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Holistic Haptic Education Platform for Developmental Disorder Children

Tami Im[1,a], In-ho Yun[2,b] and Sang-Youn Kim[2,c,*]

[1] *Online Lifelong Education Institute, Korea University of Technology and Education, Korea.*

[2*] *Interaction Lab., Advanced Technology Research Center, Korea University of Technology and Education, Korea.*
** (Corresponding author)*

[a] *Orcid: 20000-0002-5139-5159,* [b] *Orcid: 0000-0003-0018-1510,* [c] *Orcid: 0000-0002-2755-7082 & Scopus Author ID: 57194872420*

Abstract

The purpose of this paper is to develop and test a holistic haptic education platform for developmental disorder children. This system is unique in terms of portable size and control functions by smartphone, so teachers could create various haptic sensations easily with the smartphone interface. Most participants were able to identify the direction (top/bottom/left/right)of vibration flow and its speed and to recognize. More than 50% of participants were able to identify the different strength of stiffness from 2 level differences (weak to strong) and participants were more sensitive to getting cold than getting hot. Interview results with three special education teachers suggested that the proposed system would be very helpful and effective for developmental disorder children in terms of enhancing interest, attention, easiness of repetition, and multi-modal sensation by haptic feedback. It is expected that the results of this study would be beneficial to researchers and practitioners in the area of special education and haptic research.

Keywords: Vibrotactile, Kinesthetic, Thermal, Developmental Disorder Children, Haptic.

INTRODUCTION

Multidisciplinary research of haptics has grown rapidly and suggested possibilities of haptic devices to be useful as teaching and learning aids. Jones *et al.* examined the effects of haptic simulations to visual impairment students for teaching temperature and pressure [1]. The result of the study was positive in terms of participants' assessment score after studying with the device. This study found potentials of haptic devices to teach abstract science concepts to students with visual impairments. An IST European program (MUVII: Multi User Virtual Interactive Interface) developed haptic (force, torque, tactile) feedback as a part of their project and found positive effects on learning and interest toward the haptic application [2].

Sense of touch helps people understand objects and events [3]. So, haptic technology becomes a key factor to delicately manipulate virtual objects and/or to immersively interact with the object. Many studies suggested that touch information works better than visual information to perceive detailed properties of a target object like roughness/smoothness, hardness/softness, wetness/dryness, and stickiness/slipperiness [3, 4, 5, 6].

Number of children who are diagnosed as developmental disorder is increasing. It is critical to provide education and treatment for these children from early age. Developmental disorder children are known to be sensitive to sensory stimulation [7, 8], so various sensory products are developed to support these children but not specifically focusing on education [7]. In this context, it is necessary to develop an education platform which provides sensory stimulation using haptic feedback to enhance learning outcome, attention, and interest of developmental disorder children.

There is a dearth of studies on haptic based education systems for special education especially targeting developmental disorder children. In this study, we aimed to develop a holistic haptic based vibration, stiffness, temperature education platform for developmental disorder children which is portable and is controlled by a smartphone. Performance of the system was analyzed and a user test with developmental disorder children was followed to examine possibility of the proposed platform as an educational system for these children.

CONFIGURATION OF THE PROPOSED EDUCATIONAL PLATFORM

Figure 1 shows an overall structure of the proposed system consisting of five parts : 1) a vibration part, 2) a thermal part, 3) a stiffness tuning part, 4) a housing part, 5) and a smart phone. The vibration part generates vibrotactile information using four vibrotactile actuators which are attached on a plate. The thermal part is made by using of a peltier element. Thermal part is positioned on the surface of the proposed system in order to easily be touched by a user's finger. The stiffness tuning part is composed of a solenoid, MR fluids, and a mass. The solenoid creates magnetic fields to control the "stiffness" of MR fluids.

