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Research article

The Reliability and Validity of a Novel Sport-Specific Balance Test to Differentiate Performance Levels in Elite Curling Players

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Abstract
Balance as a skill and task-specific capacity is considered an essential physical quality in curling, required for executing effective stone delivery. However, no testing protocols have been developed to test curling-specific balance in the delivery position. Thus, the primary aim of this study was to investigate the reliability, validity and usefulness of a newly-developed, curling-specific balance test (CSBT) which involved the delivery position. The secondary aim was to examine the differences between elite and sub-elite curlers for core strength and flexibility, which have previously been identified as important qualities in curling and determinants of balance. Twenty curling players (13 females aged 19 ± 3.1 years; 7 males aged 19.6 ± 2.3 years) from five Swedish super-league curling clubs were divided into two groups according to playing level: elite and sub-elite. Variables included body mass, body height, body mass index, age, playing experience, training frequency, plank test, sit and reach test, standing single-leg balance test (SLBT) and CSBT. The CSBT was executed on a multiaxial tilting balance plate while mimicking the curling delivery position (i.e., a deep lunge position with the front foot on the plate). The participants completed the CSBT on three separate occasions, with each test consisting of three, 20-s attempts. Both the relative and absolute reliability were good for the CSBT (ICC = 0.90; CV = 14.5%). The CSBT demonstrated good measurement usefulness, being sensitive to detect moderate changes that exceeded 0.5 times the test standard deviation. Construct validity of the CSBT was evidenced by the large discriminatory capacity to differentiate expertise level in curling players (t-test: 2.85, $p < 0.01$; large ES), irrespective of other physical capacities (e.g., flexibility and core strength). However, the elite and sub-elite players also differed in age, playing experience and training frequency. Content validity was confirmed by a weak correlation (r = 0.21; 95%CI: -0.26 to 0.60) between the CSBT and SLBT, which suggests that curling-specific and standing balance should be considered as independent and task-specific motor skills. In conclusion, the CSBT can be used as a reliable, valid and useful tool for the assessment of curling-specific balance performance. In addition, longer and more extensive involvement in curling training contributed to superior specific balance in elite curlers.

Key words: Postural control, core strength, flexibility, skill acquisition, proprioception.

Introduction

Curling is a winter sport that is played on ice by two teams of four players who aim to deliver stones into a target area of four concentric circles by sliding them individually over an approximately 28-m long sheet of ice. Although two teammates are able to sweep the ice to guide the delivered stone towards the target, the performance of the shooter delivering the stone primarily determines the final placement of the stone and therefore team success (Kivi and Auld, 2012). The delivery involves the shooter pushing off the hack (i.e., the starting blocks), then gliding on the ice in a deep lunge position over 10 m and finally releasing the stone smoothly (Berry et al., 2013; Kivi and Auld, 2012).

A precise stone delivery involves a low, extended lunge position close to the ice in order to better visualize the target. Thus, to efficiently execute stone delivery, good balance, core strength, stability and flexibility have been considered to be important qualities in curling (Behm, 2007; Kivi and Auld, 2012). These physical attributes provide curlers with a stable delivery position, which optimize both speed and control of the stone (Shank and Lajoie, 2013). An additional unique challenge in curling is the need to perform the delivery and sweeping actions on slippery ice, so well-developed stability and balance are of further importance to exert substantial sweeping pressures and prevent the players from falling (Behm, 2007; Weinberg and Gould, 2014).

These skill- and task-dependent challenges are affected by both static and dynamic balance. Static balance, defined as the ability to sustain a stable static position, is more important in the delivery position, whereas the ability to transition from a static to dynamic or dynamic to static position (i.e., dynamic balance) is more important during sweeping (Clark et al., 2012; DiStefano et al., 2009). In both cases, to establish and maintain good body balance it is essential for a curler to keep the vertical projection of the body's center of mass inside the perimeter of the base of support (DiStefano et al., 2009; Heyward, 2010). In order to maintain a stable delivery position and good postural control over the body, a player must also possess optimal joint range of motion, flexibility and core strength as important determinants of balance (Bressel et al., 2007; Palmieri et al., 2002; Thorpe and Ebersole, 2008). While recognized as an essential quality for successful curling performance (Behm, 2007; Shank and Lajoie, 2013), no testing protocols appear to have been developed to test curling-specific balance in the delivery position.

To be established in practice, any new sport-specific test should firstly be investigated for its validity, reliability and usefulness (Boddington et al., 2019; Pojskic et al., 2018a; Pojskic et al., 2018b; Sekulic et al., 2017). The validity concept refers to what extent the test measures what it is intended to measure. In particular, face validity may refer to the extent to which a test logically measures

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an ability that it is intended to measure (Gratton and Jones, 2010). For instance, the current study aimed to establish face validity by simulating the curling delivery position. On the other hand, content validity might be evidenced through exact statistical analysis by identifying the relationship between balance performances in the delivery and standing single-leg positions. This is based on the concept that balance is task-specific rather than a general ability (Bachman, 1961; Tsigilis et al., 2001), so the lack of relationship would indicate that the tests measure independent facets of balance. Construct validity, as another important type of validity, is often evidenced by comparison of the measurement scores between different expertise and playing levels (e.g., elite vs. sub-elite), often referred to as discriminative validity (Butler et al., 2012; Pojskic et al., 2018a, Sekulic et al., 2017; Thorpe and Ebersole, 2008).

