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Authors
Kang, Seokmin
Hallman Jr., Gregory
Black, John

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The Role of Imagination in Augmenting Perceptual Representation

Seokmin Kang (sk2587@columbia.edu)
Teachers College, Columbia University, 525 W. 120th Street
New York, NY 10027 USA

Gregory L. Hallman Jr. (glh2103@columbia.edu)
Teachers College, Columbia University, 525 W. 120th Street
New York, NY 10027 USA

John B. Black (jbb21@columbia.edu)
Teachers College, Columbia University, 525 W. 120th Street
New York, NY 10027 USA

Abstract

Knowledge construction requires both perceptual information from external sources and our active interpretation of that information. Thirty one 5th grade elementary school students were asked to move plates in a Tower of Hanoi (TOH) task, which was displayed on a screen monitor. When the students were asked to respond to the weight of the plates, both imagination and non-imagination groups reported that they felt weight of the plates which actually had no weight. Also, students in imagination group reported that they felt the plates heavier than did those in non-imagination group. The result shows that haptic information can be created without providing any information through haptic channel. In addition, the result implies how knowledge is constructed based on previous knowledge and suggests that children create their own imaginary world even at a perceptual level. Also, it was discussed why imagination experience can maximize and help learning in embodiment activities.

Keywords: Imaginary world; Haptic illusion; Embodied cognition.

In Buddhism, it is said that “Everything depends on our mind.” This sentence can be interpreted as humans’ perceiving an object, or a given environment, depending on what we expect to perceive or interpret. According to Ungerleider and Pasternak (2004), when constructing knowledge we not only accept spatial and visually-guided action information (dorsal process stream), but process information of shape, form, and object identity (ventral process stream). This insight has been scientifically tried in studies about illusion in perception (Lee & van Donkelaar, 2002) and in memory (Roediger, 1996; Roediger & McDermot, 1995). Also, especially according to optical illusion studies, what we see does not always match what is actually visible. Our visual perception is influenced by our past experience and current expectations (Gregory, 1997; Gregory, 1998; Pendlebury, 1996).

According to Kant (1965), our knowledge is elicited from two fundamental sources of the mind: the capacity of receiving representations and the power of knowing an object through these representations. Intuition and concepts constitute the elements of all our knowledge, so that neither concepts without an intuition in some way corresponding to them, nor intuition without concepts, can yield knowledge (Kant, p.92). Also, Kant mentioned that “…all perceptions are grounded a priori in pure intuition, association in pure synthesis of imagination, and empirical consciousness in pure apperception…” (Kant, p.141). This also can be interpreted as that perceptual information received via different modalities, becomes knowledge by our active cognitive process. This can be called knowledge construction. Therefore, by using this nature of human perception, it is possible to create perceptual illusions. In terms of knowledge construction from perceptual information, while previous studies have dealt with people’s creation of additional perceptual information or distortion based on what was given (Day, 1990; Ellis & Lederman, 1993; Fermüller & Malmb, 2004; Mack, Heurer, Villardi, & Chambers, 1985; Suzuki & Arashida, 1992; Otto-de Haart, Carey, & Milne, 1999), this study seeks to investigate knowledge construction from a certain activity which enriches memory representation. In other words, we argue that perceptual knowledge can still be created through another perceptual channel even if no perceptual information has been delivered.

While many studies have explored visual illusion, what has rarely been investigated is how perceptual information from other modalities is created. Furthermore, while the literature offers a handful of studies about haptic illusion (Gentaz, Camos, Hatwell, & Jacquet, 2004; Robles-De-La-Torre & Hayward, 2001), these studies have limitation that they were administered under situations where haptic information was already provided to participants.

