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Embodied Making, Creative Cognition and Memory

Drawing on neurobiological knowledge of creative cognition and the role of the hippocampus in memory storage and recollection to explore the experience of carving green wood

Abstract

This article revisits previous research on the maker's experience when working with materials, and discusses this in light of new research on creative cognition and the neurobiological basis of making. It is one in a series of four articles, which draw on neurobiological knowledge to expand our understanding of the woodcarver's experience. The aim of this article is to present and discuss one element of the creative cognition of the woodcarver: memory. It reviews the basics of the nervous system and its function, cognition, and attention. I argue that one of the reasons why the woodcarver cherishes the experience of carving is that he or she can recall and relive many details in the memory of it. I will specifically discuss the role of the hippocampus in storing and recollecting declarative episodic memories. The article concludes with a short discussion of why this knowledge is useful in understanding the woodcarver's experience and, in turn, if – and, if so, why – woodcarving could be an important activity in which to engage in the twenty-first century.

Keywords: embodied making, neurobiology, memory, cognition, hippocampus

Introduction

Embodied making with green wood – revisiting a previous study

Figure 1. Working with green wood.

The experience of working with green wood (figure 1) is often described as a *making* process (Michl & Dunin-Woyseth, 2001), involving intense internal focus, immense joy, and an urge to overcome resistance (see, for example, Crawford, 2009; Dahl & Dahl, 2015; Fredriksen, 2013; M. S. Gulliksen, 2015c; Ingold, 2013; Osborne, 2014). Such experiences are *embodied*

(Rosch, Thompson, & Varela, 1991), meaning that the abstract cognitive process and the physiological, bodily process are intertwined and inseparable. They have been referred to as experiences of flow (Csikszentmihalyi, 1996) or as the experience of being creative. The term "creative cognition" is used to describe creativity as a distinct creative mental state. Developed from the functional neuroanatomy framework of creativity described by Dietrich (2004), the term has been defined by Lopata (2014, p. 8) as: "a distinct mental state that includes (a) engagement in an activity, (b) spontaneous processing of thoughts, and (c) the expression of these thoughts through a medium (e.g., voice, a writing tool, a musical instrument)".

This article addresses the themes of embodied making, creative cognition, and memory via the carver's experience of making objects in wood. Early in my research career, I studied my own woodcarving experience (M. Gulliksen, 1997, 2001), through a rigorous analysis supplemented by poetic descriptions:

> Slowly, warmth spreads from within my body – hands soar, clutching the iron as shapes evolve. I fight the wood in the first phases: The gouge is pressed down and wriggled forward, resulting in notches left to be smoothed by a knife. This part of the work feels like an exhausting negotiation between two wills. The wood and I have to compromise. I introduce my original idea about figure and shape like persuasion with gouge and club.
>
> I know this piece of birch wood already. There are some wounds along a growth ring, as if it has torn. Ax traces from the felling. I can see traces left by the power of my arm wielding the ax when felling the tree. In my memory, I have stored images of the instant it fell down. And of the instant before, when it still stood tall, up in the mountain forest. The little bowl shape is carved out of a tree that, had I not felled it, would still have been towering over the forest and shaking its leaves for several decades to come. So I chop it down and clamp it to the work bench. I attack it with tools; making holes where before there were unbroken lines, growth circles, life. I make dents where before there were untouched fibers. Peel off the bark and, underneath, the grain is smooth as silk.
>
> Reluctantly, the wood gives in, with chips falling off in their own tempo and their own direction. Before my eyes, shapes are erased and arise from shivering growth rings under the gouge's strive. Hard labor and physical strength wriggle the idea into shape.
>
> The wood needs a long period of intense persuasion to accept my ideas, and my ideas need time to adjust to the wood. But when the shapes are found at last, the knife follows the directions of the fibers. When they meet, the fibers and the knife, they unite like rivers connect, meet gliding down through shallow valleys (M. Gulliksen, 1997, pp. 64-65, 76, my translation).

Describing the experience in such ways worked as an experiential conceptualization in the study, reflecting the experience of making itself and seeking to capture some of its complexity. In the previous study, I drew upon Merleau-Ponty's perception phenomenology (1962) to analyze this activity. The study was situated within a phenomenological research tradition, positioning the body as a vehicle for being in the world (Streeck, Goodwin, & LeBaron, 2011). Studies on embodied making within the design and craft education research tradition have often drawn on such perspectives, in addition to other descriptive and/or philosophical approaches, such as the philosophy of Bergson (Bergson, 1988; Østerberg, 1995), and socially and culturally contingent perspectives, such as Bourdieu's descriptions of habitus (Bourdieu, 1984; Bourdieu & Johnson, 1993).