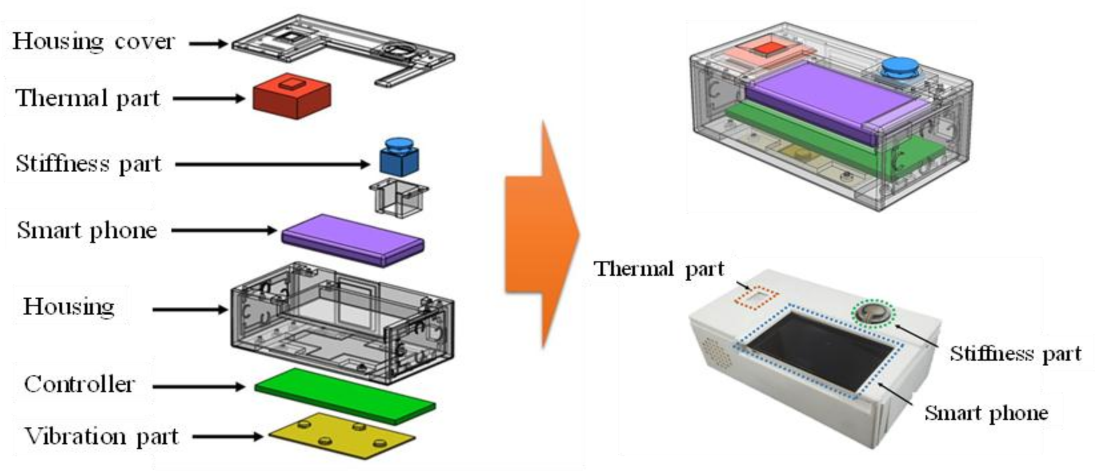


Figure 1: Schematic illustration of the developed educational platform.

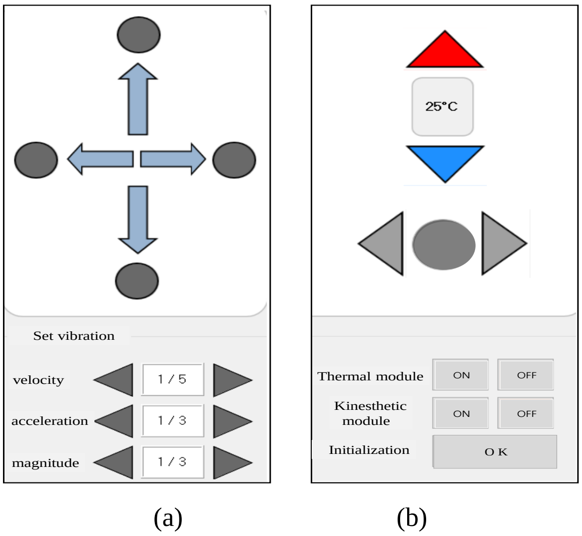


Figure 2: Graphic user interfaces for controlling the several haptic sensations.

