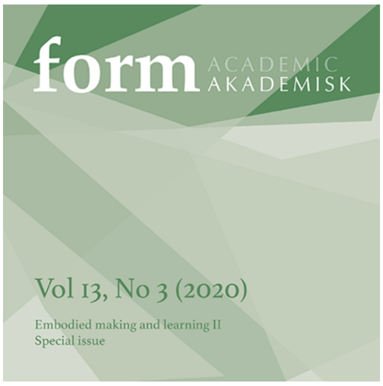

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Marte Sørebø Gulliksen
Professor, PhD,
University of South-Eastern Norway
marte.gulliksen@usn.no

Underlying the carver's experience

Sensorimotor modulation in the cerebellum when carving wood

ABSTRACT
Woodcarvers often report their experiences as having an intense internal focus, and a feeling of a close connection to the material. This article explores the key processes in cells and organs that underlie these experiences, emphasising sensorimotor modulation in the cerebellum. The article has two aims: to bring neurobiological knowledge into the making disciplines to better understand the making process and to mediate the terminological differences between disciplines and develop new research-based hypotheses and theoretical foundations for future interdisciplinary studies. The findings include three topics for further exploration: 1) the overflow of information in the cerebellum and the maker's experience of intense internal focus; 2) the cerebellum's function as a generator of deliberate actions without involving the conscious self, and the preconscious element of the maker's negotiation; and 3) the priority of neural circuits between sensory input and motor output in the cerebellum at the cost of neural circuits to the cerebral cortex's monitoring and self-reflection and the maker's experience as being close to the material. These findings expand upon previous knowledge developed in studies investigating making processes from a sociocultural and philosophical point of view, and they are useful for researchers and teachers interested in understanding and advancing the making disciplines and arts and crafts education.

Keywords:
woodcarving; cerebellum; experience; moving and sensing; neurobiology.

INTRODUCTION
Carvers working in green wood often describe their making process in similar ways. They describe processes involving an intense internal focus, joy, an urge to overcome resistance and a feeling of being closely connected to the material. Experiential descriptions of craft practices are found in a wide range of sources from the maker's blogs, such as Woodspirit (Dahl & Dahl, 2020), and online groups, such as Spoon Carving, Green Woodworking and Sloyd-Facebook Group, to theoretical studies and research approaches, such as Groth (2015, 2016), Groth et al., (2013), Ingold (2013), Crawford (2009) and Fredriksen (2011). Similarly, video narratives of craft practice experiences are found in many sources,

such as Osbourne's (2014) online TedX presentation of the project where the speaker gives people an opportunity to use one day to make a wooden spoon. In that talk, Osbourne (2014) said: 'It has allowed us to kind of tap in to a place deep within and connect with being ok, with imperfections. And to really truly be celebrating and be enjoying living in the moment'. However, what underlies these experiences and why they are described in such similar ways, are not yet fully understood.

Previously (Gulliksen, 1997, 2001), I documented and analysed my own woodcarving experience (Figure 1), and I described my experiences using poetic language in order to generate knowledge on this topic:

> Slowly warmth spreads from within my body–hands sore, 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 a persuasion with a gouge and a club.
>
> Reluctantly the wood gives in with chips falling off at their own tempo and in their own direction. Before my eyes, shapes are erased and arise from shivering growth rings under the gouge's strive. Hard labour 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 fibres. When they meet, the fibres and the knife, they unite like rivers connect, meet gliding down through shallow valleys.

FIGURE 1. Carving Purkinje Box #1, March 2020.

In the analysis of the excerpt presented above, the experience of making was described and interpreted as negotiations between 'the maker', understood as a unity [mind+body] (Bresler, 2004), and 'the material', understood as a unity [form+matter] (Gulliksen, 1997, p. 41). I described this negotiation and the process of how the initially vague intentions and projections of the intended results of the process were met and re-shaped by the material's concrete and abstract properties. Both parties, the maker and the material, were ascribed some sort of agency; however, the maker (the human) was the initiator and leader in the process. This meeting between maker and material entailed an overcoming of resistance on three levels: the physical level, the aesthetical-idea level and the cognitive level (Gulliksen, 1997, 2001). Maurice Merleau-Ponty's (1962) book, *The Phenomenology of Perception*, was used as a theoretical foundation for the discussion. Based on this, the negotiation was discussed as both a preconscious and a conscious experience of the maker. The relationship between the two types of experiences (conscious and preconscious) were central in explaining the content and the meaning of the making process. Although not used at the time, the processes I described could, in light of recent embodied cognition theory (see e.g. Varela et al., 2003), be termed 'embodied'.