The previous study described an activity moving through several different conceptual states of mind, from the intense sensory experience to critical reflections. Drawing on Merleau-Ponty's phenomenology, I referred to this as experiences having a preconscious and a conscious mode. In these modes of experience, the *maker*, i.e., the embodied unity of mind and body (Bresler, 2004; Rosch et al., 1991; Varela, Vermersch, & Depraz, 2003), and the *material*, i.e., the unity of form and matter (M. Gulliksen, 1997; Karlsen, 1994), were engaged in a negotiation, during which the maker's initially vague intentions and projections for the process's intended results were met and reshaped by the material's physical and abstract properties. The negotiation led to the overcoming of three types of resistance between old and new ideas and experiences: physical resistance, aesthetic–idea resistance, and cognitive resistance (M. Gulliksen, 1997, 2000, 2001). In that study, I was interested in understanding how sensory motor and cognitive experiences seemed to melt together in this preconscious state of mind. In accordance with the perception phenomenology of Merleau-Ponty, this negotiation process could be understood by grasping what perception is: beyond merely experiencing the material and what we are doing in a situation, our intentions shape the phenomenon itself. The negotiation between maker and material is thus "a perceptual field opening up to the body" (Gulliksen, 2001, pp. 4-5). This description of an embodied cognition aligns with other accounts; see, for example, O'Connor's descriptions of learning to blow glass (2005) or Groth's descriptions of throwing clay (2015; 2013).

Lately, knowledge from the rapidly developing neurosciences has informed creative practices and embodied making from novel perspectives (Seitamaa-Hakkarainen, 2015). Such knowledge opens up the field for other nuanced perspectives explaining the biological functions behind the phenomenological descriptions from the last century. In particular, studies conducted jointly by researchers from the practice fields and the science field have advanced our understanding of the biological basis for the designer's or artist's experiences (Goguen & Myin, 2000; Seitamaa-Hakkarainen, 2015; Seitamaa-Hakkarainen, Huotilainen, Mäkelä, Groth, & Hakkarainen, 2014; Varela et al., 2003; Zaidel, 2005). Similar results emerge from the fields of education or development studies, where such interdisciplinary perspectives have been found to support and expand previous research on complex human behaviors, development, or experiences (Ansari & De Smedt, 2012; De Smedt et al., 2011; Juelskjær, Moser, & Schilhab, 2008; Simons & Klopack, 2015).

The context – developing an interdisciplinary research project

This article is written within the context of an ongoing project that aims to develop a future interdisciplinary study of embodied making activities, bringing together neuroscientific and experiential, observational, analytical, or reflective knowledge and methods. Such an interdisciplinary study combining these different methods could potentially confirm and expand current knowledge on both the phenomenon of embodied making itself and learning in and through such making. The project aims to provide a coherent description of certain relevant neurobiological knowledge, to generate a starting point or a foundation for developing hypotheses for the future interdisciplinary study. In order to achieve this, I have written and discussed papers at international conferences, studied in courses, and organized seminars and workshops on this topic. I also practice woodcarving myself, within the context of this project development (see Figure 2 on the next page).

The project exemplifies making in wood, keeping in mind that the neural and functional distinction between woodcarving and other making activities may be small. Nevertheless, I assert that it could be possible to use neurobiological knowledge to gain a better understanding of why woodcarving, for so many, is intensely experienced and vividly remembered, and to generate new and communicable knowledge on if – and, if so, why – these experiences are important enough to pursue in education or in daily life.

The present article, written within this context, is the second in a series of four, of which three explore different neurobiological themes: the present article, another article that focuses on the role of the cerebellum in woodcarving (M. S. Gulliksen, 2015c), and a third that focuses on the role of the thalamus in directed attention in sensory experiences (M. S. Gulliksen, 2015b). The fourth article presents the project of developing a future interdisciplinary research project on neuroscientific knowledge in embodied making itself (M. S. Gulliksen, 2015b, 2015c, 2016b). There are plans for two more articles: one focusing on methodologies for the future project (M. S. Gulliksen, 2016a), and one in which I intend to discuss experience-dependent neuroplasticity and questions related to learning-induced autonomy of the sensory motor system (Basset, Yang, Wymbs, & Grafton, 2015).

Figure 2. Wooden bowl inspired by the form of a cerebellar Purkinje cell. Aspen wood, 35x7x3cm. Made while writing this article and given to Professor Peggy Mason of the Department of Neurobiology at the University of Chicago.

I am no neurobiologist. Currently, I hold the position of professor in culture education, culture production, and aesthetic practice at the University College of Southeast Norway. From this perspective, I have followed the knowledge generated in the neurosciences for some twenty years, and have participated in seminars and attended relevant courses (e.g., Mason, 2015; Western University, 2014). The immediate danger of discussing neurobiology without full scholarly knowledge of the field is that non-scientists tend to make overly strong claims based on inadequate understandings of the concepts (De Smedt et al., 2011; Goswami, 2006; Western University, 2014). There is also a concern about neuroscience content or terms being used "purely to put a new, modern gloss on some very old ideas from 1970s psychology. This is not to say that it is necessarily bad advice. But these are old ideas, given a slick re-packaging and being sold as brand new" (Wall, 2014, para. 12).

These concerns are the reason for writing a series of articles and discussing them with experts in the field. Aiming to bring together current neurobiological descriptions of what the woodcarver does and experiences in a coherent way, as seen from his or her own perspective, the descriptions can engage critical thoughts and new ideas on where to begin developing hypotheses for a future interdisciplinary study. Together, the articles are intended to form a basis for further exploration of the theme, in association with specialists in the neurosciences, within the framework of our international research group consortium and our university research group, Embodied Making and Learning, at the University College of Southeast Norway (M. S. Gulliksen, 2015a).

