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ORIGINAL RESEARCH

Test-retest reliability of power, pinch, and tripod grip strengths in male baseball players: a preliminary study

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Abstract

Since baseball players must grip and pinch the ball, grip strength is paramount. However, current assessments on various grip types need to be more comprehensive. This study aimed to determine the test-retest reliability of different handgrip strengths measured by a dynamometer connected to a player's smartphone. Sixty male baseball players sponsored by secondary schools (middle- and high-schools) or colleges varying in age (12–22 years) were selected as participants. For male baseball players, three types of grip strengths were evaluated using a dynamometer and smartphone application: power, pinch, and tripod grip. The test was conducted thrice for each grip. Overall grip strength measurements showed slight decreases across tests and tended to increase with academic grade level. Tests 1 and 2 indicated good-to-excellent retest reliability for three grip strength positions by determining their intraclass correlation coefficients (ICCs) (middle-school power grip: 0.917 (0.644–0.973); collegiate pinch grip: 0.920 (0.770–0.970); high-school tripod grip: 0.929 (0.728–0.976)). In addition, these results determined moderate reliability compared to other grip strengths in the three groups (middle-school tripod grip from Tests 1 and 2: 0.779 (0.428–0.914); collegiate power grip from Tests 2 and 3: 0.738 (0.360–0.895)). This study concluded that the studied grip strength tests are reliable measurements, with an acceptable margin of error, for male baseball players from childhood to adulthood. Therefore, these handgrip strengths may be used as preliminary values to help discipline and rehabilitate baseball players and other athletes.

Keywords

Handgrip; Dynamometer; Smartphone application; Intraclass correlation coefficients

1. Introduction

Grip strength is determined by assessing a muscle's maximum voluntary force. This is a simple, quick, and reliable method for evaluating the muscular strength of the forearm and hand [1]. Dynamometers primarily measure the muscle power produced by the hand's flexor muscles and the forearm's flexor digitorum profundus [2]. This technique not only predicts all-cause and premature mortality risk [3], but pre-training an athlete's grip strength can improve recovery, ability, and rehabilitation [4]. It is important to use reliable and validated tools when evaluating physical fitness levels; also, athletes and coaches should be able to reproduce that performance. Stronger handgrip strength (HGS) in baseball is necessary for swinging, catching, holding, and throwing the ball, but it can also prevent injury by supporting the elbow [5]. Additionally, a fast swing using HGS is the most important factor when hitting baseball [6, 7].

Professional trainers and rehabilitation specialists are concerned about whether HGS is a reliable estimate for "real" isometric muscle strength given how many production designs and mechanisms measuring HGS are commercially available (*e.g.*, hydraulic, spring, strain gauge, and pneumatic) [8]. Among them, hydraulic dynamometers and strain gauges are widely utilized in electronic systems to enhance force measurement precision.

HGS reliability is essential when developing testing protocols and can be affected by several factors, including measuring type, test duration, and an athlete's status, age, sex, or hand dominance [9]. Several studies examined HGS reliability in trained and untrained humans [10–12]. High reliability has been confirmed in untrained children [10], adolescents [11], and adults [12]. Although a baseball player's batting and pitching speed can be measured by grip strength, the reliability of various grip methods is currently insufficient.

Understanding the various grips is crucial for assessing hand-wrist strength and function in physical and rehabilitation treatments [13], especially with the unique demands of different sports and activities such as baseball. Power, pinch, and tripod grips are the three basic prehensile patterns [14]. Grip and pinch strengths are fundamental characteristics and benchmarks of the hand's structural integrity [15]. A power grip is when a hand closes with the thumb positioned opposite to all other fingers [16]. A pinch grip is from squeezing the thumb pulp against the distal phalanges of the index, middle, ring, and little fingers [17]. Lastly, when the thumb pulp presses against the lateral aspect of the index finger's proximal interphalangeal joint, this forms a tripod grip [18]. Several reports have elucidated the hand grip strength in baseball players. For example, Tajika *et al.* [15] provided normative values and evidence for grip and pinch strengths in high school baseball pitchers. Grip strength potentially influences pitcher elbow conditions, and specific pitch type frequencies may develop pinch strength in high school baseball pitchers with an elbow symptom history [19]. While it is important to evaluate a baseball player's power, pinch, and tripod grip strengths for batting, pitching speed, and preventing throwing injury, reliability tests are insufficient.

Therefore, this study explored various handgrip strength tests-retests reliability through a system that combined a hand dynamometer with a baseball player's smartphone. Based on the acquired data, we hypothesized that each hand grip strength type, including power, pinch, and tripod, would exhibit good-to-excellent reliability for each baseball player group distributed by academic level.