Measurement of reliability, by contrast, can be evidenced by multiple test-retest assessments of balance performance (Gratton and Jones, 2010; Hildebrandt et al., 2015; Hopkins, 2004). Specifically, absolute reliability may be examined by within-subject variation (i.e., the typical measurement error), whereas relative reliability is evidenced by consistency of the position of individuals in the group relative to others after test-retest trials (Weir, 2005). The greater the reliability, the more accurate the measurement may be and the easier it is to detect any changes in balance performance (Hopkins, 2004). The usefulness of a test reflects the ease of identifying a change in performance (Hopkins, 2004) and is established by comparing the typical error (TE) of the measurement and the smallest worthwhile change (SWC). Better measurement usefulness is evidenced by a higher SWC than TE (Hopkins, 2004).

The primary aim of the present study was to develop a new curling-specific balance test and to investigate its reliability, validity and usefulness characteristics. The secondary aim was to examine the differences between elite and sub-elite curlers for core strength and flexibility, which have previously been identified as important qualities in curling and determinants of balance (Behm, 2007; Bressel et al., 2007; Overmoyer and Reiser, 2015; Palmieri et al., 2002; Thorpe and Ebersole, 2008). It was hypothesized that the new test would be a valid, reliable and useful testing tool in assessing sport-specific balance in curlers (Hildebrandt et al., 2015). Moreover, it was expected that elite curlers would display superior standing single-leg balance, flexibility and core strength than their less-skilled counterparts (Behm, 2007; Butler et al., 2012; Paillard et al., 2011).

Methods

Experimental design

Both within- and between-subject experimental designs were used to determine the reliability, validity and usefulness of a newly-constructed curling-specific balance test (CSBT). The study was performed in a laboratory during the curling season and consisted of several phases. In the first phase, to establish validity, the CSBT was hypothetically created in consultation with several exercise scientists and national- and international-level curling coaches and players. All experts agreed on two important curling-specific tasks; the delivery and sweeping. They identified whole-body stability and balance over the front foot in the delivery position (i.e., during a deep lunge) as critical qualities for delivery performance. In the second phase the CSBT was designed and pilot testing was conducted with four curlers. In the third phase, 20 curlers (10 elite and 10 sub-elite) were recruited and familiarized with all physical tests before experimental measurements of curling-specific and single-leg balance were made, as well as tests of hamstrings and lower-back flexibility and core strength. In the fourth and final phase a range of analyses were made: reliability, through the test-retest measurements of the CSBT; usefulness, by comparing the SWC and TE of measurement; construct validity, through comparison of the elite and sub-elite curling groups in CSBT performance; content validity, through identification of the relationship between the CSBT and single-leg balance test (SLBT). Sample size was estimated *a priori* using SLBT score means and standard deviations from previous studies (Hildebrandt et al., 2015; Wojtyczek et al., 2014). Using G-Power software (version 3.1.9.2; Heinrich Heine University Dusseldorf, Dusseldorf, Germany), it was estimated that nine subjects (df = 8) would provide an appropriate sample size for paired-samples differences ($P \leq 0.05$, power = 0.90).

Table 1. Descriptive characteristics of the elite and sub-elite curling players.

	Elite	Sub-elite
Males (n)	3	4
Females (n)	7	6
Age (years)	21.5 ± 3.0	18.0 ± 1.3 †
Height (m)	1.73 ± 0.08	1.73 ± 0.08
Body mass (kg)	68.9 ± 8.6	69.1 ± 9.8
Body mass index (kg/m^2)	23.0 ± 1.7	23.3 ± 3.9
Playing experience (years)	9.8 ± 2.4	6.8± 1.2 †
Previous season competitions (range)	4–10	3–7
Weekly on-ice sessions (range)	3–6	2–5
Weekly gym-based Sessions* (range)	2–4	2

* = Gym-based sessions include total-body strength training and running or cycling conditioning training; † = significantly different from the elite group ($p < 0.05$). NB. There were no significant differences between the groups in body mass, body height or body mass index.

Participants

Twenty curling players (13 females aged 19.0 ± 3.1 years; 7 males aged 19.6 ± 2.3 years) from five Swedish super-league curling clubs voluntarily participated in the study (Table 1). All participants had at least five years of competitive playing experience at a national level and were required to be actively competing at the time of testing to be included in the study. Participants were divided into two groups according to their playing level: an elite group, including players who had played at national senior level and in the Swedish super-league for at least two years, and a sub-elite group, including athletes who had played for at least five years but had not competed at national senior level (Table 1). The elite group included two leads, two second players, three third players and three fourth players. Seven out of the ten players were sweepers and three were skips. The sub-elite group included two leads, two second players, three third players and three fourth players. Six out of the ten players were sweepers and four were skips. All participants were healthy and free of any reported injuries, neuromuscular diseases, or visual or vestibular impairments for at least six months before testing. All participants delivered curling stones with their right-hand. Before commencing the study, participants were informed about the study design, protocols, benefits, potential risks and right to withdraw without explanation, then provided signed informed consent. Informed consent was also provided by a parent or guardian for participants under 18 years of age (n = 6). The study was performed in accordance with the Helsinki declaration and was approved by the local institutional ethical committee of Mid Sweden University (Number: MIUN 2017/211).

