QUANTIFYING THE DIFFICULTY OF SPECIFIC MOVEMENTS IN THE STRADDLE VAULT FOR ELEMENTARY SCHOOL CHILDREN

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Abstract

The degree of difficulty of specific movements can be considered as movement information that teachers use to guide exercise instruction. The purpose of the present study was to quantify the difficulty of the movements comprising the straddle vault for 3rd and 4th grade elementary school children. A total of 538 children (263 boys, 275 girls from the 3rd and 4th grades participated in this study. Their straddle vault movements were recorded from both the left and front sides of the individuals and scored using an observational evaluation criterion. After confirming the unidimensionality of the items, item difficulty (b) was estimated using item response theory (IRT). Additionally, differential item functioning (DIF) was investigated to determine whether the difficulty varied depending on grade level. The following findings emerged from estimating the difficulty levels using IRT: Movements involving taking off from a stable run-up (b = -4.952 to -1.833) and shifting weight forward (b = -0.610 to -0.048) were classified as low-difficulty. Movements requiring a bouncy take-off (b = 0.131 to 0.360) and stable landing (b = 0.012 to 0.816) were of medium difficulty. Regarding landing, DIF was detected, indicating that this movement was more difficult for 3rd graders than for 4th graders. Movements involving turning rotation (b = 1.026 to 1.309) and landing aggressively (b = 1.152 to 1.806) were categorized as high-difficulty. Dynamic take-off movements were identified as extremely difficult (b = 2.432 to 3.824). In conclusion, it is necessary to develop a teaching program that accounts for the difficulty of these movements and to verify its effectiveness.

Keywords: *physical education, difficulty of movements, straddle vault, elementary school, item response theory, difference item functioning.*

INTRODUCTION

The straddle vault has been incorporated into the gymnastics curriculum in various countries (Kovač, 2012; Steenberg, 2019). Its achievement is closely related to physical fitness factors (e.g., flexibility, muscle strength, and endurance). Thus, the straddle vault is an important exercise for improving physical strength and evaluating motor abilities in childhood (Halilaj et al., 2018).

The straddle vault is relatively easy for many children to accomplish, as evidenced by the high achievement rates reported in studies of children (Hedbávný et al., 2017; Jovanović et al., 2019). However, as it is the most basic technique, children who cannot perform it may experience discomfort or feelings of inferiority. In Japan, gymnastics instruction begins in the 3rd or 4th grades of elementary school. The achievement rate of the straddle vault increases until the 4th grade, after which it shows little change (Kokudo et al., 2003). Therefore, high-quality instruction is essential to improve straddle vault skills at an early stage in elementary school.

Research on gymnastics instruction, including the straddle vault, has primarily focused on the effects of the number of training sets and interval settings on skill proficiency (Ivashenko et al., 2018; Rukavytsia et al., 2022), as well as the ratio of time allocated to various training methods (Ivashenko et al., 2021). These studies mainly address methods for structuring instruction. Conversely, there has been limited research aimed at understanding the characteristics of the straddle vault movement as a teaching material.

Regarding the straddle vault, Majerič et al. (2016) and Sano & Kokudo (2022) have proposed detailed evaluation criteria. These studies, which facilitate detailed movement evaluations, play an effective role in identifying the sub-movements that constitute the straddle vault and understanding the temporal order of these movements.

In addition to clarifying the constituent movements and the order of their occurrence, as described above, the degree of difficulty of specific movements that make up the straddle vault can serve as valuable information for teachers in guiding exercise instruction. Specifically, understanding the degree of difficulty of movements is highly beneficial for teachers, as it supports both skill improvement and safety in their teaching practices.

In terms of skill improvement, setting practice tasks in stages from easy to difficult and tailoring instruction to the practitioner's level is highly effective (Guadagnoli & Lee, 2004). Once the level of difficulty of the movements is clear, optimal tasks can be designed based on the difficulty of the movements to be mastered and the child's skill level.

Regarding safety, the risk of injury in gymnastics is significant, as supported by extensive research examining injury characteristics such as athletic level and injury site (Hart et al., 2018). In fact, vaulting box-related injuries account for the largest number of injuries reported annually in physical education classes at Japanese elementary schools (Hattori, 2023). Todaro (1988) noted that the incidence of injuries in gymnastics can be reduced through the proper use of equipment and instructional methods by coaches or teachers. By being mindful of the difficulty levels of movements, teachers can avoid assigning overly demanding tasks to individual children, thereby reducing the risk of injury during vaulting practice.

Despite the above potential applications to instruction, there has been no attempt to quantify the difficulty of the specific movements that make up the straddle vault (e.g., run-up, take-off, landing). One method that can quantify the difficulty of movements is item response theory (IRT). IRT allows for the estimation of both a respondent's ability score and the difficulty of items based on responses to multiple tasks. In the fields of education and sports, IRT has been applied to evaluate students' abilities and the difficulty of learning or exercise tasks (Ando et al., 2018; Magistro et al., 2020; Matsuoka et al., 2020).

A valuable example of research aimed at quantifying the difficulty of movements is provided by Čepička (2003), who identified six critical features of overhand throwing movements in elementary school students and used the Rasch model (a type of IRT model) to estimate the difficulty of each feature. Furthermore, the application of IRT enables the detection of differential item functioning (DIF), which highlights differences in difficulty across various groups (e.g., gender, grade level). It has been reported that grade-level differences exist in elementary school students' proficiency in the straddle vault (Sano & Kokudo, 2022). Detecting DIF could help clarify differences in the difficulty of movements based on grade level.