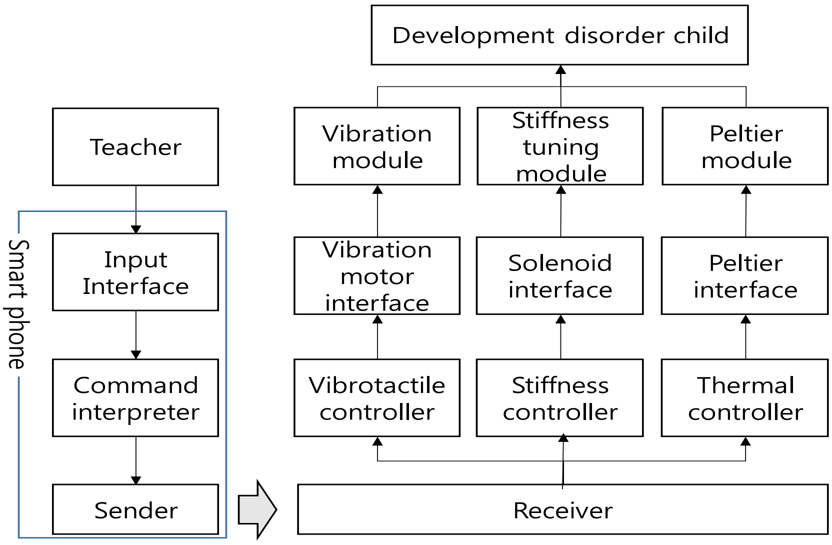


Figure 3: Signal flow of the proposed system

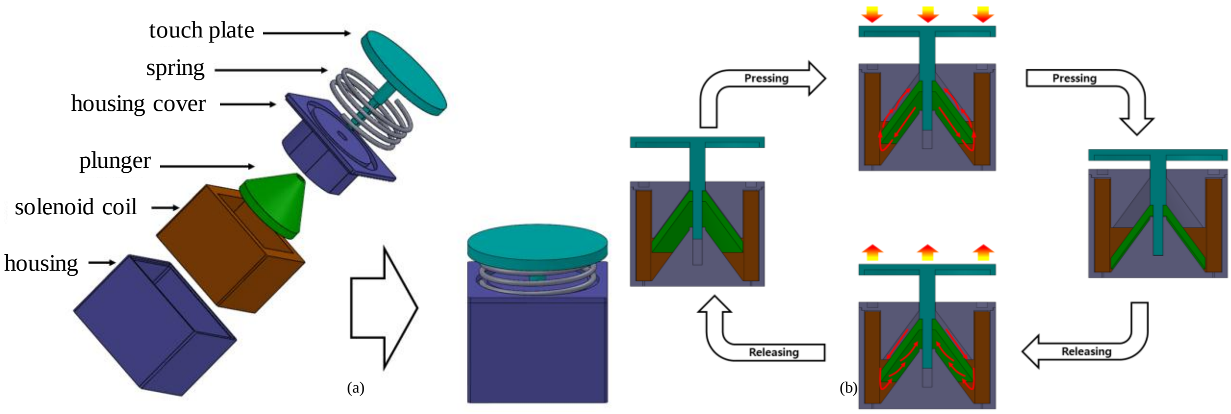


Figure 4: Schematic illustration of the stiffness tuning part and its operating principle.

Simple graphic user interfaces were made for android to provide various commands, which are used for creating a variety of haptic sensation. Figure 2 (a) and Figure 2(b) show graphic user interfaces for controlling vibrotactile, kinesthetic, and thermal sensations. A teacher can not only change the direction of vibration flow but also control its velocity, acceleration, and magnitude via the GUI (Figure 2(a)). Furthermore, the teacher can adjust the temperature of the thermal module and change the hardness of the stiffness tuning module shown in Figure 2(b).

Figure 3 shows the signal flow of the proposed educational platform. When a teacher sets a control parameter through the developed GUI (Figure 2) on the mobile device, the command is interpreted. The interpreted command is transferred to the proposed system via a wireless communication module (Bluetooth). Based on the received command, three haptically rendered signals (a vibrotactile signal, a stiffness signal, and a thermal signal) are created by the three controllers as shown in Figure 3. After that, each signal is conveyed to its corresponding module (a vibration module, a stiffness tuning module, and a peltier module) via its corresponding interface. Therefore, development disorder children can feel the sensations of vibration, stiffness, and temperature which are set by a teacher.

Vibration Part

The proposed device provides not only static vibration but also vibration flow to children. In order to make vibration flow, we applied the concept of a traveling vibrotactile wave which originates from one point and gradually propagates to other points. Four vibrotactile actuators (linear resonant actuators) were arranged at four corners of bottom side of the proposed educational platform in order to haptically simulate the moving direction/speed of the traveling vibrotactile wave. The size of the vibration plate (bottom side of the proposed system) is 50 x 40 mm^2. As we mentioned before, the vibration flow is made by the funneling effect [9].

Following example describes a case where vibration is created at left side of the plate and then flows into the right side of the plate to demonstrate the vibration flow using funneling effect. This vibration flow is made by controlling the amplitude of the two motors in opposition to each other and their driving time difference. If the amplitude of the left actuator is greater than that of the right actuator, a human senses the vibration at the left part of the vibration plate. In the case where two vibration motors are actuated at the same magnitude, he/she can feel the vibration at the middle part of the vibration plate. When the amplitude of the right actuator is greater than that of the left actuator, a human senses the vibration at the right part of the vibration plate. Therefore, the operation in this order makes vibration flow from the left to the right.

Thermal Part

For creating thermal sensation, we used a peltier element whose one side is getting cold and the opposite side is growing hot according to input current. The peltier element locates on the area where a user puts his/her finger on. The objective of the thermal part is to create the desired temperature and to keep it. In order to maintain desired temperature, the peltier element was controlled by a PID (Proportional-Integral-Derivative) controller. In this control scheme, a small temperature sensor (semitec, 223Fu3122-07U015) that can be easily attached to the peltier element's surface was used to measure the temperature of the peltier element's surface.

