JUMP PERFORMANCE IN TRAMPOLINE ATHLETES AND HOW TO MEASURE IT: DEVELOPING A REPEATED JUMP TEST

Yannick Prosch, Marie-Therese Fleddermann, Lukas Reichert & Karen Zentgraf

Department of Movement Science and Training in Sports, Institute of Sport Sciences, Goethe University Frankfurt, Frankfurt am Main, Germany

Original article *DOI: 10.52165/sgj.16.3.447-460*

Abstract

A competitive trampoline routine consists of ten scored jumps on which trampoline gymnasts need to exhibit an adequate strength endurance performance of their lower extremities. These strength endurance requirements are assessed with "Repeated Jump Tests" (RJT). However, existing tests are not designed for trampolining, but rather for game sports. Such tests aim, for example, at different number of repetitions and for minimizing ground contact time, thus lacking the specific repetitions and intensity of a trampoline routine. Therefore, the aim of this study is to develop a RJT specifically for trampolining that will assess jump height, performance decrement (PD) during RJT, and jump-to-jump fluctuations. Twenty-nine elite trampoline gymnasts (TR) from the junior national squad (JNS-TR; n = 21) and the senior national squad (SNS-TR; n = 8), 21 athletes from jump-intensive game sports (GS; comprising volleyball n = 15; handball n = 6), and 16 PE students (PE) completed the RJT consisting of twelve repeated jumps. Group differences were analyzed by ANOVA and trampoline squad differences via t-tests. Results showed that TR had a lower PD compared to GS and PE (p < .05). SNS-TR trampoline gymnasts show lower jump-to-jump fluctuations than JNS-TR trampoline gymnasts (p < .05). TR exhibited a superior performance in the RJT regarding PD compared to GS and PE. In conclusion, our RJT is proposed as a new tool for validly measuring repeated jump performance in trampoline gymnasts.

Keywords: *performance analysis, elite athletes, performance decrement, athletic performance.*

INTRODUCTION

Every year, the German Olympic Sports Confederation (DOSB) publishes a list of sports federations with the largest membership in Germany. For many years, the "Deutscher Turner-Bund" (German Gymnastics Association) has been the second most popular German federation (Deutscher Olympischer Sportbund, 2022). The disciplines it covers include gymnastics, artistic gymnastics, and trampoline gymnastics. In these disciplines, jumps induce significant mechanical strain on athletes' bodies during training and routines (Batista et al., 2016), requiring a high level of explosive jumping power and strength endurance (Jastrjembskaia & Titov, 1999). In trampolining competitions, athletes perform a routine lasting approximately 40 seconds that includes ten somersault movements of varying difficulty on a trampoline net (Jensen et al., 2013; Qian et al., 2020). Each somersault movement is scored based on difficulty, skill execution, horizontal displacement, and Time of Flight (ToF; Ferger et al., 2020). The ToF refers to the time interval between when the foot loses contact with the net and then it resumes contact after a successful movement (Fédération Internationale De Gymnastique, 2015), and serves as an objective evaluation criterion (Lenk et al., 2017). The importance of the ToF has increased in recent years, with Heinen and Krepela (2016) finding an increase in ToF when analyzing the senior World and World Age Group Championship individual finals between 2011 and 2015. Using this data, they found that ToF was the greatest contributor to trampoline scoring outcomes. Therefore, trampoline gymnasts (TR) must maintain their jump height throughout all jumps, reducing performance decrements (PD) during the routine while also avoiding fluctuations between jumps. This is essential for two reasons: first, to perform difficult movements more easily, and second, to achieve a high score according to the ToF criterion. In addition to technical components, the physical properties of the lower extremities (particularly strength endurance) play a crucial role in accomplishing this goal (Meckel et al., 2015). Consequently, this study focused on strength endurance.

To measure the strength endurance component mentioned above, "Repeated Jump Tests" (RJTs) are commonly used. Previous studies have explored different approaches to structuring an RJT depending on the specific requirements being investigated. In performance testing, RJTs often involve six sets of six consecutive jumps with 30-second pauses between sets (Meckel et al., 2015; Segev & Meckel, 2020). Another test, described by Harper et al. (2011), is the 10/5 RJT, in which athletes complete ten maximum rebound jumps with minimal ground contact times. However, these RJTs do not accurately reflect the demands of a trampoline routine, which consists of ten jumps with relatively longer contact times. Therefore, the 6×6 and 10/5 RJTs are more suited to game sports that involve fewer consecutive jumps, such as volleyball or handball. Current RJTs either focus on jump-intensive sports like handball or volleyball, which do not adequately address the specific needs of trampolining, or they require specialized equipment, as in the test by Dyas et al. (2021). This test, known as the "20-maximum trampoline jump test," involves 20 jumps on a trampoline, with measurements of ToF, force, horizontal displacement, and contact time. While this test is highly specific to trampolining, it necessitates a trampoline and a ToF measuring system, which may not be available in all locations. Compared to game sports athletes (GS), trampoline gymnasts (TR) must not only achieve maximum jump height but also maintain this height consistently throughout their routine while minimizing jump-to-jump fluctuations. Performance decrement (PD), which refers to the decrease in jump height over a defined test period, may be the most critical parameter in this context (Meckel et al., 2015). While PD is a key focus in Repeated Sprint Tests, it has not been as extensively emphasized in RJTs (Morin et al., 2011). For instance, Glaister et al. (2008) developed eight different formulas to represent the decline in sprint performance over time. This decline can be calculated as the percentage increase in time by comparing the first and last sprints to the optimal performance (i.e., the number of sprints multiplied by the fastest sprint time) and actual performance (i.e., the sum of all sprint times). For a more detailed explanation, see Glaister et al. (2008). The authors concluded that the formula incorporating both optimal and actual sprint performance was the most suitable. Girard et al. (2011) supported this conclusion in their review of Repeated Sprint Ability, recommending that all sprints be included in the formula derivation, as PD was found to be minimally affected by outliers. However, they also noted that each formula has its own strengths and limitations. In summary, reporting PD appears to be a valid method for quantifying strength endurance.

