

Article

An Inquiry-Based Learning Support System for Children in Sports Acquisition Processes

Masayuki Yamada^{1*}, Yuta Ogai², and Sayaka Tohyama³¹Institute of Liberal Arts, Kyushu Institute of Technology, 680-4 Kawazu, Iizuka, Fukuoka, 820-8502, Japan²Faculty of Engineering, Tokyo Polytechnic University, 5-45-1 Iiyamaminami, Atsugi, Kanagawa, 243-0297, Japan³Faculty of Informatics, Shizuoka University, 3-5-1 Johoku, Naka-ku, Hamamatsu, Shizuoka, 432-8011, Japan

Abstract

This study examined an inquiry-based learning support system for children in sports acquisition processes and describes the characteristics of a case study on the long-term collaborative process of children's forward and backward cycle practices on horizontal bars. We analyzed 18 horizontal-bar practices for two elementary schoolchildren who had not succeeded in their backward cycle for approximately half a year. They were required to make practice plans collaboratively to succeed in their forward and backward cycles. To support their practices, we provided them with "HDMi (HDMi is the name of a system we developed in the past.)," which was developed to support reflecting on one's physical movements using movies. The movies were also used for discourse analysis to determine where the children focused, and OpenPose software was used for motion analysis to examine how the children's actions improved on a horizontal bar. Both the HDMi and the discourse analysis suggested that two children selected their focusing points for their practice and they gradually became referring to "move toes toward opposite side of the bar" in the periods of practices. However, the motion analysis revealed that the focused points and actual movement of the body did not match completely.

Keywords: Inquiry-based learning; Learning support system; OpenPose; children.

1. Introduction

Recently, the use of sports technology systems has made it easier to record athletic activities and convert them into data (Brefeld & Zimmermann, 2017). This incorporation of Information and Communication Technology (ICT) into sports, or "SportsTech," plays a crucial role in visualizing the characteristics of athlete movements and their individual bodily trajectories. Such technology is particularly beneficial for enhancing the training of athletes, regardless of their age. Contemporary academic research has underscored the advantages of using these systems to enable children to proactively reflect on their previous training sessions. A study targeting junior high school students revealed the positive impact of reflecting on gymnastic practices over five weeks (Potdevin et al., 2018). Implementing such technological systems in school physical education programs (Yang, et al., 2018) is expected to increase in both elementary and junior high school settings. Given the call from prior research (Yang, et al., 2018) to also focus on elementary school students, this study specifically targets this younger demographic.

In sports training, acquiring new physical movements or refining existing ones can take an extended period ranging from several months to years. Insights into the effective application of SportsTech during prolonged training periods are limited. Additionally, although qualitative research methods are often used to capture the complex process of mastering physical movements, there is growing interest in combining these methods with quantitative research. Gaining a deeper understanding of how young children proactively engage with these systems could result in significant societal contributions.

Consequently, this study sought to examine the impact of an environment designed to promote proactive exploratory

Received: 28 February 2024, Revised: 26 March 2024, Accepted: 30 April 2024, Published: 27 June 2024

* Correspondence: yamada@lai.kyutech.ac.jp;

Publisher's Note: JOURNAL OF DIGITAL LIFE. stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.



Copyright: © SANKEI DIGITAL INC. Submitted for possible open access publication under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

activities among children in gymnastics practice, specifically those practicing on a horizontal bar, over a six-month period. The reason for choosing the horizontal bar as the focus of this study was that the targeted children exhibited a strong motivation to acquire horizontal bar skills. This research was conducted during the period of restricted outings due to the spread of infectious diseases starting in 2020, and the children were positive about engaging in exercises that could be performed at home, as well as training for physical skills they had not yet acquired. The limitation of this study is that the subjects (boys) was limited to highly motivated children to master the horizontal bar practice: forward and backward cycles. More study is needed for children with low-motivation. For example, how to motivate children to practice which they are not interested to master. From other point of view, to motivate children practicing who has no motivation to master the horizontal bar is difficult. We would like to propose more constructive way: change the target of expertise to something which children have motivation to master. In designing this environment, we emphasized the application of SportsTech in collaboration with reflective practices as foundational principles. As part of the SportsTech initiative, children could initially record and review their own practice sessions independently. To further encourage proactive introspection and advancement in their practices using SportsTech, the environment was configured to support collaborative interactions among participants during training sessions. To evaluate the effectiveness of this environment, we analyzed and quantitatively assessed the physical movements of the children while practicing forward and backward cycles and correlated these findings with qualitative data such as their verbal interactions.

2. Background

2.1 Support Systems for Optimizing Movements in SportsTech

As a means of practice improvement using SportsTech, one approach is to overlay the athlete's body movement trajectories with an "optimal trajectory." The optimal trajectory is based on the movements of expert athletes and represents the "correct" way in which body parts should move. For example, the golf simulator Phigolf displays the optimal trajectory of a golf swing overlaid on the user's movement trajectory. The user's body movements are captured using gravity and acceleration sensors attached to the golf club. Using this system, athletes can repeatedly compare their trajectories with the optimal trajectory, thereby facilitating movement practice that is better aligned to the optimal path. Furthermore, attempts have been made to use data from past games to predict rival team member movements in future match-ups. For example, Toda et al. (2018) developed a system for soccer that uses machine learning to predict how an entire team moves when a rival team's players are placed in arbitrary positions.

