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Original Article

Suggested methods for supporting ladder getters using computer simulation results

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Abstract:
This study used computer simulations to analyze the motion of a ball in a ladder getter setup, using a Lagrangian formulation to determine how variations in ladder installation distance and target bar height influence the ball's ability to hang on the ladder. The findings demonstrate that performing the ladder getter is a complex motor task with specific release conditions that must be met for the ball to successfully hang on the bar, requiring adjustments in the throwing technique. The results showed significant differences in the number of successful trials under different target conditions, with closer ladder installation and higher ladder placement leading to an increased number of successful attempts. The number of successful trials for each variable varied for each target condition, suggesting that the combination of variables in the interquartile range facilitated more successful throws. Analyses of median differences revealed significant main and interaction effects of ladder distance and bar height on the release position, initial velocity, projection angle of the ball, and string angle, with significant differences observed across all target conditions. Additionally, the number of successful projection angle combinations tended to decrease as the ball's initial velocity increased in each target condition. These results indicate that the ball's ability to hang is significantly influenced by its initial velocity and projection angle at the time of release, making the adjustment of these factors critical for throws targeting specific ladder distances and bar heights. Based on these findings, it is suggested that providing participants with support that clarifies specific ball release conditions and allows them to observe actual successful trials would effectively enhance their understanding and help them experience the most enjoyable aspects of the ladder getter as soon as possible.
Keywords: ladder getter, enjoyment, computer simulation, ladder distance, bar height, support method

Introduction

Sport and recreation activities refer to all recreational activities performed as sports (Ministry of Education, Culture, Sports, Science and Technology, 2011). Participation in these activities is encouraged for individuals of all ages, from children to the elderly, as a means to maintain and enhance physical and mental health while extending healthy lifespans (Japan Recreation Association, 2024a). The primary objective is for participants to achieve success and enjoyment in these activities, encouraging them to continue as a form of exercise (Japan Recreation Association, 2017). Additionally, the enjoyment of exercise promotes communication among participants and strengthens community bonds, ultimately contributing to the development of a healthy society.

In Japan, the Basic Sport Plan serves as a guideline for the comprehensive and systematic promotion of sports policies based on the Basic Act on Sports. The third phase of this plan was established in 2022 (Japan Sports Agency, 2022) and introduced a new emphasis on "creating and nurturing" sports, "gathering" to play sports "together," and "feeling connected," all aimed at enhancing the value of sports. The ladder getter is a sport and recreation activity that involves throwing two sponge balls connected by a string toward a ladder placed 7.5 m away (Japan Recreation Association, 2024b). Players compete to score points by hanging a ball on the ladder. The Japan Recreation Association developed ladder getter in 2006, inspired by similar activities such as ladder golf, brongo ball, and ladder ball, which are popular in the United States. This sport and recreation activity aligns with the third Basic Sport Plan, offering a fun opportunity for everyone to enjoy together while promoting intergenerational exchange. It is essential for sport and recreation instructors to understand the unique characteristics of this relatively new activity and nurture it carefully.

In sports and recreational activities, the emphasis should be on providing participants with a sense of accomplishment as quickly as possible (Japan Recreation Association, 2023). This means that the most enjoyable aspects of the activity should be experienced early on. For example, in ladder getter, the most rewarding moment occurs when the ball successfully hangs on the ladder and scores a point. Therefore, it is essential to facilitate this experience for participants as efficiently as possible. Sport and recreation instructors should be knowledgeable in techniques that ensure the ball hangs on the ladder, which involves throwing the ball in a specific manner to achieve this result.

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Our research group analyzed the motion of successful ladder getter trials, where participants threw the ball, to identify the release conditions necessary for the ball to hang on the ladder. Based on their findings, they proposed a support method (Nakai & Tanaka, 2022). However, the study focused solely on instances where the ball hung on the second bar and did not investigate the conditions for hanging the ball on the first and third bars. Additionally, the ladder getter textbook emphasizes the enjoyment of gradually increasing the distance from which participants aim to hang the ball on the ladder, starting from an easier distance and progressing to the standard 7.5 m (Japan Recreation Association, 2022). It also recommends a support method in which the participant throws the ball from a position close to the target. Research has shown that in guessing tasks involving throwing a ball or dart at a target, it becomes easier to hit the target as the distance decreases (Ohoka & Maeda, 2013). While the support methods mentioned seem to be based on empirical observations, their underlying rationale is not clearly explained.