To better reflect the strength endurance characteristic and to initiate and accelerate fatigue, the RJT has previously been performed with additional load (Hermes et al., 2019; Sevene et al., 2017). Loaded jumps have been shown to exert greater stress on the neuromuscular system (Natera et al., 2020). Additionally, Taber et al. (2023) demonstrated that using additional load in countermovement jumps (CMJ) results in a higher eccentric braking impulse and force. It is assumed that this mirrors the increased eccentric load during the jumping movement on a trampoline net (Márquez et al., 2013; Matsushima, 2024). Moreover, the increased stress from the loaded repeated jumps (RJs) is designed to induce performance decrement (PD) more quickly. With the selected additional load, PD can be achieved earlier, leading to an RJT that is economical, quick, and easy to perform.

The main purpose of this study is to develop a valid and reliable RJT for trampolining that examines the physical requirements stated above. To achieve this, the following research questions are addressed:

1. To evaluate whether the RJT distinguishes between TR, GS, and PE students.
2. To investigate different formulas for quantifying PD over time.
3. To assess the reliability of the RJT in PE students across two different measurements.

It is expected that TR will not achieve the highest jump heights, as participants in GS belong to jump-intensive sports such as volleyball and handball, where significantly higher values are anticipated (Borràs et al., 2011; Hermassi et al., 2019; Pereira et al., 2018; Sattler et al., 2012). However, TR are expected to achieve a lower PD and the lowest jump-to-jump fluctuations during the RJT, as these factors are more closely aligned with the demands of trampolining gymnastics.

METHODS

The study was using a cross-sectional design. Prior to testing, participants received detailed written and verbal information about the potential benefits and risks associated with the study. Written informed consent was obtained from all participants (and from parents for athletes under 18 years old). The study was carried out in accordance with the recommendations of the local ethics committee (2021–30, June 28th, 2021), with written informed consent obtained from all participants in line with the Declaration of Helsinki.

A total of 66 athletes (M_{age} = 20.15 ± 4.31 years) from three different subgroups were measured. The subgroups were TR (*n* = 29; M_{age} = 18.62 ± 3.78 years), GS (*n* = 21; M_{age} = 18.71 ± 2.43 years), and PE (*n* = 16; M_{age} = 24.88 ± 3.77 years); 60.6% of all participants were males. The TR were in either the junior (JNS-TR; *n* = 21, M_{age} = 23.13 ± 1.87) or senior Germany national squad (SNS-TR; *n* = 8, M_{age} = 16.90 ± 1.90). The squads refer to the German elite sports system. Athletes in the JNS-TR are typically under the age of 18, and compete, for instance, at youth championships such as the Youth World Championships. SNS-TR athletes are usually older, take part in senior competitions and can qualify for the Olympics. GS were either in Germany's junior national volleyball squad or players in a German second division handball team. PE were registered for a Master of Sports Science degree.

Upon arrival and after being briefed on the testing protocol, participants were weighed using a Multi-Scale-Analysis device (Bomann, Germany) to determine their additional load for the RJT (details provided below). Athletes then performed a 15-minute warm-up that included dynamic and jump-specific exercises before beginning the test protocol. All tests were conducted by the same two researchers according to a standardized manual. All jumps were performed on the ground using the OptoGait© system (Microgate, Italy) for data recording. The system has demonstrated strong validity (ICC = .99) and excellent test-retest reliability (ICC = .98), making it a suitable method for measuring jump height in field tests (Glatthorn et al., 2011).

For familiarization, participants performed three CMJs (Countermovement Jumps) ranging from submaximal to maximal effort. During these jumps, the following instructions were emphasized: keep hands on hips at all times, perform a direct CMJ without pausing to a self-chosen depth, maintain extended legs and feet during the flight phase, avoid jumping forward or backward, and land with feet extended as during take-off.

The test protocol included two normal CMJs and two loaded CMJs (SingleJ). The loaded jumps were performed using a weight vest that added 20% of the participant's body weight. If the two jumps within a condition differed by more than 10%, a third trial was conducted, which occurred with approximately 10% of the participants.

For the repeated jumps, athletes were asked to perform twelve CMJs in a repeated manner, guided by an audio signal for each jump. As shown in Figure 1, a signal sounded to initiate each CMJ every 3 seconds. The signal was the German word "VOLL," meaning "full," which was intended to motivate the participants to perform their best possible jump each time. After landing, participants were encouraged by the test administrators to straighten up, if necessary, so they always started the next jump in an upright position. They were not informed about the number of remaining jumps during the set. After completing the twelve RJs, testing was stopped. As with the CMJs, jump height was measured via the time-of-flight calculation. For further analysis, the jump height of each jump was recorded. For test–retest reliability, 16 PE participants were measured again one week later, with the procedure carried out exactly as in the first measurement. There were no dropouts between the first and second measurements.

Figure 1. RJs executed with additional load. Figure shows one RJ movement.

Previous studies have used different approaches to calculate the decrease in performance (Glaister et al., 2008). The eight formulas each applied different methods to calculate PD. They are displayed below.

In formulas 1 and 2, only 10 jumps and the highest single loaded CMJ (SingleJ) were used.

$$F1 = (((\text{sum of RJ 3 to 12}) \div (\text{SingleJ} \times 10)) \times 100) - 100$$

$$F2 = (((\text{sum of RJ 2 to 11}) \div (\text{SingleJ} \times 10)) \times 100) - 100$$

Formulas 3-5 refer to 10 selected or all jumps, and the highest jump of single loaded CMJ or repeated jumps (MaxJ).

$$F3 = (((\text{sum of all RJ}) \div (\text{MaxJ} \times 12)) \times 100) - 100$$

$$F4 = (((\text{sum of RJ 2 to 11}) \div (\text{MaxJ} \times 10)) \times 100) - 100$$

$$F5 = (((\text{sum of RJ 3 to 12}) \div (\text{MaxJ} \times 10)) \times 100) - 100$$

Formulas 6-8, similar to formulas 3-5, include 10 selected or all jumps as actual performance. However, in F6-F8, the highest jump among the twelve repeated jumps (MaxRJ) is used as the ideal performance.