2.2 Support Systems for Exploratory Activities Through SportsTech Data Utilization

Methods that assist athletes in interpreting feedback information themselves offer an alternative approach to showing the optimal trajectory. Because of the extensive information available on body movements, having system features that help select and correlate this information could enable athletes to gain valuable insights. For example, Nishiyama and Suwa (2010) demonstrated the effectiveness of providing feedback to athletes by extracting a portion of the data obtained from their body movements, converting it into graph form, and using it to support athletes in reflecting on and improving specific body movements.

Regarding utilizing feedback through SportsTech, Ikuta's (2007) remarks are enlightening. Ikuta (2007) argues that it is not sufficient for a disciple to merely imitate the master's behavior; true proficiency is achieved when the disciple manifests the skill in an optimal form unique to their body, a stage she terms "mastery." This means that it is not about the disciples replicating the master's analyzed body movements, but rather about realizing similar quality movements in a way unique to the disciple's body. Considering this, the optimal body movement trajectory may differ for each athlete. Moreover, the physical quantities that people psychologically perceive can differ from their actual physical quantities (Nagai, 2022). Therefore, when athletes utilize feedback, the mechanisms to address such discrepancies should also be considered in every training for avoiding increasing the gap between psychological and physical differences through accumulation of each discrepancy.

2.3 Support System for Long-Term Practice

As indicated by Ericsson and Pool (2016), when viewing the practice of a specific sport as a long-term skill acquisition process, changes, such as improvements in time, can be discerned quantitatively. However, to understand what athletes consciously focused on when their time improved, qualitative research methods (e.g., interviews) are necessary. With recent advancements in ICT, it is possible to observe long-term changes in individuals both quantitatively and qualitatively. For example, Roy (2009) recorded the process of language acquisition in children through dialogue with caregivers, empirically demonstrating what has been theoretically proposed regarding children's language development. Roy (2009) also showed that a preschool child in the study watched recordings of his language development and commented on how these videos might be useful in the future. This research suggests that reflecting

on children's developmental processes using recorded video data can potentially provide them with the discovery of their developmental characteristics from their metacognitive perspective. If the reflection is used for physical expertise, there are possibilities to help children to know what is a better way to move their body parts.

2.4 Children's Bodily Movements and Collaborative Activities in Problem-Solving Settings

Children possess multiple problem-solving strategies and are known to experiment with them to find better ones. Siegler (1996) demonstrated that children's problem-solving strategies vary and that they tend to choose more effective strategies as they age. He observed this through a task that involved balancing a scale with weights of different sizes, in which children added or moved weights to achieve balance. This suggests that children can independently discover ways to solve problems without being directly taught by adults.

In Siegler's (1996) study, children determined their next action by observing the movement of the scale, suggesting that they create their own strategies based on the feedback from their actions. This feedback was directly visualized as the balance or tilt of the scale, corresponding one-to-one with the child's actions of adding or moving a weight.

However, for tasks that require coordinated movements for success, it is difficult for children to judge the effectiveness of their applied strategies. In such cases, the presence of an observer has been known to be helpful. Shirouzu et al. (2002) showed that in problem-solving discussions between two people, the "monitor" who observes the task is more likely to gain insights that advance the solution than the "task performer" who is actively engaged in the task. Therefore, for complex tasks in which there is an intricate association between action and result, two or more children working together and engaging in dialogue is more effective in eliciting proactive problem-solving.

In this study, we adopted a case-study approach that involved a detailed analysis of a few participants over a long period, observing the children's process of proactive practice. To support their practice, we introduced the use of the SportsTech, "HDMi" (Ogai et al., 2021). Moreover, to encourage children to interpret feedback from the HDMi and use their own strategies during practice, a child in the role of a monitor was paired with the practicing child. We examined the activities of two children practicing forward and backward cycles on a horizontal bar in this practice environment. Both quantitative and qualitative analyses were performed. HDMi stands for the 'HATSUWA, DOUSA, MiERU system,' which means a system where speech and motion are visible, expressed in Japanese.

3. Methods

3.1 Overview

Based on field research, we utilized a method in which the skills to be practiced and the practice duration were predetermined. This approach was used to facilitate the comparison and analysis of changes in the children's discourse and movements between each practice session. Hereafter, we refer to each practice session as "practice." The skill selected for practice was the backward cycle, which the children were initially unable to perform. The analysis focused on sessions up to the 18th practice session, by which time Child A had become consistently successful in performing the backward cycle. The analysis period was approximately half a year.

The participants were two male siblings, aged 6 and 10 at the beginning of the study, Child A and Child B, respectively. Supervision during the practice sessions and data recording was conducted by the first author who has extensive coaching and research experience in children's sports through to university students. The first author was responsible for ensuring safe practice. The relationship between the children and first author was positive. The practice sessions took place at the children's home using a single horizontal bar designed for children. The bar was 90 cm above the floor and 100 cm wide, making it challenging for both children to simultaneously use. The participants were the sons of the first author, which made it possible to communicate at any time. In this study, actual life data was collected without manipulating the ages of the subjects. Before this study, the participants had been playing ice hockey once to twice a week, but they had not been able to do so during this period due to the spread of infectious diseases in 2020, resulting in a situation with virtually no exercise habits. Neither child was particularly adept at physical activities.

Practices were conducted on an irregular basis, approximately once per week. This scheduling approach prioritized occasions when the children were positively inclined toward practicing and when it was convenient for both the children and the first author. Additionally, "special training" sessions (to be described Section 3.2) were conducted by the first author upon the children's request.

