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Author(s)	Hishitani, Shinsuke; Miyazaki, Takuya; Motoyama, Hiroki
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Some Mechanisms Responsible for the Vividness of Mental Imagery: Suppressor, Closer, and Other Functions

Shinsuke Hishitani, [a] Takuya Miyazaki, [b] and Hiroki Motoyama [a]
[a] HOKKAIDO UNIVERSITY
[b] HOKKAIDO UNIVERSITY OF EDUCATION

Abstract

In this paper, studies concerned with the vividness of imagery are reviewed to elucidate the characteristics of vivid imagery, the mechanisms responsible for the vividness of imagery, and the factors that affect those mechanisms. From this review, the following characteristics of imagery can be identified: (a) imagery vividness can be defined by the amount of information in the image, and more perceptual information is in vivid than in dim imagery; (b) information structure in long-term memory (LTM) consists of meaning, affective information, perceptual information, and motoric information, and those components are interconnected; (c) imagery is generated in the image construction stages using perceptual information; (d) a mechanism called the Suppressor controls the channel capacity, or the flow of perceptual information from LTM to the image construction stages; (e) the degree of this suppression is affected by the emotional value of imagery computed on the basis of affective information stored in LTM; (f) motoric information in LTM also influences vividness by acting on the image construction stages. Given these characteristics, we propose a model of imagery processes in order to explain how a certain level of vividness is established for the visual mental image. Finally, some neural correlates of the model are described based on results from our latest fMRI studies, and problems remaining for further development of the model are discussed.

Keywords: Imagery Vividness; Suppressor; Closer; Affection; Motor Activity

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Address correspondence to Shinsuke Hishitani, Department of Psychology, Graduate School of Letters, Hokkaido University, Sapporo 060-0810, Japan.

E-mail: hishitani@let.hokudai.ac.jp

The second and third authors contributed equally to writing this paper and are listed in alphabetical order.

In the present paper, we propose a hypothetical model of the mechanisms that explain how visual mental imagery achieves a certain vividness. Since mental imagery is a basic building-block of consciousness (Marks, 1999), it is one of the indispensable subjects of scientific research on consciousness. Mental imagery is a quasi-perceptual subjective experience, and this "quasi-perceptuality" is the most salient characteristic that differentiates imagery from other forms of conscious experience. In other words, subjective sensory-like aspects of experience, namely experiences of qualia, are central to mental imagery (Hubbard, 1996). Therefore, the most important measure that represents the quality of imagery is its vividness, which is measured in terms of its similarity to perceptual experience.

The mechanisms that determine and evaluate imagery vividness have not yet been elucidated, but it is expected that solving this problem would give us an essential clue to the scientific study of conscious experience. Most imagery researchers agree about the process through which conscious mental imagery is represented in the image construction stage via transformations applied to the information retrieved from long-term memory (LTM) (e.g., Kosslyn, 1980; Kosslyn, Thompson, & Ganis, 2006; Pearson, 2001; Pearson, Logie, & Gilhooly, 1999; Pearson, Logie, & Green, 1996). Some researchers call the image construction stage the *visual buffer*, which is assumed to be in the early visual areas, and others identify it as *visuo-spatial working memory*. The relationship between the former and the latter has not necessarily been specified. Moreover, Kosslyn et al. (2006) suggest that high-resolution imagery is represented in the visual buffer, but not low-resolution imagery.

At this time, one specific image construction stage has not been identified, but almost all imagery researchers admit that it is an indispensable, effective construct for research. Thus, it is possible that there are multiple image construction stages that are used in accordance with the situation. Accordingly, we outline an image generation process in which information is retrieved from LTM and transferred to the proper image construction stage (or stages), where conscious mental imagery is formed. We adopt this process as a framework for our research on imagery vividness and consider the following topics in turn. First, we discuss the characteristics of vivid imagery and suggest that imagery vividness can be defined by the amount of information the image contains. Second, we propose a mechanism that represents interpersonal variations in imagery vividness to explain individual differences in imagery vividness or imagery ability. Third, we discuss affect as a factor that causes intrapersonal variations in imagery vividness, and we expand on the mechanism mentioned above. Fourth, we argue for a model of inter- and intrapersonal variations in imagery vividness in terms of the information structure in LTM. Fifth, we identify the neural correlates of the proposed model based on results from our latest functional magnetic resonance imaging (fMRI) studies. Finally, we discuss some problems to consider in further development of the model.

The Characteristics of Vivid Imagery

In the visual imagery questionnaires that have been developed so far, imagery vividness has been measured in terms of relative clarity in comparison with perception (e.g., Betts, 1909; Marks, 1973; Sheehan, 1967). This method, in which vividness is measured based on the similarity between imagery and perception, corresponds to a phenomenalistic definition of imagery: specifically, a quasi-perceptual experience without a perceptual stimulus (e.g., Bugelski, 1970; Richardson, 1969). It is assumed that a mental image contains perceptual information, and that more vivid images include more information. In fact, some studies that employ imagery vividness and/or individual differences in vividness as experimental variables support these assumptions. These studies have shown directly and indirectly that vivid images contain more information than dim images, and that the subjective vividness of an image is determined by the amount of information it includes (Denis, 1979). For example, Cornoldi et al. (1991) examined the characteristics that influence the vividness of imagery. They interviewed participants and found that the following six characteristics may influence the vividness of imagery: color, richness of context, salient features, richness of details, well-defined shape and contour, and generality of the represented object. Next, they examined the characteristics that have greater relevance in evaluating the vividness of voluntarily generated imagery. First, their participants constructed an image of a presented noun and evaluated its vividness; then, they rated to what extent the six characteristics existed in the image. Stepwise multiple regression analysis revealed that the vividness ratings were significantly influenced by five characteristics: shape and contour, color, details, generality, and salience.

Seligman and Yellen (1987) reported that the vivid involuntary imagery of dreams has the same characteristics as voluntarily generated imagery. In their experiment, they asked participants to describe their dreams from the previous night and to evaluate the vividness of the images in these dreams. Judges who were blind to the content and vividness of the dreams examined the characteristics of the images that were extracted from the dreams on the basis of the participants' descriptions. Vivid imagery was found to be more detailed and colorful than dim imagery. Participants were also asked to report the size of their images, and the more vivid images were found to be larger in size.

These studies directly investigated the characteristics of vivid imagery based mainly on the participants' introspection, and they all found that vivid images contained more perceptual information than dim ones. Other studies indirectly support this finding. For example, Finke and Schmidt (1978) found that when vivid imagers visualized black stripes on a colored background and then observed only the black stripes, they could see a complementary color between the stripes (i.e., an imagery-induced McCollough effect). This complementary color after-effect induced by imagery arose only at chance levels in non-vivid imagers. Further, Richardson and Patterson (1986) reported that, in comparison with dim imagery, vivid imagery induced a stronger physiological response corresponding to the content of the imagery, for example, saliva secretion while forming an image of lemons. Since vivid imagery includes much more perceptual information and has a stronger resemblance to what is imaged than dim imagery, it should function as a better substitute for a perceptual stimulus and should also function as a more effective mental stimulus in problem solving. Hishitani (1991) examined this prediction and found that a shorter time was required to find a target item in a vivid image than in a dim image. Consequently, it was concluded that an image that includes more perceptual information will be more vivid and that differences in vividness are directly related to the amount of information transferred from LTM to the image construction stage(s) (Hishitani, 1993).