F6 = (((sum of all RJ) ÷ (MaxRJ × 12)) × 100) - 100

F7 = (((sum of RJ 2 to 11) ÷ (MaxRJ × 10)) × 100) - 100

F8 = (((sum of RJ 3 to 12) ÷ (MaxRJ × 10)) × 100) - 100

All statistical operations were performed using SPSS (SPSS Version 29.0.0.0). Values are presented as means (M) ± standard deviations (SD), and normal distribution was assessed using the Shapiro–Wilk test. To quantify the jump height achieved, the mean value of all twelve RJs was calculated (MeanRJ). PD was calculated using the eight formulas presented. To provide more detailed information about fluctuations between each RJ, a jump-to-jump evaluation was performed. This was calculated using Sample Entropy (SampEn) in MatLab (MathWorks, 2023) with the "EntropyHub" toolkit created by Flood and Grimm (2021). The following variables were used to calculate SampEn: embedding dimension m = 2, sequence length N = 12, radius threshold r = 0.2×SD, according to recommendations by Mayer et al. (2014). Bm(r) is the probability that sequences match for m points, while Am(r) is the probability that two sequences match for m + 1 (Kupper et al., 2020).

$$SampEn(m, r, N) = -\ln\left(\frac{A^m(r)}{B^m(r)}\right) \quad (1)$$

Differences in the average jump height of the RJs (MeanRJ), the PD for each of the eight formulas, and the jump-to-jump fluctuations between the subgroups were analyzed using a one-way ANOVA. If a significant difference was found, Tukey's HSD test was used to identify significant differences between the subgroups. Since the distribution of the SampEn data for TR was found to be dichotomous, a squad comparison between SNS-TR and NJS-TR of the jump-to-jump fluctuations was conducted in addition to the comparison of sports. Based on the descriptive data, lower jump-to-jump fluctuations in the SNS-TR were expected, so a one-tailed t-test was used. Test–retest reliability was analyzed using Pearson's *r* between both measurements of PE. Effect sizes were interpreted according to Cohen (1988). The significance level was set at $p < .01$. Figures were created using R (R-4.3.2) within RStudio (2023.12.0.369; Posit Team, 2023).

RESULTS

The *M* and SD for the RJs, PD for all formulas and jump-to-jump fluctuations for all subgroups and squad affiliations are displayed at the end of the section in Table 1.

Differences Between Groups:

Jump height: Significant differences in the average jump height of the RJs were found between the subgroups ($F(2, 63) = 15.25$, $p < .001$). Post-hoc tests revealed significant differences between the GS and TR ($p < .001$), and between the GS and PE ($p < .001$).

PD: TR achieved a lower PD in every formula (see Table 1). The ANOVA revealed significant differences when using formulas F1 ($F(2, 63) = 7.38$, $p = .001$), F2 ($F(2, 63) = 7.83$, $p < .001$), F3 ($F(2, 63) = 4.96$, $p = .010$), F4 ($F(2, 63) = 5.33$, $p = .007$), F5 ($F(2, 63) = 8.73$, $p < .001$) and F8 ($F(2, 63) = 6.78$, $p = .002$). Tukey´s HSD test showed significant differences between the TR and PE students when using F1 ($p = .002$), F2 ($p = .002$), F3 ($p = .015$), F4 ($p = .010$), F5 ($p = .001$), and F8 ($p = .017$). Significant differences between TR and GS were found when using F1 ($p = .024$), F2 ($p = .010$), F5 ($p = .007$), and F8 ($p = .005$).

Jump-to-jump fluctuations: To compute SampEn, the radius threshold was set at $r = 1.12$ (0.2×SD, SD = 5.62). There was no significant difference between all three subgroups ($F(2, 63) = 0.715$, $p = .493$). Differences between the subgroups in jump height, PD, and jump-to-jump fluctuations are shown in Figure 2

Table 1

Means and standard deviations for the jump height, performance decrement, and jump-to-jump fluctuations in the RJT divided into the subgroups trampoline gymnasts (TR), games sports athletes (GS) and PE students (PE) as well as squad levels junior national squad (JNS-TR) and senior national squad (SNS-TR)

Sports		Jump height	Performance decrement								Jump-to-jump fluctuations
		MeanRJ	F1	F2	F3	F4	F5	F6	F7	F8	SampEn
TR	Total (*n* = 29)	22.6 ± 4.6	-8.64 ± 6.66	-7.95 ± 6.73	-10.41 ± 4.35	-10.05 ± 4.67	-9.79 ± 4.25	-6.90 ± 2.29	-6.54 ± 2.60	-6.26 ± 2.04	0.497 ± 0.296
	JNS-TR (*n* = 21)	22.2 ± 5.0	-9.05 ± 7.00	-8.20 ± 6.94	-10.60 ± 4.60	-10.15 ± 5.00	-9.86 ± 4.43	-7.10 ± 2.51	-6.64 ± 2.88	-6.33 ± 2.27	0.652 ± 0.301
	SNS-TR (*n* = 8)	23.8 ± 2.9	-7.58 ± 5.95	-7.30 ± 6.54	-9.92 ± 3.84	-9.80 ± 3.97	-9.61 ± 4.02	-6.39 ± 1.58	-6.27 ± 1.83	-6.07 ± 1.39	0.328 ±0.215
GS	Total (*n* = 21)	28.2 ± 4.1	-13.11 ± 5.56	-13.03 ± 5.84	-13.27 ± 4.79	-13.10 ± 5.06	-13.89 ± 5.18	-8.52 ± 3.33	-8.35 ± 3.55	-9.18 ± 3.83	0.603 ± 0.485
PE	Total (*n* = 16)	20.2 ± 5.2	-15.05 ± 4.03	-14.40 ± 3.87	-14.30 ± 3.67	-14.40 ± 3.87	-15.05 ± 4.03	-8.23 ± 3.42	-8.34 ± 3.56	-9.04 ± 3.80	0.779 ± 0.020

Note. MeanRJ is the mean jump height over all twelve RJs; F1–F8 denote all the PD formulas used; SampEn (r = 1.12) describes the jump-to-jump fluctuations.