Knowledge construction by imagination

It is assumed that when we process information from text, we go through a perceptual process where spoken or written messages are originally encoded (Golden, 1986; Hubel & Wiesel, 1977; Kuffler, 1953; McClelland, 1976; Syrdal & Gopal, 1986). Then the words in the message are transformed into a mental representation of the combined meaning of the words (Graf & Torrey, 1966). At higher level of comprehending of a text, readers use the mental representation of the sentence’s meaning. According to

Kintsch (1998), this level of understanding adds inferences made from the reader's knowledge and these inferences come from semantic memory, knowledge about objects, events, people, goals, beliefs, etc. However, Black and Bower (1980) argued that there is another level of text comprehension, which they called the Story World because they were only discussing stories. This level of comprehension requires a representation of the world being referred to in a story, how it is laid out visually and spatially, and how it functions. We can generalize this beyond stories by calling this level of comprehension and representation an Imaginary World. For example, after reading one or more Harry Potter fantasy books, if one has reached this "imaginary world" level of comprehension, one would have some ideas about Harry Potter's world, such as how it looks, how it is laid out, and how it functions (information which actually may not be provided in the books). Then, when seeing a Harry Potter movie, one can judge to what extent it matches this Imaginary World. Black, Turner, and Bower (1979) already showed evidence of readers creating their own imaginary world when reading a story. In their study, when people read sentences like *John was working in the front yard, then he went inside*, they read them faster than when they read *John was working in the front yard, then he came inside.* The '*came*' in the second sentence creates a switch in point of view and causes a longer reading time (and change in memory and change in comprehensibility ratings) because the reader has to switch the perspective from which they are watching the action in the imaginary world.

In imaginary world, people make plausible inferences or create a story that was not actually given. This is further activated when a goal is added, which results in a more coherent, interesting and memorable text. For example, Owens, Bower and Black (1979) had one group read an unsurprising script-based story just containing the expected actions of scripts, while another group had an introductory sentence that introduced a goal structure (the girl in the story wondering if she were pregnant). Adding this introduction, which allowed the readers to infer a goal structure with many linked story statements, leads to better recall of the story. Black (2008) took this a step further when he mentioned that learners can construct elaborate mental representations of Imaginary Worlds with minimal input such as text plus a floor plan. This implies that learners create imaginary worlds based on given information, place themselves into that situation, and retrieve a plausible story by filling out story gaps that are not given to them.

These findings can be linked to research on embodied cognition. Barsalou (1999) supports the idea that thoughts stem from dynamic interactions between the physical world and the body. These interactions, described as part of "grounded cognition," are not limited to bodily states, but are also found in situated action, social interactions, emotional states, the environment, and perceptual simulations. In this sense, active interaction can also be realized in imaginary world, since one can situate himself in a given situation and enact what is given in that imaginary world. According to proponents of embodied cognition, acknowledging these interactions is the first step towards understanding human cognition.

Research on embodied cognition reveals that when people place their bodies and move around in physical space, they create references for understanding concepts. This is evident in a study by Glenberg and Kaschak (2002). The authors found that subjects, after hearing the command "open the drawer", responded faster when the response action was a pulling motion instead of a pushing one. Likewise, work by Spivey et al. revealed that during an experiment that measured eye movement, participants were more likely to look up upon hearing a description about the top of a building (Spivey, Tyler, Richardson, & Young, 2000).

These discoveries about human cognition and space are complimented by the seminal research of Shepard and Metzler on mental rotation and imagery in the 1970s. The researchers showed participants images of 3-D geometric figures. The participants were later shown similar yet rotated images and were asked to interpret the uniformity, or lack thereof, of the two images. Results revealed that participants rotated visual mental images in much the same way that the actual objects would be manipulated in an actual physical space. The research also revealed a proportional relationship between the degree of the rotation and the time it took participants to mentally rotate and respond (Shepard & Metzler, 1971).

Glenberg and colleagues have found that physical manipulation and imagined manipulation help children learn (Glenberg, Gutierrez, Levin, Japuntich, & Kaschak, 2004). Specifically these researchers have conducted experiments using a narrative of a farmer and his farm animals. The narrative is accompanied by a set of toys in the likeness of the story's characters. Participants (1^{st} and 2^{nd} graders) were asked to use the toys to re-enact the sentences they read. The children are then asked to imagine manipulating the toys. What resulted was an increase in reading comprehension and a more positive attitude about reading (Glenberg et al., 2004).