At the start of the study, neither child perform the backward cycle, and only Child B was able to perform the forward cycle.

3.2 Flow of Each Practice Session

Each practice session lasted approximately 20 minutes and followed the procedure described in Table 1. Initially, the first author conducted a "pre-interview" with the following question: "What will you pay attention to in order to perform forward cycles and backward cycles well?" The children freely discussed their thoughts on forward and backward cycles. Subsequently, a 10-minute "training" session was conducted where both children freely practiced forward and backward cycles using the single horizontal bar. During this time, the children were allowed to use the HDMi system as needed. The children received basic instructions on what could be done with the HDMi before starting practice and were also able to discuss with each other. After training, each child performed a "practical test" of forward and backward cycles, individually, once. In the "post-interview," the first author asked each child separately, "How was it doing forward cycles and backward cycles?" and "How was it using the HDMi?" The children described their experiences in a free response format.

From the second practice session onwards, before the initial pre-interview, a "review" session was conducted where the children freely reflected on the previous practice, discussed what they had achieved, as well as their feelings and plans moving forward. The children could also use HDMi during this period, if needed. A single tablet PC was provided to the children, and they were required to collaboratively decide when to use the PC and how to use HDMi. No time limit was set. In the practices of this study, the children were checking for detailed changes in their movements using HDMi. The first author primarily refrained from giving advice, instead ensuring that the children were practicing safely.

During the special training sessions, each child received individual guidance from the first author on performing the backward cycle until the children were satisfied. In the first special training session, Child A received 15 minutes of instruction, and Child B received 5 minutes. In the second session, Child A received 6 minutes of instruction and Child B 4 min. After receiving guidance from the first author, the children were observed practicing alone for a short time. The children could watch each other's special training sessions. The first author only provided guidance on the crucial movements of the body parts necessary to successfully perform the backward cycle. This included bending the arms and kicking the legs up towards the head, while supporting the child's body. HDMi was not used in these sessions.

Table 1. Flow of each regular practice and recording method

Content	1. Review	2. Pre-interview	3. Training	4. Practical Test	5. Post-interview
Time	Arbitrary	1 minute / person	10 minutes	1 minute / person	1 minute / person
Video recording	Around the bars, HDMi screen	Children	Around the bars, HDMi screen	Around the bars	Children

3.3 Recording of Practice Sessions

All practice sessions were video-recorded. A fixed camera with a frame rate of 60 fps was used for recording. The approximate value of the edge length per pixel at the child's standing position, calculated based on the child's height, was approximately 0.15 cm. During the practical test, the recording started when the child, standing to the left of the horizontal bar facing right, gripped the bar, and continued until the forward- or backward-cycle movements were completed. For the practical test videos, an analysis of the discourse and video was conducted using the features of HDMi, as described Section 3.4, and graphs were generated. The graphs and videos were then uploaded to HDMi. For the training sessions, only the videos were uploaded to HDMi.

3.4 HDMi

HDMi is a browser-based system that encourages users to reference videos of their own or their peers' bodily movements, along with their personal linguistic reflections on those movements. It also facilitates the comparison of bodily movements and reflection outcomes across practice sessions. A new practice page is created each time a participant conducts a practice session. HDMi's browser screen is divided into left and right sections, allowing users to display and compare practice pages on these screens. Figure 1 shows the content displayed on the HDMi screen. The content selected from the left menu is displayed on both sides. By pressing the left and right arrow buttons on the top right of the right page, users can switch between practice pages. This facilitates comparing different athletes and practice sessions on the left and right sides of the screen.

On both sides, each page displays the types of practice, practice session number, the athlete's self-assessment of the practice, the success of the practice content, prospects for future practice, a video of the practice, a network graph of word co-occurrence generated from the athlete's free-form descriptions, and a line graph showing changes in body part positions during the practical test, which was analyzed using OpenPose. At the bottom of the page, freeform descriptions from the practice page are displayed on the left screen.

4. Analytic Methods

In this study, we analyzed how HDMi was utilized during practice sessions of forward and backward cycles. We also investigated at what point the children succeeded in performing forward and backward cycles and how their awareness of their proficiency in these exercises evolved over time. We used this information to interpret what occurred during their practice sessions.

To align the strategies and physical movements of the children, we first examined their successes and failures in performing forward and backward cycles in each practice session during the practical test. The results are presented in Section 5.1. Next, we investigated which HDMi features were used and how many times the videos were viewed. We counted how many times the “play” button was pressed to see the videos on either the left or right page of HDMi. The results of these video playbacks are presented in Section 5.2. Furthermore, to explore the relationship between the body parts that the children focused on during practice, we conducted a discourse analysis. To do so, we transcribed the training sessions in which both video viewing and physical movements occurred, focusing on these activities. In this process, we included the physical movements of both children in the transcription, enabling an analysis of the presence or absence of the HDMi reference and the practice of physical movements. The results are presented in Section 5.3. Finally, we analyzed the videos of the children’s practice sessions using OpenPose by plotting the positions of their joints on the XY-coordinate plane. Furthermore, we investigated the relationship between the positions of these joints and references to body movements in the discourse. The results are presented in Section 5.4.