Today, embodied cognition theory, the understanding that cognition is embodied, is widespread and accepted (Groh, 2014; Kirchoff, 2018). The general theory on the embodied mind is often summed up as the four Es: 'The mind is *embodied;* thus, we are situated, and our understandings are *embedded*. Our mind is *enacted* through the body. We offload meaning on external objects; thus, our mind is *extended'* (Gulliksen et al. 2016, p. 2889; Robbins & Aydede, 2009). Studies of brain functions have shown that the same areas of the brain that store sensory input and control motor output are used when processing abstract thoughts, such as space, distance and love (Groh, 2014). For example, from their perspective within the reading sciences, Schilhab et al. (2018) have documented how our brain uses what they refer to as 'material anchors' in memory, when discussing how we understand and read a written text: '[t]he reading activity 'speaks' to us at several levels: the sensory, perceptual, motor, conceptual and affective level. All of these levels participate in forming the so-called neural correlate, which is the bundle of neurons active during the reading' (3rd paragraph). In mathematics, Goodman et al. (2016) have found that manipulating physical objects first makes it easier to solve digital versions of similar tasks later on. There is also a well-grounded understanding in mathematic research that low visuospatial abilities can lead to decreases in accuracy, see e.g. Crollen and Noël (2015).

To date, very few studies have analysed embodied cognition in making processes. However, there is a defined promise that such studies will be able to shed light on the neural basis of designing and making (Seitamaa-Hakkarainen et al., 2014). Studies conducted by researchers from the practice fields and the science fields together have made some headway into increasing our understanding of the neuroscientific basis for designers or artists' experiences, our embodied making (see for example Huotilainen et. al. 2018; Goguen & Myin, 2000; Seitamaa-Hakkarainen, 2015; Seitamaa-Hakkarainen et al., 2014; Zaidel, 2005). Other, more theoretical and positional studies (see for example Gulliksen, 2016b, 2017) draw on neurobiological knowledge to discuss where neural correlates for the making experiences might be found, thereby developing arguments for linking the neural basis of embodied cognition theory to the phenomenological descriptions. These early works suggested that it seems likely that there is a neurobiological basis for the distinct experiences described by makers. In this paper, I continue this line of research and revisit the aforementioned earlier study on woodcarving; I also address the issue of the maker's experience from a neurobiological perspective.

This article aims to describe some of the key biological processes underlying the woodcarver's experiences and actions while engaged in carving processes. Bringing neurobiological knowledge into the making disciplines (Dunin-Woyseth & Michl, 2001) in this way, aims to provide a foundation upon which to better understand the making process. This includes describing the role of neurons, their function and the neural circuits needed for moving and sensing. In particular, this article focuses on the underlying sensorimotor modulation in the cerebellum, as this neural mechanism could play a central role in the woodcarver's experience. Three tentative directions (topics) for further exploration are presented and discussed: 1) the overflow of information in the cerebellum and the maker's experience of intense internal focus; 2) the cerebellum's function as a generator of deliberate actions without involving the conscious self and the so-called preconscious element of the maker's negotiation; and 3) the priority of the neural circuits between sensory input and motor output in the cerebellum at the cost of neural circuits to the cerebral cortex's monitoring and self-reflection and the maker's experience as being close to the material.

Integrating knowledge from different disciplines poses questions of how to translate between them and how the disciplinary knowledge could be related. Thus, a second aim of this article is to mediate the terminological differences between disciplines and, as such, develop new research-based hypotheses and theoretical foundations for future interdisciplinary studies. In their article, 'Translating neuroscience, psychology and education: An abstracted conceptual framework for the learning sciences', Donoghue and Horvath (2016) addressed this problem of interdisciplinarity. They argued that many of the seemingly unsolvable issues in educational neuroscience may come from unresolved terminological differences, from analysing the studied phenomenon based on different layers of complexity and from not being explicit in how these different layers are related (see Gulliksen, 2017) for how this could be applied to craft. For the purpose of this article, I use Donoghue and Horwath's (2016) terminology-layered abstraction framework to specify that the focus is on making activity at a *cellular* and *organ* layer of complexity, while previous studies from a phenomenological perspective have focused on making activities at the *individual* and *socio-cultural* layers.

I suggest that an exploration that combines multiple levels of analysis can advance the discussion beyond previous phenomenological distinctions between conscious vs preconscious and other similar descriptions. Presenting researchers and teachers within the arts and crafts science and the making disciplines (Dunin-Woyseth and Michl, 2001) with knowledge on the neurobiological basis of making and experiencing will inform and support their practice and contribute additional knowledge on what underlies the carver's experience.