Based on the above, the purpose of this research is to quantify the difficulty of the movements that make up the straddle vault for 3rd and 4th grade elementary school children. The quality of gymnastics instruction is influenced by the teacher's expertise (Kovač et al., 2020). However, in Japanese elementary schools, it is common for general teachers (not PE specialists) to teach physical education classes. Therefore, it is important to create evidence-based materials that supplement their expertise and are useful for teaching.

METHODS

The subjects were 538 children in 3rd and 4th grades (263 boys and 275 girls) from five elementary schools in Japan. The children's ages ranged from 8–9 years in 3rd grade and 9–10 years in 4th grade. Most children learn the straddle vault as a basic technique in the 3rd or 4th grades of elementary school. In 5th and 6th grades, they are instructed to learn the squat vault as an advanced technique. Therefore, developing sufficient skill in performing the straddle vault during 3rd or 4th grade will have a significant impact on subsequent learning. Based on this background, this study focuses on the movements of 3rd and 4th grade students.

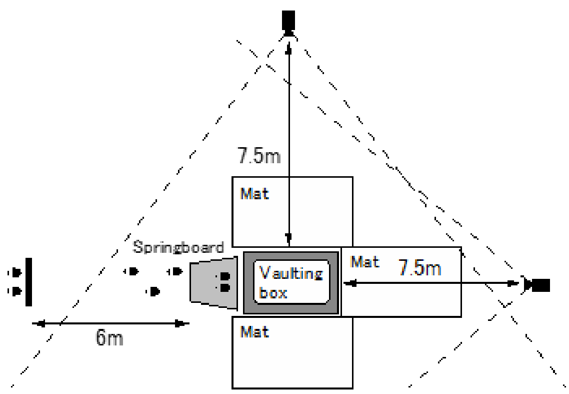


Figure 1: Shooting settings.

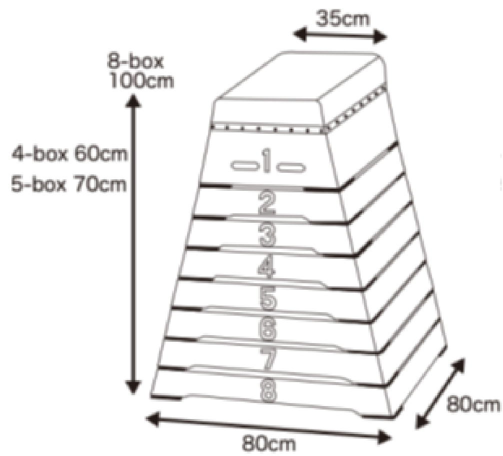


Figure 2: Vaulting box in the survey

A video recording survey of the straddle vault was conducted. After a warm-up exercise, the children performed two practice attempts followed by one actual attempt. The attempt was recorded from the front and left sides of the child, starting three steps before take-off (Figure 1). A small vaulting box compliant with Japanese Ministry of Education standards was used (Figure 2). The height of the box was set to either 4-box (60 cm) or 5-box (70 cm), corresponding to the heights used in physical education classes at the target school. The children selected their preferred height. The box was placed longitudinally, requiring children to jump over a distance of 80 cm.

The following two instructions were given verbally and displayed on flip cards for the children:

1. Even if you can't jump over the vaulting box, try to jump as far as you can.
2. If you can jump over the box, try your best to land stably.

The recording was set to 60 fps, with a shutter speed of 1/500 seconds, in 4K resolution.

Before the survey, the research was explained to the children, and consent forms were distributed to their legal representatives. Consent for participation was obtained by collecting the signed consent forms. Additionally, approval was granted by the research ethics review committee at Chukyo university (approval number: 2023-033).

For the evaluation, we used the observational evaluation criteria (Table 1) for the straddle vault developed by Sano & Kokudo (2022). According to these criteria, the straddle vault is divided into six movement phases, with a total of 30 evaluation items. These items can be assessed observationally on a scale of 1–2 or 1–3 points. If no further action was taken, such as stopping on the vaulting box, the score was recorded as 0 ("Not appear").

Videos were analyzed using normal, slow-motion, and frame-by-frame playback, and the movements were scored based on the evaluation criteria. In principle, the evaluation was conducted by observing the movements from both the front and side cameras. However, if a movement was obscured by the vaulting box and could not be seen from the front camera, the evaluation was carried out solely using the side camera footage. For example, Item 6 (Aligning legs) or Item 14 (Timing of grounding) were scored as 1 if both feet (legs) were clearly misaligned when viewed from the side.

The evaluations were conducted by two researchers who were experienced in the observational evaluation of children's movements. One evaluator was a physical education researcher with three years of experience as an elementary school teacher, and the other was a graduate student with 15 years of gymnastics experience.

Table 1
Observational evaluation criteria of straddle vault movement (Sano & Kokudo, 2022).