Aim of the article

In this article, I revisit the earlier study on woodcarving (Figure 3) described above (M. Gulliksen, 1997, 2000, 2001), as well as engaging again in woodcarving. The primary objective of the article is to present and discuss, from a neurobiological perspective, one specific aspect of the woodcarver's cognition: his or her memory of it. Carving, like every other activity in which a person can engage, is dependent on a combination of immediate memory, working memory, and long-term memory. Looking more closely at what memory is from a neurobiological perspective could therefore be relevant. To do that, I will need to present a definition of cognition and the phenomenon of attention. I do not so much discuss whether this cognition is creative or not, but rather consider a limited range of cognitive activities in the maker's experience and the memories of these experiences, which could, by some definitions, be seen as a form of creative cognition. I will argue that one of the reasons why the woodcarver cherishes the experience of carving is that the memory of it can be recalled and relived in great detail. In particular, having presented a short overview of the basics of the nervous systems and its functions, I will discuss the role of the hippocampus in storing and recollecting declarative episodic memories.

Figure 3. Carving a bowl in birch wood (1997).

As a creative making activity, woodworking has many similarities to making with other materials. I choose green woodworking specifically for a number of reasons, principal among which is my personal background as researcher and maker. Woodworking is a slow process: it is hard labor, engaging many senses and the entire body, and many different countries across the world have developed a strong cultural tradition of working in wood, as wood has traditionally been easily accessible and can be turned into useful and/or beautiful objects by a multitude of techniques. However, in post-industrial countries, the activity of woodworking is fairly rare, and even more rarely researched compared to other making activities such as music, drama, or even art therapy (Hass-Cohen & Carr, 2008; Winner, Goldstein, & Vincent-Lancrin, 2013). There is thus a lacuna in science-based knowledge on woodworking, which makes it relevant to contemplate. In this particular article, however, woodworking is seen as an example of a making process, as the knowledge presented may not necessarily be confined to woodcarving.

The professor in the neurobiology course I attended discussed an early version of this article, which was also presented as a paper at the LearnXDesign2015 conference to researchers within the fields of design and education at the symposium "Embodied making and design learning."

The nervous systems and its functions

Neurons and neural communication

Neurons are the name of the types of cells responsible for registering, translating, and transmitting information in the body. The term neurobiology refers to the study of the basic nervous system in all animals, including humans (Mason, 2011; Purves et al., 2012).

Neurons are organized in two main systems: the central nervous system (CNS), which includes the forebrain, brain stem, and spinal cord, and the peripheral nervous system (PNS), which includes all the other neurons sending or receiving information to and from the CNS

(Mason, 2011, p. 4). The nervous system has four basic functions: voluntary movement (everything we choose to do), perception (everything we consciously appreciate), homeostasis (the continuous process of keeping our body balanced and alive), and abstract functions (everything we think, feel, learn—what makes us a human being) (Mason, 2015).

The neurons communicate with one another and with other types of cells, such as muscle cells. The neurons relay information by means of electricity. At rest, the neuron has a resting membrane potential, a stable difference in electrical voltage between the outside and inside of the cell. One dedicated part of the cell, the dendrites, is responsible for registering information from other cells or from the outside world. This registration leads to a stimulus of or a change in the electrical voltage in the cell: the release of an action potential. This elevated electrical voltage will form a rhythm and intensity that together function as a signal that moves through the neuron toward the cell body, the soma, where it is processed and sent further down the neuron's axon. At the axon terminals, the action potential releases neurotransmitters that make up a chemical message, which transmits the signal to other neurons' dendrites in a synapse or by innervating another type of cell, for example muscle cells (Mason, 2011, p. 55). The signals can be affirmative, negative, fast, and slow. Each neuron is responsible for conveying a particular message.

Neurons register information from the outside world by a process called transduction. During transduction, the dendrites of the neurons register signals from the outside world (light waves, sound waves, mechanical pressure on our bodies, etc.), which, through a range of different means, stimulates the neuron and releases an action potential that sends the electrical signal into the nervous system. Whether originating from a transduction process or from processes within the nervous system, these electrical signals are therefore the means by which we can breathe, see, move, and think—everything we are as living bodies.

For the woodcarver, as for every other animal with a brain, many types and circuits of signals are active at the same time, as an integrated whole. This is why experts in the field emphasize that the "assignment of a function or functions to certain neurons or brain regions should not be viewed as a precise description of nervous system operation, but as a current best guess and as a teaching device" (Mason, 2011, p. 22). The different brain regions work together to process information and respond to it. Studies of functional connectivity (two areas of the brain that fire at the same time) and effective connectivity (firing in one area triggers firing in another area) are made possible by new technological advances (Friston, 2002). Knowledge of the whole brain's functional integration shows promise for future studies that could shed light on making activities—what is shared and what is particular to woodworking, compared to other making activities (Rosa, Daunizeau, & Friston, 2010). However, in order to deal with the complex theme of the neurobiological basis for woodcarving, the present study proceeds with the discussion one part at the time. This is the reason for developing a series of articles, each exploring different issues.

Cognition

Cognition includes all mental processes, described as "the total output of the cerebral cortex" (Mason, 2011, p. 284). The cerebral cortex is a part of the forebrain and the CNS, and is visually recognized as grey matter. This means that cognition is a very broad term for activities of neurons participating in thinking, motivation, emotion, perception, motor planning, and executive functions, such as when making deliberate choices of actions. Although cognition is a central part of the woodcarver's experience when working with wood, this does not mean that the woodcarver is necessarily aware of it. Only some of the activities that go on in our neural system are brought to our attention. Most of the activity takes place without our having any conscious control over it. Some of it could be consciously recognized, but is not. Other information is voluntary, deliberate, and sometimes even brought to our attention in a way that can be identified and named by words. For a signal to be recognized by or processed by us—for example, the sensation of green wood under our fingertips—it must travel all the way from our fingertips in the outer regions of the PNS and into the cerebral cortex. On its way there, the signal moves through a series of synapses, loops, and multiple circuits, and could end in many places at once.

