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ORIGINAL ARTICLE

Understanding the Relation between Emotion and Physical Movements

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Abstract: We present two experiments to understand the relation between the attributes of physical movement and emotional elicitation. For the experiments, we developed a physical movement generation device. Four attributes of physical movement, speed, smoothness, granularity, and volume, were identified from the review of existing theories. These attributes were used as control parameters in our study. We used the affective grid with pleasure and arousal to identify the relation between the types of physical movement and specific emotions. The results demonstrated that physical movement can easily evoke some areas of emotion. In particular, it was found that emotions in both pleasure and arousal dimension were positively correlated with speed. Finally, we discuss the implications of the results and how physical movement can enhance emotional qualities in the design of interactive products.

Keywords: *Psychology of Physical Movement, Emotional design, Interactive Product Design, Affective Grid*

1. INTRODUCTION

To create compelling products or services, it is becoming more important to consider product's emotional and experiential qualities [1, 2]. One of the common ways to enhance traditional product's emotional qualities is visual aesthetics. For smart products with digital technologies, aesthetics goes beyond visual aspects. Interactive aspects with temporal and dynamic elements, such as sound and motion, are becoming important for enhancing the emotional and experiential qualities.

Physical movement is one of the outstanding dynamic and temporal design elements. Physical movement can easily attract people's attention and emotion by changing the tangible environment. For example, we often get a sad feeling from seeing the swaying fall of a leaf from a tree in autumn, or a sense of ordered beauty from the rhythmic swing of a pendulum in an old clock. Previous studies show that physical movements can effectively attract users' attention [3], help communication, or guide people's behaviors [4]. Nevertheless, physical movement is a challenging attribute in the design of new interactive products, because of the physical constraints, such as size, shape, structure, and moving mechanisms.

There have been researches on movement in the design of interactive systems. Many of them have focused on issues of virtual movement [5] or usability [6] in relation to physical qualities, such as tactile and haptic feedbacks. Little is known about how physical movement is associated with specific emotional qualities of interactive products.

Our aim was to understand the attributes of physical movement and how they may elicit people's emotions. We expected that the results could guide the design of future interactive products by helping designers increase their emotional qualities. To this end, we reviewed existing theories on the attributes of physical movement and identified the attributes to be associated with emotion. We then developed a physical-movement generation device that could control the key attributes identified. We conducted experiments to identity the relation between the attributes of physical movement and human emotion. We used the affective grid [7] as a framework by which to classify emotions, as it is one of the most representative models of visceral emotional responses.

2. RELATED WORKS

Movement is a subject dealt with not only as an element of design but also as a means of understanding human behavior and of expression. We briefly summarize the results of the literature review which have influenced our current work.

There is rich literature in psychology explaining the relation between emotion and design elements, such as color [8], sound [9], and forms [10]. There are a few works in the field of visual design that have investigated how to apply motion to increase usability. For example, Vaughan [5] has investigated the expression of movement in theatrical arts to apply motion as a design element to graphic interface. Peterson [11] has used aspects of visual motion used in films to improve the usability of a web site.

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Kinetic typography also uses text movement to achieve clear and emotional communication [12].

While there is much work on movement or motion as a design element to enhance the usability and emotional qualities in 2D media, relatively little attention has been given to physical movement. Recently some researchers have reported on the role and the application of physical movement in interaction design. For example, Weedesteijn et al. [13] have used movement in a subsidiary educational device with which children can learn to express emotion with their bodies. Young et al. [14] have suggested the techniques of simulating motion in nature and converting this into an animation sketch to design a moving part of a product. Swindle et al. [6] have demonstrated a process for measuring and comparing visceral emotional responses of physical control. Ju and Takayama [15] have showed that the simple movements of a door can deliver welcoming and reluctant messages to pedestrians. Recently, Lee et al. [16] have introduced a design method for creating expressive movements for simple standing products by translating human torso movements into combinations of X, Y, and Z axial movements.