In this study, we extracted those body parts the children focused on and the practice methods that they adopted as faithfully as possible. This approach was inspired by Ericsson and Simon (1993), who aimed to interpret what speakers expressed directly in their discourse. As noted in Section 2, this study’s primary goal is to discover the optimal way for individuals to move their bodies and provide support to achieve these movements themselves. Therefore, no comparisons were made with experts, because the focus was on the subjective experiences of the individuals.

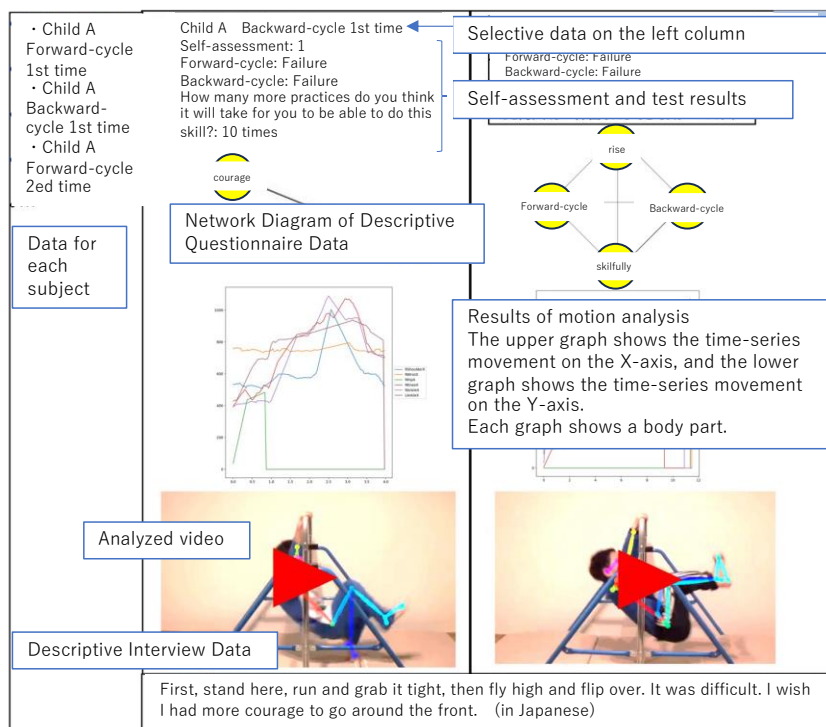


Fig.1. Example of HDMi view

5. Results and Interpretation

5.1 Outlook

Table 2 presents the children's practice schedule and the success or failure of the backward cycles in each session. For the forward cycle, because Child B consistently succeeded and Child A failed throughout, we only included changes in the success or failure of the backward cycles during the practice period. Child A succeeded in the backward cycles during the second special training session and from the 16th session onwards. It is worth noting that Child A succeeded in the backward-cycles only during the practical tests in the 16th and 17th sessions, and the first success in training occurred in the 18th session.

Table 2. Schedule of Regular/Special Practices and the success and failure of doing backward cycle

Number of times practiced	Practice date	Backward-cycle Success or Failure	Number of times practiced	Practice date	Backward-cycle Success or Failure
1st	Nov.17	Failure	9th	Feb.21	Failure
2nd	Jan.2	Failure	10th	Feb.28	Failure
3rd	Jan.5	Failure	11th	Mar.7	Failure
4th	Jan.9	Failure	12th	Mar.13	Failure
5th	Jan.13	Failure	13th	Mar.17	Failure
6th	Jan.17	Failure	14th	Apr.18	Failure
7th	Jan.24	Failure	15th	Apr.25	Failure
Special training 1	Jan.30	Failure	16th	Apr. 29	Child A succeeded
Special training 2	Feb.2	Child A succeeded	17th	May.2	Child A succeeded
8th	Feb.6	Failure	18th	May.5	Child A succeeded

5.2 Viewing videos through HDMi

At the beginning of each practice session, the children watched past practice videos and exemplary backward-cycle videos provided by HDMi. Figure 2 illustrates the frequency with which children watched videos (the order of viewing is not shown in the figure). The exemplary videos were selected by the first author in response to the children's request for a "model of backward-cycle" during the 7th session. These videos featured a single athlete performing a backward cycle from three angles: front, diagonal, and side.

During reflection, following the guidance of the first author as a coach, the children decided to watch the videos through discussion. Until the 6th session, the children watched videos of both forward and backward rolling. However, from the 7th session onwards, the viewing frequency of forward-cycle videos remained at least two times per practice. Video views were most frequent in sessions 4th and 8th sessions, while the 17th session had the fewest views. Additionally, from the 7th session onwards, the children watched the model videos. From the 9th session onwards, the frequency of viewing videos of Child A's successful backward cycles surpassed that of the model videos, likely because of Child A's success in backward cycles during the special training from the 9th session onwards.

In each practice session, the children independently selected and watched videos as needed. In the training sessions, children A and B watched videos separately, except during the 10th and 15th sessions when they watched videos together. Additionally, up to the 9th session for Child A and the 5th session for Child B, they watched their own videos. Subsequently, both children watched model videos intermittently.