Hishitani (1985) also examined the characteristics of vivid imagery, employing individual differences in vividness as the experimental variables. He gave vivid and non-vivid imagers three concrete nouns (e.g., a night stall [booth], a small bird, and a railroad), and asked them to generate and describe an integrated image scene (e.g., The street along the railroad is alive with a row of night stalls, and a night-stall vendor is calling out that small birds are for sale. The street is crowded with people.). The number of objects, people, animals, and so on that appeared in the image and the number of simple sentences that were obtained by parsing the description were calculated. There was no statistically significant difference between the two groups in the time taken to construct the image. However, vivid imagers exceeded non-vivid imagers in the number of simple sentences and the number of objects, people, animals, and so on. When the simple sentences were categorized according to Rumelhart's (1975) story grammar, it was found that the number of categories was greater and the relations between them were more complex in vivid imagers than in non-vivid imagers.

These results suggest that vivid imagers can generate images with detailed and elaborate structures. However, all the measures used in Hishitani (1985) were based on verbal descriptions, which may not fully reveal the characteristics of visual imagery. Thus, Hishitani and Murakami (1992) conducted two additional experiments using the same experimental conditions as in Hishitani's 1985 study. In the first experiment, they asked participants to sketch their images as well as to report them verbally. The analyses showed that there was no difference in image-construction time between vivid and non-vivid imagers, but the mean number of colors that appeared in the images was significantly higher for vivid imagers than for non-vivid imagers. Further, judges who were blind to the group identification of each sketch rated vivid imagers' sketches as more detailed, colorful, and drawn on a larger area of the drawing paper than those of non-vivid imagers.

To confirm these results, Hishitani and Murakami (1992) conducted a second experiment in which they employed more participants and used a triplet of concrete nouns different from those in the first experiment. They focused on the number of colors and objects imaged simultaneously as indices of the perceptual information contained in the imagery because those indices are easily quantified. They found that vivid imagers had shorter image-construction times and generated more colorful images than non-vivid imagers. Participants were classified as a single- or multiple-object possessor based on whether they imaged only one object or multiple objects when they constructed the integrated image. Among vivid imagers, the ratio of multiple-object possessors was found to be greater than among non-vivid imagers. These findings confirm Hishitani's (1985) previous result that vivid imagers, compared with non-vivid imagers, construct images with more visual information.

Many previous studies have shown that vivid imagers take less time to generate imagery (e.g., Cocude & Denis, 1988; Ernest & Paivio, 1971; Hoffman, Denis, & Ziessler, 1983; Rehm, 1973). On the other hand, it has been consistently shown that more detailed imagery requires longer image-construction time (e.g., Beech & Allport, 1978; Kosslyn, Reiser, Farah, & Fliegel, 1983; McGlynn & Gordon, 1973; McGlynn, Hofius, & Watulak, 1974; Paivio, 1975). These results appear to contradict Hishitani's (1985) and Hishitani and Murakami's (1992) findings that vivid imagers, compared with non-vivid imagers, take less or equal time to construct an image although their images are more detailed. They do not contradict their findings, however, if, as we present in this review, vivid imagers are faster than non-vivid imagers in transferring the information used to construct imagery from LTM to the image construction stages. This possibility is also compatible with the hypothesis proposed in the next section, that vivid imagers have a higher capacity than non-vivid imagers to channel information from LTM to the image construction stage(s).

The Mechanisms Responsible for Imagery Differences

Interpersonal Variation in Imagery Vividness

Kosslyn (1980) referred to conscious imagery as the *surface representation* and to information stored in LTM that is used to construct imagery as the *deep representation*. As mentioned in the first section, like many other researchers, we take the position that the deep representation is transferred to the image construction stage(s) and that mental imagery is represented in these stage(s) as a surface representation. Further, as we concluded in the preceding section, vivid mental imagery contains more information. From this, it follows that the image will be more vivid if more information is transferred to the image construction stage(s) (surface representation) from LTM (deep representation). In other words, individual differences in imagery vividness (or interpersonal variations in imagery vividness) depend on the amount of information transferred to the image construction stage(s) from LTM. Baddeley and Andrade (2000) take a similar stance, that the vividness of an image reflects the amount of information that can be retrieved from LTM, and that a vivid image is one that is richly represented in the relevant subsystem of working memory. In their view, in short, vividness is equivalent to the amount of recalled detail that can be represented in working memory.

Two possible factors may influence the amount of perceptual information transferred to an image from LTM. First, more information may be stored in LTM by vivid imagers than non-vivid imagers about what is to be imaged. Second, the capacity of the information channel that connects LTM to the image construction stage(s) may differ in vivid and non-vivid imagers. The first factor seems to be inadequate to explain individual differences in vividness. Many imagery questionnaires, such as the Vividness of Visual Imagery Questionnaire (VVIQ; Marks, 1973), assess imagery vividness of popular or familiar scenes, people, or objects that individuals have frequently experienced with and thus would likely be able to image. Although such items should preclude individual differences in the amount of information about them in LTM, individual differences in vividness of imagery still exist.

Other evidence also suggests that it is difficult to attribute individual differences in vividness of imagery only to differences in the amount of information stored in LTM. Kunzendorf (1985-1986) asked participants to rate the vividness of images evoked by odd (or even) items of the VVIQ in arousal, and the vividness of images of even (or odd) items in hypnosis. One group of participants with low scores (i.e., vivid imagers) in arousal had similar scores in hypnosis. On the other hand, another group with high scores in arousal had lower scores in hypnosis, equivalent to those of the first group in arousal. These results suggest that the vividness of images may vary depending on the individual's state of consciousness, even if the contents of the images, and therefore the amount of information stored in LTM, are virtually equivalent.

The capacity of the information channel that connects LTM to the image construction stage(s) seems to be more adequate than the content of LTM to explain the variations in imagery vividness. As discussed previously, although many studies have indicated that vivid imagers take a shorter time to construct mental imagery and that a longer time is necessary to construct detailed imagery, other evidence has shown that vivid imagers construct clear and detailed imagery that includes much information in a shorter time than non-vivid imagers. This contradiction can be easily resolved, however, if the capacity of the information channel is larger in vivid imagers than in non-vivid imagers. In this paper, we adopt this as a working hypothesis in the following discussion.

As shown by Kunzendorf (1985-1986) and Ahsen (1985a), there are occasions when the vividness of equivalent imagery changes in the same individual and individual differences in vividness are not fixed. Moreover, as discussed later, imagery vividness varies depending on what is to be imaged. This suggests that the capacity of the information channel is also variable and may be controlled by a mechanism that regulates the flow of information. Further, if an overwhelming amount of information is transferred from LTM to the image construction stage(s) without such control, the excessively vivid imagery may cause hallucinatory behavior. Along these lines, Kosslyn (1987) proposed that when the amount of information transferred from memory to the image construction stage surpasses the perceptual information, hallucinations can be experienced. This suggests, therefore, the need for some sort of regulatory mechanism. Hishitani (1993,1995) has described such a mechanism and called it the Suppressor; in the broadest terms, it suppresses the flow of information from LTM to the image construction stage(s). As it is released, a greater amount of information flows from LTM to the image construction stage(s) in vivid imagers than in non-vivid imagers, and differences in image ability, in the form of individual differences in imagery vividness, are observed.

Figure 1 shows the simplest model of mental imagery processes constructed on the basis of the above discussion. This model postulates that visual information of target items in LTM is transferred via the Suppressor to the image construction stage(s) in which conscious imagery is represented. Monitoring conscious imagery to compute its vividness by the Inspection function leads to our subjective impression of vividness.