Commercial products, such as Thanks Tail by Pet Works, Nabaztag and Rolly by Sony, have also been introduced as interactive products using physical movement as key functional and emotional features, although most of these are not on the market now. Many of the existing works, however, have focused on specific context and application domains. Few researches are conducted to articulate the physical movement in specific attribute levels. There is a lack of understanding of the detailed relationship between the physical-movement attributes and the emotional qualities of interactive devices.

Other related works include studies on understanding emotion and its relation to various attributes in design. Although many theoretical frameworks of emotion have been introduced, there are two primary approaches. The first conceptualizes emotion discretely: it describes basic emotions in terms of unique and salient categories. The other regards emotion as a dimensional construct: it uses the dimensional constructs as a common frame of reference for describing the emotions.

One representative work of a dimensional approach was initiated by Osgood et al. [17]. They proposed three factors, consisting of two major factors - evaluation and activity - and one minor factor, called potency. Following Osgood's lead, Mehrabian [18] suggested that these judgment factors are related to three fundamental emotion responses, which he labeled *pleasure*, *arousal*, and *dominance*. Recently, studies on measuring emotion have often combined both approaches of conceptualization. For example, the circumplex model by Russell et al. [19] mapped emotion-related categories in emotion space defined by pleasure and arousal. The model benefits from a geometric metaphor for the internal scale on which stimuli are judged which reconciles both discrete and dimensional approaches.

Despite the rich literature on emotion and movement in psychology, there is a lack of studies on the detailed attributes of physical movement and how we can employ physical movement as a design element for specific emotional qualities in interaction design. Understanding the attributes of physical movement and their relation to emotions can improve the design of emotionally rich products.

3. PHYSICAL MOVEMENT ATTRIBUTES AND EXPERIMENT DEVICE

3.1 Attributes of Physical Movement

To articulate the attributes of physical movement, we reviewed existing theories on physical movement. The review was also intended to find an initial assumption on the relation between general features of physical movement and emotional elicitation. One of the representative researches on the attributes of movement is Laban Movement Analysis (LMA) by Rudolf Laban [20]. LMA is a method that provides the structural aspects of movement and suggests a system of symbols to record movement directions, places, positions, and involved body parts. Ways to express the natural human body's gesture in 3D model were also investigated through the use of the elements from LMA as parameters [21].

Vaughan [5] suggested four main attributes of movement - path, area, direction, and speed - based on the investigation of the human body's movements and postures as shown by performing artists. Meanwhile, Bacigalupi [22] explained that movement is made up of several formal characteristics, including rhythm, tempo, continuity, and direction.

The relation between the general features of physical movement and emotion is reported by some researchers. For example, Pollick et al. [23] have experimented to find out emotions perceived at different levels of speed and found that the speed of movement had a correlation with activation properties of the circumplex model. Boon and Cunningham [24] have had people listen to music expressing a certain emotion and express this music in the form of movement, and deduced a correlation. They have found that larger and smoother

Table 1: Attributes of physical movement

Key Attribute	*Definition in this research*
Speed	Temporal Rate of changes between different physical states.
Smoothness	Level of continuity or jerkiness in the physical movement.
Granularity	Granularity of movement path or trajectory.
Volume	Size or volume of the moving object.

movements are associated with happy and pleasant emotions, while such movements as scrunching up the body are associated with sad or fearful emotions. Still, the matter of further identifying the attributes of physical movements that influence emotional responses remains unresolved.

Based on the review of general features of physical movement from existing theories, we identified four key attributes of physical movement: speed, smoothness, granularity, and volume for this study (see Table 1).

3.2 Physical Movement Generation Device

To study the impact of the movement attributes on emotion, we developed a physical movement generation device. We also considered the application of the device in emotionally rich interactive products. Figure 1 shows the physical movement generation device developed. In designing the device, we considered many aspects for our experiments and exploring the applications in future products. We used the metaphor of feelers, which many living creatures, including insects, use to interact with the real world. Despite the simple hardware structure, we could apply a variety of moving mechanisms in multiple combinations. On the other hand, induction of emotion could be closely related to external shape itself. Therefore, the hardware form was simplified to minimize the emotional bias that might arise from the external form. The structure was designed to provide versatility for generating physical movements such as rotation, expansion, and crouching.