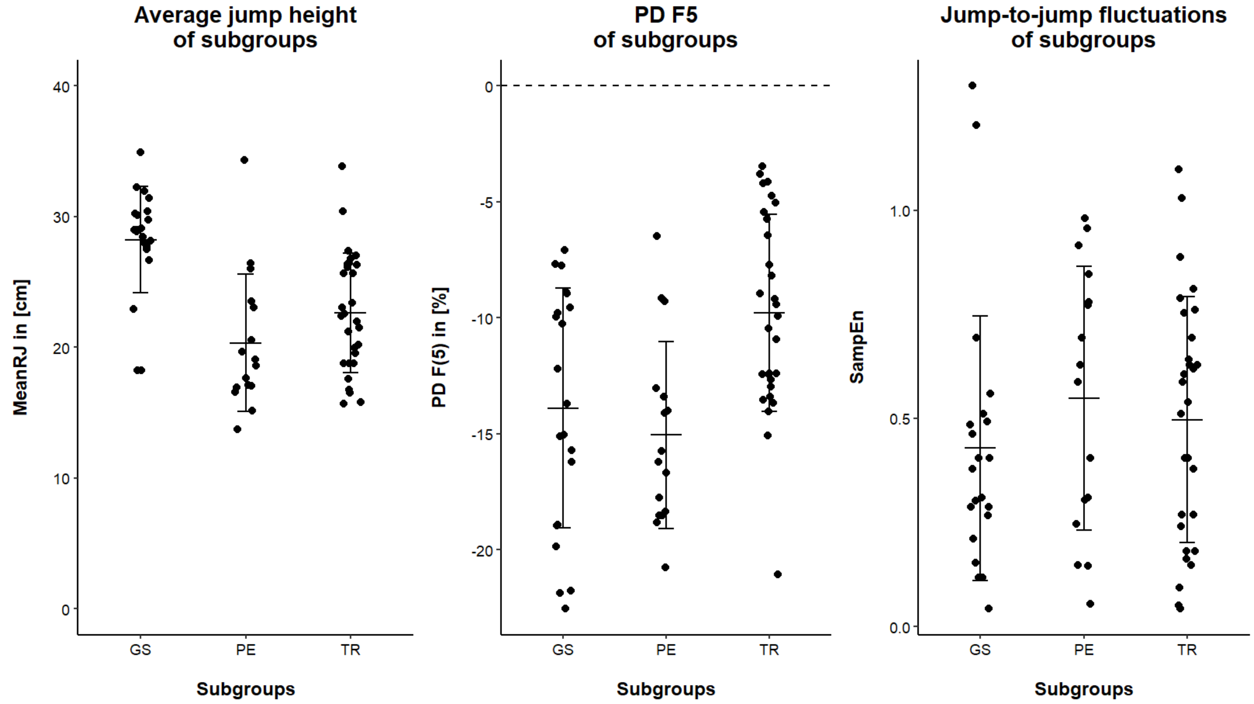

Figure 2. Subgroup comparisons in the jump height, jump-to-jump fluctuations, and performance decrement when using formula F5.

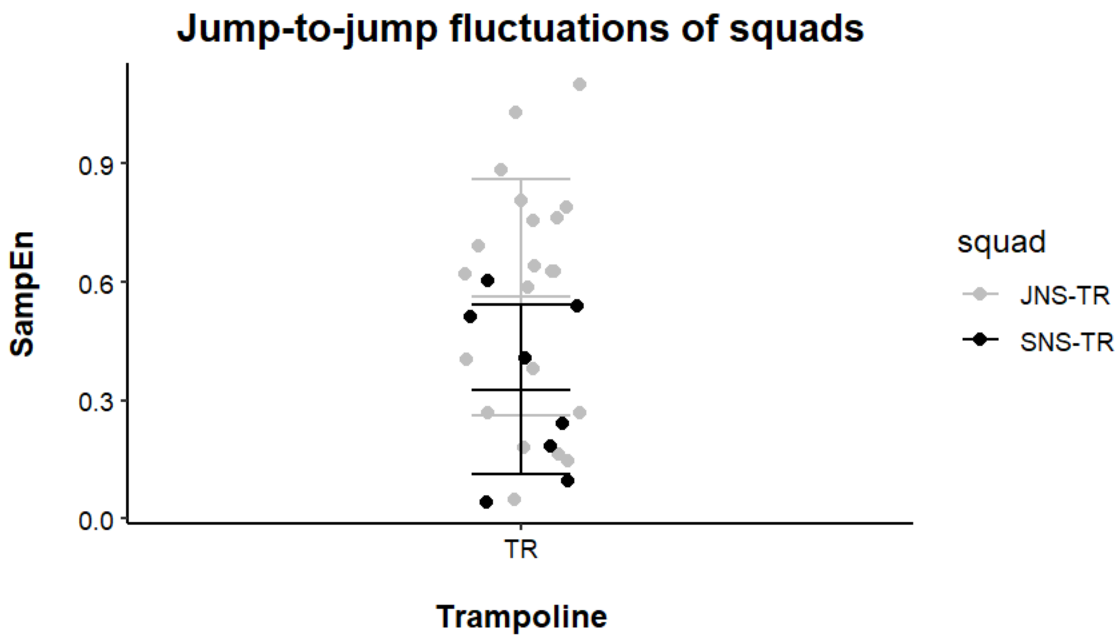

Figure 3. Dichotomous distribution of jump-to-jump fluctuations in trampoline squads.