Intrapersonal Variations in Imagery Vividness

Several studies have implied that the vividness of mental imagery varies depending on its attributes. For example, some showed that negative imagery is less vivid than positive imagery (e.g., Bywaters, Andrade, & Turpin, 2004; Motoyama, Matsumura, & Hishitani, 2010) and that a fearful scene is imaged more vaguely than a neutral one (Lang, Kozak, Miller, Levin, & McLean, 1980). These results predict that the negativity of mental imagery will decrease its vividness. Alternatively, the vividness of emotional imagery may be explained in terms of the two factors that influence information flow to an image and imagery vividness, as discussed earlier.

First, the amount of perceptual information stored in LTM and, second, the capacity of the information channel that connects LTM to the image construction stage(s) may differ in negative, positive, and neutral imagery. Specifically, the Suppressor may make the information channel narrower when negative imagery is generated.

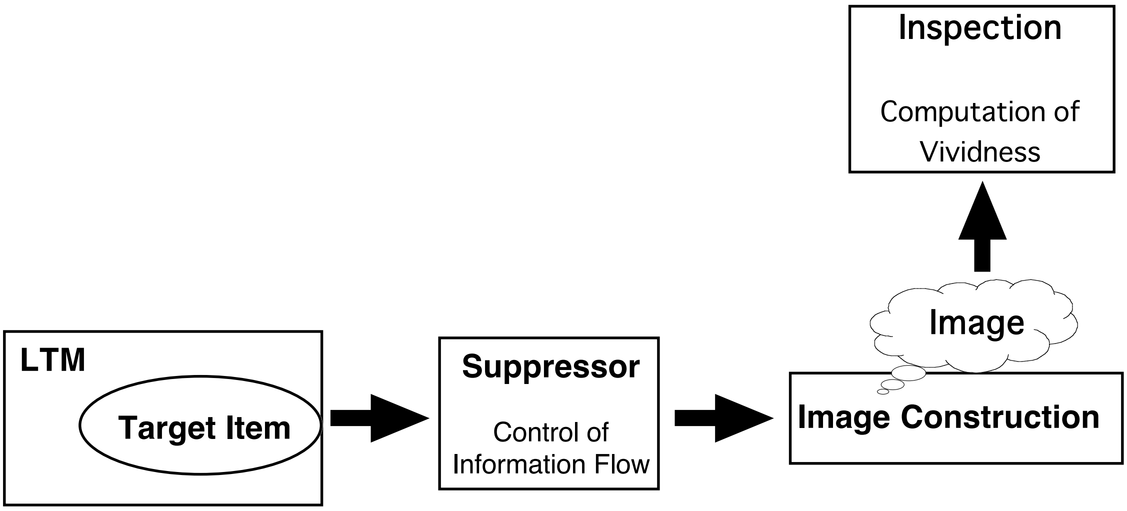

Figure 1. Model 1 of imagery processes postulates that mental imagery is constructed from the perceptual information coming from LTM via the Suppressor. The Suppressor is assumed to control the information flow from LTM to the image construction stage(s). Imagery vividness is determined by the amount of information adjusted by the Suppressor.

No research has directly examined which explanation is better. Some studies, however, suggest that the first explanation may be unlikely. For example, Clark and Paivio (2004) showed that there is no relation between the emotional value and frequency of nouns. This implies that the frequency and the amount of information we have about the objects and/or events confronting us do not depend on their emotionality. Another study indicated that negative events have a greater tendency to capture our attention than other kinds of emotional events. Öhman, Flykt, and Esteves (2001) showed that fear-relevant pictures were identified more quickly than fear-irrelevant ones. They interpreted this to mean that threatening stimuli, which are of evolutionary relevance, are effective in capturing attention. Given these two sets of results, there should be no difference in frequency for different types of emotional events, but negative events are more likely to capture our attention. It is possible that quickly acquiring and storing information about negative events is an important survival strategy. If so, then more information should be stored in LTM about negative events than about other kinds of emotional events. Nevertheless, negative imagery is not vivid in comparison to positive imagery. Thus, it is conceivable that the vividness of an image may be influenced not only by the amount of information in LTM but by how much the Suppressor adjusts the capacity of the information channel between LTM and the image construction stage(s) according to the emotional value of the mental image.

Figure 2 outlines the Suppressor mechanism. When we intend to form an image of an object and/or an event, the information associated with it is activated in LTM. The perceptual part of the information is transferred to the Suppressor and the emotional value, which is calculated based on the affective part of the information, is sent at the same time. The Suppressor then reduces the amount of perceptual information transferred to the image construction stage(s) in accordance with its negative emotional value. Accordingly, negative imagery is dimmer than positive or neutral imagery.

Although all of these processes have not been conclusively demonstrated, both inter- and intrapersonal variations in imagery vividness can be understood coherently under the following assumptions: Imagery vividness corresponds to the amount of information that the Suppressor adjusts for, and this adjustment depends on the individual and on the emotional value of the object and/or event that is imaged. As shown in Figure 2, the most important mechanism is the Suppressor. If these assumptions are valid, then a neural substrate for the Suppressor should be found. This brain region for the Suppressor mechanism will be discussed in a later section.

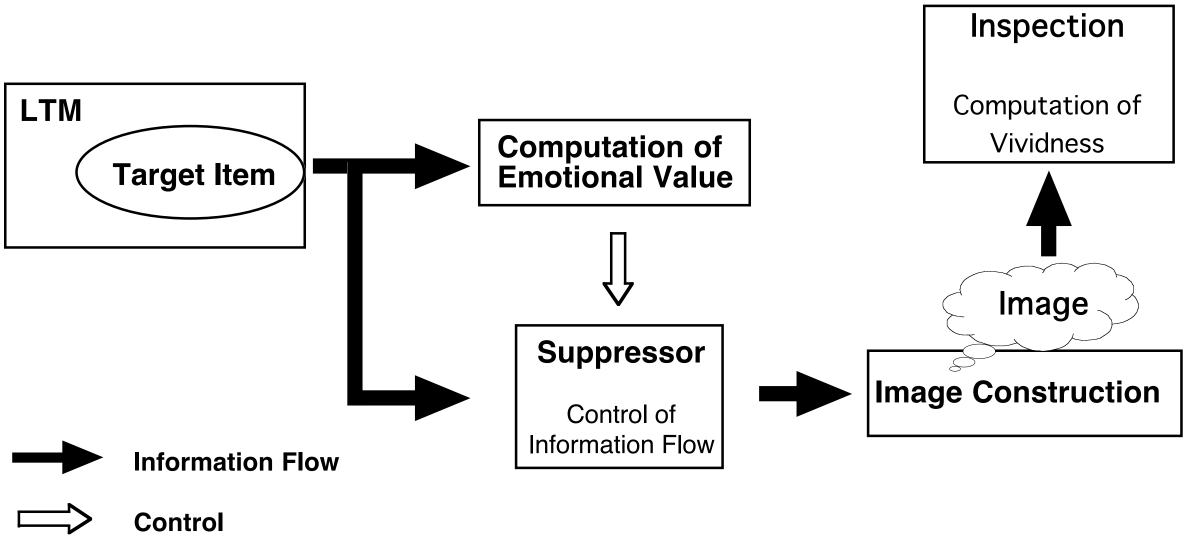

Figure 2. Model 2 shows that the Suppressor controls the information flow based on the emotional value of the imagery.