The device consists of hardware that generates physical movement and associated software that controls all the attributes of physical movement. The simple structure of a cylinder can generate a variety of physical movement. The two cylinders can reach any point in a half sphere, so that the path attribute can be controlled. The arm-like structure can be contracted or expanded so to adjust the volume of the movement. The movement's speed and smoothness can be controlled in the software's graphic interface.

The hardware is capable of expressing vertical piston movement (related to volume) and front/back and left/right movement around a fixed axis (related to speed, smoothness, and path). Each movement uses the combination of three servomotors. The horizontal movement, created by the rotation of the motor, is translated to vertical movement, and piston movement is realized through the coil spring's restoring power. Front/back and left/right rotation movement are expressed as rotation around the origin in the direction of the x and y axis in the three-dimensional space of x, y, and z axes. These two rotation movements can produce circular motion around the z axis. A light indicator is attached to the top of the arm. Figure 2 shows the system structure. This hardware was connected to the PC via two "4-Motor Phidget Servo" boards [11].

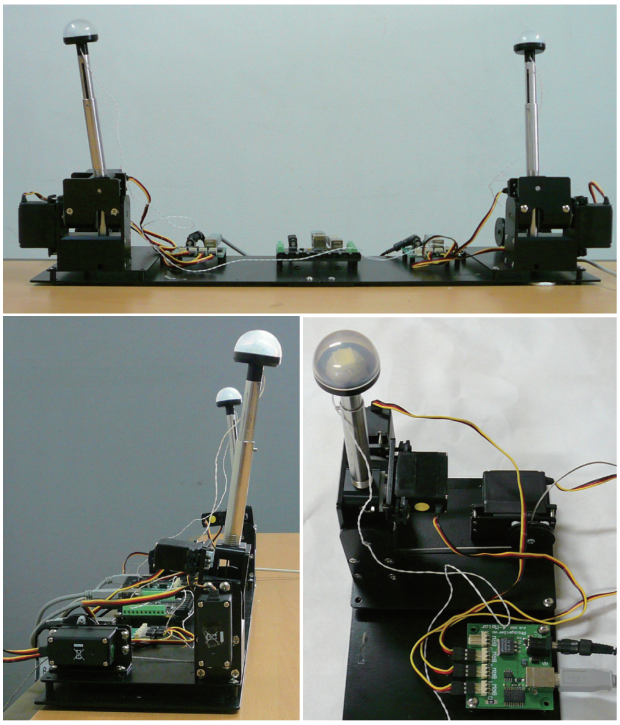

Figure 1: Hardware of the Physical Movement Generation Prototype

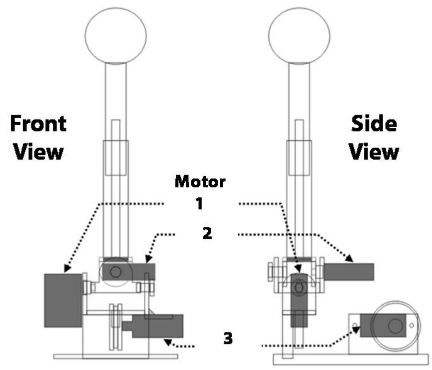

Figure 2: Hardware structure details

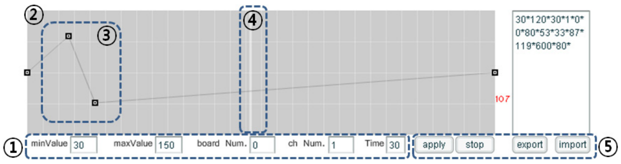

Figure 3: (1) The input field to set the min. and max. value of the motor number, position and angle and ID; (2) the main graph editor, where the angle of the arms is specified along the timeline; (3) the changing point, which can be inserted by clicking and dragging; (4) the time bar, which moves along the time-line and controls the movement; (5) buttons to make a move, stop, and export and import the path data.