Item	Category/Score	3	2	1	0
[1] Run-up and hurdle step onto the springboard					
1	Stride adjustment	-	Smooth stride	Stride becomes smaller	-
2	Speed adjustment	-	Smooth speed	Speed slows down	-
3	Leading by free leg	-	Knee angle ≦ 90°	Knee angle ＞ 90°	-
4	Pushing by stepping leg	-	There is a flight period	There is no flight period	-
5	Adjusting free leg flexion	-	Center of foot below the knee	Heels below the knee	-
6	Aligning legs	-	Aligned	Not aligned	-
7	Swing arms backward	Stretch and pull arms	Bend and pull arms	Not pull arms	-
8	Aligning arms	-	Aligned	Not aligned	-
9	Tightening aside	-	Sides are tight	Sides are open	-
10	Attracting arms	-	Hands are below the waist	Hands are above the waist	-
[2] Take-off from the springboard					
11	Making a body axis	-	Shoulders, knees, feet are in a straight line	Not in a straight line	-
12	Swing up arms	Swing up big	Swing up small	Not swing up or swing down	-
13	Preemption of grounding	Step on forefoot	Put weight on forefoot	Ground sequentially from heel	-
14	Timing of grounding	-	Ground at the same time	Not ground at the same time	-
15	Rebound jump	Knees extend at the same time as ground	Knee flexion fixed	Knees flex after ground	-
[3] First flight phase					-
16	Swing arms forward	Touch box after leg extension	Touch box at the same time as legs extension	Touch box before leg extension	-
17	Raising hips	Above shoulder	Above midpoint of shoulders and elbows	Below midpoint of shoulders and elbows	-
[4] Approach and push-off from the vaulting box					
18	Aligning both hands	-	Aligned	Not aligned	-
19	Timing of putting hands	-	Touch at the same time	Not touch at the same time	-
20	Push-off	Push-off	Push backwards	Stop or buffer by hand	-
21	Raising shoulders	Shoulders go up	Shoulders move forward	Shoulders stop at the position of hands	-
22	Keeping legs extended	-	Open legs with legs extended	Open legs with knees bent	-
[5] Second flight phase					
23	Rotating backward	-	Turn back the rotation	Not turn back the rotation	NA
24	Looking to the landing position	-	Look at the landing position	Looking straight down	NA
25	Control of leg swing	-	Control the swing	Swing legs forward	NA
26	Closing legs	-	Legs are closed and aligned	Not closed and aligned	NA
27	Raising arms	Raise forward	On the side of body	Behind the body	NA
[6] Landing					
28	Swing down arms	Swing arms down	Raise arms	Not swing down or raise	NA
29	Flexing lower limbs	Flex hips and knees	Flex knees	Stretch knees	NA
30	Stopping firmly	-	Stop firmly	Not stop firmly	NA

NA：Not appear (these children were not able to jump over the box and accomplish the vault)

Item response theory (IRT) was used to quantify movement difficulty. Compared to classical test theory, which measures ability based on overall test scores, IRT—often referred to as "new test theory"—is said to have higher validity. In IRT, an individual's ability value (θ) is estimated based on their responses to test items, while the characteristics of each item are expressed as item discrimination (a) and item difficulty (b). Because an individual's ability value is estimated while accounting for the characteristics of each item, it allows for a more accurate estimation of ability.

Item discrimination indicates how effectively an item can distinguish between different ability levels. If a test consists of items with high discrimination values, the ability levels of subjects can be evaluated more accurately. Therefore, discrimination values are often used in the process of constructing and refining evaluation scales.

On the other hand, item difficulty represents the ability level required to respond correctly to an item. For example, if a certain evaluation item has two response categories, such as 1 point ("bad") and 2 points ("good"), IRT estimates the probability of selecting each category as the ability level increases. The ability value at which the probability of selecting the 2-point category exceeds that of selecting the 1-point category is defined as the item difficulty value.

In this study, we quantified the degree of difficulty in performing movements by estimating the difficulty of items in the evaluation criteria using IRT.

As a prerequisite for conducting IRT, it is necessary to confirm the unidimensionality of the items. To do this, we performed a categorical factor analysis on the 30 items and checked whether the eigenvalue of the first factor was significantly larger than those of the subsequent factors. Additionally, items with a factor loading of less than 0.3 on the first factor were excluded from the IRT analysis.

IRT was then applied to items with factor loadings of 0.3 or higher on the first factor. The evaluation criteria included some items with three or more categories. Therefore, the IRT model used was a graded response model (Shojima, 1969), which can handle polytomous variables. In models for dichotomous variables, a single difficulty value is output for each item. However, in the graded response model, difficulty values are output for transitions between categories within an item (e.g., 3 points ← 2 points, 2 points ← 1 point).

In addition to estimating item difficulty, we examined differential item functioning (DIF) for each item by grade. DIF refers to the phenomenon in which subjects with the same ability level have different response probabilities for a specific item depending on the subgroup to which they belong. Previous studies have detected DIF in test items based on factors such as gender, age, or nationality (Okuda et al., 2017; Muelas et al., 2019; Geramipour & Shahmirzadi, 2019).

R version 4.3.1 was used as the analysis software. The Psych package (Revelle, 2011) was utilized for categorical factor analysis, and the lordif package (Choi et al., 2011) was employed for IRT. The lordif package can estimate both non-uniform DIF, which reflects differences in item discrimination, and uniform DIF, which reflects differences in item difficulty.

In this study, we focused on uniform DIF to examine differences in item difficulty by grade. The likelihood ratio test was conducted to detect DIF, using the default significance level of $\alpha = 0.01$. The effect size of DIF was evaluated using pseudo R^2, following the criteria established by Jodoin & Gierl (2001): values < 0.035 indicate negligible effects, values < 0.070 indicate moderate effects, and values ≥ 0.070 indicate large effects.

RESULTS

In this study, 414 children successfully completed the vault, consisting of 213 boys (51.4%) and 201 girls (48.6%). Meanwhile, 124 children were unable to jump over the box and complete the straddle vault, including 50 boys (40.3%) and 74 girls (59.7%). More 3rd-grade children (79) failed to accomplish the vault compared to 4th-grade children (45).

Table 2 shows the score distribution of the behavioral evaluation results and the outcomes of the categorical factor analysis. In the scree plot (Figure 3), the eigenvalues of each factor were 10.964 for the first factor, 2.747 for the second, and 1.657 for the third. Since the eigenvalue of the first factor was significantly larger, it was determined that the items in the evaluation criteria demonstrated unidimensionality. However, nine items with a factor loading of less than 0.3 on the first factor—Items 3, 6, 7, 8, 9, 10, 12, 18, and 19—were excluded from the IRT analysis.

Table 2
Score distribution and categorical factor analysis results.