In the same vein, researchers on grounded cognition suggest that how people act influences how they think by grounding perception, affect, and even language comprehension in the sensorimotor systems used to interact with the surrounding world (Beilock, Lyons, Mattarella-Micke, Nusbaum, & Small, 2008; Glenberg & Robertson, 2000; Niedenthal, 2007; Zwaan, 1999). For example, learning to produce specific walking movements (without visual feedback) aids one's ability to later visually discriminate these movements, presumably because discrimination becomes tied to the sensorimotor systems used in moving (Casile & Giese, 2006). Therefore, perception and action lead to conceptual understanding. In addition, this process requires a representation of what is being referred to, how it is laid out visually and spatially, which finally leads to the creation of "Imaginary Worlds" (Black, 2008).

Based on this "Imaginary World" concept, this study starts with a question about if learners can create their own imaginary world on a perceptual level. For example, readers develop their own mental images of a story while reading the story (Black et al., 1979) and learners can also build their own mental representation while learning from either a text, a text with floor plans plus static pictures, or a text with floor plans accompanied by a virtual tour picture (van Esselstyn & Black, 2001). In this study, we try to test that creating an imaginary world is possible on a perceptual level, which, in turn, enables us to see why imagination activity helps children more involved in embodiment activity.

So far, few empirical studies have been done to test the role of imagination in children's perception and knowledge construction. Being that this study seeks to encourage children to create perceptual information which was not initially given to them, this study is different from previous perceptual illusion studies that showed how perceptual information is distorted or how illusion is created by sensory information which is transmitted via the same modality. Throughout this study, we try to observe how children, while in the process of constructing knowledge, represent knowledge which does not exist through modality and synthesize it into knowledge.

Method

Participants Thirty-one (18 boys and 13 girls) 5^{th} grade elementary school students from the New York City public schools district participated in this study and were divided into two groups: imagination group (n = 15) and non-imagination (control) group (n = 16). The study was IRB approved.

Children of this age were chosen because they were almost at the end of concrete operational stage. Therefore, they are expected to use the appropriate level of inductive logic, such as transitivity, decentering, ability to eliminate egocentrism, and etc. (Piaget, 1977).

Apparatus The Kinect sensor for the Microsoft Xbox 360 video game console (hereafter referred to as Kinect) was connected to an HP laptop through which an interactive Tower of Hanoi problem was displayed onto a Dell 19 inch LCD monitor with speakers attached. Kinect is a motion sensing input device by Microsoft for the Xbox 360 video game console. Based around a webcam-style add-on peripheral for the Xbox 360 console, it enables users to control and interact with the Xbox 360 without the need to touch a game controller, through an infrared natural user interface using gestures and spoken commands. However, in this study, we manipulated Kinect without Xbox 360. As a way of communicating with the Kinect, FAAST (Flexible Action and Articulated Skeleton Toolkit, version 0.07) software was used. FAAST is middleware which facilitates integration of full-body control with games and VR applications. The toolkit relies on software from OpenNI and PrimeSense to track the user's motion using the PrimeSensor or the Microsoft Kinect sensors. FAAST includes a custom VRPN server to stream the user's skeleton over a network, allowing VR applications to read the skeletal joints as trackers using any VRPN client. Additionally, the toolkit can also emulate keyboard input triggered by body posture and specific gestures. This allows the user add custom body-based control mechanisms to existing off-the-shelf games that do not provide official support for depth sensors (Suma, Lange, Rizzo, Krum, & Bolas, 2011). Also, the interface of the TOH game was programmed using Scratch. Scratch is a programming language developed by the MIT Media Lab Lifelong Kindergarten Group.

Experimental Design and Procedure The experiment was administered in a quiet classroom with one student at a time. A student was guided and asked to stand in front of the Kinect and a screen monitor that was connected to a laptop computer. Firstly, the experimenter verbally explained how to move the plates in the TOH problem set on the screen. The children were told: "Your job is to move two plates from the first pole to the third pole. You can move only one plate at a time. Also, while moving the plate, you can put the small plate on top of the large one, but you cannot put a large plate on top of the small one." The plates in TOH were created to look like real steel (Figure 1).