Instead of relying on motion analysis from successful trials thrown by a participant, a computer simulation of a ladder getter's throw can be used to identify the conditions necessary for hanging the ball on the ladder across a wide range of variable combinations. This method can provide evidence to support participants. The dynamics can be formulated using either Newtonian or Lagrangian approaches. In the Newtonian framework, the dynamics are described in terms of an inertial system, while the Lagrangian approach uses a variational formulation based on the principle of least action in configuration space (Ida, 2020). In simulations, even for complex systems where deriving the equations of motion in the Newtonian form is challenging, the equations can still be derived in the Lagrangian framework. Wells (1967) formulated the dynamics in Lagrangian form for a system of two mass points connected at a specific distance, similar to the ball used in this study on ladder getter.

The aim of this study was (a) to formulate and simulate the motion of the ladder getter's ball in the air using the Lagrangian approach, assuming the ladder was positioned at a standard distance or closer, and (b) to investigate the success rate of the ball hanging on the bars at the first, second, and third levels, as well as the characteristics of the ball release conditions and the differences among them. Additionally, the study aimed (c) to clarify how throwing techniques should be adjusted when the distance to the ladder and the height of the target bar are modified. The findings suggest that implementing specific support methods can assist participants who struggle to hang the ball on the ladder, allowing them to experience the most enjoyable aspect of ladder getter—successfully hanging the ball—as quickly as possible.

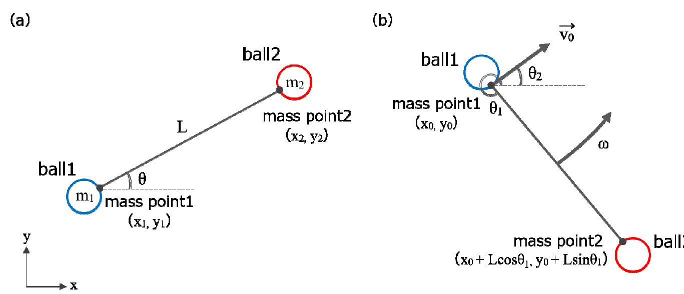

Fig. 1. (a) The model of the entire ball at a specific moment in time and (b) the values of each variable immediately after its release.

Materials and methods

Procedure/Measurement

This study established a static coordinate system with the throwing line on the floor as the origin. The positive direction of the X-axis was designated as the horizontal forward direction from the origin, while the positive direction of the Y-axis was set as the vertical upward direction (Fig. 1). In the ladder getter, the entire ball is swung like a pendulum, with a sponge ball on one side, then thrown underhand, causing the entire ball to fly toward the target in a counterclockwise rotational motion. Figure 1(a) shows the masses of the sponge balls on either side of the hand (ball 1) and the other sponge ball (ball 2), labeled as m_1 and m_2, respectively. The length of the string connecting ball 1 and ball 2 is denoted as L. The scenario assumes there is no air resistance, deformation, or mass associated with the string. At a given moment, balls 1 and 2, connected by the string, have equal masses and experience equal magnitudes of centripetal and centrifugal forces owing to their counterclockwise rotation. These forces include the tension force acting on each endpoint of the string and its corresponding reaction force. Consequently, balls 1 and 2, connected by a string (i.e., the entire ball), can be modeled as two mass points (mass points 1 and 2) with respective masses m_1 and m_2, moving at a fixed distance L.

If, at a certain moment, the coordinates of mass point 1 are (x_1, y_1) and the angle of the string relative to the floor is θ, then the coordinates of mass point 2 (x_2, y_2) can be expressed as follows.

$$x_2 = x_1 + L\cos\theta$$
$$y_2 = y_1 + L\sin\theta$$

After the entire ball is released, it moves in the XY plane under the influence of gravity. The equations of motion for this system are formulated using Lagrange's equations of motion for x, y, and θ following an example from The MathWorks, Inc. website (2024).

$$(m_1 + m_2)\ddot{x} - m_2 L\ddot{\theta}\sin\theta - m_2 L\dot{\theta}^2\cos\theta = 0$$
$$(m_1 + m_2)\ddot{y} - m_2 L\ddot{\theta}\cos\theta - m_2 L\dot{\theta}^2\sin\theta + (m_1 + m_2)g = 0$$
$$L^2\ddot{\theta} - L\ddot{x}\sin\theta + L\ddot{y}\cos\theta + gL\cos\theta = 0$$

The equation of motion by the coupled ordinary differential equations can be expressed as Equation 1 using the mass matrix.