3.3 Movement Generation Software

We developed a software application that controlled the hardware through a graphic user interface. We added save and load functions so that the authored movements could be reused. A user can adjust the angle of the servomotors in the flow of time and control the four attributes of the physical movement. A graph editor (Figure 3) was used to support the interface of generating and controlling physical movements. A timeline area of the graph editor shows the continuous change of each servomotor angle. Considering both the complexity of the control and the possibilities for future expansion, we separated the timeline areas for individual control of each servomotor. Flash with the Action Script programming language and MIDAS [25] was used for the software implementation.

4. EXPERIMENTS ON EMOTION OF PHYSICAL MOVEMENT

To achieve the aim of the research, we focused on these two questions:

a. Can physical movements elicit emotions?
b. What type of emotion does each attribute of physical movement influence, and how?

Two experiments were conducted to understand the main effects of each attribute on emotion. We expected that controlling the four attributes in one experiment would make it hard to analyze, so we divided the experiment. It was also expected that by reducing the experiment task's time and repetition, participants' fatigue and learning effects would be reduced. In the first experiment, we focused on speed and smoothness. In the second experiment, we tested the other two attributes, granularity and volume. Except for the stimuli and the participants, the environmental conditions of both experiments were identical.

4.1 Assessment of Emotional Response with SAM

In both experiments, the participants assessed the emotion induced by physical movements in terms of the pleasure and arousal dimensions. We adopted self-assessment manikins (SAM) [26] as an assessment method because it is a nonverbal, culture-fair rating system based on a three-dimensional system of emotion consisting of pleasure (or valence), arousal, and dominance. Bradley and Lang [27] have also advocated the acceptance of SAM for measuring emotion, since a graphic representation of emotions requires less awareness than a verbal expression. The original SAM rating scale is comprised of three sets of graphic figures, respectively representing the three dimensions. For our study, however, we used the primary two dimensions, pleasure and arousal (Figure 4). This was because the dominance dimension often appeared much weaker than the other two dimensions and was positively correlated with the pleasure dimension [8, 27].

The graphic figures, which depict values along each of the dimensions on a continuously varying scale, were used to indicate emotion experienced. As shown in Figure 4, SAM ranges from a frowning, unhappy figure to a smiling happy figure, when representing the pleasure dimension. For the arousal dimension, SAM ranges from a relaxed, sleepy figure to an excited, wide-eyed figure. During the introduction of the experiments, sets of adjectives were employed to describe SAM verbally. Thus, participants could capture the meaning of the dimensions before they used the SAM scales in experiments. The participants could select any of the five figures comprising each scale.

4.2 Attributes used as Stimuli in the Experiment

The attributes applied to the prototype in the experiments are shown in Figure 5. We created the three granularity levels with circular movements. The circular path movement was used in the experiment to control the granularity attribute because it is a common closed path movement for interactive products, sharing start and end

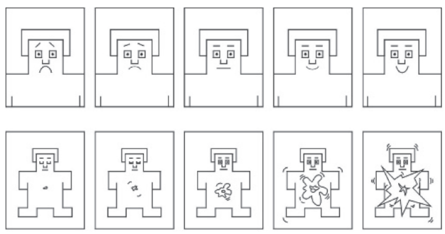

Figure 4: Self-Assessment-Manikin (SAM) used in the experiment. The above is for indicating the degree of pleasure, the below for arousal.

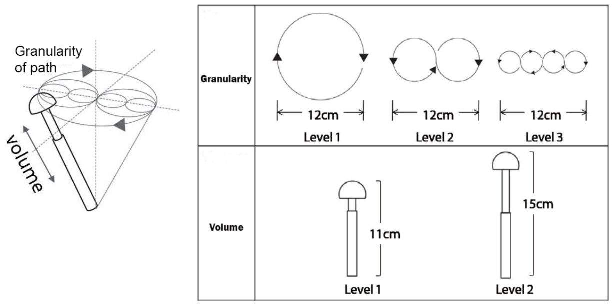

Figure 5: Granuality and Volume attributes

Table 2: Details of Speed and Smoothness Attributes.