Woodcarvers and researchers studying woodcarving often use the term "intuitive" or "spontaneous" to describe some of the carver's actions. In my previous study, I used the term "preconscious" (M. Gulliksen, 1997), which is somewhat problematic, as it also suggests a timeline or something that happens prior to consciousness. However, as Merleau-Ponty (1962) also emphasized, intuitive ideas or spontaneous actions do not necessarily occur on their own or without an obvious, preceding reason. We may simply fail to discern the reason. Mason (2011) explains it like this: "[Y]our stomach grumbled and you became aware of being hungry. In the case of neuronal firing, we do not have the luxury of being able to ask the neuron why it fired, as we can ask ourselves why we moved to the kitchen. Therefore, we tend to label activity and behavior 'spontaneous' when the precipitating reason for neuronal activity or behavior is not clearly evident. A cortical circuit that begins to fire 'out of the blue' may in fact be responding to activity elsewhere in the brain. Similarly, an original thought that occurs to us 'out of the blue' may in fact be a response, at some delay, to a previous event" (Mason, 2011, p. 285).

Perception is the part of the sensory experience where we become aware—the part of woodcarving where the carver registers what is happening. What comes to our attention is to some extent dependent on the thalamus, a component of the CNS situated between the cerebral cortex and the midbrain. The thalamus is the place where sensory input (which changes sides when entering the spinal cord) synapses to neurons in the cortex. In the thalamus, the signals coming in are translated to a rhythm the cortex can understand, and from there, they are transmitted to the designated parts of the cortex. The thalamus therefore both translates and relays information; it can also "pump up the volume": "In burst mode, thalamic neurons fire a batch of action potential upon receipt of an action potential […] to 'awaken' the cortex or to increase attention to a particular stimulus feature." (Mason, 2011, p. 280). This is a necessary function for mammals, as it allows a rapid change in behavioral state if, for example, a predator comes at us or we burn our hand. This function could explain why some information suddenly captures our attention—for example when a cut flows "just right" down the shape of the wood, and it informs the carver that the shape is right and the work is finished.

The thalamus also influences where we actively turn our attention. "Thalamic attention" (Mason, 2015) is the term used for our projections or our preconceptions of what we see. To some degree, we see, hear, smell, touch, and so forth what we expect to encounter. Mason explains this, using vision as an example (2011). The primary visual cortex (V1) only receives information from the retina of the eye through the thalamus, which translates the signals so they can be understood by the V1. The same nerve in the thalamus, however, also receives information from the V1 and the brainstem as well, informing us about where we are and what we should expect to see. This information from the V1 and the brainstem is huge. In terms of quantity alone, the information from them outweighs the information from the retina. However, the quality is another matter, and the information from the retina is more important for the thalamic synapse than the other information. Nevertheless, this feed-forward projection of the information that is sensed and later perceived means that the cerebral cortex both receives and influences information from the thalamus (Mason, 2011, p. 284). For the experienced woodcarver, this could mean that visual, aural, and, in particular, tactile sensitivity can be used to identify notches and smaller indications of imperfections in the wood, which must be taken into account when making the next cut. The skilled woodworker can discern by a soft knock and light touch exactly how dry a piece of wood is and estimate how flexible it will be, its cell structure, and what types of tools would be needed to carve it. At the same time, the carver could easily overlook information outside the scope of his or her attention at the given moment—for example, a section of the bowl not yet finished and to be dealt with tomorrow. Moreover, that attention could be used to register an irregular pattern of woodchips on the floor, indicating where a dropped knife is. Another term for such experience-dependent attention is "perceptual habits" (Mason, 2015).

This process of thalamic attention is a crucial component in memory. Perceptual habits develop through experience; they are learned and stored as memories, generating measurable traces in the brain. For the woodcarver's experience of embodied making, the memory formation and awareness are linked together, as they are for every other mammal experiencing any and all information. This topic has been discussed from many different perspectives. A recent example examines the importance of background knowledge and what is available for the working memory of a designer in the design classroom (Trogu, 2015); an interdisciplinary and pragmatic approach to awareness as a part of praxis can be found in the book *On becoming aware* by Varela et al. (2003). In this book, the authors draw on neuroscience, philosophy, and phenomenology to explore the experience of becoming aware, from a first-person perspective.

To the woodcarver, it is indeed relevant to ask: Why does she focus on one part of the forms? Why does she choose one tool over another? Several accounts discuss how the eye and hand of the artist or artisan are particularly trained to see certain things that a novice cannot see or feel. Mueller, Winkelmann, Krause, and Grunwald (2014) provide a potentially relevant example of such a trained perceptual habit. They report that manual therapists who have been practicing for a long time have better haptic perception skills and thus a more nuanced and attentive active touch than inexperienced manual therapists. An interesting finding from this study is that the experienced manual therapists do not have better passive skill—tactile perception—than the inexperienced ones. Using deliberate practice with haptic perception to both diagnose and treat patients has thus left the experienced manual therapists better able to discern and become aware of haptic information, although this has not influenced their tactile abilities. This indicates that haptic and tactile perception skills are different versions of skills, capable of developing separately. This is an example of what makes such studies useful for expanding, nuancing, and/or supporting current phenomenological, descriptive, and interpretive research. As the woodcarver, in many aspects, has a need for haptic perception as the manual therapists do, this raises the questions whether studies of woodcarvers would yield similar results, namely that they too develop the skill of a particularly attentive active touch, learned and stored as memories.