Stiffness Tuning Part

To control the hardness of a target object, we used MR fluids (Magnetic rheological fluids) whose material property is changed by applied magnetic field. The stiffness tuning part is composed of a touch plate, a spring, a housing, a housing cover, a plunger, and a solenoid coil as shown in Figure 4(a). Figure 4(b) shows the operating principle of the proposed stiffness tuning part. Initially, MR fluids are filled in the space between the plunger and the bottom surface of the housing. When a user presses the touch plate of the stiffness tuning part, the MR fluids moves up the plunger by the pressing force. If we provide a current input to the solenoid coil, MR fluids hardens and its flow becomes hindered. Therefore, a user can sense the resistive force caused by the hindrance. When a user removes his/her finger from the touch plate of the stiffness tuning part, the touch plate and the plunger is moved up and the MR fluid moves the plunger down.

PERFORMANCE ANALYSIS

An experiment was conducted whether users can discriminate the various speed of the vibration flow. The experiment was conducted with 20 subjects whose ages are between 25 and 31 years. Total of 40 vibration flow stimuli were presented to each subject. The presented vibration flow stimuli was altered in the range of 100mm/sec and 2000 mm/sec at 50 mm/sec. For this experiment, a subject closed his/her eyes and was given a pair of stimuli (a standard stimulus and a comparison stimulus). The subject was asked to answer whether two vibraton flow stimuli are same or not. White noise was presented to the subjects wearing headphones in order to block sounds generated by vibrotactile actuators. The subjects gave their answers and then they perceived the next stimulus pair until all stimulus pairs had been discharged. Each stimulus pair was presented to the subjects twice cross-balanced for presentation order and furthermore, the stimulus pairs were presented in a random order. For every stimulus pair, the answers of subjects were confined to 'Yes' or 'No'. The stimulus duration was chosen 2 sec and the interstimulus interval for each pair was 1 sec. All subjects discriminate maximum seven 'speed change' of vibratoin flow (100 mm/sec, 200 mm/sec, 400msec, 600msec, 900msec, 1150 msec, 1800msec).

Another experiment was conducted to investigated how many variations of vibration amplitude is discriminated by users. The vibration amplitude is proportional to the applied voltage. The same subjects, who were participated in the previous experiment, joined . The applied voltage was altered in the range of 0V and 3V with interval of 0.1 V. For this experiment, each subject closed his/her eyes and was given a pair of vibrotactie stimuli (a standard stimulus and a comparison stimulus. The subjects answered whether two stimuli are same or not. After that, they felt the next stimulus pair until all stimulus pairs had been discharged. Everything beyond above mentioned is same as previous experiment environment. Four vibration amplitudes can be easily discriminated by all subjects (0.25V, 1.05V, 2.05V, 3.0V). In order to convert the voltages, which are discriminated by the users, into vibrational force, experimental set-up was constructed as shown in Figure 5. In this experiment, we used a function generator (Protek 9305), an accelerometer (Bruel & Kjaer, and an oscilloscope (MSO/DPO 2000). The input voltage created by the function generator was applied to the vibrotactile actuators. To measure the vibration acceleration of the actuators, a mass of 100g was placed on the upper side of the vibration motor, and the accelerometer was attached to the mass. The measured acceleration data (0.2G 0.7G, 1.56G, 2.43G) (G=9.8m/sec^2) was displayed on the oscilloscope.

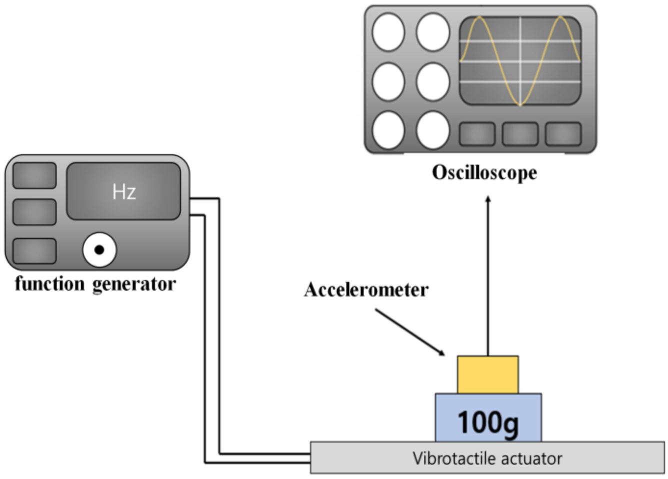
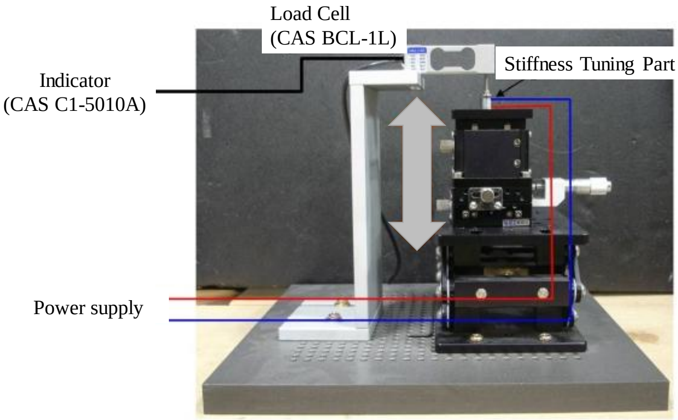