$$\begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & m_1+m_2 & 0 & 0 & 0 & -m_2 L\sin q_5 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & m_1+m_2 & 0 & m_2 L\cos q_5 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & -L\sin q_5 & 0 & L\cos q_5 & 0 & L^2 \end{bmatrix} \begin{bmatrix} \dot{q}_1 \\ \dot{q}_2 \\ \dot{q}_3 \\ \dot{q}_4 \\ \dot{q}_5 \\ \dot{q}_6 \end{bmatrix} = \begin{bmatrix} q_2 \\ m_2 L q_6^2\cos q_5 \\ q_4 \\ m_2 L q_6^2 \sin q_5 - (m_1+m_2)g \\ q_6 \\ -gL\cos q_5 \end{bmatrix} \quad (1)$$

In this study, a program to solve Equation 1 was created using numeric computing software MATLAB (The MathWorks Inc., 2023).

Constants and variables were established based on the model described above, and a program was developed using numeric computing software following the outlined process. Simulations were then performed by changing these variables, and the conditions necessary for the ball to hang on each bar were identified.

(1) The ladder was installed under two conditions: the standard installation distance of 7.5 m and a closer distance of 5.0 m for the speed ladder getter. The X coordinates of the center of the bar were set at 5.0 and 7.5 m, and the Y coordinates of the top of the bars were 0.36 m for the first bar, 0.72 m for the second bar, and 1.08 m for the third bar. Additional constants included the bar diameter (0.025 m), the weight of each ball (23.5 g), the length of the string (0.42 m), and the gravitational acceleration (9.80665 m/s^2). A structure was created that included the weight of the ball, the length of the string, and the gravitational acceleration.

(2) The coordinates of mass point 1 at the moment of ball release (x_0 and y_0), its initial velocity vector (v_0), the angle of the string (θ_1), the projection angle of mass point 1 (θ_2), and the counterclockwise angular velocity of the string (ω) were defined as variables (Fig. 1(b)).

(3) The range of variables for this study was established by referencing a previous study (Nakai & Tanaka, 2022) that analyzed successful trials on the third bar of a ladder positioned 7.5 m away. The variable ranges were as follows: x_0 varied from 0.5 to 1.0 m (in increments of 0.1 m), y_0 ranged from 0.7 to 1.2 m (in increments of 0.1 m), v_0 varied from 5.0 to 12.5 m/s (in increments of 0.1 m/s), and θ_1 varied from 260 to 320 deg counterclockwise, with 0 deg defined as the positive direction of the X-axis (in increments of 10 deg). θ_2 ranged from 6 to 46 deg (in increments of 2 deg), and ω varied from 700 to 1200 deg/s (in increments of 50 deg per second). A matrix of ball release conditions was created by combining each variable in a round-robin manner.

(4) An initial condition vector, composed of the components x_0, y_0, and v_0 along the X and Y axes, as well as θ_1 and ω, was generated by sequentially selecting values from the matrix of ball release conditions.

(5) Building on the simulation method used in previous studies, the integration time—defined as the duration for assessing the success or failure of the trial after releasing the ball—was set to 1.5 s at 1 ms intervals, resulting in the creation of a time range vector.

(6) Following a previous example (The MathWorks, Inc., 2024), we used the *odeset* function to create an options structure that passes the mass matrix function (left-hand side of Equation 1) as an argument to the ODE solver, referencing the prior structure.

(7) The system of equations in Equation 1 was solved using *ode45*, a general-purpose ODE solver for non-stiff differential equations. This involved optional structures that referenced the time range vector, initial condition vector, and mass matrix function.

(8) The slope and intercept of the line segment connecting mass points 1 and 2 at a specific moment were calculated. The intersection of this line segment with the circular cross-section of the bar was then determined using the *linecirc* function, which is designed to find the intersection of a line and a circle in the Cartesian coordinate system (specifically in the XY plane).

(9) According to a previous study by Nakai and Tanaka (2022), most successful trials involving an actual throw resulted in the ball hanging on the bar, with the string touching the top and upper lateral surface of the bar. In this study, success or failure (i.e., whether the ball was hung on the bar) was determined by checking if the line segment connecting mass points 1 and 2 at a specific moment intersected with the upper semicircle of the bar's cross-section. If the trial was successful, the ball release conditions were sequentially recorded in the matrix.