2. Materials and methods

2.1 Participant

A total of 64 baseball players were eligible for this study. All participants were healthy, and those with neuromuscular disorders that could affect muscle strength or a history of upper limb injury, pain, or discomfort were excluded (finger injury = 2; shoulder injury = 1; elbow pain = 1). Sixty male baseball players were recruited for this study. Players were divided into three groups based on their academic year: middle-school baseball players (MG, 13.4 ± 0.8 years, n = 20), high-school baseball players (HG, 16.6 ± 0.6 years, n = 20), and college baseball players (CG, 19.8 ± 1.4 years, n = 20).

2.2 Experimental protocol

All tests occurred between 09:00–12:00. Participants refrained from alcoholic beverages, caffeine, and smoking for at least 12 hours before experiments. In addition, participants were advised to rest for at least 24 hours after their last exercise session to avoid any acute effects from this test. Following orientation, anthropometry and hand preference were determined before the testing session. The preferred hand was ascertained by asking participants which hand they used to throw a ball. Participants then completed a normal warm-up that included two to three practice sessions to become familiar with the measurement process and grip strength dynamometer. Three types of grips were evaluated: power, pinch, and tripod grips (Fig. 1). Power grip was measured between the palm and partially extended fingers when the thumb exerted counter-pressure. The pinch grip was assessed between the thumb pulp and the second digit pulp. The tripod grip was measured between the thumb pulp and the third-digit pulp. The test was performed on the dominant hand thrice on the same day with a specific time interval between measurements in MG, HG, and CG. The grip order was randomly assigned. The test was conducted while seated, with the forearm and wrist in a neutral position and the forearm and elbow flexed at 90 degrees on the armrest when comfortably squeezing the dynamometer [20]. The participant's forearm and wrist were held down during the test to avoid detachment. The testing technique included three maximal voluntary contractions for 5 seconds with the preferred hand and a rest time of at least 60 seconds for each of the three grip types. Data were recorded and backed up *via* mobile application between each test. Participants received verbal and visual encouragement for feedback throughout each session and performed nine grip assessments in total. All experimental procedures were supervised and controlled by a researcher.

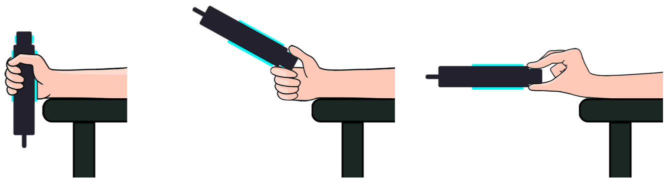

FIGURE 1. Illustration of grip strength measured. (a) power grip, (b) pinch grip, (c) tripod grip.

2.3 Anthropometry and body composition

Participants' height and weight were determined using a scale (Seca 213, Seca, Germany). Body mass index was calculated by diving body mass (kg) with height (m) squared (kg/m^2). A bioelectrical impedance analysis device assessed lean mass and body fat percentages (Inbody 270, Biospace, Seoul, South Korea).

2.4 Hand dynamometer

A portable Vernier digital hand dynamometer (HD BTA, Vernier Software & Technology, Beaverton, OR, USA) utilized in a previous study [14] was used to assess isometric handgrip strength in this study. This equipment connected to a smartphone (android and iOS), and a mobile application (Vernier Graphical Analysis, v5.16.0-2915) was created as the smartphone and dynamometer interface. HGSs were recorded as either power, pinch, or tripod grip. HGS was expressed in kilograms.

2.5 Statistical analyses

G*power analysis (ver. 3.1.9.7, Heinrich-Heine-Universität, Düsseldorf, Germany) determined sample size. Based on a previous study, a power analysis with an F-test for one-way analysis of variance (ANOVA) incorporated a 0.42 effect size, 0.05 α-level, and 0.80 power level (1-ß), establishing a sufficient sample size with 20 subjects in each group [20]. Test and retest measures are shown as means, standard deviation (SD), and 95% confidence intervals. Relative and absolute reliability was assessed for each test using a test-retest method in each group. A mixed-model analysis with a random effect (subjects) and fixed effect (test) was used to check for changes in the mean between two test sessions. SDs of the differences between the two comparable test rounds were used to determine the actual size of variability (*i.e.*, within-subject variation). Absolute reliability (the variation between two test results) was evaluated using the coefficient of variation (CV), standard error of measurement (SEM), minimal detectable change (MDC), and Bland Altman plots 95% limits of agreement (LOA).

Standard deviation to the mean ratio, or the coefficient of variation (CV), illustrates the degree of variability in proportion to the population mean. Dispersion increases with a greater CV [21].