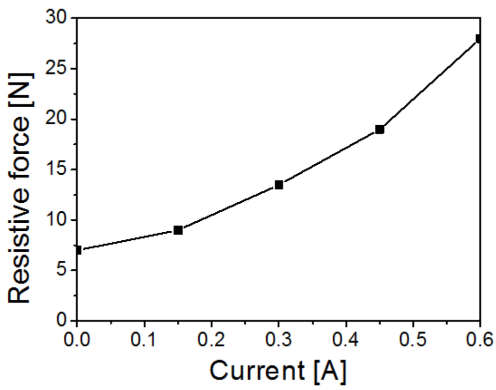
Figure 5: Experimental setup to measure vibrational force of the vibration module

We also investigate how many variations of temperature sensation are distinguished by subjects. Same subjects who have joined previous experiment were participated in this experiment. The temperature is changed in the range of 15℃ and 40℃ with interval of 1℃. Everything beyond above mentioned are same as previous experiment environment. All subjects discriminated seven 'temperature change' (15℃, 19℃, 23℃, 27℃, 31℃, 34℃, 37℃).

To quantitatively analyze the performance of the developed stiffness tuning module, we constructed an experimental setup consisting of a micro stage, a single point load cell (CAS BCL-1L), and an indicator (CAS CI-5010A) as shown in Figure 6 (a). We placed the developed stiffness tuning module on the micro stage which moves along the vertical direction (Z-axis). The applied load and the intended depth of the developed stiffness tuning module were measured by varying the input current and the position of the micro stage. Figure 6 (b) shows the measured resistive force with respect to the applied current. As shown in Figure 6 (b), the resistive force increases as the applied current increases. Like other modules, we inquired how many variations of the resistive force is distinguished by subjects. Same subjects who have joined previous experiment participated in this experiment. The resistive force is changed in the range of 7N and 28 with interval of 1N. Everything beyond above mentioned are same as previous experiment environment. All subjects discriminate nine 'force change' (7N, 9N, 11N, 13N, 15N, 18N, 20N, 23N, 26N).



(a)



(b)

Figure 6: Experimental setup to measure the generated force of the developed stiffness tuning module and its result.

USER TEST

Procedure

The main purpose of the proposed system is to aid education and treatment for developmental disorder children. The user test of this study was conducted with developmental disorder children to enhance future usage of the system. Twenty participants were recruited from three special education organizations in Seoul, Korea. The average age of participants was 15.6 years old, 13 male students and 7 female students. We have developed test questionnaires for the user test and revised to finalize them based on three special education experts' review results. Cronbach's αs for vibration, stiffness, and thermal items were .80, 79, and .82, respectively. Educational scenarios were also developed for user test.

User test was led by three special education teachers based on educational scenarios developed with researchers. Teachers had individual sessions repeatedly with participants using vibration part, stiffness part, thermal part and collected participants' reactions.

RESULTS

Vibration Module

1) Is it possible to identify the 4 different points of the vibration module?

When the vibration occurred from four different points (top/bottom/left/right) (Figure 7), more than 90% of participants were able to identify where the vibration started (Figure 8).