Procedures

Participants attended one familiarization session and one testing session separated by 24 hours (Figure 1). They were asked to avoid high-intensity activity for at least 48 hours before testing. Participants were familiarized to the SLBT and the newly-designed CSBT, receiving detailed instructions on how to perform both tests. Special attention was paid to proper foot placement on the balance-testing platform, as well as proper body posture and positioning of the hands (as described below). Participants practiced both tests several times before the test administrator was sure that they understood the procedures and were familiar with the tests. To reduce the potential effects of any systematic changes, the physical tests were performed under similar conditions for all athletes (temperature 20–25°C, without shoes) on a single day. Moreover, the participants were instructed to exert as much effort as possible during all tests, but they were not provided with any verbal encouragement. All tests and measurements were performed during the season in February and March.

Anthropometric measurements

Body height and mass were measured to the nearest 0.01 m and 0.1 kg, respectively, using a portable stadiometer and scale (Seca, Birmingham, UK) and body mass index (BMI) was subsequently calculated for each player (body mass (kg) / body height (m)^2).

Balance tests

The "MFT challenge disc" balance measuring system (TST Trendsport, Grosshöflein, Austria) was used to assess single-leg and curling-specific balance. The system connects a round, unstable, multiaxial tilting platform, 44 cm in diameter and 7.5 cm high, with software designed to assess an individual's ability to maintain dynamic balance (MFT challenge disc software). The system calculates the participant's stability index by detecting the plate's movement and its deviation from the horizontal plane during a 20-s trial. The stability index score ranges from one to five, with a lower score representing a smaller deviation and therefore better balance.

In order to assess balance, participants performed the SLBT and CSBT on both the dominant (D) and non-dominant (N) legs (i.e., SLBT-D, SLBT-N, CSBT-D and CSBT-N). The dominant leg was defined as that which the player has in front during stone delivery. Because all participants were right-handed their dominant leg was always the left leg. The balance tests were performed without shoes. Prior to starting the tests the participants were instructed to try to keep the balance platform horizontal and to stand as still as possible. When the participant was in the correct position the test administrator started the test. Throughout the tests, participants looked straight ahead at a marker that was placed on the wall at eye-level, three meters away, while all visual feedback relating to performance was hidden.

The SLBT included only two trials on each leg because of previously reported high test-retest reliability (ICC between 0.75 and 0.96) (Hildebrandt et al., 2015; Müller et al., 2015), while the CSBT included three trials on each leg. Each trial involved three, 20-s attempts with 10 s of rest between each attempt. Participants were asked not to move the foot of the test leg or to change its position on the balance platform during the 10-s rest periods and the

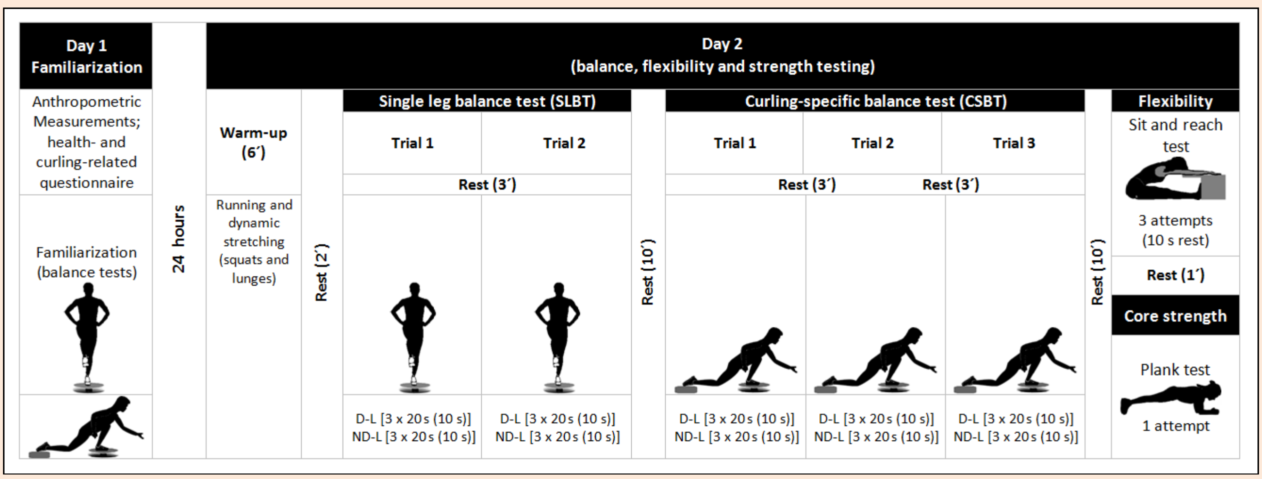

Figure 1. Experimental protocol. For balance trials, number of repetitions, repetition duration and resting periods are represented as follows: leg [number of repetitions × repetition duration (recovery between attempts)]. D-L: dominant leg; ND-L: non-dominant leg.

foot position was marked using chalk to standardize placement across the trials. In the SLBT participants were allowed to place the foot of the free leg on the ground during the 10-s rest period, while in the CSBT they were allowed to put their hands and a knee of the rear leg on the floor. There was then 3 min of rest between each trial, where participants were allowed to stand and walk before starting the next trial. If two mistakes were made within a trial then the trial was repeated.

For the SLBT the foot of the standing leg was placed in the middle of the balance plate with a slightly flexed knee joint, while the free leg was also flexed at the knee joint and raised off the ground. During the test, participants were not allowed to lean the free leg on the standing leg, to touch the floor or balance plate with the free foot, or to move the foot of the standing leg on the plate. Throughout the tests, participants kept their hands on their waist (Figure 2).