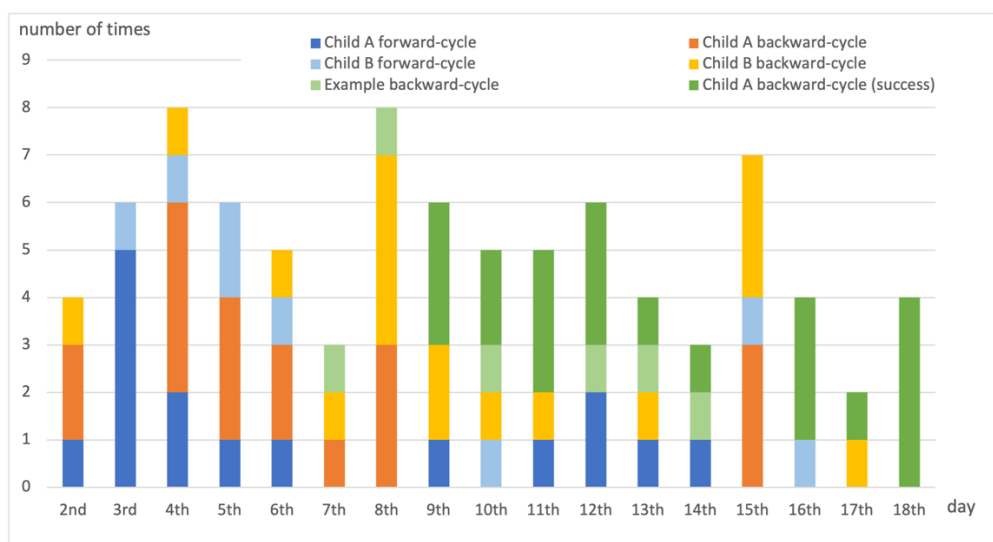


Fig. 2. The number of movie views on HDMi (during the reflection session in each practice)

5.3 Children’s Focus points and Practical Training Strategies

This section focuses on the backward cycles that the children practiced intensively. We present the discourse analysis results related to the joints and other body parts based on the children's mentions of body parts and practical strategies during each practice. The extracted points that the children referred to during their practice were as follows:

- (1) grasp the bar with palms facing down/up, (2) ensure a firm grip on the bar to prevent slipping, (3) engage the muscles in the arms, (4) bend the elbows, (5) lift the legs, (6) kick with the feet (on the ground), (7) lift the legs with the intention of reaching the ceiling, (8) imagine kicking a ball in the air and lift your legs as if kicking it, (9) move your legs across the bar in the air, (10) Bring the stomach to the bar, and (11) lift the hips.

For elements (1) to (11), the associations were counted as follows: (1) and (2) as hands, (3) as arms, (4) as elbows, (5), (6), (7), and (8) as leg ascent, (9) as foot horizontal movement, and (10) and (11) as hip and waist. The results are shown in Table 3 by counting each element as "1" if mentioned at least once in each practice. During training, the children engaged in discussions, and discourse was shared between the two children; hence, it is possible that both incorporated them into their practice. Therefore, the table does not distinguish between speakers.

In the sixth practice session, the children discovered the training method for (8) through discussion. In this practice, one child raised their hand high and the other intended to kick that hand while practicing backward cycles. At that point, Child A mentioned all the focus points listed in Table 3. This practice was continued until the seventh session. As noted in Section 5.2, the reason why the two did not watch the video in the sixth and seventh practice sessions could be that this exercise seemed promising to the children. Additionally, after the seventh session, the first author conducted special training. However, in the immediate session following the special training (eighth session), the number of points mentioned by the children (Table 3) did not increase.

Table 3. Focus Points and Practical Strategy in Backward Circle Practices

backward-cycle	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	11th	12th	13th	14th	15th	16th	17th	18th
Hands			1	1		1		1							1	1	1	1
Arms						1		1					1		1			1
Elbows						1	1	1	1					1				
Leg Ascent	1	1	1			1	1	1	1	1	1		1	1	1	1		1
Foot Horizontal Movement									1			1			1		1	1
Hip / Waist	1					1	1			1					1			1

5.4 Changes in the Body Parts' Coordinates in the Test Sessions

For Child A, who succeeded in performing the backward cycle through practice, we analyzed a video of the backward cycle in the test using OpenPose. Figures 3–5 illustrate the changes in the coordinates of each body part. As mentioned in Section 3.3, considering that one pixel is approximately 0.15 cm, each vertical axis in Figure 3 represents approximately 15 cm for the 100 scale marks. Using OpenPose, the figure examines, separately for each side, four identifiable joints among the body parts mentioned by the children in Section 5.3: hands, elbows, waist, and toes (feet). To examine the bending of the elbows, necessary for a successful backward cycle, the distance from the shoulder joint to the wrist was measured as the shoulder approached the wrist when the elbow was bent. The hand that remained in the same position while gripping the bar served as a reference point to determine the positions of the other joints. Due to slight variations in the relative positions of the bar and camera in each session, Figures 3 and 4 show the positions of each joint relative to the child's wrist coordinates.

Figure 3 illustrates the vertical (Y-axis) positions of the child's body parts. As shown in Figure 3, up to the sixth practice session, there was significant fluctuation in the up-and-down range of the Y-coordinates of each joint. However, from the seventh to eleventh practice session, except for the left toe, the graphs exhibited a smooth upward trend. Additionally, from the 12th to the 15th practice, the position of the waist remained relatively constant. In contrast, from the 16th practice session onwards, the waist position increased and surpassed the wrist position. For the 17th to 18th sessions, except for the right toe, the Y-coordinates of each joint converged around -100 to -200. The substantial variation in the right toe coordinates was likely influenced by Child A, who consistently lifted the right foot first during his backward cycle.