Information Structure in LTM and Imagery Processes

Triangular Pyramid Model of Information Structure in LTM

Careful introspection reveals that imagery is a composite conscious experience rather than the simple re-emergence of the perceptual appearance alone. In trying to re-create a past event as a mental image, we often experience not only its visual aspect but also our affect and the motion involved in the event. The composite quality that characterizes mental imagery can be found in the well-known novel, *In Search of Lost Time*, by Marcel

Proust, the famous French novelist and critic. It is filled with a cornucopia of various imagery types, conveyed through the imagery experienced by the main character, and interestingly, these depictions reflect not only visual appearances but also affect, as shown in the following quotation.

> I carried to my lips a spoonful of the tea in which I had let soften a piece of madeleine.... A delicious pleasure had invaded me, isolated me, without my having any notion as to its cause.... Undoubtedly what is fluttering this way deep inside me must be the image, the visual memory which is attached to this taste and is trying to follow it to me. (Proust, 1913/2003, pp. 47-49)

Here, the narrator's emotion was evoked by the taste of tea in which the madeleine has been dipped. He pursued the meaning of the emotion and the reason for its evocation, and finally arrived at the visual scene associated with the tea and the madeleine, showing the processes in which the memory of the past connected with the tea was recalled and completed as a synthesis of meaning, visual appearance, and affect. In other interesting and important descriptions in the novel, he frequently indicates that a kind of latent motion and/or movement in imagery is implied even in an object that seems to be static, as shown in the following quotations from *In Search of Lost Time* (Proust, 1913/2003).

> The old porch by which we entered, black, pocked like a skimming ladle, was uneven and deeply hollowed at the edges (like the font to which it led)... (p. 61)
>
> the graceful Gothic arcades that crowed coquettishly in front of it...(p. 64)

These expressions of mental imagery are not purely figments of Proust's imagination, as they are at least partially backed by Proust's autobiographical experience. For example, the source of the image evoked by the madeleine can be discovered in the preface to *Contre Sainte-Beuve* (see Proust, 1997). Proust's artistic expressions are based on introspecting and thinking about his own experiences, and the ensuing mental imagery consists of interconnected meaning, perceptual, affective, and motoric components.

Recent psychological studies have empirically supported, at least to a certain extent, that a mental image consists of multiple components. For example, several researchers have indicated that mental imagery consists of an affective component in addition to a perceptual one. In Miyazaki and Hishitani's (2004) investigation of the structures of imagery experience, participants imaged scenes in which they felt the most positive or negative affect that they had ever experienced or imaged. They rated the vividness of the image in various sensory modalities, the controllability and reality of the image, and their physiological and conscious affective responses to the image. Covariance structure analysis showed that the structures of both positive and negative imagery experiences were similarly composed of a perceptual and an affective component. While this indicates that mental imagery experience contains both components, it would be unwise to conclude that it always does since the evocation of both might have been due to the instruction, which asked participants to form a mental image based on the most positive or negative experience or image they had ever had. To avoid this artifact, Motoyama, Miyazaki, and Hishitani (2008) conducted an additional experiment.

Motoyama et al. (2008) examined whether mental imagery could cause an affective priming effect even though participants are not instructed to direct their attention to the affective aspect of the imagery. An affective priming effect refers to the phenomenon in which processing of an evaluatively polarized target word is facilitated or inhibited, that is, faster/slower or more accurate/inaccurate (e.g., Klauer & Musch, 2003). Motoyama et al. asked participants to generate visual imagery using a presented noun as a prime. To avoid directing the participants' attention to the affective aspect of the image, the following instruction was given:

> After you generate the mental imagery, a picture will be presented on the computer display. Please judge whether or not the picture corresponds to one of the nouns presented previously. The purpose of this experiment is to examine the extent to which generating mental imagery influences this picture-judgment task. However, before you perform the task, a string of letters will be presented. Please make a decision whether this is a word or a non-word. This lexical-decision task is interpolated to interrupt the picture-judgment task. Please perform both tasks as rapidly and correctly as possible.

The true purpose of this experiment was to examine the lexical-decision time required for the word/non-word decision. Emotionally positive and negative nouns were presented as cues for mental imagery (i.e., priming stimuli) and as the target words in the lexical-decision task. Therefore, there were two experimental conditions: a congruent condition in which there was correspondence in emotionality between the prime and target nouns (positive-positive or negative-negative), and an incongruent condition in which the emotionality of prime and target was opposite (positive-negative or negative-positive). A difference in lexical-decision time between the congruent and incongruent conditions would suggest that imagery-induced emotion influences the succeeding lexical-decision task. This would mean that emotion is evoked automatically during mental imagery, even in the absence of instructions directing attention to the emotional aspect of the image.

The results revealed a difference in lexical-decision time between the congruent and incongruent conditions when the participants generated a visual image of a priming noun. On the other hand, there was no difference in decision time between the two conditions when participants imaged a string of letters composing a priming noun. In other words, imaging the object indicated by the priming noun influenced the succeeding task, but the letter-string image did not. Since generating visual imagery of an object and/or an event spontaneously evoked affect related to the imagery, it was concluded that mental imagery contains an affective component in addition to a perceptual component.

A number of theories have also been proposed in support of the position that mental imagery is composed of perceptual and affective components. For example, Ahsen (1984) postulated a Triple Code ISM model, which proposes that mental imagery is made up of three interacting components. The image (I) component possesses the sensory content and provides a concrete, spatial stage for the mental enactment of events. The somatic response (S) accompanies the image and includes physiological and skeletal muscle reactions as well as affective experience; this component thus binds the inner and outer worlds. The Meaning (M) component refers to the ongoing interpretation of the image and the somatic response that incorporates both symbolic and memory dimensions (Hochman, 2002; Taktek & Hochman, 2004). Ahsen (1986) views imagery as a consciousness experience. Thus, Ahsen's model appears to view the structure of mental imagery in terms of the surface representation, to use Kosslyn's (1980) nomenclature. On the other hand, inspired by Pylyshyn's (1973) propositional model of imagery and Bower's (1981) semantic network model of mood and memory, Lang (1979,1984) proposed a bioinformational theory in which he treated the structure of mental imagery as a deep representation. According to his theory, there are three basic types of propositions: the stimulus proposition, that is, the detailed information about what is to be imaged; the response proposition, that is, the physiological activities involving affective responses; and the meaning proposition, that is, the associated declarative knowledge. Considerable evidence has accumulated in support of these two theories, especially for clinical applications (e.g., Ahsen, 1985b; Foa & Kozak, 1998; Hochman, 2002, 2007; Lang et al., 1980; Lang, Cuthbert, & Bradley, 1998; Taktek & Hochman, 2004).

From this discussion, it seems possible for the present time to view mental imagery as a surface representation having a triadic structure consisting of meaning, perceptual, and affective components and the structure of the deep representation as being triadic in LTM. How, then, can the idea that some kind of motion could be evoked even in imaging a static object, implied by Proust's depictions in *In Search of Lost Time*, be accommodated? Some studies have provided evidence supporting this idea.

Palmiero et al. (2009) used fMRI to investigate brain activities when mental images in different sensory modalities were generated in response to spoken phrases, such as "to see a bucket," "the stale smell," and "the salty taste." Significant activations were found in modality-specific cortices and, more interestingly, in the pre-motor cortex, even though the sentences did not mention moving objects. These results imply that the perceptual and motoric components of mental imagery are indissolubly linked to each other.