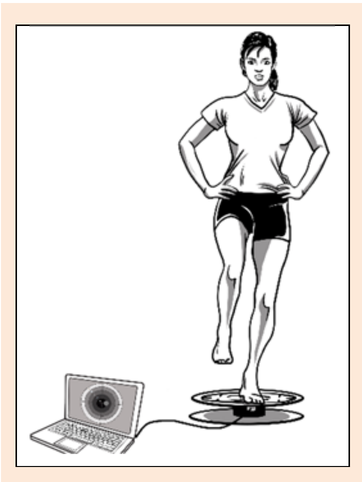

Figure 2. The single leg balance test (SLBT).

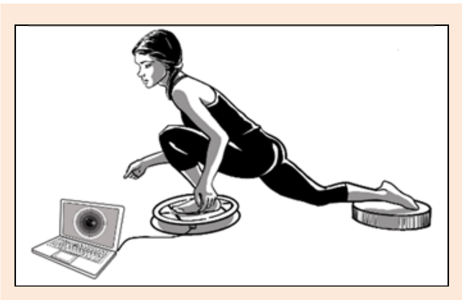

Figure 3. The curling delivery position during the curling-specific balance test (CSBT).

For the CSBT participants placed the front foot in the middle of the balance plate and the rear foot on a platform that was placed at the same height as the balance plate (Figure 3). The distance between the front and rear foot was individualized for each player, replicating their regular delivery position. The hands were held in the same position as if the participant was on the ice, simulating one hand holding the stone and the other holding the broom. During the test, participants were not allowed to touch the floor with their hands or with the knee of their rear leg. The two legs were tested in a randomized order and the mean score from each trial was used to calculate the intraclass correlation coefficient (ICC). The mean value of the trials was used to analyze the differences between the groups.

Sit and reach test

A modified sit-and-reach test was used to assess hamstrings and lower-back flexibility (Heyward, 2010). The participants sat on the floor with their back and head against the wall, the legs extended, and the feet placed against a sit-and-reach box. From this position the athletes stretched their arms towards the box and the sliding ruler was adjusted to reach the finger tips, which indicated the zero point. They then leaned forward and reached as far as possible, pushing the ruler forwards as far as possible and holding that position for 2 seconds. The participants were not allowed to bend their knees or to jerk or bounce to reach any further. Performance was recorded as the distance (in cm) between the zero position and final position after reaching forwards. The test included three attempts with a 10-s pause between each attempt and the mean score of three attempts was used for data analysis. The test showed high reliability (ICC = 0.97).

Plank test

To measure the control, muscular strength and endurance of the stabilizing core and back muscles the participants performed a plank test. They were asked to maintain an elevated position with the body supported off the floor by the elbows, forearms and toes while trying to keep the hips elevated and legs straight, with the head, body and legs in a straight line as described by Byrne et al. (2014). Participants were asked to hold the correct position as long as they could. One warning was given before a test leader stopped the test if the position was disrupted (i.e., if the hip or back was lowered by more than 10 cm beyond the reference line that was defined at the beginning of the trial). The test was only performed once with the test score being expressed in seconds. This test was used due to its excellent reliability (ICC = 0.99) and high validity for assessing core muscular strength and endurance (Saporito et al., 2015).

Statistical analyses

Descriptive statistics (mean, standard deviation [SD] and range) were calculated for each outcome variable. Data sets for all measures were found to be normally distributed using the Shapiro Wilk test (0.82 - 0.97; all $p > 0.5$) and by visual observation of the normality QQ plots. Systematic measurement error was evaluated using paired-samples t-tests for the SLBT measurements (two trials) and using repeated measures ANOVAs for the CSBT measurements (three trials). When statistically significant differences were detected between trials for the ANOVA, pairwise comparisons were performed using a Bonferroni post-hoc test.

Absolute reliability (within-subject variation) was established using coefficient of variation expressed as a percentage (CV%) according to the following formula: mean value of the trials / TE * 100, where TE was calculated by dividing the SD of the trial-to-trial difference score by $\sqrt{2}$ (Hopkins, 2000). A CV% of < 15% was defined as good reliability (Hopkins, 2000). The ICC estimates and their 95% confident intervals (CIs) were calculated based on a mean-measurements (k = 3 for CSBT and k = 2 for SLBT), absolute-agreement, 2-way mixed-effects model (Weir, 2005). An ICC > 0.70 reflected high test-retest reproducibility (DeVellis, 2016).

Usefulness was computed by comparing TE with the SWC, both expressed in the test scores for each balance test (Hopkins, 2000). The SWC was derived from the between-subject SD multiplied by either 0.2 ($SWC_{0.2}$) (Hopkins, 2004; Pyne et al., 2005), which is the typical small magnitude effect, or 0.5 ($SWC_{0.5}$), which is an alternate moderate effect (Cohen, 1988). A TE below SWC indicated test usefulness to be “good” and a TE the same as SWC was rated “acceptable”. If TE was higher than SWC, it was deemed to have “marginal” usefulness (Hopkins, 2004; Pyne et al., 2005).

Construct validity was evidenced by differentiating the elite and sub-elite groups using Student’s t-tests for independent samples. Additionally, magnitude-based effect size (ES) with 95% CIs were calculated to establish differences between the groups using the following criteria: ≤0.2 = trivial, >0.2 - 0.6 = small, >0.6 - 1.2 = moderate, >1.2 - 2.0 = large, and >2.0 very large (Hopkins, 2000).