*Speed is the velocity of the head movement.
**Smoothness is the time length of pause before moving to next position.

Level	1	2	3	4	5
Speed (cm/sec)*	3.8	11.4	19.0	26.6	34.2
Smoothness (sec)**	0	0.083	0.177	0.250	0.333

positions. With other paths, such as an open path, which has different starting and ending positions, or paths with multiple lines and curves, it is difficult to control each attribute separately as multiple attributes change at the same time. We created two levels of volume by extending the length of the arm. The length of the first level was 11 cm, and that of the other was 15 cm.

Table 2 shows the details of the speed and smoothness attributes. Speed ranged from 3.8 to 34.2 cm/second for the head part. Smoothness was varied by the duration of the pause before the next move. As stimuli for the Experiment I, five linearly increasing levels of speed and smoothness were created. The device showed a part movement with two arms. This was to make stimuli strong.

4.3 Experiment 1: Speed and Smoothness

In Experiment I, we tested whether two attributes of physical movements, speed and smoothness, elicit emotional responses.

4.3.1 Participants

Thirty paid participants (13 male, 17 female) were tested individually in Experiment I, which took approximately 20 minutes to complete. The participants' ages ranged between 21 and 31 years (M of age = 25.13, SD = 2.64).

4.3.2 Stimuli

Twenty-five physical movements were created by the combination of five levels of speed and five levels of smoothness, and they were presented to the participants in random order. The volume (the length of the arm) was set to 13 centimeters, and the granularity was set to level 2, which are mean values.

4.3.3 Procedure

After filling out their demographic information and reading through the introduction of the device, participants were presented with physical movements of the device in a random order. Participants marked on two sets of SAM graphic figures, on a 9-point scale, their emotional feeling about each physical movement.

The answer sheets were gathered and checked immediately after the survey was finished, and no missing inputs were found. Participants wore ear plugs and noise-canceling headphones to mask distracting audio cues from the device's motors. Figure 6 shows the experiment setting with the device used as stimuli.

4.3.4 Result and Analysis

Based on SAM ratings of 30 participants on pleasure and arousal, mean values of pleasure and arousal of the 25 physical movements are depicted in an emotion space as displayed in Figure 7. The plot shows that emotional reactions to the presented physical movements varied

Figure 6: Experiment setting with the device making physical movement stimuli.

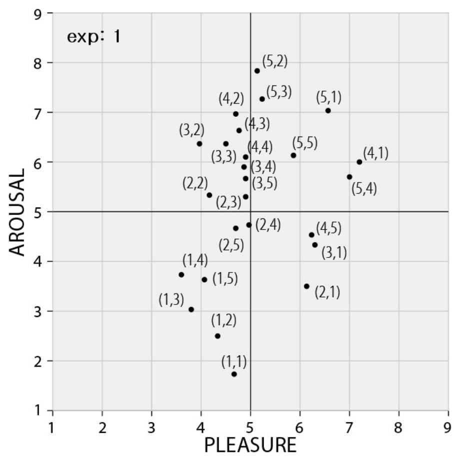

Figure 7: Plot of the means of 25 physical movements in an emotion space defined by pleasure and arousal. The number label indicates speed level, then smoothness level.

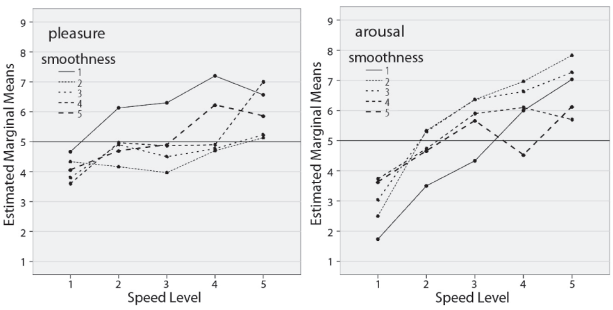

Figure 8: Profile plots: SAM ratings in pleasure (left) and arousal (right), Experiment I.

more in arousal than in pleasure. Moreover, a tendency is observed that as the speed is increasing, SAM ratings in both pleasure and arousal dimensions are also increasing.