Neuroplasticity and neural circuits

In a neurobiological context, such activity-dependent changes in brain function can be registered and measured by various means, such as the increase of blood flow to certain areas. This neuroplasticity, or activity-dependent plasticity (Purves et al., 2012), is caused by experience. If more information travels a particular path, more synapses between neurons are formed (synaptic plasticity), new neurons can be made (neurogenesis), and inherent properties of the neuron can potentially be changed (inherent plasticity), as Seghal, Song, Ehlers, and Moyer Jr (2013) suggest. If fewer signals travel, the path can wither and even disappear. This plasticity partly explains why every brain is slightly different from any other, as our experiences are important determinants of the development of our own brain.

A famous example of experience-dependent plasticity is a study of taxi drivers in London, who had an increased number of synapses in an area of the forebrain related to spatial organization (Maguire et al., 2000). Another classic example is the study showing differences in the cortex devoted to the right and left hands of musicians playing stringed instruments

(Elbert, Pantev, Wienbruch, Rockstrosh, & Taub, 1995). When doing so, the two hands perform quite different tasks, making the right and left areas of the brain develop differently. A consequence of such a plasticity could be that the brain of the experienced woodcarver might be expected to be especially tailored to process the type of signals needed in his or her carving. For the purposes of this article, one of many relevant questions would therefore be where such possible changes could occur, which processes are affected, and what this could entail for the carver's experience. In the first of my articles on this topic, changes in the cerebellum were suggested (M. S. Gulliksen, 2015c), mainly related to motor movement and thus also to intrinsic motor memory.

Neuroplasticity is, as such, a basic component of learning and memory. Learning in neuroscientific terms is referred to as "the process by which new information is acquired by the nervous system and is observable through changes in behavior" (Purves et al., 2012, p. 695). While memory "refers to the encoding, storage, and retrieval of learned information" (Purves et al., 2012, p. 695), both memory and learning are parts of the limbic system, defined as "parts of the brain involved in emotional processing, learning and memory" (Mason, 2011, p. 266). Limbic structures communicates through of one of the most important circuits in our brain, the Papez circuit, which links together distinctly separate areas of the brain as a pathway. The woodcarver's embodied making consists of acquiring, processing, and storing new information. Memory is therefore probably a central neurobiological function in this activity-dependent plasticity, and a basis for this experience.

Memory

Woodcarvers often report vivid and complex memories of their carving. They describe the smell of the wood, the position of their body, how the green wood feels damp, or their emotional state, as in the following example:

> The bowl fits into my own shapes. It is safe in my lap now, in warm, round crannies. The rough inner bowl feels wet and tepid to my left hand. Dampness seeps through my sleeve at the elbow. Right hand outside. Smooth and sandy, small, small bumps after the scraper and sanding paper. Tiny precision cuts with the gauges. Hands moving in circles. Protective. Wet, fresh smell of green birch tickles my nose. Easy itch inwards. Next day, I took it out after a thorough sanding and a spray of water. Surface like fine suede leather. Soft, furry, and slick. Slide my fingertips carefully over and feel a gentle and silent tickle (M. Gulliksen, 1997, p. 76, my translation).

In this sample text, many different types of memory can be discerned. Neurobiologists refer to (at least) six types of memory, and their distinct cellular elements and functional cycles give some indication of why these memories could be important to carvers.

Immediate memory, working memory, and variations of long-term memory

Neurobiological description of the memory distinguishes between immediate memory, working memory, and long-term memory. Long-term memory could be implicit (non-declarative) memory or declarative memory.

Immediate memory is the instant fleeing thought, when current experiences are held in the mind for fractions of seconds. Researchers believe that these immediate memories have a very large capacity and consist of a variety of semi-independent "memory registers," which are most likely distinctly different for each sense modality (Purves et al., 2012, p. 696). Working memory is the memory involved in being in the here and now, or keeping information in mind for seconds and minutes. Dietrich (2004) describes it as "the ability to process information online. It is a monitoring system of ongoing events that temporarily keeps in mind information that is relevant to the situation, so that one can 'work' with it" (p. 1013).

The carver making wooden objects continuously experiences the making process through both immediate and working memory. This may include knowing what I did a second ago, where I put the knife just now, what I need to do next when finishing the current cut with the gauge, or non-carving-related thoughts, such as what to buy for lunch. A typical example is constantly repeating a phone number while looking for a pen to write it down (Mason, 2015). Working memory seems to be a necessary ingredient in cognitive flexibility, and its role as continuous information processor probably makes it a central component in generating consciousness and a prerequisite for creative thinking (Dietrich, 2004, p. 2013).