Within- and between-test correlations were calculated using Pearson product moment correlation coefficients (r). The strength of the correlation was interpreted using the following qualitative descriptors: ≤0.20 = very weak, >0.20 - 0.40 = weak, >0.40 - 0.70 = moderate, >0.70 - 0.90 = strong and >0.90 = very strong (Salkind, 2007).

Statistical analyses were performed using freely available MS Excel charts (Hopkins, 2001) and SPSS®24.0 (IBM SPSS Statistics, New York, USA) for Windows and the alpha level was set at $p \leq 0.05$.

Results

Differences in descriptive characteristics between the elite and sub-elite groups

There were no significant differences in body height (t_{score}: 0.11, p = 0.91; trivial ES), body mass (t_{score}: 0.06, p = 0.95; trivial ES) or BMI (t_{score}: 0.20, p = 0.80; trivial ES) between the elite and sub-elite groups (Table 1). However, the elite curlers were both older (t_{score}: 3.20, p < 0.01; large ES) and had more playing experience (t_{score}: 3.47, p < 0.01; large ES) than the sub-elite curlers (Table 1).

Reliability and usefulness of the balance tests

Descriptive, reliability and usefulness data for the balance tests are presented in Table 2. There were no significant differences in trial-to-trial index of stability scores for the CSBT (F = 0.85 - 1.29; p = 0.29 - 0.44) or the SLBT (t = 0.59 - 0.80; p = 0.42 - 0.56). For the CSBT-D there was a 5.9% (CI: -8.7 - 20.6) improvement from trial 1 to trial 2, a 5.3% (CI: -5.7 - 16.3%) improvement from trial 2 to trial 3, and a 1% (CI: -11.7 - 13.6%) improvement from trial 1 to trial 3. For the CSBT-N there was an 8.8% (CI: -5.4 - 23.2%) improvement from trial 1 to trial 2, a change of 0% (CI: -0.84 - 0.19%) from trial 2 to trial 3 and an 8.8% (CI: -8.7 - 26.4%) improvement from trial 1 to trial 3. There were no significant differences in SLBT performance either on the dominant or non-dominant legs between the two repeated trials (t = 0.59, p = 0.56 and t = 0.80, p = 0.42, respectively). For the SLBT-D and SLBT-N tests, there was a 2.4% (CI: -6.3 - 11.2%) and 2.6% (CI: -4.2 - 9.5%) improvement in balance scores, respectively, from trial 1 to trial 2.

The absolute reliability for the SLBT was shown to be better than that of the CSBT, with CV values of 11.3% and 8.9% for SLBT-D and SLBT-N, respectively, and 14.5% and 19.0% for CSBT-D and CSBT-N, respectively. The relative variability for CSBT was shown to be better than for SLBT (ICC: 0.86 - 0.90 and 0.77 - 0.85, respectively). In SLBT, the TE exceeded both $SWC_{(0.2)}$ and $SWC_{(0.5)}$. In contrast, for CSBT the TE was larger than $SWC_{(0.2)}$ but smaller than $SWC_{(0.5)}$.

Table 2. Descriptive and reliability parameters for the curling-specific and single-leg balance tests.

Balance tests	Mean ± SD (index of stability)	Min – Max (index of stability)		CV%	ICC	CI95% of ICC	$SWC_{(0.2)}$ (index of stability)	$SWC_{(0.5)}$ (index of stability)	TE (index of stability)	CI95% of TE (index of stability)
CSBT-D	3.56 ± 1.01	1.76	4.88	14.5	0.90	0.79–0.96	0.31	0.50	0.41	0.32–0.56
Trial 1	3.64 ± 1.03	1.45	5.00							
Trial 2	3.42 ± 1.13	1.60	4.93							
Trial 3	3.61 ± 1.16	1.42	5.00							
CSBT-N	3.43 ± 0.97	1.84	4.99	19.0	0.86	0.67–0.93	0.29	0.48	0.41	0.32–0.56
Trial 1	3.64 ± 0.97	1.72	5.00							
Trial 2	3.31 ± 1.10	1.39	4.98							
Trial 3	3.31 ± 1.23	1.26	5.00							
SLBT-D	3.62 ± 0.70	2.51	4.90	11.3	0.77	0.42–0.91	0.21	0.35	0.48	0.38–0.66
Trial 1	3.67 ± 0.73	2.08	4.99							
Trial 2	3.57 ± 0.83	2.17	5.00							
SLBT-N	3.68 ± 0.72	2.20	5.00	8.8	0.85	0.64–0.94	0.22	0.36	0.39	0.31–0.53
Trial 1	3.73 ± 0.79	2.37	5.00							
Trial 2	3.63 ± 0.75	2.03	5.00							

CSBT-D = curling-specific balance test, dominant leg; CSBT-N = curling-specific balance test, non-dominant leg; SLBT-D = single-leg balance test, dominant leg; SLBT-N = standing balance test, non-dominant leg; SD = standard deviation; Min = minimum value; Max = maximum value; CV% = *within-participant* coefficient of variation; ICC = intraclass correlation coefficient; SWC = smallest worthwhile change; TE = typical error of measurement; CI95%, 95% confidence interval.

Table 3. Index of stability (IOS), sit and reach and plank scores for the group as a whole and the elite and sub-elite groups.