The two charts in Figure 8 confirms that the mean values of SAM ratings on pleasure as well as arousal increase as the speed level (1 to 5) increases (faster). Pearson correlation analysis was used to estimate the strength of the positive correlation and yielded coefficients r of 0.29 ($p<0.01$) for pleasure and 0.58 ($p<0.01$) for arousal.

In addition to the speed level, the smoothness levels are also indicated in Figure 7. Each separate line corresponds to the smoothness level ranging from 1 (*very smooth*) to 5 (*not smooth; very jerky*). However, no overruling tendency is yet visible. To examine the effect of both speed and smoothness more precisely, multiple regression analysis was performed, and the stepwise method was facilitated. With regard to the pleasure both speed and smoothness are included in the regression model.

Pleasure = 4.35 + 0.40·speed – 0.15·smoothness ($R^2=0.10$)
$F(2, 749) = 39.93$, $p<0.01$
Standardized β coefficient: 0.29 (speed), −0.11 (smoothness)

The standardized beta coefficients of speed and smoothness are 0.29 and -0.11 respectively, which quantifies the strength and direction of the impact of each attribute. Concerning with arousal, a regression model was also yielded. However, in this case, the stepwise method rejected the smoothness as a predictor variable.

Arousal = 2.63 + 0.88·speed ($R^2=0.36$)
$F(2, 749) = 377.32$, $p<0.01$
Standardized β coefficient: 0.58 (speed)

Moreover, as the unstandardized beta coefficient of speed in regression model of arousal (0.88) is almost twofold greater than that of pleasure (0.40), indicating that one's emotional response to speed is more drastic in arousal dimension than pleasure dimension.

4.4 Experiment II: Granularity and Volume

Experiment II employed two additional attributes of physical movements, which are path granularity and volume. We included speed as a common attribute across the two experiments as we found that the effect of the speed attribute was consistently positively correlated with SAM ratings on both the arousal and pleasure dimensions in the first experiment. Accordingly, the characteristics of the movement stimuli in Experiment II were profiled in terms of speed, granularity, and volume. The smoothness was fixed to level 3, which is the middle value. In Experiment II, we tried to figure out where elicited emotions inhabited in the emotion space.

4.4.1 Method

Thirty paid participants (8 male, 22 female) were tested individually in Experiment II, which took approximately 20 minutes to complete. Their ages ranged from 20 to 26 years (M of age = 21.5, SD = 1.57).

4.4.2 Stimuli

Thirty physical movements were prepared by the combination of five levels of speed, three levels of path granularity, and two levels of volume. They were presented in a random order.

4.4.3 Procedure

The procedure and the physical environment of Experiment II were identical to those in Experiment I.

4.4.4 Result and analysis

Based on the SAM assessments of 30 participants on 30 stimuli, the mean values are plotted in Figure 9. As observed in Figure 7, the emotional responses to the physical movements in Experiment II also varied more strongly in arousal than in pleasure. Interestingly, the plotted mean values are clustered in a diagonal shape

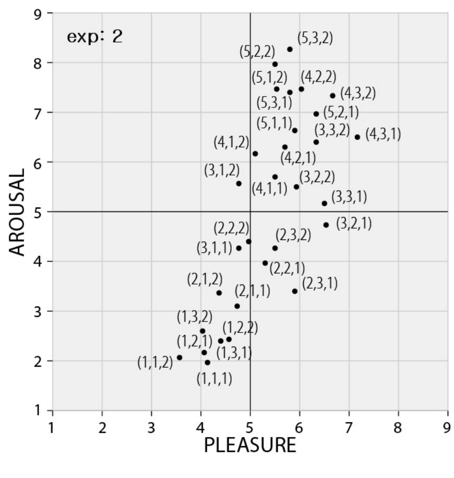

Figure 9: A plot of the means of 30 physical movements in an emotion space defined by pleasure and arousal. Number labels show speed level, movement type, and openness level, respectively.

indicating that a more pleasing movement evoked a more arousing emotion and vice versa.

