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Dynamics of the Interaction with the Environment in Creativity: Embodied Imagination Framework

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Abstract

In creativity, the importance of interaction with the environment through bodily movement and perceptual information acquired therein has been discussed anecdotally. However, past creativity studies have mainly focused on the connection of creativity with memory and knowledge and the relationship between creativity and cognitive manipulations. The above process of bodily movement and environment was not sufficiently discussed. In this study, we developed a model of the above process and partially checked its validity through an experiment. Our model and the results of our experiment suggested the following processes. The interaction with the environment through the bodily movement changes the content and quality of the ideas generated. That interaction also changes the content of the cognitive manipulations in the idea generation. The above change in the cognitive manipulations partially described the change in the content and quality of the ideas. In these processes, the acquisition of perceptual information that differs greatly from the prediction has an important function. The dynamical relationship between the bodily movement, perception, and cognition in creative activities will require further investigation.

Keywords: creativity; interaction with the environment; bodily movement; perception; cognitive manipulation; embodied cognition

Introduction

Interaction with the environment through bodily movement and perceptual information acquired from that interaction is strongly related to artistic creation and creative activities. For example, Paul Klee, a famous Swiss painter, explained that the lines of the motifs that were gradually depicted by his hand movement would refine his understanding of the motifs. A similar statement can be found in Merleau-Ponty's critique of Cézanne's paintings. As these descriptions suggest, the interaction with the environment through the bodily movement in creative activities has attracted people's attention. This study aims to model the above processes and investigate the model's validity through a psychological experiment.

While these anecdotes indicate the importance of the interaction with the environment, they have only recently come into focus in creativity research (e.g., Botella, 2013; Glaveanu, 2013). The creativity research has mainly investigated the creation process from the perspective of cognitive manipulations of knowledge (i.e., memory). Theories and findings on analogy and conceptual combination are such examples (e.g., Dunbar et al., 1988; Holyoak & Thagard, 1995; Mahon et al., 2009). Studies on analogy describe the process of deepening the understanding of a phenomenon or developing a new knowledge connecting two different knowledge domains (Holyoak & Thagard, 1995; Okada et al., 2009). These studies suggest that applying the features or structures of a source domain to a target domain based on certain similarities facilitates the understanding and development of both of the source and target knowledge domains (Holyoak & Thagard, 1995; Okada et al., 2009).

Moreover, in the study of imagination assumed to be strongly related to creativity, the close relationship between memory and imagination has been investigated. They indicate that imagination is mostly based on the episodic memory experienced in the past (McDermott et al., 2015; Schacter et al., 2007). Moreover, semantic memory can serve as a scaffold to connect these multiple episodic memories in imagination (Irvine et al., 2008; McDermott et al., 2015; Schacter et al., 2007). Memory has a function to imagine and predict what may happen in the future, which is why memory is flexible and changes easily (Schacter et al., 2007, 2016). A finding that may be strongly related to the above comes from the study of structured imagination (Mace & Ward, 1997; Ward, 1994). In these studies, participants were asked to create a creature that lived on an extraterrestrial planet, and researchers investigated the tendency to include some specific features into the creatures. Interestingly, in creating a flying extraterrestrial, they found that many features such as beaks, which are not directly related to the function of flying, were also incorporated in addition to wings and feathers. This result shows that people's imaginations are strongly structured by their knowledge and the cognitive manipulation of this knowledge (bird in the above example).

As described above, many studies of creativity have investigated the connection of knowledge and their cognitive manipulations with creative activities. However, little discussion has been performed on the connection between the interaction with the environment and creative activities (except Ross & Vallée-Tourangeau, 2020). Some studies tried to consider this connection based on predictive

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coding theory, which has been actively tested in recent years. In predictive coding theory, perception is understood as a process of correcting the error (differences) between the prediction of environmental information and the perceptual information acquired through active interaction with the environment. Based on this viewpoint, the above study theoretically proposes that imagination is developed by decreasing the weight of attention to perceptual information acquired through that interaction. It suggests that people develop their imagination by repeating the prediction of perceptual information and the simulation of perceptual feedback in their minds.

These studies suggest that creation and imagination are strongly dependent on memory and knowledge. Also, creation and imagination may develop when attention to various perceptual information acquired from the outside world is weakened. However, the latter has not been empirically investigated and needs further testing.