Data analysis/Statistical analysis

The success rate was calculated by dividing the number of successful trials for each combination of ladder installation distance and bar height (hereafter referred to as the target condition) by the total number of ball release conditions from the simulations. Additionally, chi-squared goodness-of-fit tests were performed on the number of successful trials for each target condition, and post hoc multiple comparison tests were performed using Bonferroni's method. The distributions of x_0, y_0, v_0, θ_1, θ_2, and ω for successful trials in each target condition were analyzed using frequency distribution tables. The goodness of fit and normality of the data for each variable were assessed using a chi-square distribution and the Kolmogorov–Smirnov test, respectively. Scatter diagrams were created to illustrate the relationships between v_0 and θ_2 in the successful trials. Because normality could not be assumed for all variables, the median and interquartile range were calculated for each variable. Following the approach of Wobbrock, Findlater, Gergle, and Higgins (2011), a two-way analysis of variance for a between-subjects design was performed to investigate the main effects and interactions of ladder distance and bar height. Before this, an aligned rank transform (ART) was applied to the data. A post hoc multiple comparison test using ART-C (Elkin, Kay, Higgins, & Wobbrock, 2021) was also performed. All statistical analyses were performed using R version 4.3.1 (R Core Team, 2023), with a significance level set at 5%.

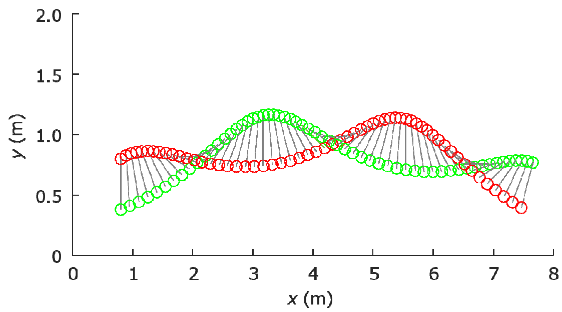

Fig. 2. A typical example of the motion of the entire ball, from the moment of release to hanging on the second bar at 7.5 m. This figure depicts a scenario where the ball is released under the following conditions: x_0 = 0.8 m, y_0 = 0.8 m, v_0 = 9.0 m/s, θ_1 = 270 deg, θ_2 = 18 deg, and ω = 900 deg/s.

Results

Figure 2 shows the typical trajectory of the entire ball, from the moment of release to the point of hanging on the second bar of the ladder positioned at 7.5 m, based on successful trials from the simulations performed in this study. This trajectory closely resembles that of the successful trials thrown by the subjects, as reported by Nakai and Tanaka (2022).

This study simulated a total of 2,174,040 ball release conditions, incorporating 6 different x_0 values, 6 different y_0 values, 61 different v_0 values, 6 different θ_1 values, 15 different θ_2 values, and 11 different ω values, combined in a round-robin fashion. At an installation distance of 5.0 m, there were 84,130 successful trials for the first bar, 137,556 for the second bar, and 192,459 for the third bar. At a distance of 7.5 m, the successful trials included 130,409 for the first bar, 153,450 for the second bar, and 167,532 for the third bar. The results of the chi-square and post hoc tests indicated that the number of successful trials varied significantly across target conditions ($\chi^2(5)$ = 47149.63, p < .001, w = 0.23), with significant differences observed between all conditions (all p < .001). The calculated success rates for the first, second, and third bars at an installation distance of 5.0 m were 3.9%, 6.3%, and 8.9%, respectively. At a distance of 7.5 m, the success rates were 6.0%, 7.1%, and 7.7%, respectively.

Figure 3 shows the frequency distributions of successful trials for x_0, y_0, v_0, θ_1, θ_2, and ω across each target condition. The chi-square test results indicated that the distributions of these variables were not uniform (χ^2(5–75) = 13.60–128396.18, all p < .05, w = 0.01–1.05), showing that the number of successful trials varied with changes in the variable values. Specifically, at an installation distance of 5.0 m, the number of successful trials decreased as x_0 increased, while at 7.5 m, it showed a slight increase (Fig. 3(a)). Conversely, the number of successful trials consistently decreased with increasing y_0 at both distances (Fig. 3(b)). As θ_1 increased, the number of successful trials increased at both 5.0 and 7.5 m until reaching a peak, after which it declined at a specific angle (Fig. 3(c)). For v_0, the number of successful trials decreased for the first bar at 5.0 m but increased up to a certain speed before declining for the second and third bars. At 7.5 m, all bars exhibited a similar bimodal distribution, with successful trials increasing to a certain speed, then decreasing, followed by another gradual increase before declining again (Fig. 3(d)). As θ_2 increased, the number of successful trials decreased at 5.0 m, while at 7.5 m, it increased to a certain angle before declining (Fig. 3(e)). For ω, there was a slight increase at 5.0 m, but a decrease was observed at 7.5 m (Fig. 3(f)). The successful trial combinations of v_0 and θ_2 were 568, 786, and 1,025 for the first, second, and third bars at 5.0 m, respectively, and 930, 1,059, and 1,170 for the first, second, and third bars at 7.5 m, respectively (Fig. 4).