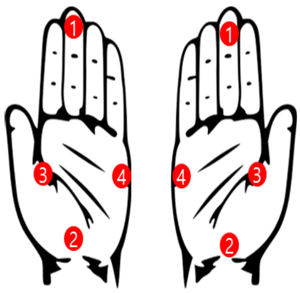


Figure 7: Four Vibration Points of the Vibration Module

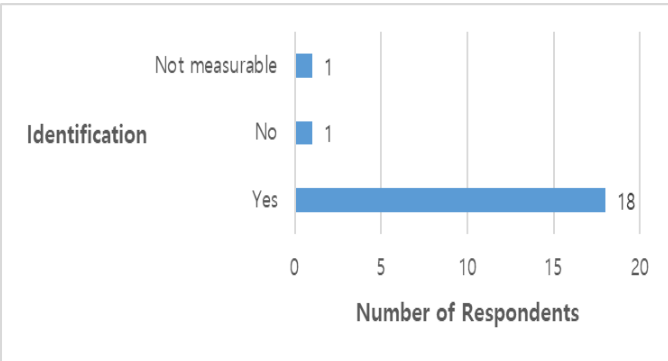


Figure 8: Identification of the Vibration Point

2) Is it possible to identify the different force of the vibration module?

When the vibration occurred by different force, more than 90% of participants were able to identify the difference (Figure 9).

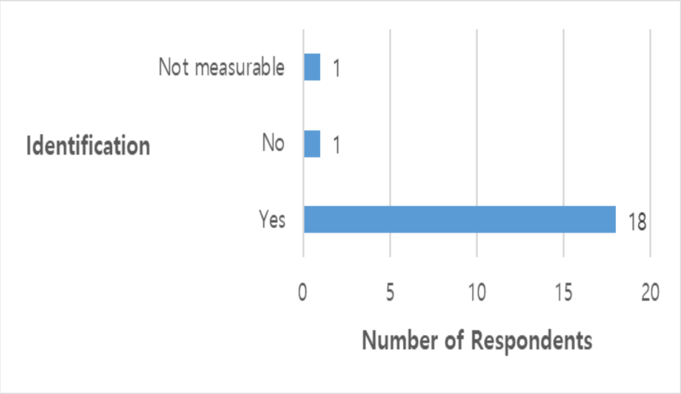


Figure 9: Identification of the Vibration Strength

Stiffness Module

1) Is it possible to identify the 4 different points of the vibration module?

For the user test, we set the strength level as three, weak, medium, and strong. And 1 level difference refers to difference between medium and strong, and 2 level difference refers to difference between weak and strong. We would like to know if participants were able to identify the different strength of stiffness from this test. Only 25% of participants were able to identify 1 level difference, between medium and strong. And 55% of participants were able to identify the different strength of stiffness from 2 level difference as shown as Figure 10. These results suggest it is necessary to provide at least 2 level difference for teaching stiffness to developmental disorder children.

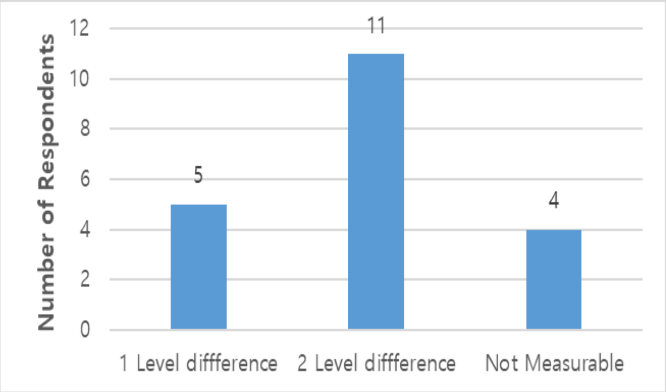


Figure 10: Identification of the Stiffness Strength

Thermal Module

1) From which temperature difference, are participants able to identify that it is getting cold?

For the user test, we set the default temperature as 25 ℃. We provided lower temperature through the thermal module to participants from 25℃ to 20℃, 15℃, 10℃, step by step. The purpose of this test was to find out from which temperature difference the participants are able to identify that it is getting cold. 75% of participants were able to sense it is getting cold when the temperature goes down 5℃ from the thermal module, and total of 95% recognized the temperature difference with 10℃ difference.