Many scholars have implied that a motoric component is included in visual mental imagery. For example, O'Regan (1992) argued that we experience the impression of seeing something through some physical action on, or mental assessment of, outward things. In other words, perception is getting to know or verifying the sensations caused by possible actions (O'Regan, 1992, p. 472). Therefore, it is quite natural that mental imagery, which depends on visual experience, contains components of the actions and motions accompanying visual perception. James and Gauthier (2006) also asserted that the motor information resulting from our interaction with objects may be stored and linked to their visual appearance. Similarly, Gibbs and Berg (2002) mentioned the link between mental imagery and kinesthetic activity based on the idea that perception is grounded on kinesthetic action. As Marks (1999) recognized, Newton (1996) also claimed that "understanding anything is knowing the possible actions one might perform in relation to that thing, and being aware of that understanding is consciously imagining (some of) those actions" (p. 52).

If we argue that perceiving an object is fundamentally based on overt and covert kinesthetic interactions with it, and that mental imagery involves those interactions, the following two stances are predictable: Mental imagery is useful to plan and simulate in advance an action that will be performed in the future (e.g., Isaac & Marks, 1994; Marks, 1999); and, conversely, doing an action is helpful in processing the imagery that relates to the action. An example of the former stance is Imai and Matsumoto's experiment in this issue of the *Journal of Mental Imagery*, which demonstrated that motor performance is influenced by outcome imagery (i.e., imagery of what happens immediately after the completion of an action). The latter example is found in the work of Hishitani (2003) and Hishitani and Nishihara (2007), who showed that imagery vividness and imagery task performance were enhanced in a drawing condition in which participants, with their eyes closed, moved their index fingers as if they were drawing the contents of a mental image.

Classical cognitive psychology and cognitive science have studied only the perceptual component of mental imagery. According to the above discussion, however, the idea that mental imagery is purely visual must be rejected; it also includes a motoric component in addition to its meaning, affective, and perceptual components. On the basis of a wealth of clinical experience, Ahsen (1984) and Lang (1979, 1984) proposed that the perceptual, affective, and meaning components form a triad in mental imagery. On the basis of the above discussion, this triadic model can be expanded into a triangular pyramid model to account for the hypothetical information structure in LTM. The triangular pyramid model thus consists of meaning, affective information, perceptual information, and motoric information; these components are interconnected as shown in Figure 3. If we accept the triangular pyramid model of information structure in LTM, and further assume that there are imagery processes corresponding to each component of the information structure, we can obtain a better understanding of imagery vividness.

Correspondence between Information Structure in LTM and Imagery Processes

As shown in Figure 4, Model 3 of imagery processes is formed by integrating the triangular pyramid model of information structure in LTM into Model 2. In order to develop Model 2 into Model 3, two information channels are posited, corresponding to the two components of information structure in LTM. The first channel is used to transfer affective information to the mechanism responsible for computing an emotional value, on the basis of which the Suppressor controls the flow of perceptual information. The second channel is employed to convey the perceptual information to the Suppressor. While it may be possible to assume that affective information has direct access to the Suppressor and makes it control the amount of the information that passes through, there seems to be some fluctuation in the relationship between imagery vividness and emotion; that is, the relationship is not fixed and varies even when the same imagery is constructed under different situations. In order to explain the fluctuations, we introduce a mechanism that computes the emotional value depending on the situation. This triangular pyramid model of information structure in LTM, which was developed from previous studies (Ahsen, 1984; Lang, 1979, 1984), is naturally integrated with the imagery processes proposed in other studies in which mental imagery is represented in the image construction stage(s) on the basis of information retrieved from LTM (e.g., Kosslyn, 1980; Kosslyn et al., 2006; Pearson, 2001; Pearson et al., 1999; Pearson et al., 1996). Therefore, the present model

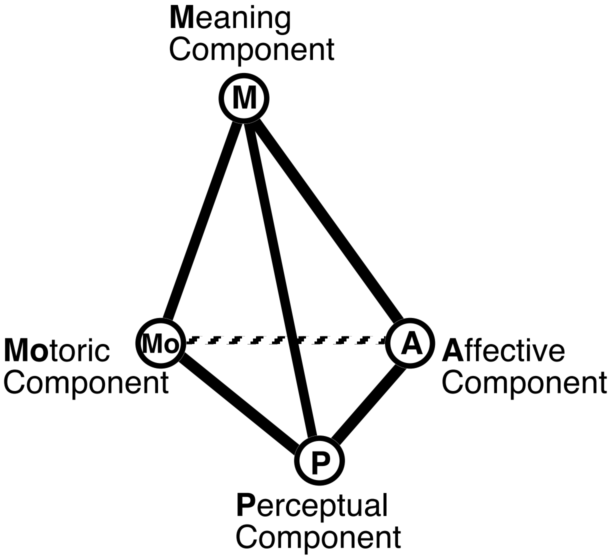

Figure 3. The triangular pyramid model of information structure in LTM.

inherits its fundamental functions from previous models. For example, the following processes are hypothesized: When a meaning component is activated by the intrinsic or extrinsic intention to image, activation is propagated to the other components according to the strength of the linkage between them, the information is transferred from the components to the processes outside of LTM, and imagery is generated. Imagery generation could also begin from an activated component that is not a meaning component.

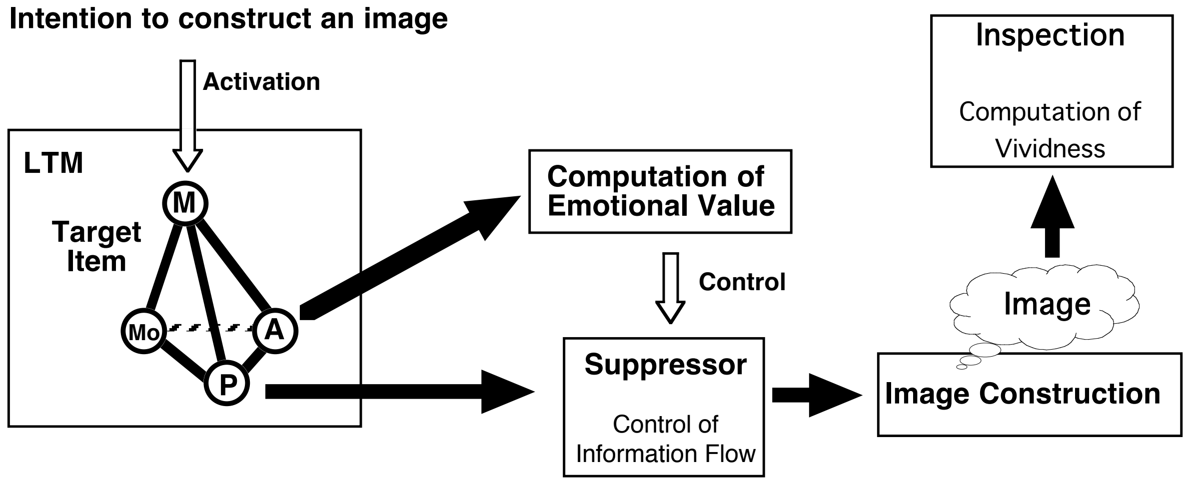

Figure 4. Model 3 is constructed by integrating the triangular pyramid model of information structure in LTM into Model 2, shown in Figure 2.