Differences Between Squads:

Jump-to-jump fluctuations: After finding a dichotomous distribution of the jump-to-jump fluctuations within the TR, which was due to lower jump-to-jump fluctuations of SNS-TR compared to JNS-TR, a one-tailed *t*-test was used to identify differences within the TR. The distribution within the TR is presented in Figure 3. The SNS-TR showed significantly lower jump-to-jump fluctuations compared to the NJS-TR ($t(27) = 2.00$; $p = .028$).

Test-Retest Reliability (PE Students)

Jump height: Reliability, calculated using the MeanRJ, showed a strong positive correlation between Measurement 1 and Measurement 2 ($r = .989$, $p < .001$).

PD: In addition, another calculation of reliability was performed when using all PD formulas. Pearson's *r* values obtained from all formulas ranged from $r_{F2} = .167$ ($p = .537$) to $r_{F5} = .384$ ($p = .151$), thus indicating a poor to moderate yet no significant correlation.

Jump-to-jump fluctuations: The SampEn for the test retest was calculated on the basis of the PE population using the radius threshold r = 1.05 (0.2×*SD*; *SD* = 5.26). The test–retest reliability of the jump-to-jump fluctuations showed a moderately positive correlation ($r = .432$, $p = .094$). A graphical representation of the respective test–retest reliability is shown in Figure 4

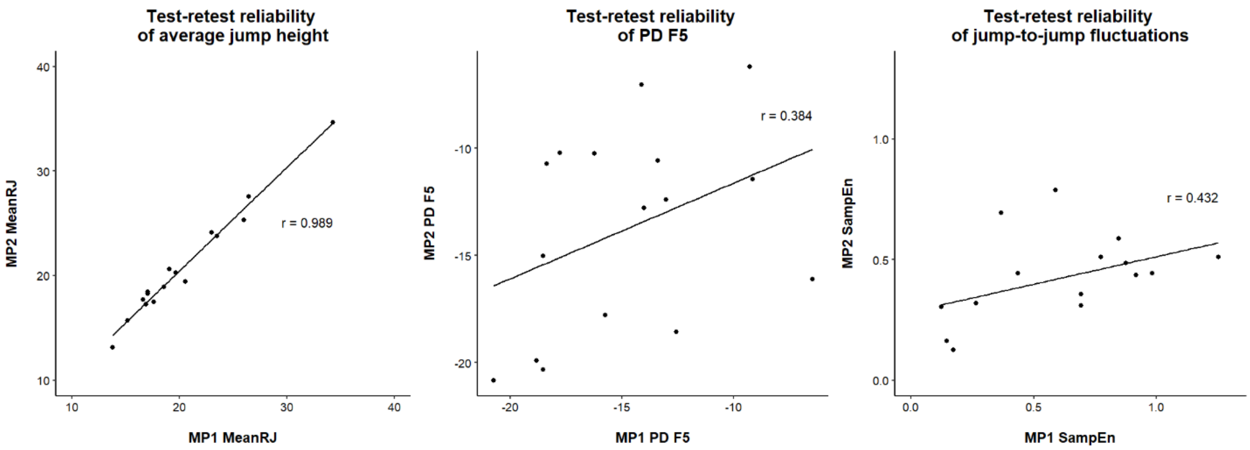

Figure 4. Test-retest reliability of the PE students via the MeanRJ, SampEn, and PD obtained from F5 using Pearson's r of each test–retest.
Note. The x-axis is defined as Measurement 1 (MP1) and the y-axis as Measurement 2 (MP2) of the variable under consideration.

DISCUSSION

In trampolining, athletes must be able to jump as high as possible and maintain their jump height at a high level throughout their routine while also avoiding jump-to-jump fluctuations. This requires adequate strength endurance in the lower extremities. Therefore, the main purpose of the present study was to develop a valid and reliable RJT specifically for trampolining. The sports group comparison shows that trampoline gymnasts (TR) achieve a lower PD than game sport athletes (GS) and PE students (PE). Our results indicate that, regardless of the evaluation formula chosen, different levels of experience in repeated jumping can be distinguished. Additionally, the test-retest reliability of the RJT was acceptable when mean jump height was considered.

Three groups with different preconditions were examined using the average jump height of the RJs, PD, and jump-to-jump fluctuations. Group comparisons between the trampoline gymnasts (TR), game sports athletes (GS), and PE students (PE) show that TR achieved a significantly lower PD compared to the other groups. This suggests that RJT is well-suited for trampolining, as a low PD indicates better maintenance of jump height and, therefore, greater strength endurance. Regarding the different formulas for calculating PD, the TR group consistently showed smaller PD compared to the other subgroups across all formulas, with significant differences occurring in Formulas F1, F2, F3, F4, F5, and F8.

As stated earlier, years of trampoline training enable trampolinists to meet the demands of repeated jumping, allowing them to maintain their jumping performance more consistently (Jensen et al., 2013). In contrast, all GS participants came from jump-intensive sports in which single, maximal, and explosive jumps are performed (Ortega-Becerra et al., 2018; Sattler et al., 2012). Consequently, while they need to achieve a maximal jump height, they may struggle to reproduce this in a series of jumps (Meckel et al., 2015). Given the significantly smaller PD observed in TR, the test appears to effectively assess the specific physical requirements of trampolining.

When analyzing jump height between groups, the results show significant differences, with GS achieving the highest average jump height during the RJ compared to TR and PE. This was expected since GS participants were from jump-intensive sports such as volleyball and handball (Borràs et al., 2011; Hermassi et al., 2019; Pereira et al., 2018; Sattler et al., 2012). Jastrjembskaia and Titov (1999) note that TR athletes specifically require more strength endurance in their lower extremities due to the sport's demands. Moreover, TR athletes must utilize the elastic capabilities of the trampoline net in their routines to achieve maximum flight time (Qian et al., 2020).

