Interactive Rock Climbing Playground Equipment: Modeling through Service

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Abstract. Rock-climbing is a tool for investigating a full-body interaction. To design physical and psychological interaction with rock-climbing equipment, it is critical that scientific data on children's interaction with the equipment be collected. We developed a rock-climbing wall with embedded sensors to record the physical behavior of children while playing on the wall. Over 1000 children participated in this study. With the aim of creating an evidenced-based interaction design of climbing, we formulated a climbing behavior model to see the relationship among influencing variables that describe climbing activities.

Keywords: embedded sensor network, full-body interaction, children's behavior model, playground equipment.

1 Introduction

Physical activity is essential for all children to grow healthy [1]. According to the American College of Sports Medicine recommendation, children between the ages of 5 and 18 years old need to have 60 minutes of moderate to vigorously intense physical activity a day [2]. Rock-climbing has become a popular sport worldwide to get physically active. The difficulty of a climb is determined based on a grading system developed around the world [3]. Many studies on rock-climbing have researched on the relationship between physiological responses such as oxygen consumption, heart rate, blood pressure and the level of climbing difficulty [3], anthropometric factors [4], rock-climbing related injury [5].

From a human-interaction point of view, rock-climbing is a tool for investigating a full-body interaction. Sibella et al. gathered data on climbing movements using an optoelectronic system with six infrared cameras to research on common patterns and different climbing strategies in a group of recreational climbers [6]. Quaine and Martin conducted to study on the vertical and the horizontal force distribution on the holds and its distribution changes after a hold had been released based on the principles of Newtonian mechanics [7].

In the present study, we deal with the full-body interaction of children when they play with rock-climbing equipment. In this study, we focused on the following points:

1. Collect children's climbing behavior data to develop a climbing model
2. Understand what influences children's climbing behaviors

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3. Discuss the possibilities of designing evidence-based interactive playground equipment

In trying to understand how children interact with rock-climbing wall, we conducted two types of experiment. The first experiment was to develop a climbing behavior model by observing children while they played with outdoor climbing wall. The second experiment was to understand which factors related to climbing behavior. We developed the rock-climbing wall equipped with sensors to record children's climbing activities while playing on the wall. The climbing holds with sensors enable the measurement of children's climbing behavior in a natural situation. We discuss what variables influence climbing behavior based on the developed climbing behavior models.

2 The First Attempt to Develop a Children's Climbing Behavior Model, Using the Outdoor Climbing Wall

We first attempted to develop a children's climbing behavior model by observing how children play on the rock climbing wall, as shown in Figure 1.

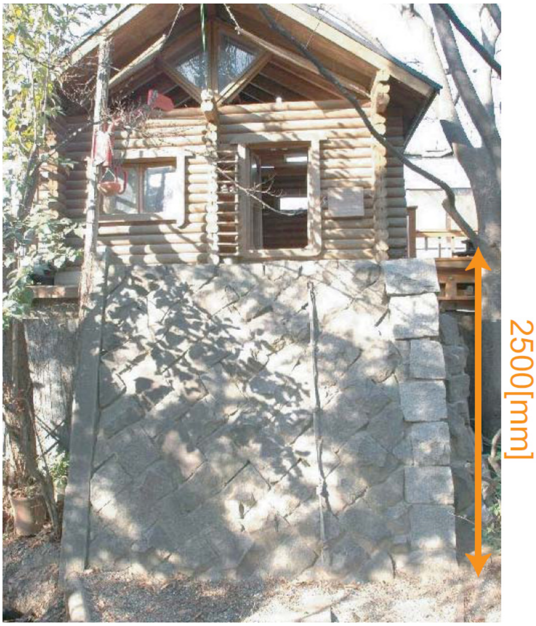

Fig. 1. Rock climbing wall in Kawawa Kindergarten

To collect children's climbing behavior data, we set up cameras to records the process of children's playing on the wall. We worked with 47 three to six year-old boys and girls enrolled in Kawawa Kindergarten in Yokohama, Japan. As a very first step to formulate a climbing behavior model, we decided to employ the following variables: age, weight, height, the rock depth that a child touched, and a child's posture. We considered a child's climbing posture as a link structure as shown in Figure 2 and calculate the distance based on the following definitions:

1. Relative distance between the left hand and right hand (L1)
2. Relative distance between the right hand and right foot (L2)
3. Relative distance between the right foot and left foot (L3)
4. Relative distance between the left foot and left hand (L4)
5. Relative distance between the left hand and right foot (L5)
6. Relative distance between the right hand and left foot (L6)

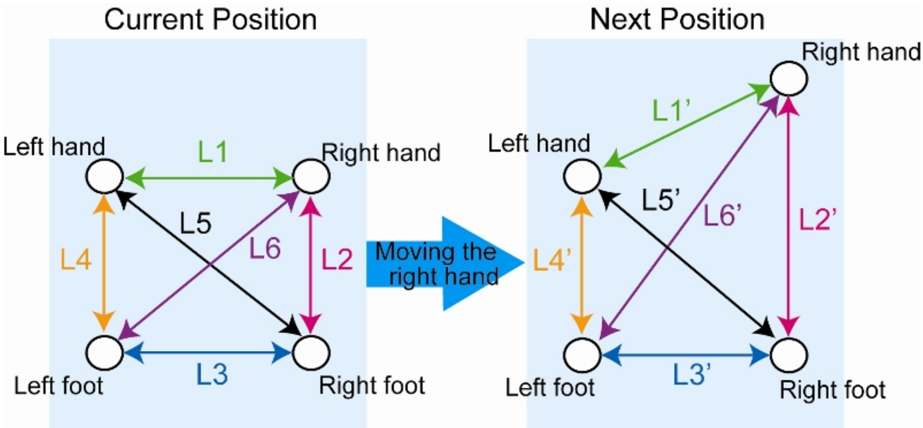

Fig. 2. Link structure for expressing body movements as a child scales the rock-climbing equipment

We extracted children's behavior data each time a child changed his or her climbing posture and generated a cross-tabulation table. The structure of the Bayesian network is computed based on the cross-tabulation table of organized data from 20 children, using custom-developed software [8]. We determine conditional probabilities by providing each node with the node's parent variables. The Bayesian network is constructed using a stepwise method based on AIC [9] in order to determine a set of proper parent nodes and to construct the model. We can find a relationship among chosen variables from a Bayesian network model.

A model of a child's climbing behavior for the right hand is presented in Figure 3. The line width indicates the strength of the relationship between nodes. The model can estimate the distance a child covers when changing from their current position to next position. The model indicates current positions influenced next positions, and children's characteristics such as weight, age, and height influenced current positions. In addition, the rock depth strongly affected the current position. However, we could not formulate a precise climbing behavior model because the real phenomenon of climbing was very complex. From this experience, we learned that we should understand how one variable influenced the others first before explaining the phenomenon of climbing behavior as a whole. Thus, we decided to start over from scratch to develop a climbing behavior model.