As mentioned earlier, some studies have suggested that the vividness of mental imagery depends on its emotional value (e.g., Bywaters et al., 2004; Lang et al., 1980). In order to explain this phenomenon, an information channel is posited in Model 3 between the affective component of the information structure in LTM and the mechanism that computes the emotional value. That is, we take into account the psychological phenomenon by adhering to the principle that a component of the information structure in LTM is related to a mechanism that will process the information coming from that component. The rest of this section will address another imagery phenomenon, that is, the effect of kinesthetic activity on vividness, in accordance with this principle, and expand Model 3 into Model 4.

Imagery vividness is also influenced positively or negatively by some form of kinesthetic activity (e.g., Andrade, Kavanagh, & Baddeley, 1997; Baddeley & Andrade, 2000; Hishitani & Nishihara, 2007). These findings are not unpredictable, because it might be expected that image generation is necessarily accompanied by manipulation of constituent elements of the imagery. According to Bartlett (1932) and Neisser (1967), mental imagery is not a copy of experience but a creative construction. This implies that in generating imagery the constituent elements must be complemented, manipulated, adjusted, controlled, and so on, rather than replayed untouched from LTM; some studies have indicated that the human motor system is involved with the manipulation of mental imagery (e.g., Kosslyn, Thompson, Wraga, & Alpert, 2001; Wexler, Kosslyn, & Berthoz, 1998; Wohlschlaeger & Wohlschlaeger, 1998).

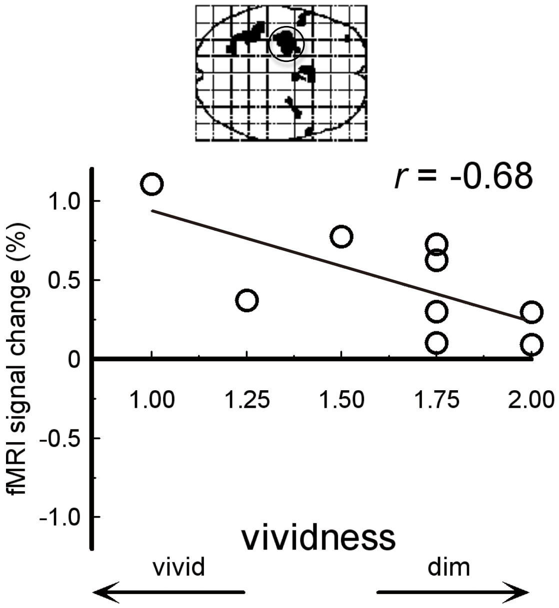

Figure 5. The brain map shows the areas that are more activated under the condition of imagery with drawing, compared to the baseline condition. The activation of the supplementary motor area (SMA) is correlated with the subjective vividness of imagery. The correlation coefficient is -0.68. This suggests that an increase in activation of the SMA leads to enhancement of subjective vividness. (From Hishitani, 2008)

Hishitani (2008) showed that when participants were asked to generate imagery with their eyes open, activation of the supplementary motor area (SMA) was greater in a drawing condition, in which they moved their index fingers as if drawing the contents of the mental image, than in a rest condition, in which they looked at a white screen. If this were all that was found, the stronger activation of the SMA would simply reflect the finger movement. As shown in Figure 5, however, activation of the SMA was correlated with the subjective vividness of the imagery, suggesting that vividness was enhanced by the imagery-related action. In the results of this study, moreover, the essential nature of imagery generation as a creative construction (Bartlett, 1932; Neisser, 1967) was reflected in that the participants were required to construct an integrated image consisting of multiple objects suggested by concrete nouns. That is, the constituent elements had to be complemented, manipulated, adjusted, controlled, and so on. It is, indeed, interesting that these results were obtained under such a condition. This suggests that the motor system is generally involved in an ordinary case of image generation and that this determines the quality of the imagery. It is conceivable that the SMA may function as an enhancer, making the imagery more vivid, if it is involved in drawing the contents of imagery. On the other hand, it is known that a concurrent irrelevant action like spatial tapping lowers imagery vividness (e.g., Andrade et al., 1997; Baddeley & Andrade, 2000). In this case, the SMA must work as a dimmer, deteriorating imagery vividness, because it is used to plan the irrelevant actions instead of the actions appropriate to the imagery content. Model 4 in Figure 6 is therefore derived by embedding in Model 3 the postulate that image generation is affected by motor action.

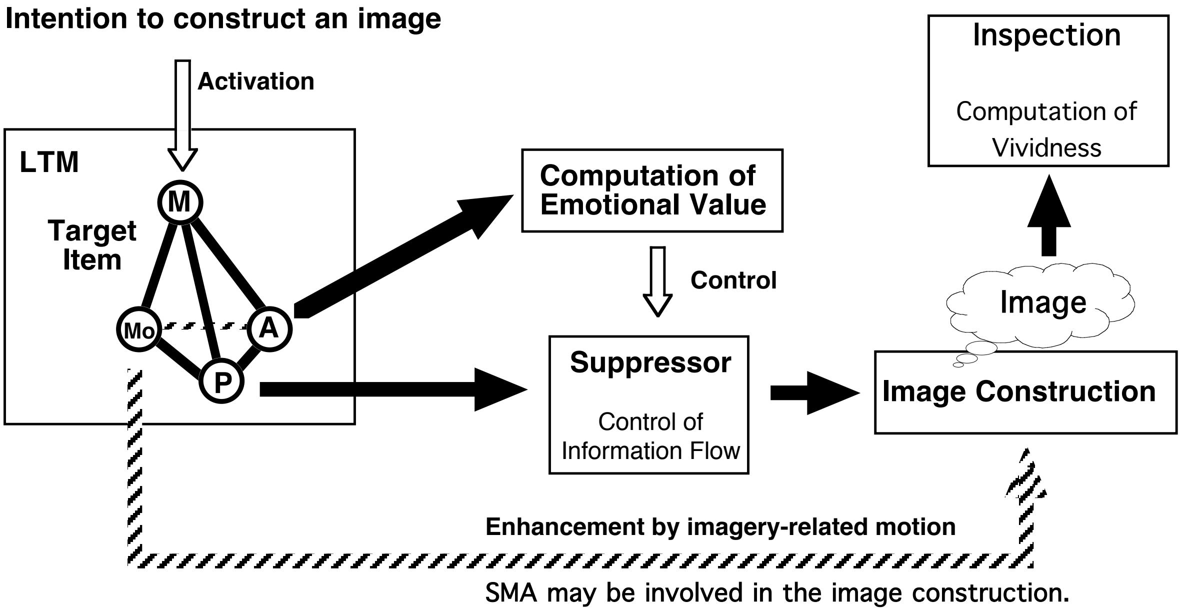

Figure 6. In Model 4, the oblique arrow indicates that the supplementary motor area may be involved in imagery construction.

Neuroimaging Studies on the Model of Imagery Processes: Suppressor and Closer

In this section, we introduce the construct of the Closer into the model of imagery processes. When we intend to experience a mental image as vividly as possible, irrelevant external stimulation interferes with the image. This has been shown in Brooks' (1968) classic study. On the other hand, *Da Xue* or *The Great Learning* (trans. 2010), a work of classical Confucian literature, says, "When the mind is not present, we look, but do not see." This suggests that even if a sensory stimulus arrives at a sensory receptor, perception cannot be established without active processing to extract the information from it. This idea in *Da Xue* has something in common with the idea of embodied cognition, mentioned in an earlier section, in which perceptual experiences are obtained through action on the external world. If the assertion in *Da Xue* is valid, there should be a mechanism that necessarily shuts out the visual information coming from the outside during image generation. This mechanism is called the *Closer*. In this section, we will examine the neural correlates of the Suppressor and the Closer.