An exploratory data analysis revealed a different distribution of jump-to-jump fluctuations within the TR group, which was linked to squad affiliation. A post-hoc analysis identified significant differences in jump-to-jump fluctuations between the squads, with SNS-TR having significantly lower fluctuations than NJS-TR. Higher-level TR athletes, therefore, seem to exhibit more consistent jumps. A greater level of expertise in TR athletes appears to correspond to a lower decrease in jump height and better consistency in jump height from one jump to the next.

Another goal of this study was to differentiate between the various evaluation formulas of the RJT and identify the most suitable one. Upon closer examination, different aspects can be captured by each individual formula. To account for potential difficulties in initiating the Repeated Jump Protocol, only Jumps 3–12 were included in Formulas F1, F5, and F8, as a strong decline in jump height during the first two RJs was not anticipated. The formulas that include Jumps 2–11 (F2, F4, F7) aim to minimize the impact of an exceptionally good first jump or a poor last jump. Nonetheless, using all jumps in the formulas should provide insight into the athletes' actual performance, with the total jump height representing the sum of these jumps. This can then be compared to an “optimal performance”.

The ideal jump height was divided into three different values: the highest single jump (F1–F2), the highest jump during the entire RJT (MaxJ; F3–F5), and the highest jump only during the repeated jumps (MaxRJ; F6–F8). Formulas F1–F5 are quite similar, as the MaxJ value often corresponds to the value of the single jump, so these formulas can be considered as representing one aspect. Thus, Formulas F1–F5 describe the difference between the optimal and actual performance, showing how close the athletes perform to their best possible performance.

Formulas that include MaxRJ (F6–F8) represent a second characteristic, potentially reflecting fatigue induced by the loaded jumps. However, this may not be solely attributed to fatigue, as some athletes reached their highest jump not in the first few jumps of the RJT but later on.

Based on our results, it is not possible to recommend only one formula. It is reasonable to consider both criteria in order to draw different conclusions about an athlete’s performance. Glaister et al. (2008)

pointed out that the most valid and suitable formula is the one that includes all sprints and the fastest sprint time multiplied by the number of sprints. In our study, this corresponds to Formulas F3 and F6. Other authors, such as Natera et al. (2023), suggest that eliminating the first and last repetition provides the most reliable measure. In our study, this applies to Formulas F2, F4, and F7.

In summary, a single formula may not be sufficient to fully represent the different characteristics of performance. To assess the discrepancy between actual and best possible performance, a formula from F1–F5 should be used. For examining potential fatigue, a formula from F6–F8 should be considered. Since only F8 showed significant differences in this second characteristic, we recommend using this formula to assess fatigue. It is more challenging to select a single formula for the first characteristic. Our results show that all formulas from F1–F5 differentiate between the sports groups. Additionally, using Jumps 3–12 reflects a more accurate trampoline routine, as the first two jumps can simulate the ascending jumps before the routine starts. Therefore, F5 is recommended for assessing the first characteristic.

It is also worth noting that TR and athletes in higher squads exhibit a lower performance decrement compared to those in lower squads across all formulas, highlighting the robustness of the test. Moreover, our RJT for TR can distinguish between groups and identify elite TR, regardless of the evaluation formula used. In summary, the study's findings align with theoretical expectations. While elite TR do not show the highest jump heights, they are more consistent and superior in trampoline-specific parameters such as performance decrement (PD) and jump-to-jump fluctuations. The most successful TR athletes also show the least PD in this test, supporting the validity of RJT. Additionally, TR demonstrated significantly lower PD in six out of eight formulas.

As a reliability analysis, we conducted correlation analyses between two separate measurements taken one week apart. Since it was only possible to measure PE twice, the reliability analysis was conducted only with this non-elite group. Pearson’s correlation is a common method for measuring test–retest reliability (Di Mascio et al., 2015; Temfemo et al., 2011). Considering only the mean jump height in the RJT, strong reliability was observed between the two separate measurements. However, when comparing the PD formulas, reliability varied from poor to moderate. For jump-to-jump fluctuations, a moderate correlation between Measurements 1 and 2 was found. Similarly high reliabilities in absolute values (MeanRJ) have also been reported in other studies (Temfemo et al., 2011). Since only the PE performed the retest, several factors may have affected their jumping performance or PD during the RJT. As noted, the PE group had the lowest MeanRJ, as well as the highest PD and jump-to-jump fluctuations, indicating they were unable to maintain jump height at a high level. This suggests the RJT’s sport specificity, as elite TR, with generally lower PD and jump-to-jump fluctuations, might maintain their performance more consistently. However, this study did not evaluate the test–retest reliability for TR, which should be addressed in future research. We expect higher test–retest reliability in trampoline gymnasts due to their lower PD and jump-to-jump fluctuations in the RJT.

In addition, participants did not receive any information about the remaining number of jumps during the test, although it was not possible to prevent them from counting along. This is important because Billaut et al. (2011) noted a higher risk of pacing in repeated high-intensity efforts when the exact number of repetitions is known. Consequently, athletes may have adjusted their efforts to manage early fatigue. While athletes in this study were instructed to perform at their maximum with every jump, they may have conserved energy for specific jumps, which could explain why the last RJ was often higher than the previous ones. Another psychological factor could be the use of audio cues, as participants did not decide when the next jump would occur. The predetermined audio and the time intervals between jumps might have negatively affected jumping performance. For future measurements, incorporating automatic acquisition of knee angles with fixed anatomical landmarks would be useful, as this could help determine if changes in knee angles occur during the RJT. Variations in knee angles might indicate greater fluctuations in jump height during the RJT.