CV was defined as: $CV = 100 \times \frac{\sqrt{\sum d^2/2n}}{x}$

SEM percentage (SEM%) was obtained by multiplying by 100 and dividing SEM by the mean of all measurements from the two comparative test occasions. As SEM% values are independent of measurement units, they demonstrate that lower values indicate higher reliability [9].

SEM was defined as: $SEM = SD \times \sqrt{1 - ICC}$

The MDC with 95% confidence (MDC_{95}), which is based on the SEM, is characterized by minimal variation in scores. MDC_{95} denotes the smallest within-person score change that may be regarded as a "genuine" change over and beyond an individual's measurement error [22].

$$MDC_{95} = 1.96 \times \sqrt{2} \times SEM$$

Bland-Altman plots graphically display the differences between two tests plotted against the mean difference of the two tests, enabling a visual evaluation of the scoring distribution and potential measurement bias. The 95% LOA was estimated as the mean difference $\pm$ 1.96 $\times$ SD of the difference [23].

Intraclass correlation coefficients (ICCs) were computed using a two-way mixed absolute agreement model to assess the relative measurement reliability. Results from the ICC were interpreted using the following reliability benchmarks: >0.90 = excellent; 0.80 to 0.89 = good; 0.7 to 0.79 = moderate; and 0.70 = low [24].

The means and SDs were analyzed for each basic characteristic among groups. Variable group differences were compared with a one-way variance analysis. If a significant F value was shown, a *post hoc* test (Tukey test) was used to determine significant differences among groups.

A significance level of $p < 0.05$ was used to determine the statistical difference. All statistical analyses were conducted using SPSS version 26 (SPSS Inc; IBM, Armonk, NY, USA), and graphical figures were created using GraphPad Prism 7.0 (GraphPad Software, San Diego, CA, USA).

3. Results

3.1 Participants characteristics

Sixty baseball players 12 to 22 years of age were recruited from middle-schools, high-schools, and colleges in South Korea (Table 1). Age, BMI, and training duration significantly differed among the three groups ($p < 0.05$). In addition, MG's height, weight, and lean mass considerably differed from HG and CG ($p < 0.05$). However, there was no significant body fat (%) disparity.

TABLE 1. Participant characteristics.

	Academic groups		
	MG	HG	CG
Age (yrs)	13.4 ± 0.8	16.6 ± 0.6*	19.8 ± 1.4*†
Height (cm)	165.8 ± 5.5	176.8 ± 4.4*	176.0 ± 5.1*
Weight (kg)	59.5 ± 10.5	78.1 ± 10.9*	84.1 ± 7.8*
BMI (kg/m²)	21.6 ± 3.3	25.0 ± 3.0*	27.1 ± 1.8*†
Lean mass (kg)	26.4 ± 4.0	35.5 ± 3.8*	38.0 ± 3.5*
Body fat (%)	18.9 ± 7.6	19.7 ± 5.1	20.8 ± 4.8
Training duration (yrs)	4.0 ± 0.9	7.2 ± 1.5*	10.7 ± 1.7*†

*Data are mean ± standard deviation. BMI = body mass index; MG = middle-school baseball players; HG = high-school baseball players; CG = collegiate baseball players. *$p < 0.05$ vs. MG; †$p < 0.05$ vs. HG.*

3.2 Grip strength

All handgrip dynamometer tests for each position provided strength measurements for analysis. Fig. 2 displays the individual and group mean $\pm$ SD in Tests 1, 2 and 3. Overall measurements showed slight decreases in grip strength across all tests (Fig. 2).

3.3 Reliability assessments of the various grip strength

Table 2 shows absolute and relative reliability assessments of the various grip strengths for the three participant groups. Relative changes were negligible in all tests. HG's pinch and tripod grips and CG's tripod grip had the highest absolute dependability (within-subject variance), as shown by CV% and SEM%. According to ICC, the relative reliability for retest measurements of overall variables ranged from good to excellent, except for CG's power grip. In addition, MDC_{95} was small in the retest, but the CG's power grip was higher than other tests.

3.4 95% limit of agreement for the test

The 95% LOA for the tests is displayed on the Bland-Altman plots (Figs. 3,4,5). It is justifiable to report that most values in each plot were within 95% of the limit of agreement, which suggests that the variance between Tests 1 and 2 and Tests 2 and 3 was normally distributed. However, power grip tests in CG had a wider LOA than all other group measurements.

TABLE 2. Reliability assessment of three grip strength types (kg) between groups.