Motoyama et al. (2010) conducted an fMRI experiment to find the brain region that functions as the Suppressor. In a previous discussion in this review, the Suppressor was defined as the mechanism that controls the flow of perceptual information between LTM and the image construction stage(s), and it was noted that the Suppressor should function more actively in the generation of negative imagery than positive imagery. Thus, Motoyama et al. focused on areas in which a stronger blood oxygenation level dependent (BOLD) signal is observed for negative imagery than for positive imagery. It was expected that the region functioning as the Suppressor, which decreases the amount of visual information used to generate mental imagery, exists within such an area. Since mental imagery vividness is reduced if the amount of information decreases (e.g., Baddeley & Andrade, 2000; Hishitani & Murakami, 1992), activation of the region identified as the Suppressor should negatively correlate with mental imagery vividness: When the region shows much activation, then the imagery should be rated as less vivid. Motoyama et al. thus examined the correlation between the subjective vividness rating and the fMRI signal in this region during imagery.

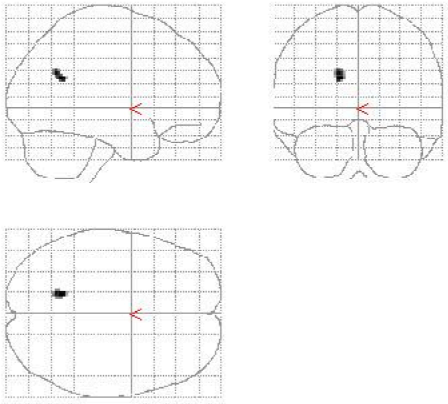

Figure 7. Areas of greater activation in the generation of negative imagery compared to positive imagery. (From Motoyama, Matsumura, & Hishitani, 2010, p. 8)

As shown in Figure 7, Motoyama et al. (2010) found that a part of the left posterior cingulate gyrus was the brain region where the activation was significantly greater in the negative condition than in the positive condition. Next, they examined the correlation between activation of this region and the subjective vividness of the mental imagery. The correlation analysis showed a significant correlation in the negative imagery condition, $r = 0.82$, $p < .05$, but no significant correlation in the positive imagery condition, $r = -0.27$, *ns*, as seen in Figure 8. These results clearly suggest that an increase in activation of the left posterior cingulate gyrus leads to reduction of the subjective vividness of negative imagery. Therefore, it can be concluded that this brain region plays the role of the Suppressor.

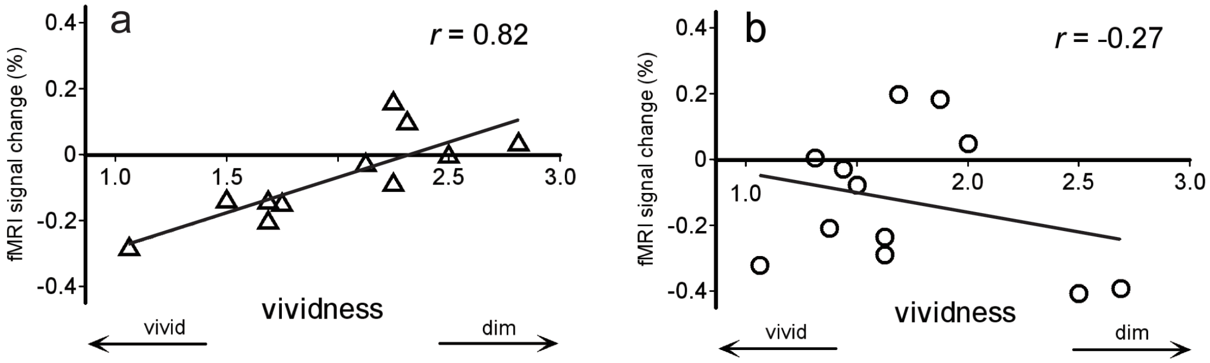

Figure 8. Scatter diagrams (a) between the vividness of negative imagery and fMRI signal change, and (b) between the vividness of positive imagery and fMRI signal change (from Motoyama, Matsumura, & Hishitani, 2010, p. 9). In Motoyama et al. (2010), the ratings of the vividness of the mental imagery ranged from 1 (very vivid) to 4 (very vague). If the vividness ratings negatively correlated with the activation of the posterior cingulate gyrus, a positive correlation coefficient would result.

Hishitani's (2008) study, described in the previous section, also attempted to locate the brain regions that work as the Closer. The results of the data analysis showed that a part of the cuneus, which is involved in primary visual processing, was activated more strongly in the rest condition than in the drawing condition. In other words, the cuneus was deactivated in imagery generation. This indicates that when an image is being generated, visual processing is inhibited. In this study, the participants were asked to construct an image scene with their eyes open, so that the Closer might work and the information channel might shut down to prevent interference between the internal imagery and the visual information coming from the outside. Furthermore, as shown in Figure 9, deactivation of the cuneus was correlated with imagery vividness. This shows that the cuneus probably deactivates more when the imagery vividness is lower. Specifically, this implies that when the imagery is not vivid, the Closer works more actively to shut off the interfering visual information. Model 5 in Figure 10 is derived by adding the function of the Closer to Model 4.

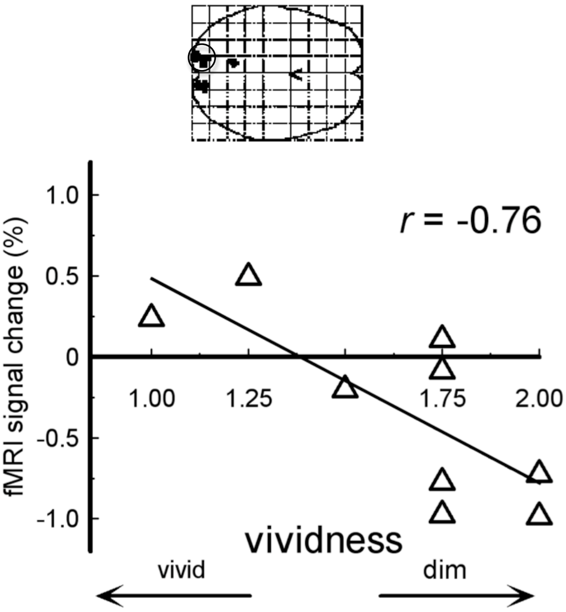

Figure 9. The brain map shows the right and left cuneus regions, which are more activated in the baseline condition than in the condition of imagery with drawing. Deactivation of the left cuneus is correlated with imagery vividness. The correlation coefficient is -0.76. This implies that visual processing is inhibited when an image is being generated. (From Hishitani, 2008)