Actually, some studies indicated that perceptual information acquired from the environment and mental images constructing imagination are closely linked. For example, in an experiment using visual and auditory stimuli identification tasks, a study showed that the response time and correct response rate decreased when each stimulus was presented repeatedly over a short period (Segal et al., 1970). This study also indicated that the response time and correct response rate decreased in the same manner when participants were asked to imagine each stimulus in their minds (Segal et al., 1970). Similarly, in a task that produces the illusion of tilt, some studies confirmed that an illusion similar to that produced by the actual visual stimulus occurs when the participants imagine the same stimulus in their minds (Mast et al., 2000). These findings indicate that the perceptual information acquired through interaction with the environment and the mental images constructing the basis of imagination are closely connected and somewhat overlapped.

Furthermore, studies on the artistic creation process also suggested that perceptual information acquired from the interaction with the environment strongly influences creative activities and imagination. Yokochi and Okada (2005) conducted a case study on the creative process of an expert Chinese-ink painter. In that study, they found that before painting, the artist drew a mental image in the air, called Kuusho in Japanese, and developed his images based on the visual traces and tactile information obtained during that process. Shimizu, Hirashima, and Okada (2019) conducted a case study on the creative process of an expert dancer in a laboratory by using motion capture system. They found that the dancer used somatosensory and tactile information acquired through his movement to develop his images. This perceptual information was very different from what he predicted before his movement. This type of image development did not occur under the condition that limited his physical movement.

Based on these findings, we can speculate a close relationship between the perceptual information acquired

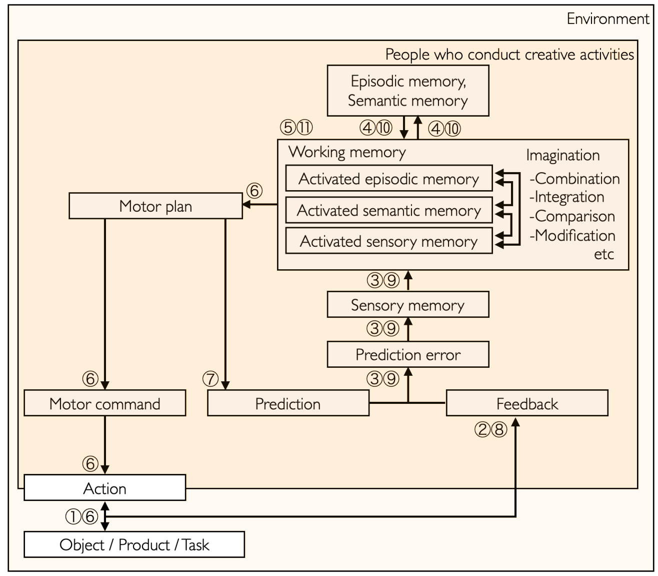


Fig. 1. Model of the Embodied Imagination framework

from interaction with the environment and the creative activities. The perspective of embodied cognition that has been discussed actively in recent years also suggests that the perceptual information acquired through our bodies strongly influences various cognitive processes (e.g., Barsalou, 1999, 008). Investigating the relationship between cognition and interaction with the environment in creativity has great importance in the research of Cognitive Science.

Based on the above discussion, this study aimed to develop a model that explains how interaction with the environment through the bodily movement and the perceptual information acquired therein affect creative activities and imagination. Fig. 1 shows the model which includes the process of cognitive manipulation of memory and knowledge investigated in past creativity research. It also explains the influence of the perceptual information from the interaction with the environment on the above cognitive manipulation focusing on the prediction error discussed in predictive coding theory and Shimizu and Okada. (2019). The process assumed in the model is as follows.

(1) Interaction with the task's materials and the environment through the bodily movement occurs.
(2) Various perceptual information is acquired through the above interaction.
(3) Sensory memory associated with the acquired perceptual information is activated and processed in working memory.
(4) Episodic and semantic memory associated with the above sensory memory are activated and processed in working memory.
(5) Imagination is developed by the subconscious and conscious cognitive manipulations on the above memories and related knowledge.
(6) Interaction with the materials and environment through the bodily movement occurs based on the above imagination.