Long-term memory has two main variations: implicit memory and declarative memory. Implicit memory is a collective term for the many types of memory that we cannot deliberately and explicitly recall—for example, motor memory of how to hold the carving knife, associations, priming cues, and emotional memory, such as the carver feeling comfortable in the wood shop. Procedural memory is also a type of implicit, non-declarative memory (Mason, 2011; Purves et al., 2012). To the woodcarver, implicit memory is a large part of the making experience. This could involve such memories as those of the pungent smell of juniper compared to the fresh and crisp scent of birch, and the feeling of pine sap versus willow sap under warm fingers. Also, the implicit perceptual memory lets a skilled carver register where the form needs more work or recognize patterns in the curled planer cuts on the floor that allow her to locate the exact position of a dropped knife that is hidden from view—a possible developed perceptual habit, a trained, directed visual attention. In the example presented above, the body experience of the gauge sliding "just right" down the wood fiber is combined with a recollection of previous experiences: how resistance feels in the arms, and how it should feel when the shape is beginning to come together. The anatomical and functional elements of this motor memory are related to voluntary movement and sensory input, monitored in the cerebellum (M. S. Gulliksen, 2015c). As with long-term memory, such implicit memories could last a lifetime (Mason, 2015).

Declarative memory is the type of long-term memory that can be remembered explicitly. It consists of two main types: episodic memory and semantic memory. Episodic memories are rich and varied, comprising a suite of sensory experiences and details, some of which are also implicit memories. It is possible to "dive back into" them (Mason, 2015) and recall lesser details, and even implicit memories, for example whether you were comfortable at the time or how your hand feels sore after a full day of carving. Semantic memories, on the other hand, are our recollection of facts, definitions, and told stories memorized. Episodic memories could be turned into semantic memories if re-told many times as a story. The woodcarver uses declarative memory in many ways when carving: The names of tools, types of wood, other craftsmen, memories of previous carving situations, and the intended plan of the work, which tells her which section to carve first or later, are stored as declarative memories.

Changing working memory into long-term memory

In order to change working memory into long-term memory, several circuits and areas in the brain are needed. For example, a decision must be made about what is and is not stored in long-term memory. Forgetting is as important as remembering in order for a mammal to function. Only information considered important enough is stored; this indicates that it is likely that the thalamus is involved (Mason, 2011, p. 284ff). Memories are stored as engrams or "the physical embodiment of any memory in neuronal machinery," and the general consensus, according to Purvis et al. (p. 698), is that these engrams are related to the efficiency of the synapses. However, some new studies, like the experiment of Seghal et al. (2013), indicate that the neurons themselves also store information.

This process for storing or consolidating memory varies between the types of memory. Implicit and declarative memories are not stored by the same brain circuits. Indeed, not even the different varieties of implicit memory are stored using the same processes. For example, the cerebellum would be involved in motor memory (M. S. Gulliksen, 2015c; Mason, 2011, p. 538), and the amygdala would be involved in storing emotional memory (Mason, 2011, p. 288). The amygdala contributes to several functions linked to our emotional understanding of our social environment—for example, decoding another person's facial expressions as registering fear. Because of the amygdala's contribution to storing emotional memories, we remember evocative memories with strong emotions and great sensory input—experiencing a fire in your house or cutting your finger—more strongly than non-evocative memories (Mason, 2011, p. 289; 2015). Neuropsychologists use this particular knowledge in post-traumatic stress disorder (PTSD) therapy. Individuals suffering from PTSD have an overactive amygdala, which leads to a high level of emotions in traumatic situations. Treatment requires the patients to relive their traumatic memories while repressing their emotional side with drugs or other means, so that the memory is restored but with less fear attached to it.

Changing working memory into long-term declarative memories, both episodic and semantic memories, involves the hippocampus. The hippocampus is a section of the cerebral cortex, situated in the medial temporal lobe of each side, and is thus a part of the three-layered cerebral cortex (Mason, 2015) (Figure 4).

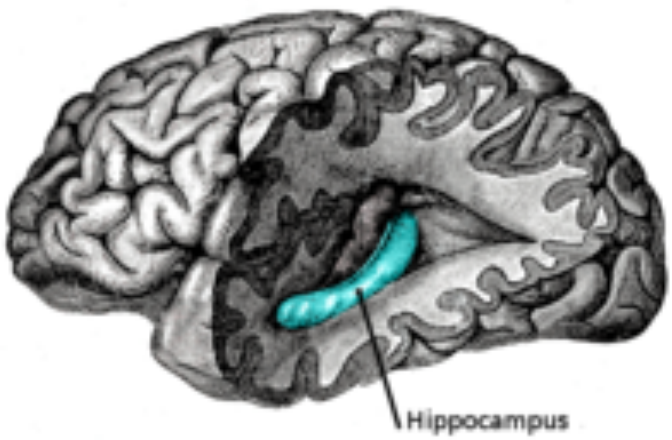

Figure 4. The hippocampus. Image credit: https://en.wikipedia.org/?title=Hippocampus

Different areas of the hippocampus are linked to different types of memory; for example, spatial memory appears to be relayed by the posterior hippocampus. The study that found experience-dependent plasticity in the brain of taxi drivers, mentioned above, also found differences in this section of the hippocampus: The size of the posterior hippocampus co-varied with the number of months of taxi-driving experience of the drivers (Maguire et al., 2000; Purves et al., 2012, pp. 707-708).

As implicit memories are not stored by the same brain circuits that turn working memory into explicit memory, persons suffering amnesia may remember them, even though much else is lost. This may be observed in older amnesic people, who may not remember their children's names or how to read, but could be dancing, carving, or knitting perfectly (Mason, 2015).