Group	Type	Test	Diff. Between tests mean (SD) (95% CI)	%-change mean (SD) (95% CI)	*p*-value	CV%	SEM%	MDC_{95}	ICC (95% CI)	Interpretation of ICC
MG	Power	1–2	1.5 (0.4) (0.6; 2.4)	6.1 (1.9) (2.2; 10.1)	0.003	9.5	12.4	3.4	0.92 (0.64–0.97)	Excellent reliability
		2–3	0.8 (2.2) (−0.2; 1.9)	2.4 (11.4) (−2.9; 7.8)	0.108	11.0	11.9	3.3	0.89 (0.72–0.96)	Good reliability
	Pinch	1–2	0.2 (1.4) (−0.4; 0.9)	0.7 (12.6) (−5.1; 6.6)	0.506	11.2	7.2	2.0	0.87 (0.67–0.95)	Good reliability
		2–3	0.6 (1.6) (−0.1; 1.3)	4.9 (3.1) (−1.5; 11.4)	0.107	14.8	8.7	2.4	0.82 (0.56–0.93)	Good reliability
	Tripod	1–2	0.7 (1.3) (0.1; 1.2)	6.4 (12.9) (0.3; 12.5)	0.034	13.6	7.5	2.1	0.78 (0.43–0.91)	Moderate reliability
		2–3	0.2 (1.1) (−0.3; 0.8)	1.2 (13.0) (−4.8; 7.3)	0.325	12.1	5.8	1.6	0.83 (0.58–0.93)	Good reliability
HG	Power	1–2	1.4 (2.4) (0.3; 2.6)	4.5 (1.9) (0.4; 8.5)	0.016	7.6	14.5	4.0	0.82 (0.49–0.93)	Good reliability
		2–3	0.8 (2.2) (−0.2; 1.9)	2.6 (8.1) (−1.1; 6.4)	0.109	8.1	12.1	3.3	0.89 (0.73–0.96)	Good reliability
	Pinch	1–2	0.7 (1.3) (0.1; 1.3)	3.5 (8.2) (−0.3; 7.4)	0.030	8.5	7.2	2.0	0.92 (0.77–0.97)	Excellent reliability
		2–3	0.9 (1.1) (0.5; 1.5)	6.4 (7.2) (3.0; 9.8)	0.001	7.6	7.3	2.0	0.89 (0.48–0.97)	Good reliability
	Tripod	1–2	0.6 (0.8) (0.2; 1.0)	5.2 (7.8) (1.6; 8.9)	0.006	7.8	5.4	1.5	0.93 (0.73–0.98)	Excellent reliability
		2–3	0.4 (1.2) (−0.2; 0.9)	3.1 (10.7) (−1.9; 8.1)	0.156	11.0	6.5	1.8	0.88 (0.70–0.95)	Good reliability
CG	Power	1–2	1.4 (2.6) (0.1; 2.6)	3.5 (7.6) (0.0; 7.1)	0.032	7.3	15.3	4.2	0.87 (0.63–0.95)	Good reliability
		2–3	1.4 (3.9) (−0.4; 3.2)	4.1 (11.5) (−1.2; 9.5)	0.131	13.7	22.4	6.2	0.74 (0.36–0.89)	Moderate reliability
	Pinch	1–2	0.5 (1.4) (−0.1; 1.2)	3.1 (10.1) (−1.6; 7.8)	0.125	10.5	7.9	2.1	0.89 (0.72–0.96)	Good reliability
		2–3	0.6 (1.3) (0.1; 1.2)	4.7 (9.0) (0.4; 8.9)	0.031	9.9	7.3	2.0	0.92 (0.77–0.97)	Excellent reliability
	Tripod	1–2	0.1 (1.2) (−0.4; 0.7)	0.3 (10.1) (−4.4; 5.1)	0.675	10.1	6.5	1.8	0.88 (0.70–0.95)	Good reliability
		2–3	0.7 (0.9) (0.3; 1.2)	6.3 (7.9) (2.6; 10.0)	0.002	8.7	6.1	1.6	0.88 (0.50–0.96)	Good reliability

SD = standard deviation; MG = middle-school baseball players; HG = high-school baseball players; CG = collegiate baseball players; CV% = %-coefficient of variation; SEM% = %-standard error of measurements; MDC = minimal detectable change; ICC = intraclass correlation coefficient; CI = confidence interval.