Tests	Whole group Mean ± SD (CV%)	Elite Mean ± SD	Sub-elite Mean ± SD	ES (Cohen's d)	CI95% of Cohen's d
CSBT-D (IOS)	3.56 ± 1.02 (28.5)	2.99 ± 1.01	4.13 ± 0.66*	1.30	0.31–2.26
CSBT-N (IOS)	3.43 ± 0.97 (28.2)	2.85 ± 0.80	4.02 ± 0.76*	1.50	0.48–2.49
SLBT-D (IOS)	3.62 ± 0.70 (19.4)	3.24 ± 0.50	4.00 ± 0.70*	1.25	0.27–2.20
SLBT-N (IOS)	3.68 ± 0.72 (19.6)	3.40 ± 0.64	3.97 ± 0.73	0.84	-0.08–1.75
Sit and reach (cm)	38.18 ± 6.56 (17.2)	38.1 ± 4.1	38.3 ± 8.6	0.37	-0.84–0.91
Plank (s)	135.40 ± 65.30 (48.2)	136.4 ± 66.3	150.4 ± 89.3	0.30	-0.85–0.90

CSBT-D = curling-specific balance test, dominant leg; CSBT-N = curling-specific balance test, non-dominant leg; SLBT-D = single-leg balance test, dominant leg; SLBT-N = single-leg balance test, non-dominant leg; SD = standard deviation; CV% = *between-participants* coefficient of variation; ES = Effect size; CI95% = 95% confidence interval; * = significantly different from the elite group, $p < 0.05$.

Table 4. Pearson's product-moment correlation coefficients (r) with 95% confidence interval (CI95%) within and between the balance tests.

Balance tests	CSBT-N r (CI95%)	SLBT-D r (CI95%)	SLBT-N r (CI95%)
CSBT-D	0.83 (0.61–0.93)*	0.21 (-0.26–0.60)	0.25 (-0.22–0.62)
CSBT-N	-	0.16 (-0.30–0.56)	0.13 (-0.33–0.54)
SLBT-D	-	-	0.83 (0.61–0.93)*

CSBT-D = curling-specific balance test, dominant leg; CSBT-N = curling-specific balance test, non-dominant leg; SLBT-D = single-leg balance test, dominant leg; SLBT-N = single-leg balance test, non-dominant leg; CI95% = 95% confidence interval; * = significant correlation, $p \leq 0.05$.

Construct validity of the balance tests

Balance stability score was significantly different in the two groups of differing performance levels (Table 3). The elite group had significantly better performance scores in CSBT-D (t-test: 2.85, $p < 0.01$; large ES), CSBT-N (t-test: 3.37, $p < 0.01$; large ES) and SLBT-D (t-test: 2.79, $p < 0.01$; moderate ES). However, no significant differences between the two performance levels were identified for the sit and reach and plank tests.

Content validity

Within-test correlations showed that balance performance was significantly correlated between the dominant and non-dominant legs for both CSBT and SLBT ($r = 0.83$; $p < 0.05$), while between-test correlations were not significant (Table 4).

Discussion

This study provides several important findings: 1) the CSBT is a reliable test for curling players, 2) the CSBT test evidenced construct (discriminative) validity by differentiating the elite and sub-elite groups, and 3) curling-specific balance performed in the delivery position and single-leg balance performed in an upright standing position should be considered independent motor capacities.

Reliability and usefulness

Previous studies have reported the relative reliability of similar types of balance tests (e.g., using multiaxial balance boards) with acceptable ICC values ranging between 0.71 and 0.97 (Hildebrandt et al., 2015; Müller et al., 2015). Findings from the current study are consistent with these previous studies, evidencing good test-retest reproducibility (i.e., ICC > 0.70) (DeVellis, 2016). In particular, performance in the CSBT was more consistent than in the SLBT (ICC = 0.90 versus 0.77). This means that the participants maintained their ranking order more consistently relative to others in the group when performing the CSBT compared with the SLBT (Weir, 2005).

A higher ICC in the CSBT can be explained by the greater number of trials performed (i.e., 3 vs. 2) and larger between-participant variability (see Table 3) than in the SLBT (Weir, 2005). That is, when between-participant variability (i.e., heterogeneity) is high, it is easier to consistently maintain the ranking order (i.e., a high ICC) in test-retest measurements (Weir, 2005). In particular, the balance scores were more heterogeneous when the participants performed the CSBT than SLBT, which reflected lower familiarity to the newly-designed test. This between-participant heterogeneity is also evidenced by the differences observed in the CSBT scores between the elite and sub-elite groups, as discussed below. Moreover, performing the CSBT on the dominant leg was more consistent than on the non-dominant leg. Understandably, the execution of the sport-specific test on the dominant side, and higher relative consistency, is almost certainly related to training-specific adaptations (Asseman et al., 2004). Briefly, curlers always execute the delivery using the same dominant leg as the main supporting leg (i.e., the front leg in the delivery position). To summarize, the CSBT showed good ability to detect and measure systematic differences between participants (Weir, 2005). However, a large ICC (i.e., relative reliability) can mask poor within-participant (i.e., trial-to-trial) absolute reliability when between-participant variability is high. Conversely, a low ICC can be found even when absolute reliability is excellent (i.e., a low trial-to-trial variability), if the between-participant variability is low (Weir, 2005).