CONCLUSIONS

Time of Flight (ToF) is of growing importance in competitive trampolining (Dyas et al., 2021), and performing a high and consistent jump height has become increasingly crucial for TR. Therefore, the aim of this study was to develop an RJT specifically for trampolining athletes and to verify its validity and reliability. An RJT should also be easy to execute and quick to evaluate. For this purpose, TR, GS, and PE performed two loaded CMJs (with 20% of their body weight) and twelve loaded RJs. Eight different evaluation formulas were used to assess their individual PDs, differing in the number of jumps and units of actual and ideal performances. The TR exhibited the lowest PD using all formulas. TR in the higher squad also showed significantly lower jump-to-jump fluctuations compared to TR in the lower squad. Test-retest reliability, measured by PE, showed high reliability when comparing the average jump height of both measurements, as well as a moderate correlation for PD and jump-to-jump fluctuations. In conclusion, the RJT developed and investigated in this study appears to be a valid and reliable tool for measuring strength endurance in TR. A higher level of expertise in TR is reflected in this RJT by lower PD and lower jump-to-jump fluctuations.

ACKNOWLEDGEMENTS

We cordially thank all the coaches from the National Teams and all the athletes and students for their time and engagement in this project. The authors thank Jonathan Harrow for native-speaker advice.

REFERENCES

Batista, A., Lebre, E., & Avila-Carvalho, L. (2016). Explosive power of lower limbs in rhythmic gymnastics athletes in different competitive levels. *Revista Brasileira de Educação Física e Esporte*, *30*, 41–50. https://doi.org/10.1590/1807-55092016000100041

Billaut, F., Bishop, D. J., Schaerz, S., & Noakes, T. D. (2011). Influence of knowledge of sprint number on pacing during repeated-sprint exercise. *Medicine & Science in Sports & Exercise*, *43*(4), 665–672. https://doi.org/10.1249/MSS.0b013e3181f6ee3b

Borràs, X., Balius, X., Drobnic, F., & Galilea, P. (2011). Vertical jump assessment on volleyball: A follow-up of three seasons of a high-level volleyball team. *The Journal of Strength & Conditioning Research*, *25*(6), 1686–1694. https://doi.org/10.1519/JSC.0b013e3181db9f2e

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Routledge. https://doi.org/10.4324/9780203771587

Deutscher Olympischer Sportbund (2022). *Bestandserhebung 2022: Fassung vom 01.10.2022; Stichtag der Erfassung: 1. Januar 2022* (1st Digital edition). Deutscher Olympischer Sportbund. https://cdn.dosb.de/user_upload/www.dosb.de/uber_uns/Bestandserhebung/BE-Heft_2022.pdf

Di Mascio, M., Ade, J., & Bradley, P. S. (2015). The reliability, validity and sensitivity of a novel soccer-specific reactive repeated-sprint test (RRST). *European Journal of Applied Physiology*, *115*(12), 2531–2542. https://doi.org/10.1007/s00421-015-3247-0

Dyas, N., Green, D., Thomas, K., & Howatson, G. (2021). Reliability and characterisation of the 20-maximum trampoline jump test. *Isokinetics and Exercise Science*, *29*(2), 131–137. https://doi.org/ 10.3233/IES-203179

Fédération Internationale De Gymnastique (2015). *FIG apparatus norms*. http://www.fedecolgim.co/reglamentos/Normas%20de%20los%20aparatos%20FIG%202015.pdf

Ferger, K., Helm, F., & Zentgraf, K. (2020). Estimating horizontal displacement deduction in trampoline gymnastics by means of constant and variable errors of landing position: A new gold standard? *Science of Gymnastics Journal*, *12*, 203–216. https://doi.org/10.52165/sgj.12.2.203-216

Flood, M. W., & Grimm, B. (2021). EntropyHub: An open-source toolkit for entropic time series analysis. *PloS One*, *16*(11), e0259448. https://doi.org/10.1371/journal.pone.0259448

Girard, O., Mendez-Villanueva, A., & Bishop, D. J. (2011). Repeated-sprint ability part I: Factors contributing to fatigue. *Sports Medicine*, *41*(8), 673–694. https://doi.org/10.2165/11590550-000000000-00000

Glaister, M., Howatson, G., Pattison, J. R., & McInnes, G. (2008). The reliability and validity of fatigue measures during multiple-sprint work: An issue revisited. *The Journal of Strength & Conditioning Research*, *22*(5), 1597–1601. https://doi.org/10.1519/JSC.0b013e318181ab80

Glatthorn, J. F., Gouge, S., Nussbaumer, S., Stauffacher, S., Impellizzeri, F. M., & Maffiuletti, N. A. (2011). Validity and reliability of optojump photoelectric cells for estimating vertical jump height. *The Journal of Strength & Conditioning Research*, *25*(2), 556–560. https://doi.org/10.1519/JSC.0b013e3181ccb18d

Harper, D., Hobbs, S. & Moore, J. (2011). The 10 to 5 repeated jump test. A new test for evaluating reactive strength. [Paper Presentation]. BASES Student Conference 2011, Chester, UK.

Heinen, T., & Krepela, F. (2016). Evaluating routines in trampoline gymnastics. *Science of Gymnastics Journal*, *8*(3), 229–238.

Hermassi, S., Chelly, M. S., Wagner, H., Fieseler, G., Schulze, S., Delank, K.-S., Shephard, R. J., & Schwesig, R. (2019). Relationships between maximal strength of lower limb, anthropometric characteristics and fundamental explosive performance in handball players. *Sportverletzung · Sportschaden*, *33*(2), 96–103. https://doi.org/10.1055/s-0043-124496

Hermes, M., Fry, A., Herda, T., Wray, M., Sontag, S., & Hatcher, M. (2019). Kinetics of vertical jump fatigue following a repeated jump protocol in recreationally trained males [Poster presentation]. 42nd National Strength and Conditioning Association Annual Conference.

Jastrjembskaia, N., & Titov, Y. (1999). *Rhythmic gymnastics*. Champaign: Human Kinetics.