Item		Score distribution				Factor loading				
		3	2	1	0	1	2	3	4	5
1	Stride adjustment	-	93.5%	6.5%	-	0.360	0.561	0.054	-0.373	-0.041
2	Speed adjustment	-	96.1%	3.9%	-	0.486	0.503	0.106	-0.338	-0.101
3	Leading by free leg†	-	71.9%	28.1%	-	0.264	0.239	0.331	-0.219	0.051
4	Pushing by stepping leg	-	93.1%	6.9%	-	0.360	0.359	0.504	-0.233	0.149
5	Adjusting free leg flexion	-	46.1%	53.9%	-	0.617	-0.291	0.229	0.377	0.091
6	Aligning legs†	-	77.7%	22.3%	-	0.289	0.234	0.415	-0.085	0.365
7	Swing arms backward†	2.2%	9.7%	88.1%	-	0.042	0.599	0.057	0.304	-0.217
8	Aligning arms†	-	61.2%	38.8%	-	0.206	0.282	-0.117	0.066	0.409
9	Tightening aside†	-	54.6%	45.4%	-	0.203	0.357	-0.055	0.338	-0.017
10	Attracting arms†	-	21.0%	79.0%	-	0.038	0.696	0.040	0.371	-0.153
11	Making a body axis	-	49.6%	50.4%	-	0.669	-0.295	0.163	0.296	0.035
12	Swing up arms†	2.6%	12.5%	84.9%	-	0.144	0.573	-0.012	0.477	-0.197
13	Preemption of grounding	3.7%	46.8%	49.4%	-	0.570	-0.328	0.207	0.367	0.069
14	Timing of grounding	-	66.7%	33.3%	-	0.329	-0.027	0.382	0.046	0.462
15	Rebound jump	5.0%	44.2%	50.7%	-	0.670	-0.252	0.147	0.346	0.072
16	Swing arms forward	33.3%	28.6%	38.1%	-	0.572	0.222	-0.100	0.200	0.136
17	Raising hips	5.8%	60.8%	33.5%	-	0.690	0.018	-0.009	-0.005	-0.052
18	Aligning both hands†	-	79.7%	20.3%	-	0.024	0.177	-0.594	0.100	0.370
19	Timing of putting hands†	-	75.5%	24.5%	-	0.075	0.235	-0.559	-0.002	0.420
20	Push-off	7.2%	69.1%	23.6%	-	0.919	-0.083	-0.082	-0.047	-0.057
21	Raising shoulders	13.4%	63.0%	23.6%	-	0.890	-0.073	-0.091	-0.050	-0.060
22	Keeping legs extended	-	53.3%	46.7%	-	0.492	-0.229	-0.106	-0.016	-0.185
23	Rotating backward	-	5.9%	70.6%	23.4%	0.916	-0.078	-0.081	-0.061	-0.060
24	Looking to the landing position	-	55.6%	21.0%	23.4%	0.847	-0.002	-0.090	-0.109	-0.067
25	Control of leg swing	-	4.8%	83.3%	11.9%	0.814	-0.069	-0.013	-0.136	-0.026
26	Closing legs	-	53.9%	22.7%	23.4%	0.884	0.006	-0.134	-0.076	-0.074
27	Raising arms	2.4%	16.7%	57.4%	23.4%	0.841	-0.056	-0.100	-0.062	-0.083
28	Swing down arms	5.6%	29.2%	41.8%	23.4%	0.819	-0.021	-0.137	-0.107	-0.016
29	Flexing lower limbs	13.8%	43.1%	19.7%	23.4%	0.821	0.022	-0.124	-0.092	-0.037
30	Stopping firmly	-	40.9%	35.7%	23.4%	0.871	0.036	-0.131	-0.086	-0.046
				Eigenvalue		10.964	2.747	1.657	1.553	1.080

†: Items were excluded from the analysis of IRT

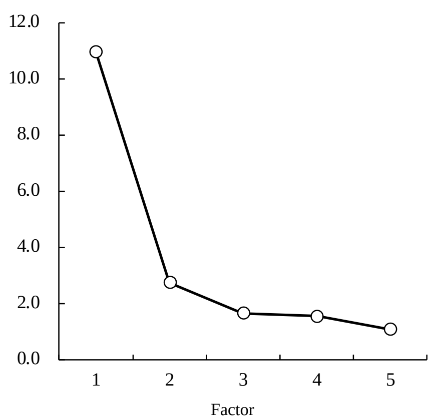


Figure 3. Scree plot.

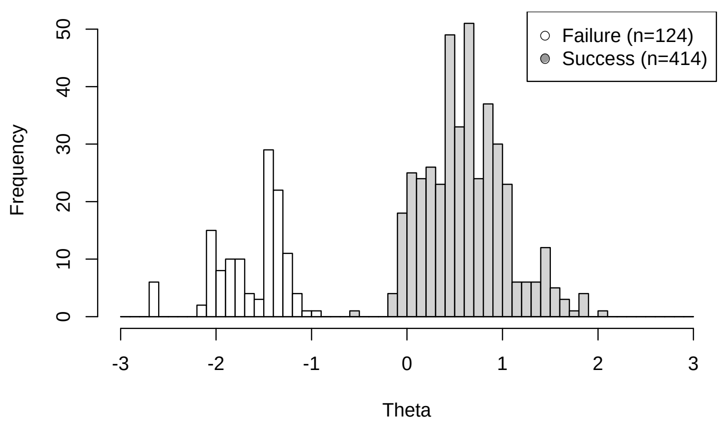


Figure 4. Distribution of subject's ability values.

As a result of applying IRT to 21 items, the ability value (θ), item discrimination (a), and item difficulty (b) were estimated. Figure 4 shows the distribution of the subjects' ability values, which displayed a bimodal distribution. This was due to the clear separation between the ability values of children who were unable to jump over the vaulting box ("Failure": n=124) and those who successfully jumped over the box ("Success": n=414).