(7) In parallel with the sixth process, the prediction of perceptual information to be acquired in that interaction occurs.
(8) Perceptual information that differs significantly from the prediction is acquired through the above interaction (only when the creative activity changes drastically).
(9) Sensory memory associated with the acquired perceptual information and significantly differs from the previous one is activated and processed in working memory.
(10) Episodic and semantic memories associated with the above sensory memory and differs from the previous one are activated and processed in working memory.
(11) Imagination is developed and expanded by the subconscious and conscious cognitive manipulations on the above memories and related knowledge.

As described above, this model suggests that creative activities and imagination are developed based on memory and knowledge and their manipulation. Also, this process has a close relationship with the interaction with the environment through the body. The activation and manipulation of memory and knowledge strongly depend on the perceptual information acquired in that interaction. Furthermore, the creative activity develops through the repetition of the following cycle. A: interaction with the environment through the bodily movement and its prediction, B: acquisition of perceptual information, and C: generation of imagination. In particular, we consider that the relationships between A, B, and C processes and the dynamics of their changes are key factors that promote or inhibit creative activity. For example, if A (interaction with the environment and its prediction) and B (acquisition of perceptual information) matches well, the imagination will not be well developed. However, if there is a significant difference in that relationship (e.g., when perceptual information acquired is greatly different from the prediction), the imagination is developed creatively, and the above cycle may be actively developed. We focus on the prediction error as a critical factor in developing creative cognition in this process. However, people try to reduce this error in everyday cognition, as predictive coding theory suggests.

We call the process proposed in the above model Embodied Imagination. We aim to check the validity of this model using psychological experiments. In this study, we reinterpret the experimental results of Shimizu and Okada (2021) based on the above model as one of such trials.

Methods

Experimental Design

We set the following three conditions in the experiment in Shimizu and Okada (2021). 1: Verbal condition, 2: Visual condition, and 3: Embodied condition. The experimental procedure and the first three results are the same as Shimizu and Okada's (2021). Therefore, we skip some of the descriptions (please see the above study for details).

Participants

Forty-seven undergraduate and graduate students belonging to the University of Tokyo participated in this experiment (19 males, 28 females). Their mean age was 21.57 (1.89).

Procedure

We used a modified version of the product generation task used in Finke, Ward, and Smith (1992). In this experiment, the participants combine three figural parts to generate a novel toy for children three times. To prevent the spread of COVID-19, we conducted the experiment in an online system, Zoom (Zoom Video Communications, Inc.).

The outline of the procedure is as follows. 1: The experimenter explained the outline. 2: The three parts to be used in each task were explained. 3: The participants worked on each task for 10 minutes. The ways to work on the task are different among the conditions. In Verbal condition, the parts were not handed out, and the participants generated their products by manipulating these parts in their minds. The details of the parts were written in the response sheet and explained verbally. In Visual condition, the parts were handed out, and the participants generated their products by manipulating these parts in their minds while looking at the parts. In Embodied condition, the parts were handed out, and the participants generated the products by manipulating the parts physically. The participants wrote their products on the response sheet using pictures and sentences. 4: The participants reported what they had been thinking. The participants repeated the above second to fourth processes three times. Finally, the experiment was finished with a debriefing about the purposes of the experiment. By comparing the three conditions above, we were able to investigate the differences in the creative activities that occur with the acquisition of visual and tactile feedback. In particular, by comparing the second and third conditions, we were able to investigate the influences of errors (differences) between predicted and actual visual feedback produced by physical manipulation, in addition to the haptic feedback influences. This experiment was conducted with the permission of the Ethical Committee of the University of Tokyo.

Analysis

Evaluation of creativity of the products We measured the creativity of the toys and compared them across the conditions. We developed the following evaluation items based on previous studies (e.g., Besemer and O'Quin, 1999; Finke et al., 1992; Kaufman and Sternberg, 2010). 1: novelty, 2: physical enjoyment, 3: intellectual enjoyment, 4: physical learning, 5: intellectual learning, 6: feasibility, and 7: surprise (see Shimizu & Okada, 2021 for details). The first author and two graduate students working on creativity research and did not know the experiment's purpose worked on the evaluation ratings individually.