The number of successful trials for all variables in each target condition was not normally distributed, as confirmed by the Kolmogorov–Smirnov test, which indicated a lack of normality (D = .09 to .23, all p < .001). Consequently, all variables in this study were treated as ordinal scales, and the median, along with quartile deviations, was calculated to assess the overall changes in ball release conditions for successful trials in relation to the target conditions. These results are presented in Table 1 and Fig. 5. The results of the two-way between-subjects ANOVA using ART showed that the main effects of both ladder distance, bar height, and their interactions had significant effects on x_0, y_0, v_0, θ_1, and θ_2, as shown in Table 1. For ω, both ladder distance and bar height had significant effects. Multiple comparison tests using ART-C revealed significant differences across all target conditions for x_0, y_0, v_0, θ_1, and θ_2, with a significant difference between the first and second bars at 5.0 m for θ_1 (p = .031) and all others showing p < .001.

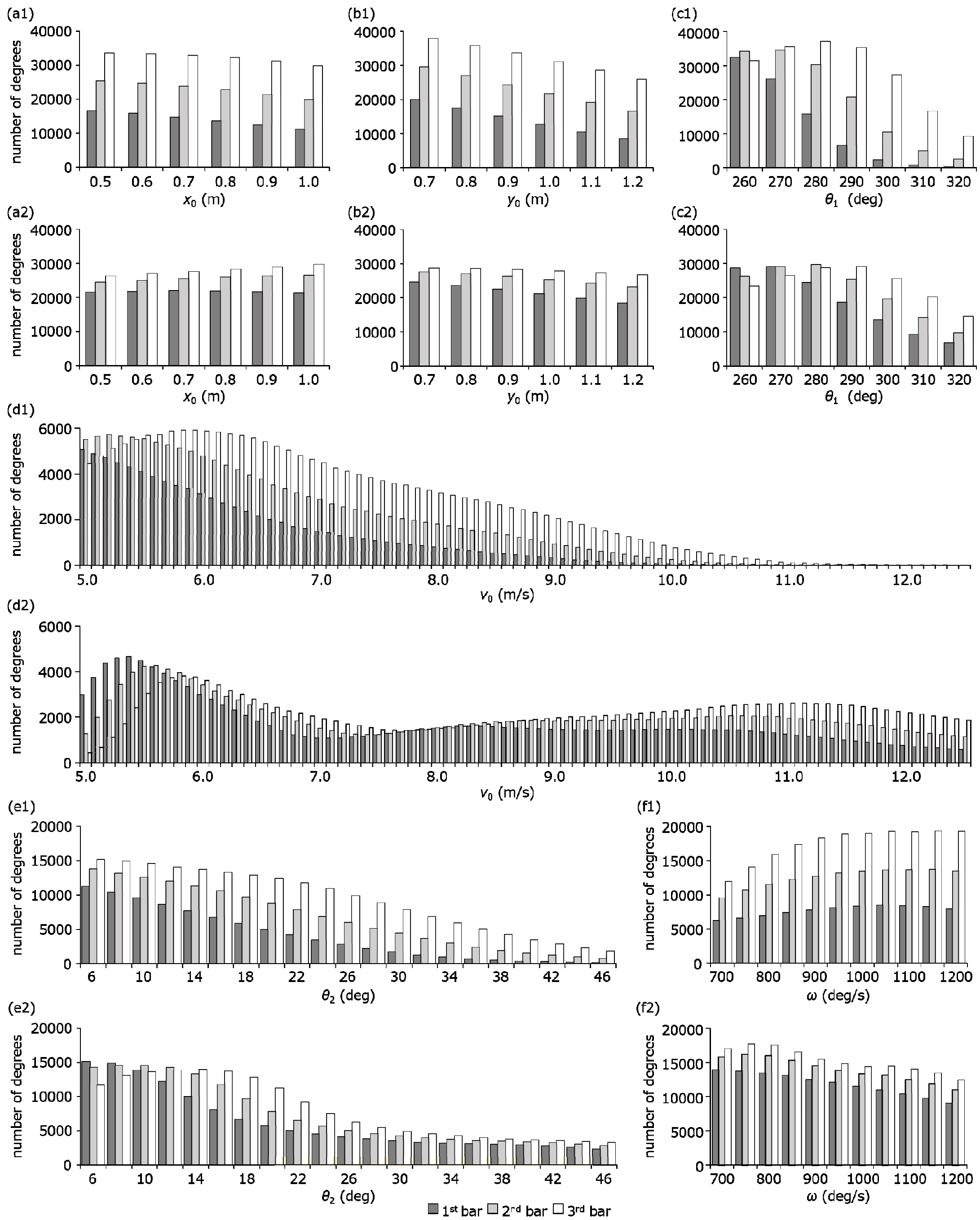

Fig. 3. Frequency distribution of the number of successful trials for the following variables in each target condition: (a) X coordinate, (b) Y coordinate, (d) initial velocity and (e) projection angle of mass point 1 and (c) angle and (f) rotational angular velocity of the string. The subscripts 1 and 2 refer to the installation distances of the ladder, specifically 5.0 and 7.5 m, respectively.

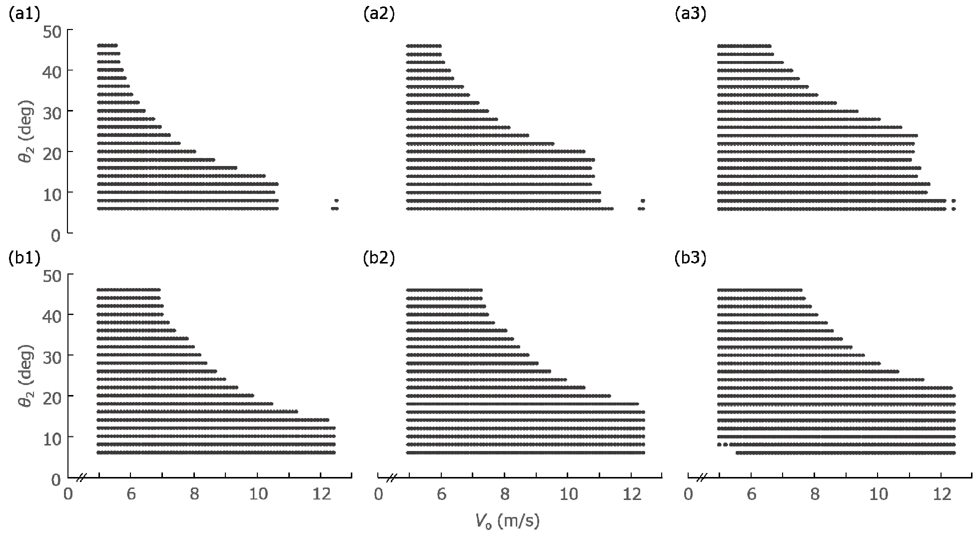

Fig. 4. All combinations of initial velocity and projection angle at the ball's release point. "a" and "b" denote the ladder installation distances of 5.0 and 7.5 m, respectively, while subscripts 1, 2, and 3 correspond to the first, second, and third bars.

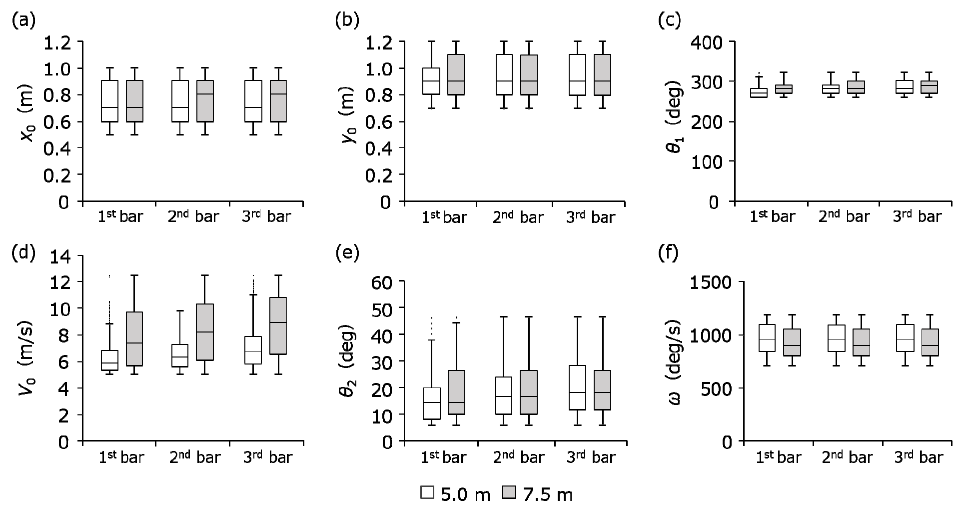

Fig. 5. Median and quartile deviation of (a) X coordinate, (b) Y coordinate, (d) initial velocity and (e) projection angle of mass point 1 and (c) angle and (f) rotation angular velocity of the string at the moment of ball release during successful trials for each target condition