Table 3 presents the discrimination and difficulty values of the items without considering DIF. Discrimination values were estimated to range from **a** = 0.393 to **a** = 41.068. A general trend was observed where discrimination values were higher in the later movement phases, with Item 23 (**a** = 41.068) and Item 20 (**a** = 18.516) being particularly high. Difficulty values ranged from **b** = -4.775 to **b** = 3.809. The difficulty level was lower in the run-up and hurdle step phases, while it was higher in the upper categories of the take-off phase.

Table 3
Values of item discrimination (a) and item difficulty (b).

Item		*a*	*b*	
			3←2	2←1
1	Stride adjustment	0.642	-	-4.406
2	Speed adjustment	0.970	-	-3.796
4	Pushing by stepping leg	0.571	-	-4.775
5	Adjusting free leg flexion	1.068	-	0.355
11	Making a body axis	1.209	-	0.205
13	Preemption of grounding	0.974	3.809	0.128
14	Timing of grounding	0.393	-	-1.737
15	Rebound jump	1.370	2.702	0.235
16	Swing arms forward	0.985	1.019	-0.420
17	Raising hips	1.529	2.416	-0.441
20	Push-off	18.516	1.257	-0.534
21	Raising shoulders	6.254	1.127	-0.613
22	Keeping legs extended	0.810	-	-0.046
23	Rotating backward	41.068	-	1.314
24	Looking to the landing position	3.507	-	0.230
25	Control of leg swing	3.434	-	1.701
26	Closing legs	5.478	-	0.306
27	Raising arms	4.323	1.820	1.023
28	Swing down arms	3.675	1.571	0.688
29	Flexing lower limbs	3.811	1.217	0.220
30	Stopping firmly	6.036	-	0.557

Table 4 shows the estimation results using IRT when considering DIF by grade. The range of estimated discrimination values was **a** = 0.373 to **a** = 39.183, and the range of difficulty values was **b** = -4.952 to **b** = 3.824, which were almost identical to the estimation results without considering DIF. Non-uniform DIF, which indicates differences in item discrimination by grade, was not detected because the α value in the likelihood ratio test was not less than 0.01 in any case. On the other hand, uniform DIF, which indicates differences in item difficulty by grade, was detected for Items 24, 26, 29, and 30. This revealed that the movements evaluated by these four items differed in difficulty between 3rd and 4th graders.

- **Item 24** evaluates the direction of the line of sight after jumping over the box. The difficulty value for 3rd graders was **b** = 0.377, while for 4th graders, it was **b** = 0.114, indicating a higher difficulty level for 3rd graders.
- **Item 26** evaluates the movement of closing and aligning the legs that were opened before landing. For 3rd graders, **b** = 0.502, and for 4th graders, **b** = 0.137, showing that the difficulty level was higher among 3rd graders.
- **Item 29** evaluates the movement of bending the hips and knees to buffer the impact upon landing. For 3rd graders, the difficulty from 1 to 2 points was **b** = 0.444, and from 2 to 3 points was **b** = 1.340. For 4th graders, the difficulty from 1 to 2 points was **b** = 0.012, and from 2 to 3 points was **b** = 1.152, indicating a higher level of difficulty for 3rd graders.
- **Item 30** evaluates the static posture upon landing. For 3rd graders, **b** = 0.816, and for 4th graders, **b** = 0.380, again showing higher difficulty among 3rd graders.

The effect size (pseudo R^2) was negligible for Item 24 (0.011), Item 26 (0.034), and Item 29 (0.023), but moderate for Item 30 (0.067).

Table 4
Values of item discrimination (a) and item difficulty (b) considering DIF.

Item			*a*	*b* 3←2	*b* 2←1	Uniform DIF *α*	Uniform DIF *Pseudo R^2*	Non-uniform DIF *α*	Non-uniform DIF *Pseudo R^2*
1	Stride adjustment		0.621	-	-4.557	0.302	0.004	0.311	0.004
2	Speed adjustment		0.938	-	-3.924	0.877	0.000	0.868	0.000
4	Pushing by stepping leg		0.550	-	-4.952	0.474	0.002	0.827	0.000
5	Adjusting free leg flexion		1.067	-	0.360	0.708	0.000	0.738	0.000
11	Making a body axis		1.212	-	0.211	0.868	0.000	0.153	0.003
13	Preemption of grounding		0.972	3.824	0.131	0.695	0.000	0.999	0.000
14	Timing of grounding		0.373	-	-1.833	0.199	0.002	0.286	0.002
15	Rebound jump		1.383	2.693	0.243	0.556	0.000	0.711	0.000
16	Swing arms forward		0.959	1.041	-0.432	0.080	0.003	0.967	0.000
17	Raising hips		1.519	2.432	-0.445	0.975	0.000	0.472	0.001
20	Push-off		31.620	1.214	-0.497	0.834	0.000	1.000	0.000
21	Raising shoulders		6.439	1.129	-0.610	0.294	0.001	0.980	0.000
22	Keeping legs extended		0.799	-	-0.048	0.684	0.000	0.469	0.001
23	Rotating backward		39.183	-	1.309	0.772	0.000	0.704	0.000
24	Looking to the landing position	3rd	3.168	**-**	**0.377**	**<0.01***	**0.011**	0.195	0.002
		4th	3.533	**-**	**0.114**				
25	Control of leg swing		3.410	-	1.707	0.314	0.002	0.955	0.000
26	Closing legs	3rd	5.319	**-**	**0.502**	**<0.01***	**0.034**	0.548	0.000
		4th	5.098	**-**	**0.137**				
27	Raising arms		4.465	1.806	1.026	0.164	0.002	0.463	0.001
28	Swing down arms		3.647	1.579	0.700	0.033	0.003	0.677	0.000
29	Flexing lower limbs	3rd	3.687	**1.340**	**0.444**	**<0.01***	**0.023**	0.802	0.000
		4th	3.769	**1.152**	**0.012**				
30	Stopping firmly	3rd	5.829	**-**	**0.816**	**<0.01***	**0.067**	0.010	0.006
		4th	6.326	**-**	**0.380**				