Cognitive process Next, we analyzed how people thought in the product generation process. We transcribed the verbal reports and generated categories based on their contents,

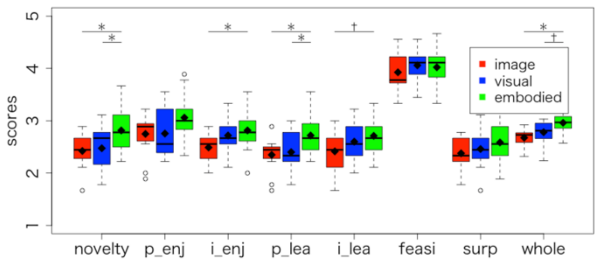


Fig. 2. Creative evaluation score of the product (Shimizu & Okada, 2021). ＊: $p < .05$, †: $p < .10$

such as 1: feature of objects, 2: possible fabrication of objects, 3: combination of objects, 4: analogy of objects, 5: memory of the past, and 6: material of objects. We classified the reports into each category and calculated the frequency of the category. We compared each category's frequency among the conditions.

Mediation effect of the cognitive process Thirdly, we investigated the degree to which the cognitive processes explain the influence of condition on the creative evaluation. We conducted a mediation analysis, setting the condition as the explanatory variable, the creativity evaluation as the objective variable, and the cognitive process as the mediator variable (Baron & Kenny, 1986). We included the evaluation items and cognitive categories that showed statistical significance in the above two analyses into this analysis.

Case report Finally, we focused on specific participants who showed high evaluation scores in Embodied condition. We conducted a detailed investigation of that participant's interaction with the parts and the cognitive manipulation during idea generation. This case report tried to investigate how the interaction with the environment through the bodily movement influences creative activities in detail.

Results

We show the results of each analysis below. The first three results, creativity evaluation, cognitive process, and mediation effect of the cognitive process, are the same as those of Shimizu and Okada (2021). Therefore, we skip some of these results (please see the above paper for further details).

Evaluation of the creativity of the products

We show the results of the creativity evaluation in Fig. 2. This figure shows that Embodied condition was higher than the Visual and Verbal conditions in the novelty, physical enjoyment, physical learning, and overall evaluations.

We conducted One-way ANOVA and multiple comparisons adjusted by Bonferroni method for each evaluation item. These analyses showed consistent results

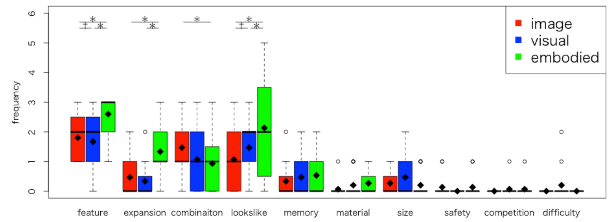


Fig. 3. Category's frequency of the cognitive manipulations (Shimizu & Okada, 2021). ＊: $p < .05$

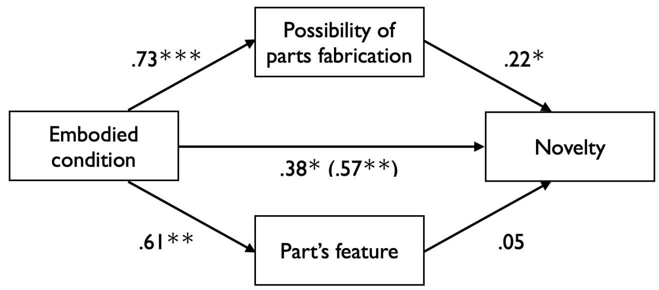


Fig. 4. Result of mediation analysis on product's novelty (Shimizu & Okada, 2021). ＊＊＊: $p < .001$, ＊＊: $p < .01$, ＊: $p < .05$

with the above observation of the figure (Please see Shimizu & Okada, 2021 for details). For example, one-way ANOVA showed significant differences among conditions for the novelty score (F (2, 42) = 4.89, $p < .05$, $\eta 2 = .19$). Also, the multiple comparison showed significant differences between Embodied condition and the other two conditions (Visual condition: $p < .05$, $d = .88$, Verbal condition: $p < .05$, $d = 1.12$). These results suggest that toys that are more novel were generated in Embodied condition.

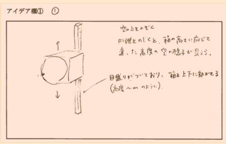
Cognitive process

We show the result of cognitive process in Fig. 3. This figure indicates that Embodied condition showed a higher frequency than the other two conditions for 1: part's feature, 2: possibility of part's fabrication, and 4: part's analogy.