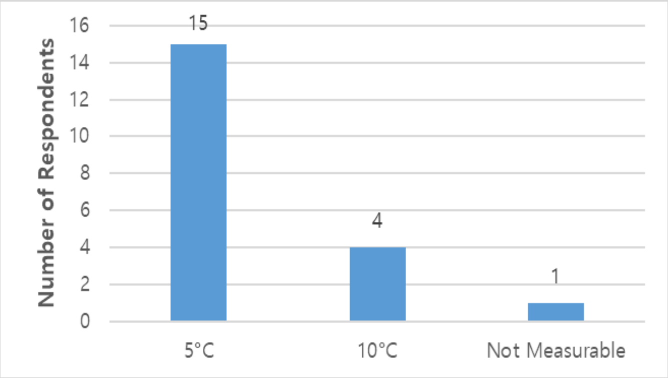


Figure 11: Identification of Coldness

2) From which temperature difference, are participants able to identify that it is getting hot?

For the user test, we set the default temperature as 25 ℃. We provided higher temperature through the thermal module to participants from 25℃ to 30℃, 35℃, 40℃step by step. The purpose of this test was to find out from which temperature difference the participants are able to identify that it is getting hot.

Only 25% of participants were able to sense it is getting hot when the temperature goes up 5℃ from the thermal module, and total of 60% recognized the temperature difference with 10℃ difference. These results show these participants were more sensitive to getting cold than getting hot. It is possible to suggest that giving bigger variations of temperature when teaching warmth than coldness to developmental disorder children.

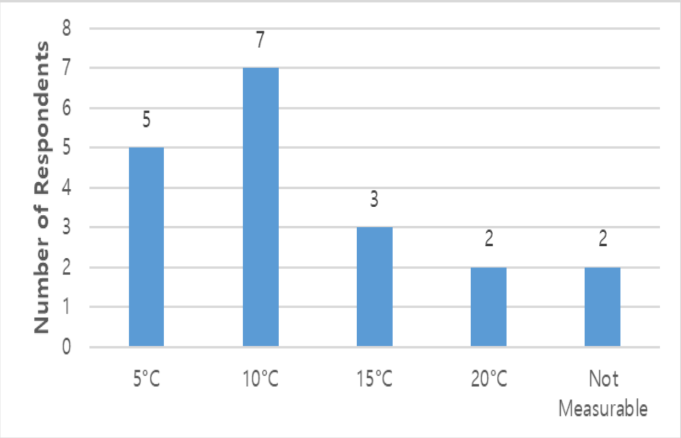


Figure 12: Identification of Warmth

CONCLUSION

In this paper, we proposed a holistic haptic based education system, consists of a vibration part, a thermal part, a stiffness tuning part, a housing part, and a smart phone, for developmental disorder children. Since this system has portable size and is controlled by a smartphone, teachers could create various haptic sensations easily with the smartphone interface. The performance of the system was examined with 20 adult subjects. First, all subjects discriminate maximum seven 'speed change' of vibration flow as a result of vibration module performance test. Second, all subjects discriminate maximum seven 'temperature change' from the performance test of the thermal module. Third, all subjects discriminate maximum nine 'force change' from the stiffness module performance test.

User test was conducted to figure out whether real target users could use our proposed system and key functions work fine with them. Twenty developmental disorder children participated in the user test and three special education teachers led the test with researchers. Results of the user test can be summarized as below. First, most participants were able to identify where the vibration started, given the vibration occurred from four different points (top/bottom/left/right) and to identify the difference of vibration force. Second, more than 50% of participants were able to identify the different strength of stiffness from 2 level difference (weak to strong) not from 1 level difference (medium strong). Third, participants were more sensitive to getting cold than getting hot.

From the user test results, three suggestions can be made for future researchers and practitioners who are willing to adapt the proposed education system for developmental disorder children. First, this haptic based system shows possibility as an education aid to teach vibration, stiffness, temperature for developmental disorder children. Second, designing enough variation between "hard" and "soft" in the system is important for educating developmental disorder children about stiffness. Finally, it is necessary to provide bigger variations of temperature through the system when teaching warmth than coldness to developmental disorder children.

Interview results with three special education teachers who supported the user test suggested that the proposed system would be very helpful and effective for developmental disorder children in terms of enhancing interest, attention, easiness of repetition, and multi-modal sensation by haptic feedback. They also mentioned they were willing to use this system in their class. Also, researchers' observation found out that participants did not express any anxiety, fear, or inconvenience toward the proposed system and showed high interest and attention during the test sessions.

It would be meaningful to examine the effects of proposed system within the context of real developmental disorder children class for a long term to identify children's behavioral and attitudinal changes. It is expected that the results of this study would be beneficial to researcher and practitioners in the area of special education and haptic research.

ACKNOWLEDGEMENTS

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