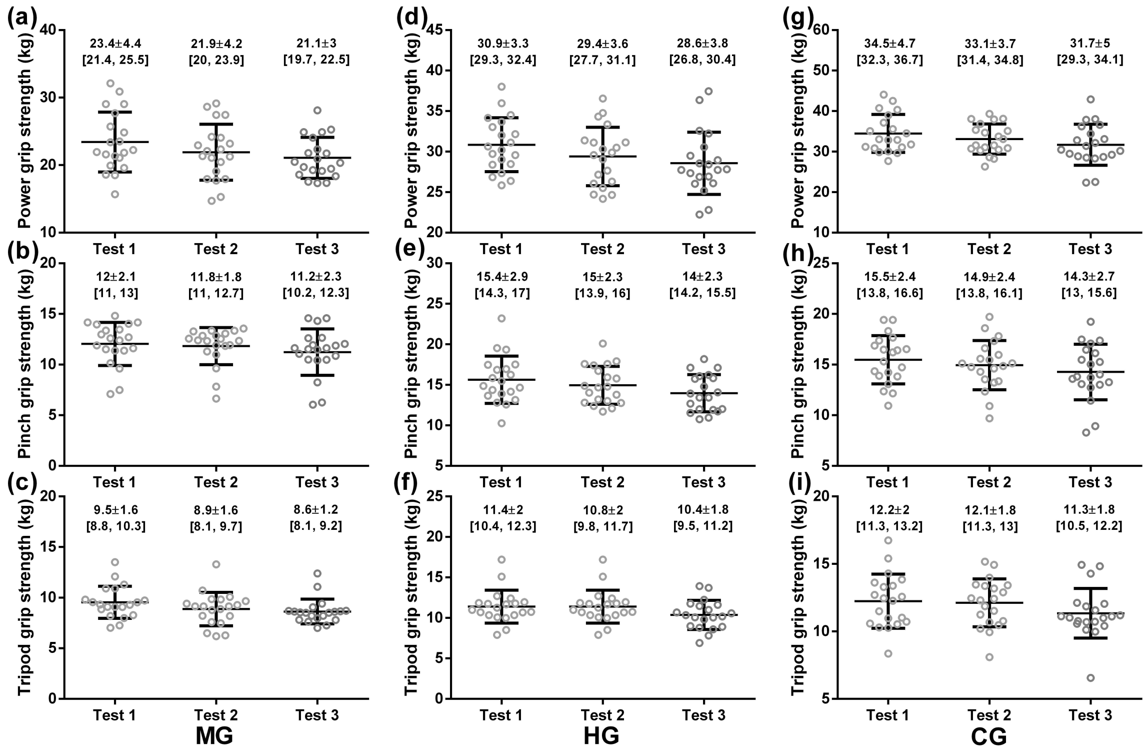

FIGURE 2. Test-retest measurements of baseball players' power, pinch, and tripod grips in MG (a–c), HG (d–f), and CG (g–i) from tests 1, 2 and 3, respectively. Each test represents mean ± standard deviation and the 95% confidence interval. The open circles represent individual results, and the horizontal lines represent the mean and error bar in the scatter plot. MG = middle-school baseball players; HG = high-school baseball players; CG = collegiate baseball players.

4. Discussion

The present study investigated the test-retest reliability of three grip strength types in young baseball players by using a dynamometer connected to a smartphone. Sixty baseball players performed the grip strength test protocol three times. It was hypothesized that each grip strength type would be accurate for each group distributed by academic level. This study's main finding was that most grip strength values had good-to-excellent absolute dependability and reliability in baseball players from childhood to adulthood. Particularly, the pinch grip was the most reliable value in every group. However, there was a moderate retest reliability in MG's tripod grip strength Tests 1 and 2 and in CG's power grip strength Tests 2 and 3. When comparing Tests 1 and 2 outcomes, within-subject variation and mean change remained comparatively high for this grip test. This suggests that the two trials had more methodological errors than the other grip strength tests considered in this study. After the first test, the methodological error of each grip strength test increased; future studies evaluating muscular function and strength should account for fatigue.

Forearm and hand strength are easily assessed using hand grip strength measurements as an indicator [25]. Furthermore, it has been suggested that grip strength may also be used to predict mortality and disability in many patients and the elderly [26]. Hand grip evaluations offer clinical data that represent a variety of human traits. For young baseball players, grip strength is a key predictor of a pitched ball's kinetic energy. Baseball players, particularly pitchers, have a variety of throws that use intrinsic hand muscles [15]. Therefore, measuring pinch and grip strength is crucial when assessing athletic performance. A precision-type grip is necessary to hold a baseball, whereas a power-type grip is needed to use the hand dynamometer correctly. Holding and throwing a baseball requires specific muscle interactions that are not accurately reproduced through general grip strength tests on a power-type grip. Baseball players hold baseballs with low power and numerous repetition during their athletic careers, which may not be sufficient when training to significantly improve the dominant hand's maximal grip force [27]. As previously demonstrated, the specific-adaptation-to-imposed-demand (SAID) principle means adaptations are specific to the imposed stimulus [28]. This is confirmed by the data that shows an increase of three HGS types of HGS with academic level. Determining a standard for evaluating grip strength in baseball players and managing hand injuries incurred during baseball practice or games can provide a greater benefit than normative grip strength data [15]. While many publications have investigated the general population [10], only a few have reported normative data on the grip strength of young baseball players [15]. Thus, this study sought to collect preliminary data and investigate the reliability of three grip strength positions in baseball players.