Mann-Whitney's U test adjusted by Bonferroni method showed consistent results (see Shimizu & Okada, 2021 for details). 2: possibility of part's fabrication showed significant differences between Embodied and Visual conditions, and between Embodied and Verbal conditions ($U = 48.00$, $p < .05$, $r = .52$; $U = 39.00$, $p < .01$, $r = .60$). This result suggests that in Embodied condition, the participants generated the products with more attention paid to the various possibilities of the part's fabrication.

Mediation effect of the cognitive process

We show the mediation analysis's results with the novelty evaluation as the objective variable, part's feature, and possibility of part's fabrication as the mediator variable in Fig. 4 (see Shimizu & Okada, 2021 for details). This figure

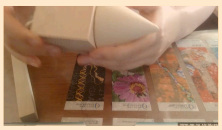


Toy's idea of participant 12

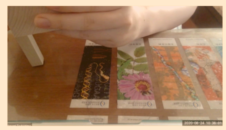
Title: Looking into the sky

Children look into the cone tip. They can see the sky at different altitudes depending on the height and position of the box.

Picture of physical manipulation of Participant 12: she connected the two parts



Picture of physical manipulation of Participant 12: she connected rectangle part to the other two parts



Verbal reports of participant 12 during the above manipulation

When I was thinking about what to do with these parts, I thought I could look into them from here, thin part of the cone tip.
(Could you describe what you were thinking when you came up with the idea of looking into the cone tip?)
There was some special tool like these parts in Doraemon (famous Japanese animation). It was the Gulliver Tunnel. It's probably the tool to become small by going from the big part to the small part. I had some images like that tunnel that an entrance is small and an exit is large. I also had an image of a kaleidoscope.

Verbal reports of participant 12 during the above manipulation

When I tried to make the best use of this rectangle part, I suddenly manipulated this part standing up. Then, I thought if I attached this standing part to the above two parts, I could move cone parts up and down.

Fig. 5. Product, interaction with the environment, and verbal reports of participant 12

indicates that the standardized direct effect of Embodied condition was $\beta = .38$ ($p < .05$), the standardized indirect effect of part's feature was $\beta = .03$ ($p = .62$), and the standardized indirect effect of possibility of part's fabrication was $\beta = .16$ ($p < .05$). These results suggest that the increase in the novelty evaluation in Embodied condition can be partly explained by the cognitive process such as possibility of part's fabrication.

Case report

Finally, we describe the creation process of a specific participant (Participant 12) in Embodied condition, whose toy was evaluated exceptionally high for novelty and other evaluation items. Fig. 5 shows the pictures of that participant when she was interacting with the parts and her verbal reports of how she was thinking when the idea about the toy was generated. In this process, participant 12 physically manipulated the parts in various ways and connected the two parts by accident. The connected shape of these parts activated her memory of special tools in a famous animation and kaleidoscopes. Based on this memory, she added a fictional feature to these parts to be looked in from the cone tip. Then, she manipulated the remaining rectangle and connected it to the above parts. From this connected shape, she came up with the idea of moving the above-mentioned parts up and down along that rectangle, and changing the scenes that people look at. Based on these ideas, she finally generated the toy's idea that changed the view of the sky from the cone tip depending on the position of the above parts. As described above, participant 12 acquired unpredicted perceptual information by interacting with the parts through her bodily movement. She recalled various memories and knowledge based on this perceptual information. Then, she performed different cognitive manipulations based on these memories. By repeating these processes and changing the contents in each process dynamically, this participant developed novel toy ideas.

Discussion

The experiment showed the following three results: 1: the interaction with the parts through the bodily movement changes the participants' ideas. It facilitates the tendency to generate more novel ideas. 2: the interaction with the parts through the bodily movement changes the type of cognitive manipulations in the idea generation process. It facilitates the tendency to focus on manipulation such as "part's fabrication." 3: the above facilitation of the specific cognitive manipulation may facilitate the generation of more novel ideas. These findings indicate that the interaction with the environment through the bodily movement strongly influences cognitive manipulations in the creation and imagination. This experiment has partially tested the validity of the model proposed in the introduction. A comparison of the Visual and Embodied conditions suggests that creative cognitive processes and their products may be significantly altered by tactile feedback or the visual prediction error revealed by physical manipulation.