Furthermore, the movement of the toes beyond the parallel position of the horizontal bar towards the left side of the screen (indicated in Table 3 as "foot horizontal movement"), can be interpreted as having been achieved. Figure 4 illustrates the coordinates of the child's toes in the horizontal direction (X-axis), with the wrist as the reference point. Figure 4 shows the X-coordinates of the toes from the moment both feet leave the ground until the completion of the backward cycle. Figure 4 utilizes a video in which the horizontal bar was centrally positioned and the child is stood to the left of the bar. In Figure 4, 0 represents a position identical to that of the wrist, with decreasing values towards the left side of the screen. Throughout practices 1–14, there was significant variability in the values for each round, and, as observed in the 2nd, 4th, 9th, 13th, and 14th practices, there were notable differences in the coordinates between the left and right feet. However, in practices 15–18, there were minimal differences in the positions of both feet, and during the successful backward cycles in practices 16–18, the values ranged from approximately -400 to -500. This suggests that the toes moved beyond the child's wrist position towards the left side of the screen. It is worth noting that in the 4th practice, the right toes were closer to the left side of the screen, but during this instance, the children hung from the horizontal bar with their feet hooked onto it.

Moreover, the Euclidean distance between the right shoulder and right wrist of Child A was calculated, and the results, including the minimum and maximum values during practice, are shown in Figure 5. This study focused specifically on the right hand, which was visually presented in the foreground of the video. Based on the minimum values, Figure 5 indicates that there was significant variability in the early stages of practice; however, as the practices progressed, the variability tended to decrease towards the end.

The integrated results from Table 3 and Figures 3 to 5 were presented in Table 4. In Table 4, each mention by the children in each round from Table 3 is marked as "1" (considering both arm and elbow as 1 if mentioned in either). Hatching was shown for each body part where the movement improved compared with the previous practice, as shown in Figures 3 to 5. The results for "arm/elbow" are based on Figure 5, "leg ascent" and "hip/waist" on Figures 3, and "foot horizontal movement" on Figure 4. Of the 18 practices, the total number of mentions by the children for each body part was 41. Compared with previous practices, improvement in movement was observed 24 times on both sides. Of the 41 mentions, there were 11 instances in which the movement of the mentioned body part improved. Conversely, improvement was observed 13 times in body parts that the children did not mention.

Therefore, it was more common for the improvement in body parts mentioned by the children to not co-occur with improvements in body movements. Nevertheless, the children demonstrated the ability to perform the backward cycle. Furthermore, in the skill acquisition process, intermittent improvements in body part movements, excluding "hip/waist," were evident. Focusing on the instances where movement improvement and children's mentions co-occurred, occurrences were noted four times in "elbow" and "leg ascent," once in "foot horizontal movement," and twice in "hip/waist."

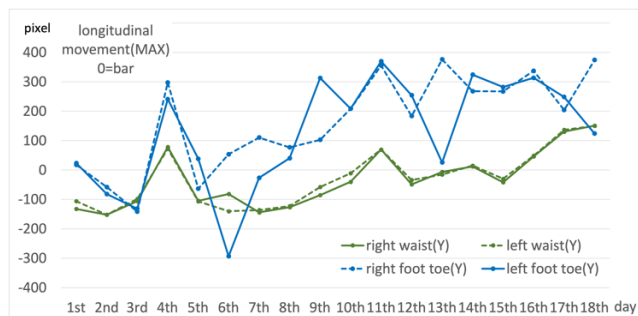


Fig.3. y-coordinate of body parts (Child A)

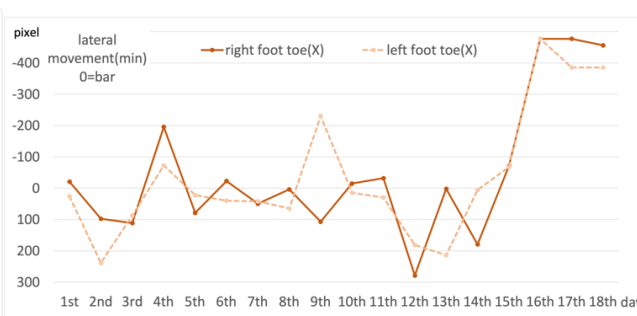


Fig.4. x-coordinate of small toe (Child A)

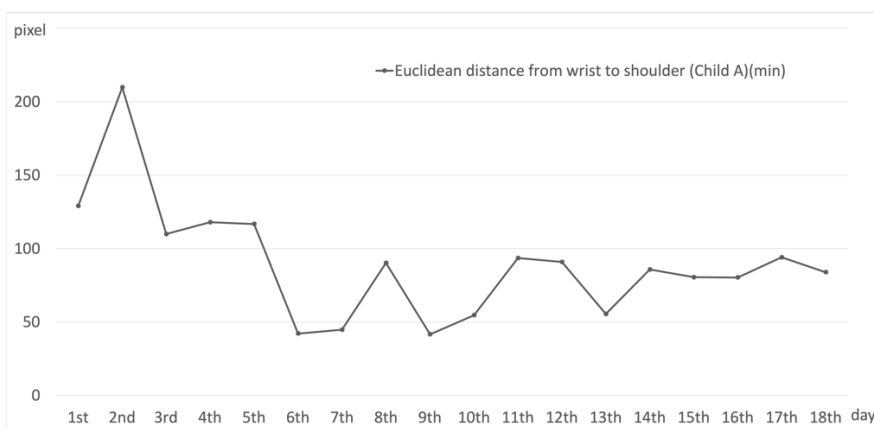


Fig.5. Euclidean distance from wrist to shoulder (Child A)