*: The *α* of the likelihood ratio test to detect DIF was less than 0.01

DISCUSSION

As a result of categorical factor analysis, unidimensionality was confirmed. The straddle vault is performed by purposefully combining multiple movements, from the run-up to landing. It is thought that the unidimensionality of the items was found because each movement contributes effectively to the performance of the straddle vault. However, nine items were excluded from the IRT analysis, seven of which were related to arm movements before reaching the box (Items 7, 8, 9, 10, 12, 18, 19). These items were also excluded from the analysis in the study by Sano & Kokudo (2022). At the elementary school stage, it is thought that the arm movements in the take-off phase have little relation to the overall proficiency level of the straddle vault.

Estimation of ability value and item discrimination using item response theory

The distribution of straddle vault ability values among the 538 children showed a bimodal pattern. It has been noted that gymnastics has a characteristic that clearly differentiates between those who can perform the exercise and those who cannot, and this was reflected in the distribution of ability in this study. What should be emphasized is that the ability values within each group span a certain range. The ability scores of children who successfully jumped over the box were widely distributed from $\theta = -0.5$ to $\theta = 2.5$. Based on these results, although jumping over the box is often set as an achievement standard when learning the straddle vault, there remains potential for improvement and further development in movement even after this milestone.

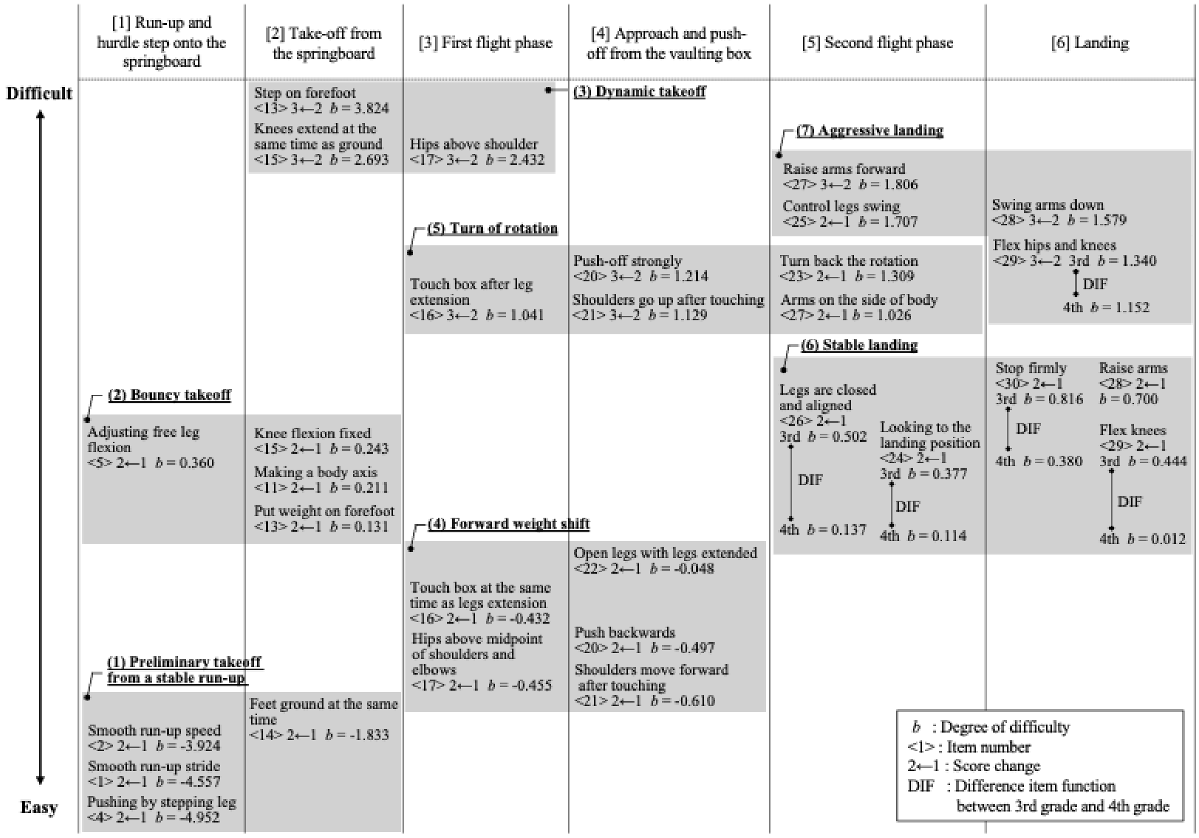
Ayanwale et al. (2024) indicate that the criteria for item discrimination values are as follows: less than 0.65 is considered low, and less than 0.35 is considered very low. In the analysis results, there were no items with a value less than 0.35, and the items with values less than 0.65 were Item 14, 4, and 1. Discrimination values for evaluation items in the later stages tended to be higher. The average from [1] Run-up and hurdle step onto the springboard to [3] First flight phase was 0.971 (range: 0.393-1.529), while the average from [4] Approach and push-off from the vaulting box to [6] Landing was 8.810 (range: 0.810-41.068). Kokudo (2012) shows that the outcome of the previous movement influences the subsequent movement, and the performance of the whole sequence is significantly impacted by the latter movements. Therefore, in evaluating the overall performance of the straddle vault, it is highly effective to assess movements after the push-off phase. However, successful performance in the vault requires the connection and optimization of each movement's elements (Bradshaw, 2010). In terms of exercise instruction, it is important to design a comprehensive instructional program that takes into account the difficulty level of each movement rather than focusing solely on practicing movements with high discrimination values.