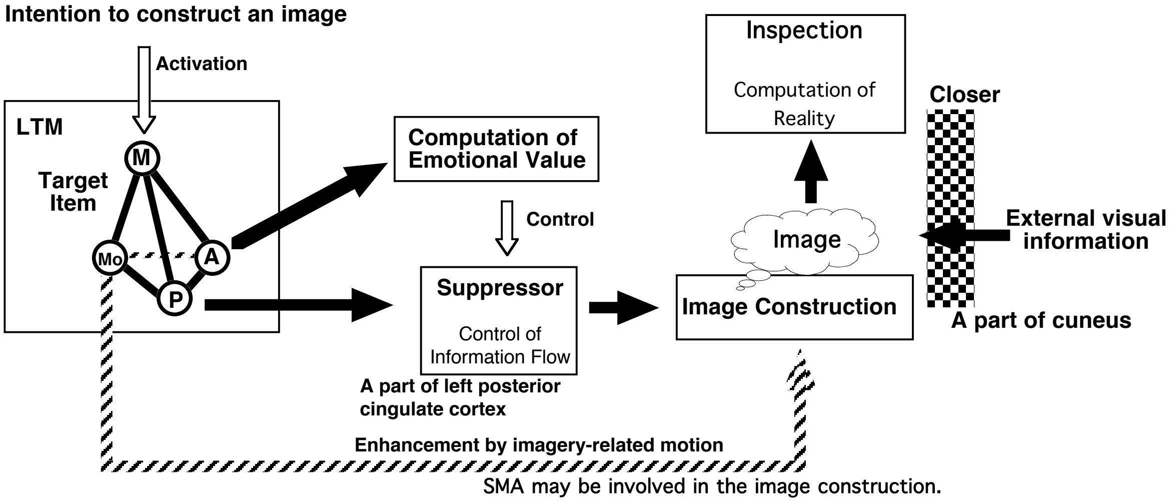

Figure 10. Model 5, derived by adding the function of the Closer to Model 4.

Toward Further Development of the Model

Thus far, we have addressed the problem of mental imagery processes, especially focusing on those that control vividness. We now reconsider the concept of vividness to further develop our theories and models of mental imagery processes. We have postulated that the amount of information defines the vividness of imagery; that is, more information is associated with greater vividness. Particularly in clinical observations, the following case is often reported: Even if mental imagery is described as perceptually clear as an actual experience, there are occasions when the imagery is not necessarily vivid because it is emotionally flat or dull, and vice versa. Accordingly, in agreement with this argument, we should consider vividness not only as a percept-like property of cognitive features but also as an affective one. McKelvie (1995) claimed that vividness can be defined as a combination of clarity and liveliness, where clarity refers to the brightness of the colors and the sharpness of the details while liveliness refers to how dynamic and lifelike the image is. He also argued that the elements of vividness be defined so that greater vividness is associated with greater clarity and greater liveliness. From a similar point of view, Marks (1995) published a revised version of the VVIQ that assesses the liveliness of visual mental imagery in addition to vision-like vividness, which was the only aspect assessed in the previous version.

These studies try to redefine the construct of vividness by emphasizing affective features. Instead of vividness, however, it may be better to employ a new construct, *reality*, which combines perceptual clarity and emotional liveliness. As noted by Richardson (1994), when imagery is described as vivid, it undoubtedly contains percept-like content, but it may also contain a sense of reality; in other words, the feeling of being there. A vivid image places the imager in the situation that is to be imaged. As noted earlier, Miyazaki and Hishitani (2004) have provided empirical evidence that the structures of image reality consist of both a perceptual and an affective subcomponent.

Given this perspective, we propose that the affective aspect in mental imagery should be inspected as well as its percept-like one, and that because the reality of imagery includes both, this would also be inspected. Therefore, it is reasonable to hypothesize that there is an additional information flow from the computation of emotional value to Inspection of the image.

In order to answer the question of how imagery vividness is determined, we have so far discussed imagery processes and proposed the psychological model shown in Figure 11, which is partially based on neural substrates. We have estimated the locations of the brain regions for the Closer and the Suppressor, shown the relationship between vividness and kinesthetic action in imagery, and implied that imagery vividness is a special case of imagery reality. However, one function in the model has not been sufficiently considered and still remains to be examined, namely, the function of Inspection in the final evaluation of imagery reality or vividness. In closing, we now provide a discussion of the Inspection.

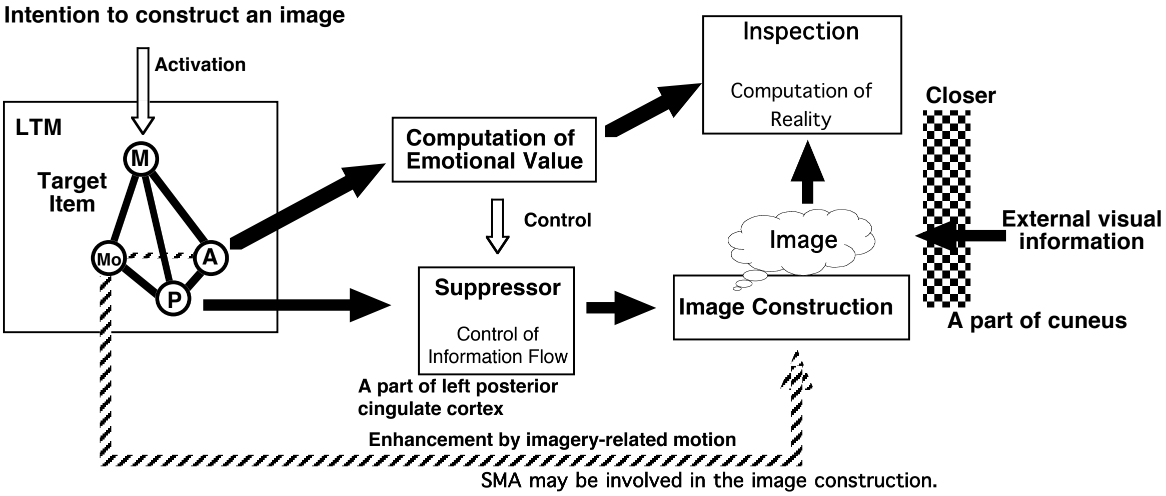

Figure 11. Model 6 indicates that the Inspection function computes imagery reality based on both the emotional value and the amount of perceptual information in an image.

What stage of imagery processes does the Inspection function observe? Based on a review of previous studies, we have indicated that more vivid images contain more visual information. Imagery processes must work more actively when greater amounts of information are to be processed. Accordingly, "the more vivid the image, the more strongly these mechanisms would respond" (Finke, 1980, p. 130). Certainly, Amedi, Malach, and Pascual-Leone (2005) and Cui, Jeter, Yang, Montague, and Eagleman (2007) have shown that there are statistically significant positive correlations between imagery vividness or its individual differences and activation of the primary visual cortex during mental imagery. Furthermore, according to the model proposed by Kosslyn (1980, 1994), mental imagery is constructed in the visual buffer, which is proposed to be in the primary visual cortex. Therefore, it may be hypothesized that the function of Inspection is to observe the primary visual cortex and compute vividness in proportion to its activity.

Nevertheless, there seems to be more to imagery mechanisms than this, because the primary visual cortex is not necessarily activated for all types of imagery (e.g., Kosslyn et al., 2006). It has been shown that activation of multiple brain regions correlates with imagery vividness. It has been also revealed that the cuneus is deactivated when imagery is vivified, and that the degree of deactivation correlates with imagery vividness. Consequently, we may hypothesize that the Inspection function observes concurrently multiple processes involved with image generation, takes the amount of emotional value and perceptual information synthetically into account, and finally determines imagery reality or vividness.

In the present review, we have developed a simplified model in which the Inspection function monitors only the final products of the image generation processes in order to evaluate the amount of perceptual and affective information. We do not necessarily think, however, that this model represents the complete truth about Inspection. As noted above, the Inspection function may observe multiple stages of imagery processes. We constructed a simplified diagram of the Inspection function because most of the mechanisms and the brain areas involved in imagery vividness have not yet been fully elucidated. This problem is a great challenge that requires further examination in the field of imagery research.

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