Grip strength validity has been discussed in relation to dynamometer devices, including hydraulic, spring, strain gauge,

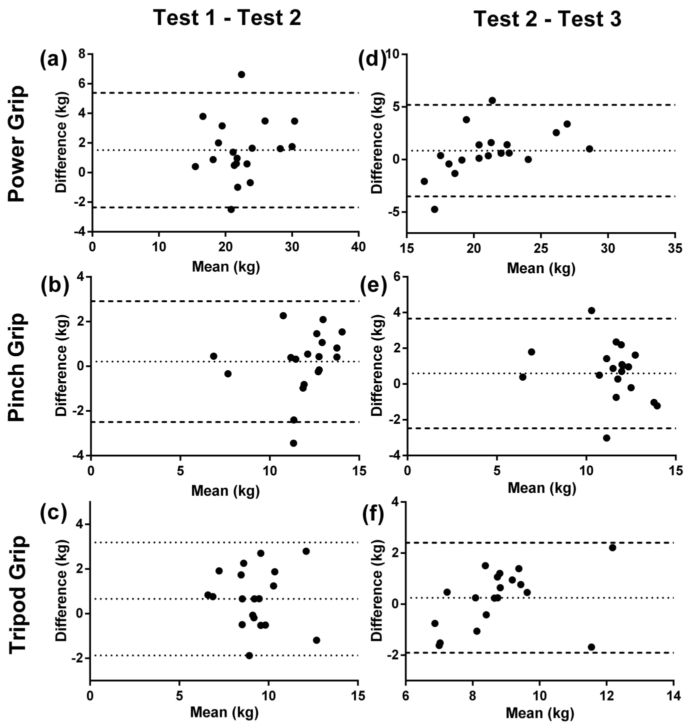

FIGURE 3. Bland-Altman plots for test-retest measurements of power (Test 1–2; a, Test 2–3; d), pinch (Test 1–2; b, Test 2–3; e), and tripod (Test 1–2; c, Test 2–3; f) grips in MG. The middle-dotted lines represent the mean difference between test-retest. The upper and lower dotted lines represent the 95% limits of agreement (mean differences ± 1.96 SD of differences). MG = middle-school baseball players.

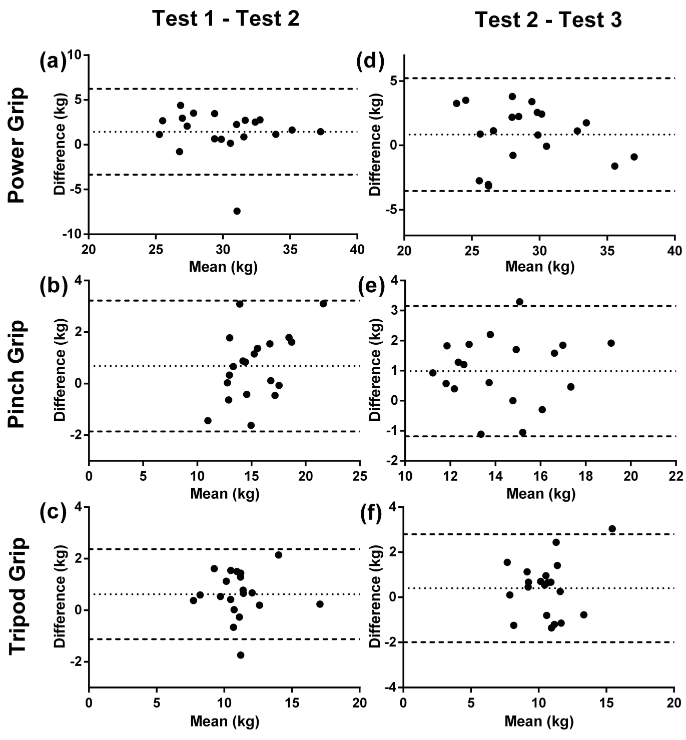

FIGURE 4. Bland-Altman plots for test-retest measurements of power (Test 1–2; a, Test 2–3; d), pinch (Test 1–2; b, Test 2–3; e), and tripod (Test 1–2; c, Test 2–3; f) grips in HG. The middle-dotted lines represent the mean difference between test-retest. The upper and lower dotted lines represent the 95% limits of agreement (mean differences ± 1.96 SD of differences). HG = high-school baseball players.