Possibility of application to instruction on movement difficulty level

The evaluation criteria used in this study clearly define the goals for each movement phase. Therefore, the difficulty values of each item estimated by item response theory directly reflect the level of difficulty in achieving the movements described by the items. Table 5 presents a diagram that lists the six movement phases along with the corresponding difficulty levels of the movements indicated by the items. The movements progress from left to right in this diagram, with the difficulty increasing from bottom to top. Additionally, the difficulty of items where differential item functioning (DIF) was detected is shown by grade level. Based on this diagram, the movements were grouped into the following seven categories: "(1) Preliminary take-off from a stable run-up", "(2) Bouncy take-off", "(3) Dynamic take-off", "(4) Forward weight shift", "(5) Rotation turn", "(6) Stable landing", and "(7) Aggressive landing." Below, we discuss the theoretical background of these movements and their relevance to exercise instruction.

Table5

Motor phases of straddle vault and difficulty level of each movement.



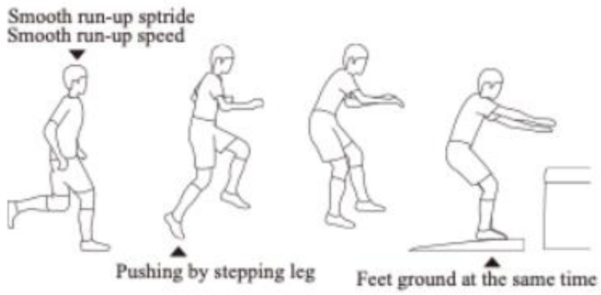


Figure 5. Preliminary take-off from a stable run-up.

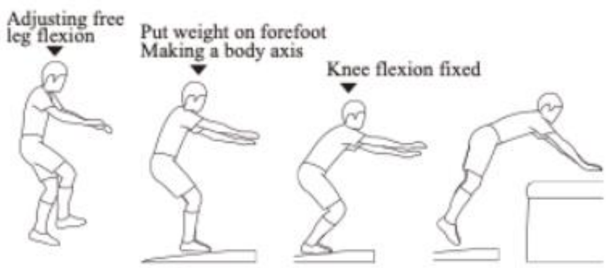


Figure 6. Bouncy take-off.

Performing a hurdle step from a stable run-up and touching the springboard with both feet simultaneously—without slowing down or narrowing the stride length—is relatively difficult (Figure 5). While many children can perform these movements even if they cannot jump over the box, they are crucial for preparing the main phase of the vault. Studies on adult vaulting have emphasized the importance of a stable run-up (Filius et al., 2012; Bayraktar et al., 2021). In children's straddle vaults, the technical demands for the run-up are less challenging; however, the results suggest that tasks focused on mastering rhythm and step timing before take-off are effective. The kinesthetic sense associated with these movements can be developed through motor play at an earlier age than 3rd-4th grade.

The movement of jumping with a firm body axis and bouncing on the springboard was of medium difficulty (Figure 6). In the take-off phase, it is important to avoid touching the ground with the heel or jumping with deeply bent knees. Instead, the knees should remain flexed, and the jump should be executed in a bouncy manner (Kaneko, 1987; Shindo, 1988). When learning the take-off, it is helpful to practice in advance by developing the feeling of a bold take-off, such as jumping from a springboard to a safety mat without using a vaulting box. Studies suggest that incorporating tasks that enhance the basic kinesthetic sense is more effective than simply practicing gymnastics techniques (Ivashenko et al., 2021). This basic sense, developed through such exercises, can then be applied and refined during the straddle vault.

The dynamic jump during the take-off phase was found to be extremely difficult (Figure 7). While a dynamic take-off leads to more impressive technical movements, Shiraishi (1985) cautioned against focusing solely on teaching children to perform a powerful take-off. The analysis results show that the difficulty of this movement exceeds b=2.0, making it almost unattainable for elementary school children. It is believed that learning this movement is not essential for small vaulting boxes commonly used in elementary schools but becomes more relevant when performing the technique on larger vaulting boxes

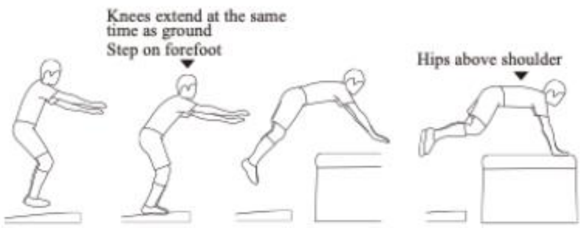


Figure 7. Dynamic take-off.

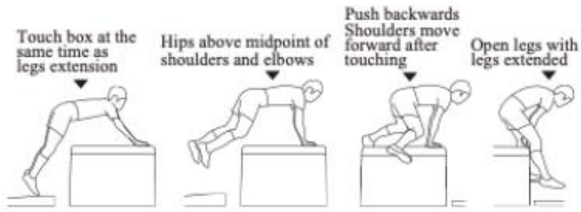


Figure 8. Forward weight shift.

After contacting the vaulting box, the movement of shifting the weight forward by pushing backward with the hands and bringing the shoulders forward was of low difficulty (Figure 8). Shindo (2017) emphasizes that when focusing on jumping over the vaulting box, it is important to allow children to experience the movement of shifting their weight using their arms. The successful execution of this movement significantly influences whether the jump is successful or not. As shown in the distribution of ability values, children in the "Failure" and "Success" groups diverged around θ=-0.5. Sano & Kokudo (2022) also highlight the proficiency level of the straddle vault, where the take-off is weak and the jump is achieved primarily through weight shifting. This suggests that shifting weight using the arms is less challenging than the take-off movement and can be accomplished earlier in the learning process. However, at this stage, the grand second flight phase may not yet be visible, indicating the need to further develop movements involving bouncy take-off and sharp push-off.