Table 4. Integrated results of Table.3 and Figs.3-5

Number of times practiced	Arm / Elbow	Leg Ascent	Foot Horizontal Movement	Hip / Waist	Number of times practiced	Arm / Elbow	Leg Ascent	Foot Horizontal Movement	Hip / Waist
1st		1		1	10th		1		1
2nd		1			11th		1		
3rd		1			12th			1	
4th					13th	1	1		
5th					14th	1	1		
6th	1	1		1	15th	1	1	1	1
7th	1	1		1	16th*		1	1	1
8th	1	1			17th*			1	
9th	1	1	1		18th*	1	1	1	1

6. Conclusion

In this study, we examined scenarios in which children practiced forward and backward cycles on a horizontal bar with the support of a HDMi system and collaborative activities. We conducted a combined qualitative and quantitative analysis to investigate the detailed outcomes. The analysis period spanned six months, qualifying as a long-term study. After 18 practice sessions and two special training sessions, one of the two children was successful in performing the backward cycle, a skill that they could not execute before the practice. Although Child A succeeded in the backward cycle just before the 8th practice session, they could not consistently replicate the success from the 8th to 15th practice sessions. This suggests that achieving stability in a skill that was incidentally successful requires expertise not only in body movements but also in cognitive aspects.

In "reflection" sessions where the children could carefully review videos, it was revealed that they watched more videos of themselves successfully performing backward-cycles than videos demonstrating the model by the athlete. Additionally, they had the opportunity to watch videos even after the practice started, but practicing with the horizontal

bar took precedence over watching the videos. Therefore, to encourage the use of SportsTech, such as watching videos, it is considered effective to allocate time specifically for activities involving SportsTech and to ensure that children can watch their own videos.

Furthermore, we analyzed the discourse between the children during practice, extracting points and strategies they consciously focused on. Consequently, lifting the legs and firmly gripping the horizontal bar were frequently mentioned throughout the entire practice period. However, horizontal movement of the toes toward the head was first mentioned in the middle of the practice period. Additionally, sporadic mentions were observed regarding "Hip/waist."

Finally, focusing on Child A, who succeeded in performing the backward cycle, we analyzed the positions of Child A's body parts. A comparison between the positions obtained through the OpenPose analysis and the body parts mentioned in the children's discourse reveals that the improvement in the mentioned body parts did not necessarily coincide with their actual positional improvement. Among the analyzed body parts, "hip/waist," which was sporadically mentioned, showed the most consistent improvement. Furthermore, when examining the co-occurrence of improved movements and children's mentions, there was a tendency for frequent occurrences in "elbows" and "leg ascent" and fewer occurrences in "foot horizontal movement" and "hip/waist." This suggests that children may focus directly on the parts they want to improve, or indirectly enhance their movements by addressing various body parts towards the desired action.

Based on these results, it is suggested that each child consider strategies for successfully mastering backward cycles while watching model videos and videos of their own successful movements. This implies the occurrence of exploratory activities aimed at improving motor skills, possibly facilitated by using HDMi for exploration and improvement.

6.1 Remarkable Observations

From the perspective of the unique practice environment of this study—specifically, the focus on authentic practice at home initiated by the children's motivation to "become proficient at the horizontal bar"—insights were gained into when the children sought advice from the first author while actively practicing using HDMi. Requests for support from the first author were not present at the beginning of the practice but emerged after the sixth and seventh sessions, where the children practiced collaboratively without using HDMi. Moreover, during the special training conducted after the seventh session, Child A successfully executed a backward cycle. While this study did not set conditions for the first author to actively intervene in the children's practice, by proactively determining practice content and reviewing the results with HDMi, the children may have felt the sense of "almost there" and subsequently requested special training from the first author.

Another interesting aspect was that the children watched each other's practice videos and collaborated in their practice. In the sixth and seventh sessions, one child stood on the right side of the horizontal bar and raised his hand, while the child practicing the backward cycle swung their leg upward, intending to kick the hand. In particular in the sixth session, the child mentioned the five most frequent points from the start of practice. However, the children did not use HDMi during the sixth session. This suggests a tendency in the collaborative practice of body movements that aligns with the findings of previous research on collaborative learning, indicating that collaborative processes stimulate the discovery of new perspectives (Miyake, 1986). Moreover, the system was not used at all during the collaborative practice when the children attempted various strategies. Therefore, the children may have used the system when attempting to discover new strategies or when trying to find ways to combine strategies. In other words, the system supported the children's exploratory activities. In this study, the children freely utilized the system. However, feedback might be particularly necessary when the children are trying new strategies. It was considered that further investigation is needed on methods to more effectively use the system at better timings.

7. Limitations and Future work

Despite its novel findings, this study had some limitations. First, the extraction method of the points and practice strategies focused on by the children were noteworthy. Given the inclusion of young children as participants, this study extracted statements related to body parts from children's expressions in a bottom-up manner. Furthermore, instances in which different expressions were used to refer to the same body part were grouped into the same category, focusing on the presence or absence of mentions rather than frequency. Future research should conduct more detailed analyses, exploring whether the frequency of references to body parts increased and whether the children's explanations regarding the highlighted body parts became more detailed over time.