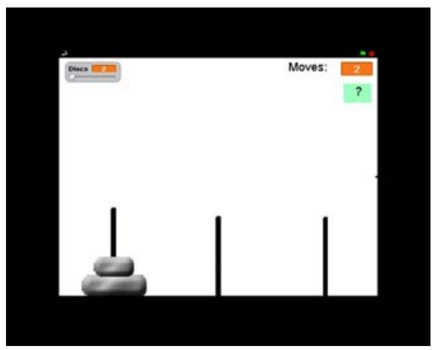

Figure 1. Snapshot of TOH problem used in the task

Afterwards, the experimenter demonstrated how to move plates on the screen. The student was then allowed to participate in a practice session of moving plates from one pole to another until he/she felt comfortable controlling the game using only hand gestures. Students were then given a challenge of two plates for the TOH problem. Unlike the practice session, in the experiment session, audio speakers attached to the LCD monitor were turned on, so as to provide students with the sound of plate being dropped (in this case, the sound of a heavy metal plate dropping to the ground).

Figure 2 shows a student moving a plate in the problem-solving task. All 31 students completed the given task. During the experimental session, children completed the TOH problem by carrying plates without touching any objects such as a monitor screen, a keyboard, or a laptop computer. Immediately after they solved the problem, short survey questions were given.

All the procedures were identical for both imagination group and non-imagination group except that at this stage, students in imagination group were prompted to imagine how they moved the plates before answering how heavy the plates were. Non-imagination group received exactly the same survey except an imagination prompt, "Imagine how you moved the plates." in question 1.

As dependent measure variables, students' responses to the survey questions were compared. Students were asked to choose a number that best described what they felt while playing the game. The survey intended to measure the perceived weight the participants felt from moving the virtual plates, the level of interest in the activity, and the amount of difficulty encountered in controlling this Kinect-based embodiment tool. As they answered the questions, the experimenter read aloud each question and response options (i.e., labels of a Likert-scale). After the survey, students were sent back to their class. Totally participation time for one student amounted to about 15 minutes for the entire session.

Figure 2. A student solving Tower of Hanoi problem.

Results and Discussion

Students' responses in two groups for plate weight, level of motivation, and amount of difficulty in controlling the plates were compared and analyzed.

First, to find out whether students in each group felt the weight of the plate or not, one sample t-test was administered for responses asking how heavy the plate felt. In the analysis, it was found that students in both imagination group (M = 2.87, SD = 1.36, $t(14)$ = 5.33, p < .01) and non-imagination group (M = 1.94, SD = 1.12, $t(15)$ = 3.34, p < .01) reported that the virtual plate they moved indeed had a tangible weight.

Also, students in both groups reported that it was relatively easy to use their hands to move the plates. Average response was 2.27 (SD = 1.22) in imagination group and 2.81 (SD = 1.47) in non-imagination group. In addition, students in both groups showed strong interest in the game task. All students in imagination group responded that they enjoyed the game very much (M = 5.00, SD = 0.00). Similarly, average response in non-imagination group was 4.94 (SD = 0.25).

In group comparison analysis, independent sample t-test was administered. The students in imagination group felt the plates significantly heavier than non-imagination group, $t(29)$ = 2.08, p < .05, d = 0.75. Figure 3 shows response averages of feeling of plates' weight in two groups.

In terms of students' interest, there was no difference between two groups (p = .34). Also, in a question of asking how easy it was to use hands to carry the plates, there was no group difference in difficulty of carrying the plates (p = .27).