As in Experiment I, we used a multiple regression analysis to examine the effect of attributes and measure them. Also, the stepwise method was employed to derive the equations. The results show that the influence of all three attributes are statistically significant on both pleasure and arousal dimensions. Consequently, two regression models were yielded as follows:

$$\text{Pleasure} = 3.56 + 0.43\cdot\text{speed} + 0.49\cdot\text{path complexity} - 0.27\cdot\text{volume openness}\ (R^2 = 0.13)$$

$F(3, 896) = 44.07$, $p < 0.01$

Standardized β coefficient: 0.30 (speed), 0.19 (path complexity), -0.07 (volume openness)

$$\text{Arousal} = -0.70 + 1.32\cdot\text{speed} + 0.37\cdot\text{path complexity} + 0.71\cdot\text{volume openness}\ (R^2 = 0.63)$$

$F(3, 896) = 505.54$, $p < 0.01$

Standardized β coefficient: 0.77 (speed), 0.13 (path complexity), 0.15 (volume openness)

A regression model for arousal has much higher determinant coefficient ($R^2 = 0.63$) indicating that the assessments on arousal is better explainable in terms of the three attributes. It also implies that a physical movement is more adequate to elicit emotion in arousal dimension rather than that in pleasure dimension. Secondly, the standardized beta coefficients of speed is the greatest in both regression models meaning that the influence of speed change is the most dominant in emotional expression of a physical movement. Moreover the emotional impact of speed is more drastic in arousal than in pleasure. In comparison with speed, both granularity of path and volume played minor roles. Path granularity is positively correlated with degree of pleasure as well as with arousal. With regard to volume, it is negatively correlated with pleasure but the impact is very marginal as the standardized beta coefficient is only −0.07. In aspect of arousal dimension the volume is positively correlated and its contribution is slightly bigger (0.15) than the impact of path granularity (0.13).

Resuming the empirical evidence three tendencies are drawn as follows: First, a faster movement elicits more pleasing as well as arousing emotion; Second, emotional responses to a physical movement are more drastically varying in arousal than in pleasure; Third when the movement includes high granularity of path, the pleasant and arousing effect is increased.

5. DISCUSSION

The results from the two experiments showed that emotional responses to the speed of physical movement were positively correlated with degree of both pleasure and arousal. Moreover, the standardized beta coefficients in multiple regression models showed that the contribution of speed to emotional response was always the greatest among the attributes. The tendency has been found consistently in both experiments confirming that the speed of physical movement is a dominant and effective attribute to elicit emotion. Therefore, the speed of physical movement should be facilitated as the main control attribute in a limited-control condition.

Although the impact is much smaller than the speed, we found that the granularity of path influences one's emotional responses in both pleasure and arousal dimensions. The higher granularity the movement has, the more pleasing and arousing is the emotion.

With regard to the smoothness and volume, their contributions were only limited to either pleasure or arousal. The smoothness is correlated with pleasure, and volume is correlated with arousal only.

Some results were unexpected in comparison with our initial expectation. We expected that larger movement would be associated with happy and pleasant emotion and scrunching movement associated with sad and scary emotions [5]. It was not clear to see this in the result. In the experiment, the volume was controlled by the length of the arms. The length was 15 centimeters in the highest volume and 11 centimeters in the lowest. The preliminary relation of the volume was inferred from the human-like movements. We speculate the weak impact of the volume on emotional response in our experiment could be due to the device's neutral shape and relatively little difference of the arms' length. We consider that if the volume is tested with real products such as a robot or flower-shaped interactive media with petals, then different results could be expected. Further investigation is needed to clarify this.

Previous works showed that human-like physical movement created an emotional reaction [28]; our results showed that physical movement of the device with an abstract form also elicit emotional responses. This confirms the previous study and elaborated the relationship between the movement attributes and emotion.