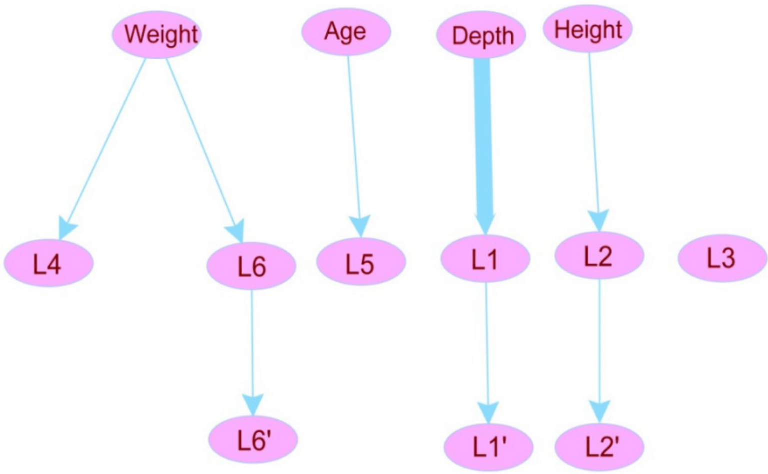

Fig. 3. A model of a child's climbing behavior for the right hand

3 Development of a Children's Climbing Model, Using a Sensor-Embedded Rock Climbing Equipment

To understand the whole phenomenon of outdoor climbing, we started with the development of a climbing model, using an artificial climbing wall with embedded force sensors. The benefit of an artificial climbing wall is that we can manipulate variables that affect climbing behavior. This way, we can develop a precise climbing model and understand what influences climbing. Based on a scientific understanding of climbing behavior, it will be possible to develop artifactually-produced playground equipment. Moreover, as we will discuss shortly, LEDs and force sensors are embedded in our developed rock-climbing equipment. This interactive equipment allows us to collect a variety of children's climbing movements because a target that a child climbs up is programmed by software. On the other hand, when we gathered data using the outdoor climbing wall, we could not obtain good data of various movements since children tended to climb some particular fixed routes they preferred. In this section, we discuss the development of a rock-climbing wall and the construction of a child climbing model.

3.1 Development of Rock-Climbing Equipment with Sensors

To gather children's behavioral data, we developed two rock-climbing equipments which embedded force sensors as shown in Figure 4. Every time children put their hands or feet on the climbing holds, the sensors collect load data. The colors of holds changes using the sensor data. The rock-climbing equipment is 2.7m high, 1.8m wide. The hardware of the rock-climbing equipment comprises a main control device, four data collection devices, LED-unit and force-sensor control devices, force sensors, and LED units. There are two differences between Type 1 and Type 2. The first difference is the number of climbing hold attached to the wall. There are 50 holds in Type 1 and 54 holds in Type 2. Each hold comprises a climbing hold, an LED unit, and a metal case with a strain gauge and these are screwed to the climbing wall. The other difference was a hold shape. We use one shape of holds (type C in Figure 5) in Type 1 and five shapes of holds in Type 2 (Figure 5). The main reason to use only one hold shape in Type 1 is to remove the influence of hold shape from climbing behavior when we develop the model. This way, we can find the influence of hold shape by comparing the climbing model of Type 1 with the model of Type 2. We will discuss it more later.

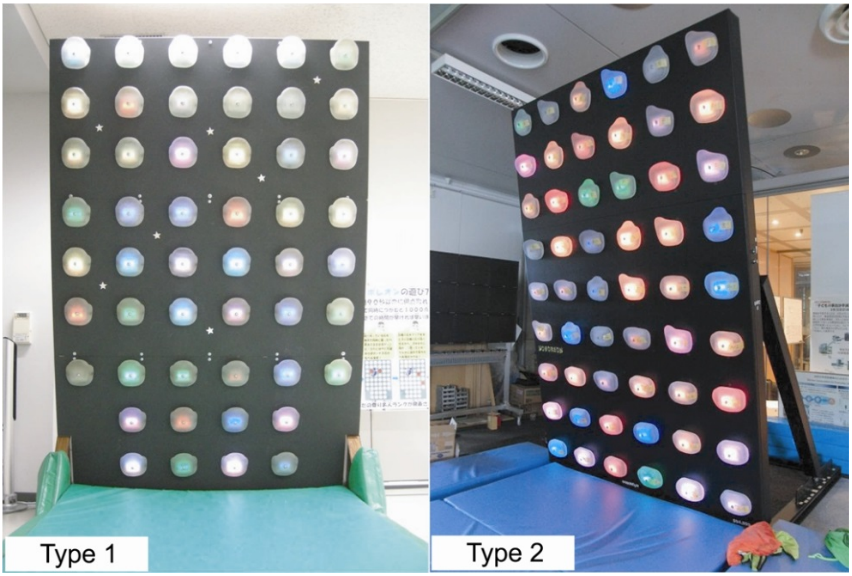

Fig. 4. Sensor-embedded rock-climbing equipment

Fig. 5. Hold shapes

3.2 Collecting Climbing Behavior Data, Using the Rock-Climbing Equipment

We conducted experiments for measuring the children's playing behavior, using Type 1 and Type 2 climbing equipments in cooperation with four events in 2009-2010.