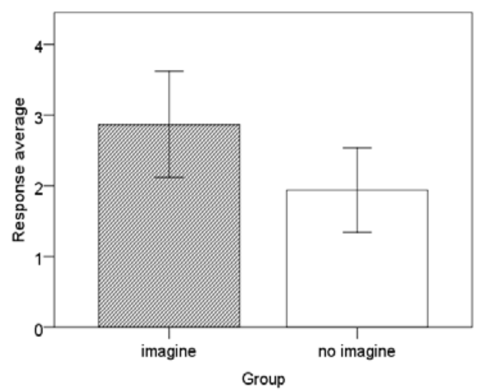

Figure 3. Response average of feeling of weight. Error bars represent standard errors of the means.

This study shows how children develop and organize perceptual information, and create their own imaginary world based on an experience. Surprisingly, children in both groups felt the weight of plates which actually had no weight. In this case, it would be a haptic illusion that falls at the intersection of perceiving and remembering.

It is even more surprising that children in imagination group weighted the plates heavier than non-imagination group. It is assumed that the memory of what plates would feel like was drawn into the procedure as expectancies and then affected performance, and the feeling of weight would be augmented by the imagination employed during the embodied activity. It may be like the case when someone thinks he is about to pick up a heavy object (e.g., a brick) but then he lifts it way too high too fast because it turns out to be light (e.g., styrofoam). According to Winograd, Peluso, and Glover (1998), self-reports of high degrees of vivid mental imagery correlate with enhanced false recall and false recognition. In our study, it is possible that, with a prompt, "imagine," students in imagination group further developed haptic information than those in non-imagination group. As a result, children in both groups reported the weight of plates by activating what they expected to feel. This is realistic when considering that upon judging a situation, value, or an object, individuals rely more on reasoning, which, in turn, is based on their prior knowledge or experience. Nonetheless, participants should not have responded that the plate had a weight in this situation.

What is interesting is that, even though the activities in this study were obvious and physically concrete, children in this study reported their haptic experience which was not provided to them. Based on our observations, it seems that when it comes to deciding the characteristics of a given object, children evolve into relying more on their own representation of the concept which was created by synthesizing subjective sensation and representation, rather than relying on pure sensation.

Another plausible explanation is that children might mistake a plate's supposed weight with the feeling of fatigue from arm movement caused by moving. Yet, considering that controlling plates was relatively easy and that activity was enjoyable, it is assumed that illusion of a plate's purported weight was created by the embodied activity and it was further augmented by the participants' imagination.

In our case, with imagination, children who acted out using their body added new perceptual information, creating their own representation of the TOH game and the plates in the task. This also corresponds to grounded cognition studies. It is maintained that new representation is based on individual actions and action plays an important role in the emergence of new representations (Beilock & Goldin-Meadow, 2010; Boncoddo, Dixon, & Kelley, 2010).

Children used information available to fill the knowledge gap with information that was not actually provided. In other words, as Black and Bower (1980) mentioned, children's representation of an object when derived from an imagined activity has information implicit in it beyond that which is available in the propositional listing of the scene. It is assumed that embodied cognition in a learning environment must first be physically enacted. Then, the learning activity is maintained through imagined embodiment, and is finally used within a task where transfer of learned content can occur.

Again, this study showed that by having children imagine, unsupplied information can be derived not only in text understanding, but also in perceiving an object's property which was not provided via any sensory channel. The study result implies that having children imagine activities that they involved or acted out can enrich their experience. The phenomenon we observed here has many implications of how teachers can use imagination in teaching concepts, such as ones that have information which is implicit or hard to be captured with a visually aided material.

Also, in our study, to observe how children construct knowledge from perceptual information, interactive media technology was used. Interactive media technology carries with it the benefit of enhancing students' comprehension across several frames of reference because of its ability to present information in varying ways. This ensures success for all types of learners: visual, active, auditory, and tactile. There are many technologies at use today that take advantage of these varying styles of presentation and each caters to one or several simultaneous types of learners at once. With a help from these characters of technology, we could capture the moment at which children construct knowledge from perceptual information. The motivation observed in this study is also unprecedented and will no doubt enlighten pedagogical methods in future classrooms.

In future studies, by investigating how information in other modalities affects level of embodiment, we will learn more about the role of imagination and the interaction of imagination and perceptual channel in knowledge construction.

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