Storing and recalling memories

Declarative memories are stored in specific, designated areas of the neocortex, the six-layer section of the cerebral cortex (Mason, 2015). The hippocampus relays the converted new memories to the neocortex. Both semantic and episodic memories are stored and can be retrieved from there.

Retrieving memories from the neocortex is a process that differs noticeably between semantic and episodic memories: whereas semantic memories can be pulled out directly from the neocortex, episodic memories need to be shipped back to hippocampus before they can be accessed (Mason, 2015). As episodic memory is recalled with the help of the hippocampus, it follows that it is re-stored or even relived each time it is recollected. This forms a circuit of storing and re-storing of the experienced episodes, permitting the memory to be changed each time (Mason, 2015).

For the woodcarver spending many hours in the workshop, old memories will continually be supplemented and merged with new memories. For example, one day when I was carving outside my workshop (Figure 5), I remembered episodes of carving outdoors in a medieval market four years before. I remembered the particular event in my childhood when I was alone in my parents' workshop and cut my thumb, how it bled, how I ran to get a towel and to track down my mother. At the same time, I remembered for whom I was making this bowl now, and why. It all melted together, filling my here-and-now experience with ghosts from the past, present, and future.

Figure 5. Making the aspen bowl in Figure 3 while writing this article (2015).

Tentative ideas of where to look for a neurobiological basis for creative cognition and embodied making

This article has discussed the role of the hippocampus in the working memory, as well as long-term memory storage and retrieval when engaged in embodied making. Neurons, neural communication, neural circuits, and the neural basis for cognition and awareness have been briefly introduced. Current neuroscientific knowledge has been used to explain the difference between cognition, defined as the total output of the cerebral cortex, and awareness, the part that we perceive and become aware of. Moreover, the difference between spontaneous (but not random) and deliberate states of mind has been discussed. The role of thalamic attention, and how touch and other sense modalities are trained to be particularly attentive through practice has been emphasized, and the relatively small amount of information that comes into a person's awareness, how our preconceptions influence our perceptions, and how perception as such is a form of interpretation has been problematized.

Most emphasis has been put on describing the neural basis of immediate memory, working memory, and variations of long-term memory—in particular, implicit motor and emotional memory, semantic memory, and episodic memory, along with information about how working memory is stored and retrieved. I have referred to specific studies of memory and learning that have documented physiological changes (i.e., neuroplasticity) in the hippocampus. Experience-dependent neuroplasticity is a crucial function in our ability to learn, at least according to the neurobiological definition of learning: "the process by which new information is acquired by the nervous system and is observable through changes in behavior" (Purves et al., 2012, p. 695). A particular point of interest is the difference between storing and recollecting declarative semantic versus episodic memory. Whereas semantic memories, such as facts and numbers, are recollected directly from their long-term storage in the cerebral cortex, episodic memories are remembered through the hippocampus—the same area of the brain that stores and re-stores memories. This means that each time an episodic memory is remembered, it is re-remembered and re-stored, and could therefore be subject to change by the new "here-and-now" experience. When looking for a neurobiological basis for creative cognition and embodied making, the neural circuit in the hippocampus that retrieves, stores and re-stores memories could be a central key.

Here I will mention three tentative ideas that could be relevant for further exploration based on this neural circuit of memory storage and retrieval.

First, as declarative episodic memories are always complex and may be linked with implicit motor and emotional memories, the many layers in these memories—sensations, emotions, motor memories—could suggest a neural basis for the woodcarver's ability to recall and relive making experiences in great detail, and perhaps even explain why such memories are vivid and rich in detail and meaning for the carver.

Second, the neural circuit in the hippocampus may provide another key to understanding how the woodcarver's sensory–motor and cognitive experiences "melt together" in the negotiations between maker and material. This circuit of memory storage runs in parallel with the overload of sensory input and motor output of the cerebellum (M. S. Gulliksen, 2015c), only some elements of which come to our attention. This may serve to expand current descriptions of the making experience as intense negotiations and interactions between maker and material. This supports and expands the previous phenomenological descriptions of making processes (M. Gulliksen, 1997). The making experience is not necessarily something we are aware of in every aspect, but it could nevertheless direct our attention toward something in a way that I, in my previous study, would have called preconscious.

Third, for a woodcarver spending a great deal of time carving and negotiating with raw materials, the continuous circuit of retrieving and re-storing memories combines the overload of sensory input (M. S. Gulliksen, 2015c) with emotions of identity. The carving experience includes who I am, who I was, and who I could be. This continuous circuit could create the experience of being here-and-now, which makes it more difficult to discern from what was and what will be. The intense experience referred to by woodcarvers of "being-here" (M. Gulliksen, 2001; M. S. Gulliksen, 2014) could then be understood not as an independent event or an independent experience of immediacy, but as an experience of being here, now, as the result of the carver's previous experiences and projections for the future.

To take another example:

Figure 6. A five-year-old boy making a bowl in linden wood, at a medieval market (2011). Parent permission to publication of photo is obtained.