In line with this, the absolute reliability was shown to be lower for CSBT than SLBT, reflected in the higher CV% values in the CSBT (see Table 2). This higher within-participant variation in the CSBT could be due to a lack of the required test-dependent motor proficiency (i.e., the ability to maintain balance in a delivery-specific position) (Buchheit et al., 2011). This non-familiarity with the test could cause some additional covariates of performance and consequently result in measurement error, which could inherently lower the test-retest reliability (Sekulic et al., 2017). By contrast, lower within-subject variability in the SLBT test is not surprising and may be attributed to the test requirements, that is to say, standing in an upright stance, which is a natural position.

The absolute reliability reported in the current study is generally poorer than that previously reported for similar balance tests (Troester et al., 2018). However, the balance tests in the current study did not show any significant systematic variation (i.e., consistent trial-to-trial differences). Practically, this means that as long as the familiarization is conducted as described, two CSBT testing trials would be sufficient (Weir, 2005). Moreover, this form of typical error (CV%) might allow direct comparison of reliability with some future sport-specific balance tests irrespective of calibration or scaling, measurement devices used, and participants tested (Hopkins, 2000), compared to ICC which is a unitless quantitative estimate of between-participant trial-to-trial differences (Weir, 2005).

For the SLBT, both $SWC_{(0.2)}$ and $SWC_{(0.5)}$ were shown to be "marginal" (i.e., TE > SWC). In contrast, the TE was shown to be larger than $SWC_{(0.2)}$ and lower than $SWC_{(0.5)}$ in the CSBT tests, showing "good" usefulness. That is, the CSBT can be utilized to detect moderate changes that exceed 0.5 times the test's SD, showing "good" measurement usefulness in curling players (Hopkins, 2004; Lockie et al., 2013). Practically, if a participant achieved mean ± SD baseline balance scores of 3.56 ± 0.46 then any retest change (i.e., reduction) higher than 0.23 (0.46 * 0.5) after an intervention (i.e., a balance index less than 3.33) could be considered a real change in performance (Hopkins, 2000).

Construct validity

It was found that both the CSBT-D and the CSBT-N was able to discriminate the different level of curling players, with the elite players evidencing better balance. That is, the CSBT showed a large discriminatory capacity to differentiate expertise levels in curling players with a Cohen's d > 1.2 (Hopkins, 2004). These results are in accordance with findings from other sports, such as soccer, judo, golf, surfing and gymnastics (Asseman et al., 2004; Butler et al., 2012; Paillard et al., 2011; Paillard et al., 2006; Palmieri et al., 2002; Sell et al., 2007). Briefly, previous authors have reported advanced balance in more proficient athletes competing at higher playing levels, suggesting that balance may be sensitive to playing experience, training status and/or sport-related adaptations. This superiority may result from longer involvement in systematic curling training, where experience was 9.8 versus 7.0 years, previous season competitions (range) were 4 - 10 versus 3 - 7, weekly on-ice sessions (range) were 3 - 6 versus 2 - 5 times and weekly gym-based sessions (range) were 2 - 4 versus 1 - 2 for elite versus sub-elite players, respectively (Paillard et al., 2011; Paillard et al., 2006). It seems that specific postural adaptation in the elite group may have been facilitated both by the repetition of the curling-specific movement (i.e., the delivery) (Paillard et al., 2011) and the amount of learning time (i.e., the law of practice) (Schmidt et al., 2018).

The significant difference in CSBT performance between the elite and sub-elite players is particularly relevant since the two groups did not differ in any other physical characteristics investigated in the current study (i.e., body height, body mass, BMI, SLBT, core strength or flexibility). This finding was somewhat unexpected, since previous studies have regularly confirmed the importance of core strength and flexibility in maintaining balance and postural control (Bressel et al., 2007; Overmoyer and Reiser, 2015; Palmieri et al., 2002; Thorpe and Ebersole, 2008). Specifically, core strength has been shown to be important in the stabilization of the spine and trunk during movements of the lower and upper limbs (Behm, 2007; van Dieën et al., 2012). However, it seems that longer playing time and higher training frequency and volume may be more important determinants of curling-specific balance than the investigated physical capacities and body dimensions (i.e., body height and mass) (Pojskic et al., 2018a). Indeed, the power of a test to discriminate playing levels is higher if the test protocol and conditions are more challenging and include more sport-specific features (Asseman et al., 2008).

Based on previous training studies, it can be speculated that more curling-specific training in the elite players might have reduced spinal reflex activity, causing reduced activation of the muscles encompassing the joints (e.g., around the knee and ankle), which may inherently prevent unwanted and uncontrollable joint oscillations during the balance testing (Keller et al., 2012; Taube et al., 2007a; Taube et al., 2007b). Furthermore, longer and more extensive training might enable the elite players to be more efficient in perceiving essential sensory cues to anticipate potential balance perturbations (Dimitriou and Edin, 2010; Gollhofer et al., 2013; Hrysomallis, 2011; Morasso and Schieppati, 1999) and to learn and store more sport-specific postural programs (Pojskic et al., 2019; Taube et al., 2008), which could in turn lead to superior CSBT performance compared to sub-elite players.

Content validity

To establish content validity, the correlations between CSBT and SLBT were examined. The very weak correlation obtained between the two tests (i.e., between 1.7 and 6.2% of the shared variance) provides strong evidence that they measure different balance constructs. These findings are logical because theoretically, factors that increase the center of gravity (COG) (i.e., standing) and decrease the base of support (i.e., a single vs. bipedal stance) decrease both postural stability and balance (i.e., in the SLBT) (Bouisset and Do, 2008). By contrast, the CSBT was designed to test a player's balance in the sport-specific slide position, with a low COG and a very wide support base (i.e., a large distance between the front and rear foot).