A SHORT INTRODUCTION TO THE NERVOUS SYSTEM AND ITS FUNCTIONS

Neurons are types of cells that are responsible for registering, translating and transmitting information in the body. Neurobiology is a term used to refer to the study of the basic nervous system in all animals, i.e. humans in this article (Mason, 2011; Purves et al., 2012).

Neurons are organised in two main systems: the central nervous system (CNS), which includes the forebrain (the two cerebral hemispheres in the cortex), the cerebellum, the brain stem and the 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 do), perception (everything we consciously appreciate), homeostasis (the continuous process of keeping our body balanced and alive) and higher abstract functions (everything we think, feel, learn—what makes us a human being) (Purves et. al. 2019, p. 13; Mason, 2015).

In these systems, neurons are linked together in task-specific circuits sending information, enabling us to breathe, act, feel and think. These circuits are interconnected, and we draw on the same areas and circuits to execute different actions. For example, spatial information is stored in the sensorimotor areas used to facilitate abstract spatial thinking (Groh, 2014). Thus, the complex web of sensations, thoughts, emotions and ideation that the carver experiences when carving are thus, on the cellular level, generated by neurons communicating with each other in the CNS and PNS (Friston, 2002). Therefore, in order to move forward in our understanding of the carver's experience, we need more information on how neurons function.

Neurons register information from the outside world by a process called transduction. In a variety of different ways, parts of the neuron, called dendrites, are stimulated by signals from the outside world (light waves, sound waves, mechanical pressure on our bodies, etc.). The neuron, at rest, has what is referred to as a resting membrane potential; in that case, there is a stable difference in the electrical voltage between the outside and inside of the cell. The stimulus of a cell will result in a change in the electrical voltage in the cell, thereby releasing an action potential. This elevated electrical voltage forms a rhythm and an intensity that functions as a signal that moves through the neuron towards the cell body, the soma, where it gets processed and sent further down the neuron's axon. At the axon terminals, the action potential releases neurotransmitters, which sends a chemical message that either transmits the signal to other neurons (in a synapse) or innervates another type of cell, such as muscle cells (Mason, 2011, p. 55). The signals can be affirmative, negative, fast or slow. These electrical signals enable us to breathe, see, move and think—thus, encompassing everything we are as living bodies.

More synapses between neurons, and even new neurons, can be made if much information travels a particular path. If fewer signals travel, the path can wither and even disappear. This plasticity, called neuroplasticity or activity-dependent plasticity (Purves et al., 2012), causes every brain to be slightly different, since our experiences are important for how it develops. There are two main types of neuroplasticity: experience-expectant plasticity and experience-dependent plasticity (Twardosz, 2012, p. 100). A famous example of this is a study on taxi drivers in London in which the participants had an increased number of synapses in an area of the forebrain related to spatial organisation (Maguire et al., 2000). Likewise, Elbert et al. (1995) showed differences in the cortex devoted to the right hand and left hand of musicians playing stringed instruments; where the two hands performed very different tasks. A probable consequence of this type a plasticity could be that the brain of an experienced woodcarver could be expected to be especially trimmed to process just the type of signals needed in his or her carving. Therefore, for the sake of this article, it would be important to ask where such possible changes could occur in a woodcarver's brain, what processes cause them, and what this could entail for the carver's experience.

THE NEURAL SYSTEMS THAT ARE ACTIVE WHEN WOODCARVING: AN OVERVIEW

For the woodcarver, like every other organism with a neural system, many types and circuits of neural signals are active at the same time, as an integrated whole. This is why experts in the field emphasise: '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). Nevertheless, to be manageable, the discussion needs to proceed by examining one part at a time. Carving wood is a manual practice; therefore, the neurons and neural circuits needed for moving and sensing would be of particular interest for understanding the carver's experience and actions, and the relationship between the maker and the material. Moving forward, the scope narrows toward the neurons that transmit sensory input to and within the CNS, and those that transmit motor output to the PNS.

Some of the information is autonomous; thus, we do not have any conscious control over it. While some information could be consciously recognised but is usually done automatically, and without thinking. Other information is voluntary, deliberate and, sometimes, conscious. For a signal to be recognised or processed by us, as 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, a part of the forebrain, and the CNS. On its way there, the signal moves through a series of loops and multiple circuits of synapses and it could end up in many places at once.