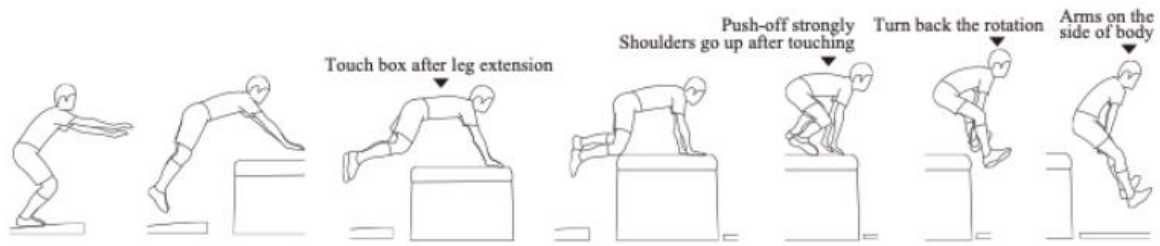


Figure 9. Turn of rotation

The movement of switching from forward rotation to backward rotation by pushing off the box was highly difficult (Figure 9). A key aspect of the straddle vault is the sharp push-off from the box with the hands and the clear rotation switch that lifts the shoulders upwards (Kaneko, 1987; Miura & Oyama, 1989; Shindo, 1988). This movement should be targeted for mastery after the child has successfully jumped over the box.

From the second flight phase to landing, movements related to posture control and shock absorption were of medium difficulty (Figure 10). Previous research has emphasized the importance of body control in the air and a cushioning function after landing for achieving a stable landing (Shindo, 1988). Regarding body control, Miki (2005) highlights that children who can jump well often demonstrate an understanding of spatial relationships and can predict their landing position, making the direction of the child's gaze after jumping an important consideration. Furthermore, key techniques for cushioning include flexing the knees and extending the arms forward (Kaneko, 1987).

It is notable that a difference was observed in the difficulty level of movements related to landing between 3rd and 4th graders. For 3rd graders, a stable landing is clearly more difficult than a bouncy take-off movement. This suggests that many children who have just mastered the bouncy take-off may struggle with landing stability. Additionally, gymnastics exercises in schools are associated with a higher risk of injury (Singh et al., 2008), and in Japan, the highest number of injuries occurs during vaulting exercises in elementary school classes (Japan Sports Council, 2023). One possible reason for this may be an imbalance between take-off and landing skills. For 3rd graders, it is important to focus on the safety aspects of the exercise. In addition to practicing take-off movements, children should have ample opportunities to practice landing techniques to ensure they master the landing phase.

The aggressive landing movement was classified as high difficulty (Figure 11). This movement involves not only bending the knees but also the hips, along with swinging the arms downward during landing. Mills (2005) noted that there is a trade-off between the difficulty of the technique and the stability of the landing: the higher the difficulty of the technique, the more challenging the landing becomes. Once a clear rotation switch is achieved, the second flight phase becomes more dynamic. To absorb the significant amount of energy generated during this phase, a more aggressive landing motion is thought to be necessary.

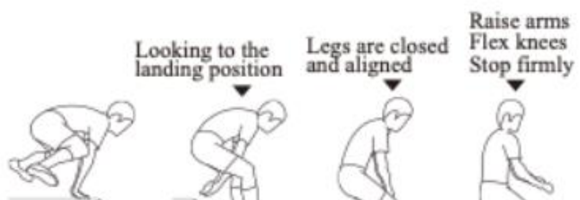


Figure 10. Stable landing.

Figure 11. Aggressive landing.

STUDY LIMITATIONS AND FUTURE RESEARCH

One limitation of this study is that we were unable to quantify the difficulty of all the movements involved in the straddle vault. Of the 30 items in the evaluation criteria developed by Sano and Kokudo (2022), only 21 items were analyzed and quantified. Therefore, there may be important movements that were not captured in this study but are essential for mastering the straddle vault.

Secondly, while this study targeted children from five elementary schools, it did not account for differences in achievement levels between schools or classes. Additionally, although differential item functioning (DIF) was used to explore the difficulty differences between grades, we did not incorporate physical factors such as height and weight into the analysis. Future research should investigate how group characteristics and individual physical factors impact the achievement of the technique and the difficulty of specific movements.

Finally, we quantified the degree of difficulty of the straddle vault movements to provide valuable information for exercise instruction. This allows for the design of instructional programs that account for movement difficulty. However, the effectiveness of an instructional sequence based on these quantified difficulty levels remains unverified. Future research should focus on developing teaching programs that integrate movement difficulty and assess their impact on learning outcomes.

CONCLUSION

This study aimed to quantify the difficulty of the movements involved in the straddle vault for 3rd and 4th grade elementary school children using item response theory. The findings reveal the following:

- The movements involved in taking off from a stable run-up and shifting weight forward are low-difficulty and can be addressed in the early stages of learning.
- The movements required for a bouncy take-off and stable landing are of medium difficulty, with landing movements being more challenging for 3rd-grade children compared to 4th graders.
- Movements involving turning back and aggressive landing are highly difficult and should be introduced as skill levels increase.
- The dynamic take-off movement is extremely difficult, and it may not be necessary for children in 3rd and 4th grade to master it.

Looking forward, it will be crucial to develop a teaching program that takes into account the difficulty levels of these movements and to verify its effectiveness in improving skill acquisition.

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