s$ should be examined.

LIMITATIONS

This study has several limitations. The first is the small sample size. This created two clusters and risked overestimating the validity of BPA by the Nordic Angle. In addition, the sample size was set based on the effect size of a previous study when determining the sample size, but the effect size in this study was not as large as that of that previous study. Future studies are needed to test the validity of the BPA for the Nordic Angle when the sample size is increased. The second was the use of Bland-Altman analysis on non-normally distributed data. The limits of agreement in the Bland-Altman analysis might not be exact values. It is expected that the limits of agreement in the Bland-Altman analysis might be tested in the future when the sample size is increased. The third is that the measurement method was only applied to two-dimensional motion analysis. In the future, the validity of three-dimensional motion analysis needs to be examined. The final limitation is that data

from repeated trials within a day make it impossible to draw conclusions about inter-session testing.

CONCLUSION

In conclusion, this study examined the validity and reliability of the Nordic Angle by comparing the BPA values of the Nordic Angle with those of two-dimensional motion analysis software. The results indicate a very large (non-significant) correlation between the Nordic Angle measurement and the angle determined using Motion analysis, however, the mean difference between the Nordic Angle measurement and motion analysis data was not statistically significantly different ($0.4 \pm 2.1^\circ$). The limits of agreement ranged from -3.9° to 4.6° and the Nordic Angle showed perfect reliability ($ICC = 1.00$, $p < 0.001$). The Nordic Angle might be appropriate for field measurement because it provides immediate feedback regarding the BPA in many athletes. However, the small sample size suggests that the validity of the BPA may be overestimated.

DISCLOSURES

Nordic Angle is a smartphone application developed in collaboration with S-CADE. Co., Ltd. and Athletic Training Laboratory at Waseda University (instructed by Professor Norikazu Hirose). The first author of the article collected and analyzed the data. However, the authors of the current study assert no conflicts as they do not receive any fees from S-CADE. Co., Ltd. for developing the Nordic Angle, and the installation of the Nordic Angle app is free.

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