One interesting finding from the experiments was the patterns of physical movement mapped onto the emotion space. As shown in Figure 7 and Figure 9, the mean values of pleasure and arousal on the physical movements are not distributed in all quadrants of the emotion space. They are more widely distributed over the arousal dimension. This distribution implies that physical movement is more related to emotions in the central and vertical portions of the emotion space. Referring to the circumplex model [19], physical movement can evoke emotions such as tension and alertness. It may be difficult, however, to associate it with such emotions as sadness and contentment.

In both experiments, we found the impact on the pleasure dimension to be weaker than we have anticipated. This may be because pleasure dimension is often associated with the context or semantic meaning of stimuli. In our experiments, we measured emotional feelings by observing simple physical movement in a laboratory setting. The device's abstract and neutral form could have affected the weak impact on the pleasure dimension, as the prototype was hard to associate with any reference. If we were to include semantic association in the device's visual appearance or movement pattern (e.g. the look of a living creature or the physical movement of a humanoid robot), the influence on the pleasure dimension could be different. Further studies may be necessary to clarify this issue by studying the emotional effect of physical movements employed in different types of products and systems.

One issue to consider to interpret the impact of the granularity attribute is the influence of the circular paths used in the experiments. We used a circular path to control the degree of the granularity parameter because of practical implications. Circular paths with different granularities can be utilized in many interactive products. It can be simply generated through a pivot structure with a servo motor. Therefore, it is the most common joint-making physical movements for robots and other interactive products with arm-like structures. The closed paths sharing the start and end positions can also be widely used to indicate the diverse interface information of interactive products, such as status information, communication, or feedback. The simple circular paths were also used to minimize compound effects of the attributes. However, further investigation is needed in order to apply our findings to more complex path movements and understand the compounded effects of multiple attributes, such as a robot's movement mimicking human gestures.

Finally, the results of this research provide a basis for expanding our vocabulary of design language by introducing physical movement as a design element. This can be applied to the design of many emerging products. In robot design, for example, the physical movement can be carefully generated to evoke a pleasant emotion. Ambient display or telepresence systems can be advanced by adding physical movement to provide emotionally actuating feedback. When the movement generation device is embedded on a computer monitor, different states of the computer (e.g. listening pleasant music, attacked by a virus, tried from heavy system load, and so on) can be emotionally expressed with the physical movements. It can be applied to an animal-like character with feelers to show emotional behavior. Other consumer products such as TVs and audio systems, can be enriched by emotional movement generation. Another particular application can be an emotionally expressive cradle for a smart phone. For example, the cradle with movement generation arms can express various emotional notifications of the phone by physical motion.

6. CONCLUSION

Physical movement is one of the outstanding dynamic and temporal design elements to increase interactive products' emotional qualities. We articulated the four attributes of physical movement and developed a device for generating interactive physical movement. The experiments were conducted to identify the relation between the attributes of physical movement and the emotions induced.

Our contributions are threefold. First, we have articulated four attributes of physical movement that are highly related to interactive products and systems: speed, smoothness, granularity, and volume. Second, we have presented how such attributes can be realized as a physical-movement generation device. Third and finally, we have revealed the relationship between the attributes and emotion through experiments. The results indicate that the device's physical movement induced emotions for participants. In particular, among the four attributes, speed was the most influential and especially positively correlated to both pleasure and arousal dimensions in the emotion space. Another particular finding was that the emotions induced by physical movement were widely distributed in the emotion space's arousal dimension, and narrowly in the pleasure dimension. This gives insight to designers and researchers on what attributes should be manipulated for a desired emotion and what are the limitations of physical movement in inducing emotion.

For future research, the relation framework between emotion and physical movement needs to be further tested and refined with more advanced devices in the context of natural use. It would be necessary to investigate the impact of the attributes on emotional responses when they are incorporated into everyday interactive products. We used continuous-emotion models. Relations should be further understood in terms of discrete emotional responses and diverse movement types generated by the combinations of the identified attributes. Design exploration and testing with people should be followed by the development of real product applications. Then, it would help designers incorporate physical movements into products that support emotionally rich user experiences.

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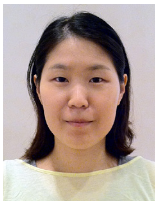

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