A second method for establishing content validity was to correlate the balance scores obtained from the dominant vs. non-dominant legs within the same test. In this case, the results showed strong correlations, implying that the test measured the same motor quality independent of the leg. These findings are consistent with some previous studies, which have failed to demonstrate leg dominance in balance in healthy subjects (Paillard et al., 2018), but conflict with other studies reporting differences between the dominant and non-dominant legs (Hoffman et al., 1998). The reason for these different findings may be due to different methods and measurement protocols used (e.g., with athletes in a fatigued or rested state). That the current study demonstrated a weak relationship between the CSBT and SLBT is consistent with Henry's Specificity Hypothesis, which proposes that motor abilities are specific to the particular task (Henry, 1958). Bachman (1961) confirmed this theory, testing 320 subjects on two motor tasks that were supposed to highlight balance as a general ability (i.e., climbing a free-standing ladder and balancing on an unstable balancing board). The results showed very weak correlations between the two tasks ($r = -0.15 - 0.25$), confirming balance as being task dependent.

The findings from the current study might be explained by skill- and stance-dependent postural adaptations that are not transferable to the usual upright position (Asseman et al., 2004; Paillard et al., 2011). Consistent with this notion, Tsigilis et al. (2001) have suggested balance as being task-specific rather than a general ability. Specifically, they did not find any significant correlations between laboratory and four dynamic-balance field tests, indicating multifactorial characters of balance. Moreover, investigating the mechanisms of enhanced balance, Granacher et al. (2006) and Taube et al. (2007b) reported that the spinal reflex adaptation was task specific and could not be transferred or generalized to all investigated postural tasks. It seems that specific balance training leads to specific and optimal reflex settings that efficiently modulate known (i.e., trained and learned) postural perturbations (Granacher et al., 2006; Taube et al., 2007b). Furthermore, it was reported that after several weeks of balance training motor cortical activity was reduced and subcortical (e.g., the basal ganglia and the cerebellum) activity was increased, indicating movement automatization (Puttemans et al., 2005; Schubert et al., 2008; Taube et al., 2007a). Not surprisingly, it seems that this shift in movement control from cortical to subcortical regions modulated by the cerebellum is task specific (Gollhofer et al., 2013). As such, the results from the current study suggest that curling-specific training challenges different facets of balance that might elicit task-specific balance adaptations (Behm, 2007; Gollhofer et al., 2013). While the sweeping may challenge dynamic balance in a standing position to a greater extent, the delivery may challenge the gliding-related static balance, which in turn resulted in a weak relationship between the CSBT and SLBT tests (DiStefano et al., 2009).

Limitations

One limitation of the current study relates to the cross-sectional design, which limits the extent to which the group differences can be attributed to curling-specific training. Thus, further research is needed to evaluate the predictive validity and responsiveness of the test. In addition, while the participants from both groups were selected based on playing level, the established differences may not be explicitly attributed to the group definitions of elite and sub-elite used in the present study *per se*, rather they may be a result of other non-tested physical and mental capacities (e.g., lower-body strength, proprioception sensitivity, perception, etc.). A further limitation is the relatively small and specific sample size, making it difficult to generalize the data to other types of curling players. Moreover, to perform the CSBT the same or similar testing equipment as used in the current study (i.e.,a multiaxial tilting platform) would be needed. Finally, this study did not evaluate physiological responses related to balance, such as the spinal reflex and brain activity, which could help to explain the underlying mechanisms responsible for the observed differences between the groups.

Conclusion

No previous studies appear to have attempted to design a curling-specific balance test or used such a test to differentiate elite and sub-elite curling players. There are several important findings from the current study that should be acknowledged. As the newly-designed curling-specific balance test demonstrated good reliability, validity and usefulness, coaches and professionals working with curling players are encouraged to use the test to optimize training strategies and to monitor balance and improvements over time. Moreover, the test could be used in talent identification procedures as it showed good discriminatory power to differentiate curling players of differing levels. However, specific curling balance and standing balance were shown to be independent abilities in curlers, so they should be tested and trained separately. The coaches and professionals who work with young curling players should be aware that the development of curling-specific balance may be largely dependent on the amount of practice time and the training of curling-specific balance proficiency. At the same time, it must be noted that the development of curling-specific balance performance does not necessarily appear to be related to the development of other capacities that are regularly considered important determinants of balance (i.e., flexibility, core strength, and standing balance). Consequently, the CSBT may be used not only as a testing tool, but also as a curling-specific drill to positively influence delivery performance. It should be noted that this study recruited trained curling players and as such, the data provided could be used as normative values for physical capacities among elite and sub-elite curlers.

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Key points

- Both the relative and absolute reliability were good in the CSBT (ICC = 0.90; CV = 14.5%).
- The CSBT demonstrated good measurement usefulness, being sensitive enough to detect moderate changes that exceeded 0.5 times the test standard deviation.
- Construct validity of the CSBT was evidenced by the large discriminatory capacity to differentiate expertise level in curling players ($d = 1.3$; $p < 0.01$), irrespective of other physical capacities (e.g., flexibility and core strength).
- In conclusion, the CSBT can be used as a reliable, valid and useful tool for the assessment of curling-specific balance performance.

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