Second, this study closely approximated authentic practices using minimal experimental controls. Consequently, factors not considered in this study could have influenced the success of children's practice, forward cycles, and backward cycles. Gymnastics practice, occurred regularly only during the designated times. It would be feasible to conduct experiments by ensuring that practice is performed exclusively during specified times, with complete reporting of practice time and the success or failure of forward and backward cycles whenever practice is conducted outside designated hours, such as at school. However, adopting these methods may hinder the children from becoming proactively engaged in practice. This concern is not unique to this study but is broadly applicable to research in learning and education. Future research should explore methods akin to those of Roy (2009), who recorded the children's entire learning process while taking care not to diminish their motivation. It is believed that the children's collaborative discussions led to success in this study. Such influences also warrant further investigation.

Third, although the children utilized HDMi, the results of the OpenPose analysis were not mentioned. In the future, we aim to explore the potential of utilizing the OpenPose results by conducting investigations, including improvements in usability, to enhance its applicability.

Suggestions for future improvements to the system to support children's explorative activities are as follows. First, whether the person practicing is distributing attention across their various body parts or focusing on specific ones should be investigated, and any changes in the movement of each body part quantitatively analyzed. Second, stable states should be detected in both distributed and focused attention. Subsequently, if there is no change in the movement of a particular body part, exploring other parts that are not currently attended to should be conducted. Video viewing is also considered in this context. However, further investigation is needed to determine the effectiveness of encouraging video viewing when there is limited mention of practice methods or when the dialogue is stagnant, and whether it enhances or inhibits children's autonomy.

Author Contributions

Conceptualization, M.Y., S.T., and Y.O.; methodology, M.Y.; software, Y.O.; validation, S.T.; resources, M.Y.; data curation, M.Y.; writing—original draft preparation, M.Y. and S.T.; writing—review and editing, M.Y., S.T., and Y.O.; project administration, M.Y.; funding acquisition, M.Y. All authors have read and agreed to the published version of the manuscript.

Funding

This work was supported by JSPS KAKENHI Grant Numbers 22K12315.

Institutional Review Board Statement

The study was conducted according to the guidelines of the Declaration of Helsinki, and approved by the Ethics Committee of Institute of Liberal Arts, Kyushu Institute of Technology (protocol code 39, July 13, 2022).

Informed Consent Statement

Informed consent was obtained from all subjects and parents involved in the study.

Data Availability Statement

The data of this study are stored at Kyushu Institute of Technology. Data are from a small number of subjects and will not be made public due to privacy considerations.

Acknowledgments

This study is based on the manuscript presented at the following workshop, with substantial additions and revisions. Tohyama, S., Ogai, Y., & Yamada, M. (2021). A Case Study of Collaborative Discussion about Expertise in Horizontal Bar Practices. *JSiSE Research Report*, 35(7), 119-125, (in Japanese)

Conflicts of Interest

The authors declare no conflict of interest.

References

- Brefeld, U., & Zimmermann, A. (2017). Guest editorial: Special issue on sports analytics, *Data Mining and Knowledge Discovery*, 31(6), 1577–1579.
- Ericsson, K. A. and Simon, H. A. (1993) *Protocol Analysis: Verbal Reports as Data (Revised Edition)*, The MIT Press, Cambridge MA.
- Ericsson, K. A., Pool, R. (2016). *Peak: Secrets from the New Science of Expertise*, Houghton Mifflin Harcourt, MA.
- Ikuta, K. (2007). *Collection of Cognitive Science 6 Knowing via Waza*, University of Tokyo Press. (in Japanese)
- Miyake, N. (1986). Constructive Interaction and the Iterative Process of Understanding, *Cognitive Science*, 10(2), 151-177.
- Nagai, S., Utsumi, A., Susami, K., Yamashita, K. & Okada, A. (2022). Effect of Posture on Motor Performance Based on Somatosensory System, *Journal of Human Interface Society*, 24(1), 63-71. (in Japanese)
- Nishiyama, T. and Suwa, M. (2010). Visualization of posture changes for encouraging meta-cognitive exploration of sports skill, *International Journal of Computer Science in Sport*, 9(3), 42-52.
- Ogai, Y., Rin, S., Tohyama, S., & Yamada, M. (2021). Development of a Web Application for Sports Skill Acquisition Process Visualization System. *Proceedings of 2021 International Symposium on Educational Technology (ISET 2021)*, 235–237.
- Potdevin, F., Vors, O., Huchez, A., Lamour, M., Davids, K., & Schnitzler, C. (2018). How can video feedback be used in physical education to support novice learning in gymnastics? Effects on motor learning, self-assessment and motivation, *Physical Education and Sport Pedagogy*, 23(6), 559–574.
- Roy, D. (2009). New horizons in the study of child language acquisition, *Invited keynote paper, Proceedings of Interspeech 2009*, 13-20.
- Shirouzu, H., Miyake, N., & Masukawa, H. (2002). Cognitively active externalization for situated reflection. *Cognitive Science*, 26(4), 469–501.
- Siegler, R. (1996). *Emerging minds: “The Process of Change in Children’s Thinking”*, Oxford University Press, New York.
- Toda, K., Teranishi, M., Kushiro, K., & Fujii, K. (2022). Evaluation of soccer team defense based on prediction models of ball recovery and being attacked: A pilot study. *PLoS ONE*, 17 (1 January), 1–8.
- Yang, Q. F., Hwang, G. J., & Sung, H. Y. (2018). Trends and research issues of mobile learning studies in physical education: a review of academic journal publications, *Interactive Learning Environments*, 28(4), 419–437.