Moreover, from the case report's result, we can speculate that the following processes facilitated the novel idea generation. Firstly, when the participants actively interact with the parts, they receive perceptual information different from their prediction. Examples are visual and tactile information that cannot be acquired without that bodily interaction. By paying attention to this unpredicted perceptual information, the participants can focus on the part's features that they have not focused on before. Then, by performing cognitive manipulations related to those features, they can generate novel ideas they have never generated. In Embodied condition, the participants frequently face these differences between their prediction and perception. These differences facilitate the repetition of the following cycles. A: Interaction with the environment through the bodily movement and the prediction of the perceptual information, B: Acquisition of perceptual information, C: Generation of imagination. This activation of the cycle would promote the novel idea generation in Embodied condition. The importance of activating the above cycles of cognition, bodily movement, and perception for creativity facilitation has not been well studied. In the following section, we will discuss the relationships between these findings and previous studies of creativity.

First, we will discuss the relationship between this study's findings and the process of creativity and imagination. Most traditional creativity research has focused on cognitive manipulations of memory and knowledge, as exemplified by analogy and conceptual combination (e.g., Dunbar et al., 1988; Holyoak & Thagard, 1995; Mahon et al., 2009). Moreover, the few studies attempting to discuss the relationship between creativity and perception suggested that people decrease their attention to perceptual information when they perform imagination (). As these studies described, the relationship between the bodily movement, environment, perception, and creativity has not been sufficiently discussed. The present study offered a concrete explanation and quantitative investigation about the above relationships. In particular, this study aimed to connect the process of the interaction with the environment through the bodily movement with the theory of cognitive manipulation in traditional creativity research.

Next, it seems necessary to discuss the connection of this study's findings with the studies of artistic creation. Recently, a few studies have gradually suggested the close connection of the interaction of the body and environment with imagination (cognition) in artistic creation (e.g., Botella, 2013; Glaveanu, 2013; Shimizu et al., 2019; Yokochi & Okada, 2005). However, these studies only offered theoretical suggestions or case-study investigations. The present study made a concrete model about the above connection and investigated the model's validation by quantitative methods. The proposed model and its process are consistent with the above theories. We consider it worthwhile to verify that model and process through experiments targeting artistic creation in the future studies. Furthermore, this study's findings will offer some suggestions about the following question: under what circumstances will the interaction with the environment through the bodily movement facilitate artistic creation? The model suggests that the unpredicted perceptual information would be effective when people continually pay attention to a specific aspect of the environment and repeatedly generate similar imaginations. It would be needed to conduct some investigations about the educational methods and effects of supporting artistic creation.

Finally, we would like to discuss the limitations and prospects of this study. This study’s experiment have only partially investigated the process in the model. To verify the proposed model more comprehensively, further investigation will be necessary for future studies, as shown below.

First, a study investigating the effects of the types of perceptual information is necessary. The two types of perceptual information that the participants in Embodied condition would receive were visual and tactile information acquired by the physical manipulation. However, the effects of each perceptual information have not been distinguished. In the future, it will be necessary to set up a situation in which each perceptual information can be manipulated separately and to verify each effect and the process.

Second, we were not able to quantitatively investigate the relationships between A: interaction with the environment through the bodily movement and the prediction, B: acquisition of perceptual information, C: generation of imagination. Especially, we were not able to detect the dynamic change of these relationships accompanying the time development. The above dynamical change of the relationships is the core component of the model. However, we only have conducted an exploratory investigation by describing a case. In future studies, we need to develop some measurements and analyses to capture these relationship dynamics between cognition and bodily movement in a quantitative manner.

Finally, we need to test the model's generality using real-life creative activities and artistic creations. In this experiment, we tested the model using a famous idea generation task (Finke et al., 1992). However, we are unsure whether similar results can be obtained in real-life product development and artwork creation. It is necessary to verify the model in situations closer to real life, targeting the various processes described above. Especially, the types of perceptual information typically acquired and the types of physical interaction with the material in the above situation would greatly differ depending on such situations. To develop the model that explains the above processes comprehensively, it is necessary to elaborate the model further and develop the method to check its validity in real-life situations.

Acknowledgments

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