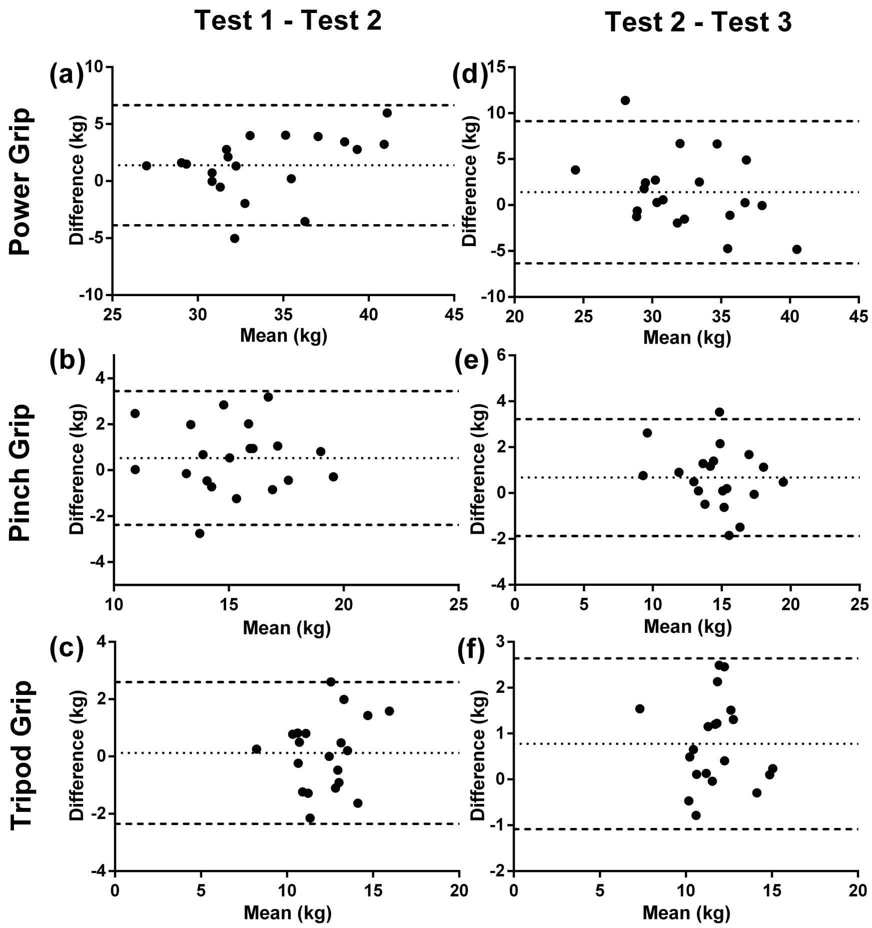

FIGURE 5. Bland-Altman plots for test-retest measurements of power (Test 1–2; a, Test 2–3; d), pinch (Test 1–2; b, Test 2–3; e), and tripod (Test 1–2; c, Test 2–3; f) grips in CG. The middle-dotted lines represent the mean difference between test-retest. The upper and lower dotted lines represent the 95% limits of agreement (mean differences ± 1.96 SD of differences). CG = collegiate baseball players.

and pneumatic equipment. This is the first investigation to report baseball players' various grip strengths measured by a dynamometer connected to a smartphone. There was a significantly high reproductivity of three grip strength positions from Tests 1 and 2 (MG power grip ICC = 0.917 (0.644–0.973); CG pinch grip ICC = 0.920 (0.770–0.970); HG tripod grip ICC = 0.929 (0.728–0.976)). This is consistent with previous studies, confirming that the good to excellent ICCs and the low variability of hand grip strength tests using different types of hand dynamometers are valid methods for assessing upper extremity strength in children, adolescents, and young adults [29]. Particularly, Gerodimos (2012) [20] reported excellent test-retest hand grip strength reliability (ICC = 0.94–0.98) by using Jamar digital hand dynamometers with prepubertal children, adolescents, and adult male basketball players. There have been several studies on the test-retest reliability of pinch grip strength measurements. For example, Li *et al.* [30] examined an electronic digital force dynamometer's reliability for measuring tip (*e.g.*, two-pint pinch), key (*e.g.*, lateral pinch; identical to "pinch" in this study), and palmar pinch (*e.g.*, three-point pinch, identical to "tripod" in this study) force levels (10, 30, and 50% of maximal voluntary isometric contraction) in healthy subjects [30]. They demonstrated moderate to excellent test-retest reliability of tip (ICC = 0.783–895), palmar (0.752–0.903), and key pinches (ICC = 0.712–0.881) [30]. Another study used a pinch gauge on healthy adults to examine pinch grip strength reliability. They concluded good to excellent test-retest reliability for all three pinch grip strength types (tip, key, and palmar), with a 0.86 to 0.96 ICC range [13]. These results corroborate this study's good to excellent reliability findings of various HGS types, including power, pinch, and tripod grips in baseball players from childhood to adulthood.