Jensen, P., Scott, S., Krustrup, P., & Mohr, M. (2013). Physiological responses and performance in a simulated trampoline gymnastics competition in elite male gymnasts. *Journal of Sports Sciences*, *31*(16), 1761–1769. https://doi.org/10.1080/02640414.2013.803591

Kupper, C., Roemer, K., Jusko, E., & Zentgraf, K. (2020). Distality of attentional focus and its role in postural balance control. *Frontiers in Psychology*, *11*, 125. https://doi.org/10.3389/fpsyg.2020.00125

Lenk, C., Hackbarth, M., Mylo, M., Weigand, J., & Ferger, K. (2017). Evaluation eines Messsystems für die Flugzeitmessung im Trampolinsport. *Technologien im Leistungssport 2: Tagungsband zur 18. Frühjahrsschule am 13./14. April 2016 in Leipzig*, pp. 74–79

Márquez, G., Aguado, X., Alegre, L. M., & Férnandez-del-Olmo, M. (2013).

Neuromechanical adaptation induced by jumping on an elastic surface. *Journal of Electromyography and Kinesiology*, *23*(1), 62–69. https://doi.org/10.1016/j.jelekin.2012.06.012

Matsushima, M. (2024). Difference between muscle activities during jumping motion in descent and ascent phases on a trampoline. *Science of Gymnastics Journal*, *16*(1), 5–13. https://doi.org/10.52165/sgj.16.1.5-13

Mayer, C. C., Bachler, M., Hörtenhuber, M., Stocker, C., Holzinger, A., & Wassertheurer, S. (2014). Selection of entropy-measure parameters for knowledge discovery in heart rate variability data. *BMC Bioinformatics*, *15*(6), S2. https://doi.org/10.1186/1471-2105-15-S6-S2

Meckel, Y., May-Rom, M., Ekshtien, A., Eisenstein, T., Nemet, D., & Eliakim, A. (2015). Relationships among two repeated activity tests and aerobic fitness of volleyball players. *The Journal of Strength and Conditioning Research*, *29*(8), 2122–2127. https://doi.org/10.1519/JSC.0000000000000859

Morin, J.-B., Dupuy, J., & Samozino, P. (2011). Performance and fatigue during repeated sprints: What is the appropriate sprint dose? *The Journal of Strength & Conditioning Research*, *25*(7), 1918–1924. https://doi.org/10.1519/JSC.0b013e3181e075a3

Natera, A. O., Cardinale, M., & Keogh, J. W. L. (2020). The effect of high-volume power training on repeated high-intensity performance and the assessment of repeat power ability: A systematic review. *Sports Medicine*, *50*(7), 1317–1339. https://doi.org/10.1007/s40279-020-01273-0

Natera, A. O., Chapman, D. W., Chapman, N. D., & Keogh, J. W. L. (2023). The reliability and validity of repeat power ability assessments and measurement indices in loaded vertical jumps. *PeerJ*, *11*, e15553. https://doi.org/10.7717/peerj.15553

Ortega-Becerra, M., Pareja-Blanco, F., Jiménez-Reyes, P., Cuadrado-Peñafiel, V., & González-Badillo, J. J. (2018). Determinant factors of physical performance and specific throwing in handball players of different ages. *The Journal of Strength & Conditioning Research*, *32*(6), 1778–1786. https://doi.org/10.1519/JSC.0000000000002050

Pereira, L. A., Nimphius, S., Kobal, R., Kitamura, K., Turisco, L. A. L., Orsi, R. C., Cal Abad, C. C., & Loturco, I. (2018). Relationship between change of direction, speed, and power in male and female national Olympic team handball athletes. *The Journal of Strength & Conditioning Research*, *32*(10), 2987–2994. https://doi.org/10.1519/JSC.0000000000002494

Posit team (2023). RStudio: Integrated Development Environment for R. Posit Software, PBC, Boston, MA. http://www.posit.com/

Qian, J., Mao, Y., Tang, X., Li, Z., Wen, C., & Zhang, S. (2020). A finite element model for estimation of contact dynamics during a jumping movement on a trampoline. *Journal of Human Kinetics*, *73*(1), 59–72. https://doi.org/10.2478/hukin-2019-0127

Sattler, T., Sekulic, D., Hadzic, V., Uljevic, O., & Dervisevic, E. (2012). Vertical jumping tests in volleyball: Reliability, validity, and playing-position specifics. *The Journal of Strength & Conditioning Research*, *26*(6), 1532–1538. https://doi.org/10.1519/JSC.0b013e318234e838

Segev, S., & Meckel, Y. (2020). Repeated jump ability of young basketball players at different game stages and its relationship to aerobic capacity. *International Journal of Physical Education, Fitness and Sports*, *9*(3), 24–31. https://doi.org/10.34256/ijpefs2034

Sevene, T. G., DeBeliso, M., Carson, C., Berning, J. M., Harris, C., & Adams, K. J. (2017). Continuous weighted jumping: Effects on vertical jump height. *European Journal of Physical Education and Sport*

Science, *3*(9). https://doi.org/10.5281/zenodo.847756

Taber, C., Butler, C., Dabek, V., Kochan, B., McCormick, K., Petro, E., Suchomel, T., & Merrigan, J. (2023). The effects of accentuated eccentric loading on barbell and trap bar countermovement jumps. *International Journal of Strength and Conditioning*, *3*(1). https://doi.org/10.47206/ijsc.v3i1.213

Temfemo, A., Lelard, T., Carling, C., Mandengue, S. H., Chlif, M., & Ahmaidi, S. (2011). Feasibility and reliability of a repeated sprint test in children age 6 to 8 years. *Pediatric Exercise Science, 23*(4), 549–559. https://doi.org/10.1123/pes.23.4.549

Corresponding author:
Yannick Prosch
Institute of Sport Sciences
Movement Science and Training in Sports
Ginnheimer Landstrasse 39
60487 Frankfurt am Main, Germany
Phone: +49 (0)176 31603703
e-mail: prosch@sport.uni-frankfurt.de

Article received: 4.4.2024
Article accepted: 5.9.2024