Discussion

Chi-square test results on the number of successful trials for each target condition indicated that success rates were influenced by the ladder's installation distance and the bar's height. For both the 5.0 and 7.5 m installation distances, the number of successful trials was significantly higher on the second bar than on the first bar and on the third bar than on the second bar, indicating that the top bar has more successful ball release conditions, i.e., more likely to be successful, for the ladder getter's throw. On the third bar, the number of successful trials was significantly higher at 5.0 m compared to 7.5 m. This result agrees with previous research by Ohoka and Maeda (2013), which suggests that in general target-hitting tasks, closer targets are easier to hit. Conversely, the number of successful trials was significantly higher at the 7.5 m distance compared to the 5.0 m distance for the first and second bars, which contrasts with the findings of the previous study. In the earlier simulation (Nakai & Tanaka, 2023), success rates at the 7.5 m installation distance were 2.7%, 2.6%, and 2.2% for the first, second, and third bars, respectively. However, in this study, based on a larger number of trials, success rates were higher at 6.0%, 7.1%, and 7.7%, respectively. However, both success rates were lower overall. In a previous study (Nakai & Tanaka, 2022), participants achieved a success rate of 8.6% when throwing at the second bar from 7.5 m, which is higher than the 7.1% observed in this study. Notably, most successful trials in this study occurred in a specific range of initial velocities and projection angles. These findings suggest that the ladder throw, where the ball spins as it flies, is a complex motor task with only a limited set of conditions under which the ball will successfully hang over the bar. Thus, the throwing technique must be adapted to meet these

Table 1. Median and quartile deviation of individual variables at the moment of ball release during successful trials for each target condition

Variables		ladder distance						A: F(1,865529) B: F(2,865529) AxB: F(2,865529)		η_p^2
		5.0 m			7.5 m					
		bar height								
		1st bar	2nd bar	3rd bar	1st bar	2nd bar	3rd bar			
x_0	*Mdn*	0.7	0.7	0.7	0.7	0.8	0.8	A	1640.461 ***	< .01
	Q1	0.6	0.6	0.6	0.6	0.6	0.6	B	396.013 ***	< .01
	Q3	0.9	0.9	0.9	0.9	0.9	0.9	AxB	72.076 ***	< .01
y_0	*Mdn*	0.9	0.9	0.9	0.9	0.9	0.9	A	3085.480 ***	< .01
	Q1	0.8	0.8	0.8	0.8	0.8	0.8	B	918.280 ***	< .01
	Q3	1.0	1.1	1.1	1.1	1.1	1.1	AxB	134.230 ***	< .01
v_0	*Mdn*	5.9	6.3	6.7	7.4	8.2	8.9	A	119207.920 ***	.12
	Q1	5.4	5.6	5.8	5.7	6.1	6.5	B	918.280 ***	.02
	Q3	6.8	7.3	7.9	9.7	10.3	10.8	AxB	545.110 ***	< .01
θ_1	*Mdn*	270	280	280	280	280	290	A	32383.916 ***	.03
	Q1	260	270	270	270	270	270	B	22409.681 ***	.05
	Q3	280	290	300	290	300	300	AxB	2624.455 ***	< .01
θ_2	*Mdn*	14	16	18	14	16	18	A	14.065 ***	< .01
	Q1	8	10	12	10	10	12	B	6090.533 ***	.01
	Q3	20	24	28	26	26	26	AxB	890.561 ***	< .01
ω	*Mdn*	950	950	950	900	900	900	A	10200.872 ***	.01
	Q1	850	850	850	800	800	800	B	72.093 ***	< .01
	Q3	1100	1100	1100	1050	1050	1050	AxB	2.540	< .01

Note. x_0 and y_0 = coordinates of mass point 1, v_0 = initial velocity vector, θ_1 = angle of the string, θ_2 = projection angle of mass point 1, ω = angular velocity of the string at ball release; Factor A = ladder distance; Factor B = bar height; η_p^2 = partial eta squared; *** p < .001.

specific conditions. In real-world throwing, certain conditions are selectively used from this set, suggesting that the understanding of successful release conditions is developed through repeated practice. As a result, the throwing technique is refined over time, leading to a higher success rate compared to simulations. Therefore, in the ladder getter, it is important to communicate the conditions for a successful ball release by demonstrating specific examples and allowing participants to observe actual successful trials. For participants unfamiliar with the ladder getter, repeatedly practicing throws at the third bar at 5.0 m, which has the highest success rate, and adjusting their throwing technique accordingly is considered an effective way to help them achieve success more quickly.