So far, we collected 1226 children's behavior data (Table 1).

Table 1. The number of participants per event

Events	The event duration	Number of participants
Yokohama's 150th year in 2009	3 days	188 children
Kids Design Award 2009	4 days	435 children
Kids Create 2010	3 days	398 children
Childhood Injury Prevention Project in 2010	3 days	205 children

The instructions for playing were provided to participants as follows:

1. Climbing up to the two holds that turn to red. These red holds are your target.
2. When you reach these two targets, two new targets will activate.
3. Climbing to these new targets for 90 seconds.

Fig. 6. The snapshots of children playing on the rock-climbing equipment

The targets appear at random since the positioning of targets is programmed by software. Children were not allowed to touch the targets with their foot. When the game was over, children got their game scores based on the number of targets reached. All participants were recorded using two video cameras. Snapshots of the experiments in progress during the events are shown in Figure 6.

3.3 Constructing a Climbing Model

A Climbing Model, Using Type 1 Equipment. To formulate the model of Type 1 equipment, we employ the following variables in the model: sex, age, height, weight, target direction (to top or to bottom), a child posture, and the distance a child advances in a step. This time, we particularly looked at how target direction influences children's climbing behavior. Since only one hold shape was used in Type 1 equipment, we can find how target direction influences a child's posture.

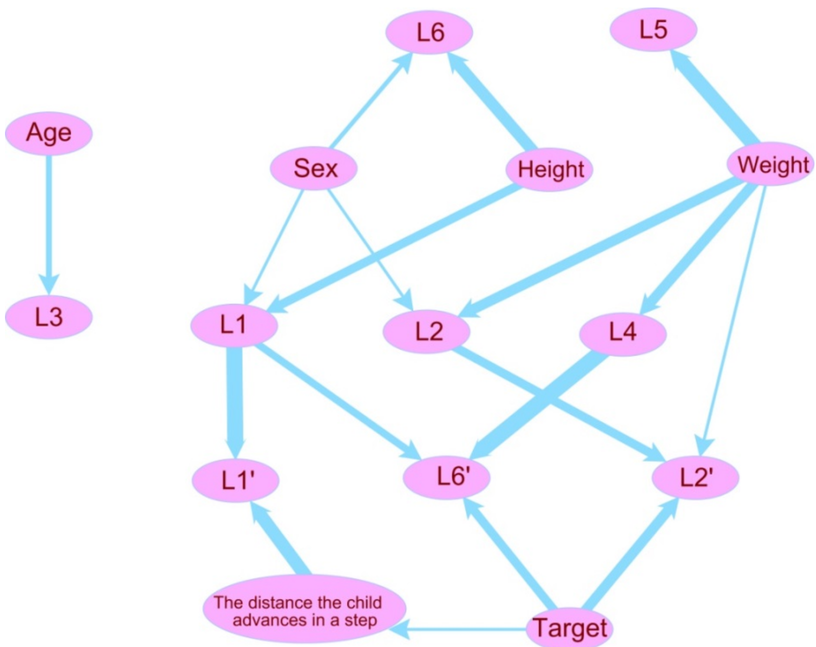

Fig. 7. Climbing behavioral model when a right hand moves (Type 1)

A children's climbing behavior model for Type 1 is shown in Figure 7. This is the right hand's model. It predicts how and where a child will climb when given the height of a child, target direction and his or her current posture. The developed model indicates that the next position was influenced by the current position, target direction, and the distance the child advances in a step. In addition, the current position was influenced by age, sex, height, and weight. The climbing model of Type 1 became more precise compared to the model of outdoor climbing wall shown in

Figure 3 because of the following reasons. First, unlike the outdoor climbing wall, there is a limitation of where children hang onto. Second, children need to climb up to a direction where targets appeared when they play with Type 1. This means how children climb is controlled. Thus, a direction of climbing is an important factor to describe the phenomenon of rock-climbing behavior.