The boy in Figure 6 is overcoming resistance. He is totally immersed in his carving, undisturbed by me taking his photo. He has just mastered this spoke shave, and has a good grip on the bowl with his toes. As he is dressed only in his ninth-century-style linen tunic, his bare legs can feel the soft, wet grass underneath him, and he is exploring the shape with his hands, toes, body position, eyes, and smell. He is negotiating the resistance in his bowl. His cerebellum is monitoring sensory input and gradually adjusting the motor output to keep the angle of the spoke shave just right. When perfect curls of the wet wood emerge from the sharp knife, he smiles and hums. The joy of controlling this new tool and making a bowl of his own for the very first time makes this situation emotional. Today, four years later, he still remembers it. He sometimes mentions this particular episode and other similar ones. He asks if he can make something, and, when given the spoke shave, his hands know what to do.

The five-year-old boy's awareness was at the time tuned into his making, totally focused, but probably not deliberately reflecting on what to do. As a maker, his working memory negotiates with the material in an associative way, turning his attention toward what is brought to his attention. This is drifting and unsystematic, yet it is fully controlled by his attentive and seeking haptic perception. As such, he could possibly be evincing a creative cognitive state of mind (Lopata, 2014), in which the "sequence of thoughts manifesting itself in consciousness is more chaotic, permitting more 'loosely connected' associations to emerge" (Dietrich, 2004, p. 1017). Different areas of his brain fire at the same time, simultaneously and/or causally (Friston, 2002), causing him to sense, perceive, respond, and act together with his environment. Such associative working memories are turned into associative, episodic long-term memories by the hippocampus, which be recalled by the hippocampus through similar instances of associations.

It is therefore probable, or, as Mason would have said, a current best guess (Mason, 2011, p. 22), that, through this experience (and other similar experiences), his hippocampus has changed slightly, as a response to its contribution to making memories, in the same way as the hippocampus of the musicians in Elbert et al.'s study (1995) or the taxi drivers in Maguire et al.'s study (2000) changed. As he grew older and continued these activities, his attentive active touch could also be modified, like that of the manual therapists in the study of Mueller et al. (2014). An implication for further research would therefore be to develop a strategy for studying short- and long-term consequences of making activities, in order to explore further if this is the case.

Tentative conclusions - ideas for further exploration

This article aims to understand parts of the embodied making experience, drawing on neurobiological knowledge. It arose from phenomenological descriptions of woodcarving in a previous study (1997), in which I described the experience of carving as a negotiation in a preconscious and conscious state of mind, and "a perceptual field opening up to the body" (Gulliksen, 2001, pp. 4-5). The current article's exploration of the maker's cognition and attention, through discussion of the central aspects of the neurobiological basis for experience, memory, and, specifically, the relationship between working memory and long-term memory, has expanded and moderated the conclusions from the previous study. The neurobiological knowledge supports the descriptions of embodied making, both from my previous study and from similar accounts (Groth, 2015; O'Connor, 2005), and allows for enhanced understanding and explanation of the biological function behind this.

The ideas for future studies, presented above, are necessarily tentative and speculative, as they are developed only to open up a small piece of neurobiological knowledge relevant for understanding the woodcarver's experience. However, they may become a starting point for future work that aims to develop possible interdisciplinary and researchable hypotheses.

In the future, it could be possible to build on this description and develop a research-based hypothesis on the activity-dependent plasticity of the woodcarver's hippocampus. This could possibly be designed to replicate or discover similarities to the studies of the hippocampus plasticity of musicians (Elbert et al., 1995) and taxi drivers (Maguire et al., 2000). Such a study could, for example, examine experienced woodcarvers compared to non-experienced woodcarvers, or study the changes in people's brains caused by an intervention of carving in green wood.

Furthermore, it would be interesting to study whether the perceptual habits in haptic perception of experienced carvers are more accurate than those of inexperienced carvers, and to replicate the study of the manual therapist (Mueller et al., 2014) in this context. It could even be relevant to design a study of the possible changes in thalamic attention in experienced versus non-experienced carvers, or the changes caused by learning to carve or actively carving over a period of time.

Such studies could reveal more about the woodcarver's experience and its consequences. This could be crucial knowledge in today's society. As many of us who carve are aware, the activity of carving becomes rarer every day. In schools, at least in Norway, few do it. Although phrases such as "active learning" and "experiential learning" are much heard in discussions about education, policymakers and school principals seem to set little store by them in practice. The focus of attention in schools is the so-called core subjects. Consequently, decision makers often regard carving and similar activities as pleasant but not very important (Bamford, 2006, 2012). It thus seems that compelling current and scientific knowledge on the benefits of making activities does not influence a school's core curriculum. There are probably a complex set of reasons for this. However, there seems to be a tendency for policymakers and school principals to prefer certain types of research-based knowledge over other types. Given the new methodologies and techniques available in neuroscience, it may be possible to support previous phenomenological, descriptive, or reflective research findings with findings from transdisciplinary studies. If successful, this could possibly generate new and communicable knowledge that policy makers could understand, appreciate, and give priority to in schools.

Worldwide, there is a demand for skilled hands in various occupations, ranging from electricians, plumbers, and carpenters to robotics constructors and machine operators. Likewise, surgeons, veterinarians, researchers working in advanced labs, and other highly educated professions require nimble and skilled hands. Developing more knowledge about such skills and how they are learned is crucial. If research on the actual neurobiological changes in children and adults engaging in embodied making could explain whether and how making contributes significantly to developing these valuable skills, it could possibly lead to new approaches to learning in schools and elsewhere. Specifically, understanding the woodcarver's experience and the process of embodied making in green wood could therefore demonstrate why woodcarving could be an important activity in which we should engage in the twenty-first century.

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