Goodness of fit tests on the number of successful trials for each variable revealed that their frequencies were not uniform across all variables, indicating that the number of successful trials fluctuated with changes in variable values (Fig. 3). For each target condition, the number of successful trials did not show significant increases or decreases with changes in x_0 and y_0, but did significantly vary with changes in v_0, θ_1, or θ_2, as previously described. These results suggest that for each target condition, there are specific variable values associated with a higher number of successful trials in the range identified in this study, i.e., ball release conditions that are more likely to be successful. As y_0 or θ_1 increased, the number of successful trials correspondingly decreased. This phenomenon may be attributed to the relationship between y_0 and θ_1, where attempting to release the swung ball from a higher position tends to result in the string facing forward during release. In general, the reach of a projectile is influenced by three factors: initial velocity, projection angle, and release height (Ishii, 1980). The number of successful trial combinations for the v_0 and θ_2 variables across each target condition (Fig. 4) tended to decrease once v_0 surpassed a certain threshold, with the angle θ_2 at which the ball hung on the bar becoming smaller as v_0 increased. This pattern mirrors the trend seen in the number of successful trials, indicating that both the initial velocity and the projection angle of the ball significantly affect the number of successful trials. The number of combinations for v_0 and θ_2 in successful trials was more frequent for the upper bar at the same installation distance and for the bar at the same height at a greater installation distance. These findings align with the trends discussed in the number of successful trials based on target conditions. This reflects a "speed–accuracy trade-off," where the accuracy of a target-hitting task is influenced by the speed of the projectile—focusing on speed tends to reduce accuracy while prioritizing accuracy can decrease speed (Toyoshima & Hoshikawa, 1976; Toyoshima, Hoshikawa, & Ikegami, 1981; Sakurai, 1992). When the target is farther away, a higher initial velocity is inevitably necessary, which often leads to reduced accuracy. This study's finding that a greater θ_2 corresponds with successful trials at low v_0, while a smaller θ_2 is associated with high v_0, is consistent with previous research. In summary, the success or failure of the ladder getter is significantly influenced by the initial velocity and the projection angle of the ball, as well as the angle of the string at the moment of ball release.

The interquartile range of variables for each target condition presented in Table 1 and Fig. 5 represents the central 50% of data from successful trials. It is believed that throwing under ball release conditions where each variable falls in these ranges is likely to result in success. As previously mentioned, having participants observe throws directed at the target under these conditions is thought to effectively enhance their understanding. As indicated in Table 1, all variables, except ω, significantly increased with greater ladder installation distances, and all variables were significantly higher at increased bar heights. These relationships suggest that as the ladder installation distance increases and the bar height increases, the ball must be released more forward and upward. Taking into account the previously mentioned relationship between y_0 and θ_1, the patterns illustrated in Fig. 4, and the effect sizes presented in Table 1, adjusting the initial velocity and projection angle at the moment of release is essential for successful throws across varying ladder installation distances and bar heights.

Conclusions

In this study, we developed a Lagrangian formulation to analyze the motion of the ball when thrown by a ladder getter and simulated it under various conditions to investigate the scenarios in which the ball successfully hangs on the ladder as the installation distance and target bar height are changed. The results revealed the following. 1) The ladder getter has only a limited number of release conditions that allow the ball to hang on the bar, making it a complex motor task that requires adjustments in the throwing technique. 2) The closer the ladder is installed and the higher the bar, the greater the likelihood of successful ball release conditions. 3) Throwing with ball release conditions that align each variable in the interquartile range increases the chances of success. 4) The ball's ability to hang is significantly influenced by the initial velocity and projection angle at the moment of release, making it crucial to adjust these factors when setting the ladder distance and bar height. Based on these findings, it is believed that providing support to reinforce participants' understanding by demonstrating specific ball release conditions and allowing them to observe actual successful trials will be beneficial. Additionally, for those unfamiliar with the ladder getter, having them repeatedly aim for the third bar at 5.0 m—where the success rate is highest—would effectively help them quickly experience the most enjoyable aspects of the task. The next step will be to implement these supportive measures for the participants and evaluate their impact.

Conflicts of interest The authors have no conflicts of interest directly relevant to the contents of this article.

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