A Climbing Model, Using Type 2 Equipment. To develop a climbing model, using Type 2 equipment, we used eight variables: sex, age, height, weight, target direction (to top or to bottom), a child posture, the distance a child advances in a step, and hold shape. There are 5 types of shape as already shown in Figure 5. The definition of the hold shape is a hold shape that a child actually touched.

A children's climbing behavior model for Type 2 is shown in Figure 8. This is also the right hand's model. The model indicates that a hold shape for a child's four appendages strongly affects his or her current position, and target direction influences the next position. Hold shape influences the current position more strongly than children's physical characteristics such as sex and age. This means that the current position (or more specifically the relative distance between appendages) was strongly influenced by hold shape that each appendage touched. The interaction between the current position and hold shape then affects the next position. For this reason, hold shape is also a critical factor that describes the phenomenon of rock-climbing behavior.

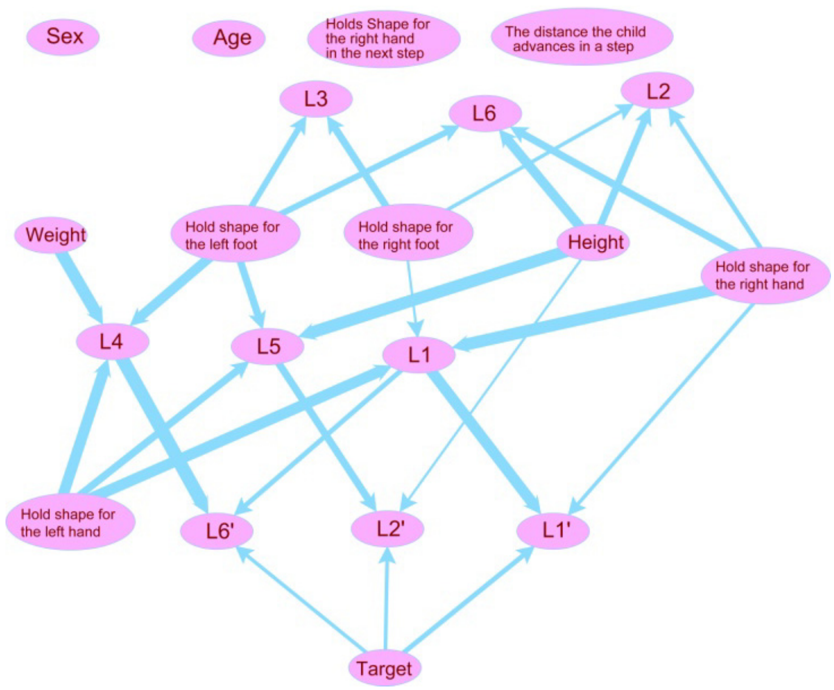

Fig. 8. Climbing behavioral model when a right hand moves (Type 2)

4 Conclusion

In this paper, based on the result of the climbing model of outdoor climbing wall, we developed an artificial rock-climbing equipment to understand what factors influence children's climbing behavior. We gathered data on how children climb while they play with the developed equipment. So far, 1226 children participated in this study, and we constructed two climbing behavioral models to determine influencing variables of climbing behavior. The model of Type 1 showed that the next position was influenced by the current position and target direction, and the current position was influenced by children's physical characteristics. We developed the model of Type 2 to see how hold shape influenced climbing behaviors. The model of Type 2 showed that the next position was influenced by target direction, and the current position was strongly influenced by hold shape that each appendage touched.

As a result of our present study, we conclude that rock-climbing is a hypercomplex interactive phenomenon that was created from the combination of three things: 1. the abundance of hold shape which four appendages can use is intricately allocated, 2. the current position is affected by hold shape, and its position affects the next position, and 3. a direction in which a child is supposed to climb keeps changing over time. Most importantly, our research revealed that the hypercomplex interactive phenomenon can be modeled and quantitatively described through creating the artificial sensorized equipments. We hope to gain a further understanding of rock-climbing behavior, and also we hope that our research will contribute to evidence-based interaction design of rock-climbing.

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