Even though grip strength increased with age, there was no clear age effect on the dynamometer's test-retest reliability; thus, this study's findings were consistent with those of Gerodimos [20]. Peak absolute HGS significantly increased with age in prepubertal, adolescent, and adult male basketball players ($p < 0.05$). However, there was a moderate reliability in MG's tripod grip in Tests 1 and 2 (ICC = 0.779 (0.428–0.914)) and CG's power grip in Tests 2 and 3 (ICC = 0.738 (0.360–0.895)) compared to the other grip strengths in the three groups. It is justifiable that these differences in reliability may be due to alterations in mood, motivation, concentration, and fatigue between the test and retest, as well as biomechanical parameters with hand size.

There is still controversy about the frequency of hand grip strength tests and the length of time between assessments [31]. According to the American Society of Hand Therapists (ASHT), the grip strength test should be performed at least three times on each hand with an average of three trials for analysis [32]. However, there are varying and complicated views on whether HGS tests should be repeated twice or three times and whether average or maximum values should be used. A recent study analyzed the protocols for handheld dynamometer measurements and found that the majority of studies adapted the maximum and mean of two or three trials [14]; a few studies were conducted only once. After careful consideration, this study followed ASHT's recommendation in this study's design.

HGS measurement intervals also varied between recent investigations. In 2011, Cadogan *et al.* [33] studied middle-aged adults and found that a 30-second break was required; nevertheless, other literature suggested a 5-second rest [34]. Additional studies reported that continuous monitoring diminished power, whereas a 1-min break offset the effects of fatigue [9, 23]. Overall, the ASHT advised that an interval greater than 15 seconds should be used [20, 32]. Although a 1-minute break during each trial was attempted, a bias included fatigue effects as repeated measurements in this study.

The present study had several limitations. First, this preliminary study's sample size is relatively small for a normative study generalizing baseball player populations and subgroups. Future studies should include larger sample sizes and additional comparisons with participants who do not play baseball. However, despite the small sample size, data points were calculated as each statistic group's average, and HGS reliability was negligible in all tests. Second, although most test-retest reliability studies measured twice daily [9], three attempts were met with sufficient recess. This was possible due to the simple design of 3 grip types and 3 repetitions. Even though this design allowed us to evaluate retest reliability with or without familiarization [9], tests were performed with familiarization. Third, results may have been influenced by variations in unmeasured parameters (*i.e.*, position). Fourth, we did not measure participants' puberty stage or time, which may affect grip strength. Additionally, results should be generalized for different age subgroups strictly designated as athletic.

5. Conclusions

For the first time, this study demonstrated handgrip strength with a Vernier dynamometer connected to a smartphone proved to be test-retest reliable when assessing baseball players from childhood to adulthood. All grip strength measurements slightly decreased across all tests. Most group measurements demonstrated good to excellent reliability concerning ICC and MDC_{95}; however, MG's tripod grip in Tests 1 and 2 and CG's power grip in Tests 2 and 3 expressed moderate reliability. The 95% LOA for the test-retest was normally distributed. Therefore, this reliable and precise HGS measuring method allows test-retest quantification and improved baseball player HGS analysis. In addition, this study establishes normative baseball player data. This test-retest reliability suggests preliminary values to improve the discipline and rehabilitation of baseball players and other athletes more precisely.

AVAILABILITY OF DATA AND MATERIALS

All data are contained within this article.

AUTHOR CONTRIBUTIONS

These should be presented as follows: WP and KH—designed the research study; wrote the manuscript. DL and HC—performed the research; analyzed the data. All authors contributed to editorial changes in the manuscript. All authors read and approved the final manuscript.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

Participants and their parents were informed about experimental procedures before providing their written consent. Protocols and informed consent forms were approved by the Institutional Review Board of Chung-Ang University in South Korea (1041078-202206-HR-146), and all study procedures were carried out in compliance with the Declaration of Helsinki.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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