The sensory input and motor output of the woodcarver

The woodcarver needs both sensory input and voluntary motor control in order to carve or to experience her/his carving. Various receptive sensory cells (hearing, seeing, tasting, light touch, hard touch, pain, body position receptors) in the body register information from outside and inside of a person's body. This is referred to as sensation. The woodcarver senses all her/his surroundings, all in a relative scale depending on how much stimuli there is. For example, receptors in the carver's hand will send information about friction, vibrations, hair movements, temperature and the oxygen levels in the muscles, as well as the state and position of the muscles, limbs and joints. A carver will perceive or consciously appreciate this as meaningful information about the wood, such as its shape, surface or dryness, and information about the state of the hand and the rest of the body, such as pain, tired muscles, injury (blisters or cuts). However, a carver only perceives a very small part of the many sensations. Her/his conscious self will not register the low oxygen levels in the tired muscles, but she/he will begin feeling the resulting fatigue and her/his unconscious self will engage in measures to increase the oxygen levels.

The carver's tactile sensory input from the arms enters the spinal cord in the cervical region near the top of the spine. At the same time, sensory input from the trunk and legs to the thoracic and lumbar regions of the spinal cord provides information about where she/he is in relation to the workbench and the room. The sensory input from the PNS changes sides when entering the spinal cord and synapses to other neurons in an area of CNS in the brain, called the thalamus. The thalamus translates the signal to a rhythm that the cortex can understand, and it transmits it further into a part of the cortex called the primary somatosensory cortex. The thalamus could also 'pump up the volume' of a sensory signal by firing a batch of action potentials to increase attention to a particular stimulus' feature if necessary (Mason, 2011, p. 278). This explains why some information suddenly captures our attention, for example when a cut flows 'just right' down the shape of the wood, and it provides the carver with information about where on the object the shape is just right, and that the work is finished (Gulliksen, 2016a).

When recognising that more cuts are needed, the carver decides where and how to cut. Motor output to the arms and hands travels from the CNS and comes out through the cervical area, the same region of the spinal cord as the sensory input from these limbs. Instructions to the legs are sent to make sure that the cut has enough strength behind it, and the muscles controlling the gaze are also central for the wood worker when steering the gouge and knife. These actions engage a large part of the brain, for example areas called the primary motor cortex (an area of the cortex in the frontal lobe of the brain that controls the movement of arms/legs, etc.), the pons (controls the horizontal gaze) and the midbrain (controls the vertical gaze). Like the sensory input, the motor output comes in the form of an electrical signal, an action potential. The action potential travels through a very long axon of a motoneuron that begins in the primary motor cortex in the frontal lobe and travels all the way down into the spinal cord. It changes sides at the point where the medulla meets the spinal cord and the synapses in the spinal cord with a motoneuron that innervates a muscle and makes it move. Humans have over 1 million fibres in the cortico-spinal tract, which enable us to do the very fine movements necessary to hold a gouge and carve detailed patterns in wood.

One interesting part by this detailed and complex process is that neither the sensory input nor the decision to make a movement needs to be consciously controlled all the time. Although it is too complex a movement to be a reflex (such as the knee-jerk reflex), it happens semi-automatically the same way we walk with a particular gait (Mason, 2011, p. 509). This information could be relevant to explain some of the neural basis for the carver's so-called 'tacit knowledge' (Polanyi, 1966) or the master-carver's instincts. According to Mason (2011, p. 511), one reason for this neural function is what can be referred to as the 'patterned activation and relaxation of specific muscles […] in the absence of peripheral feedback or supraspinal input'. This is called the central pattern generator (CPG). The notion behind the CPG is that the interlinking of single circuits of neurons can generate multiple movements without our conscious choice of action. The CPG is located in the brainstem and the cerebellum. However, neurobiologists do not know how this CPG actually works on a cellular level in humans, as experiments have only been conducted on animals. Therefore, the CPG remains a conceptual framework (Mason, 2011, p. 511). There is more knowledge about the cerebellum, a very central part of this system of semi-automatic motor control and decision-making.

The cerebellum and sensorimotor modulation

The cerebellum is part of the brain stem; as such, it is part of the CNS. It is wrinkled and lies at the back end of the brain, underneath the large grey forebrain (Figure 2).

Even though all our conscious perceptions and abstract thoughts are controlled by the forebrain, the cerebellum is extremely important in motor learning (both long-term and short-term) and motor execution/coordination. The cerebellum is the site where the data-driven coordination of muscles takes place; it is always sensing and interpreting sensory input to make sure that our movements are smooth.

The cerebellar topography consists of a middle part, called the vermis, which controls core body movements, such as standing, walking and talking. Next to the vermis is the paravermis, which controls arm and leg movement. For the woodcarver, the paravermis is particularly important, as it is necessary for reaching out, grasping, making small finger movements, etc. The outer region of the cerebellum, the lateral lobes, is important for the ability to learn new motor movements. Thus, for the woodcarver, the lateral lobes of the cerebellum could be important when learning a new technique, or even becoming familiar with the particularities of a new type of wood.

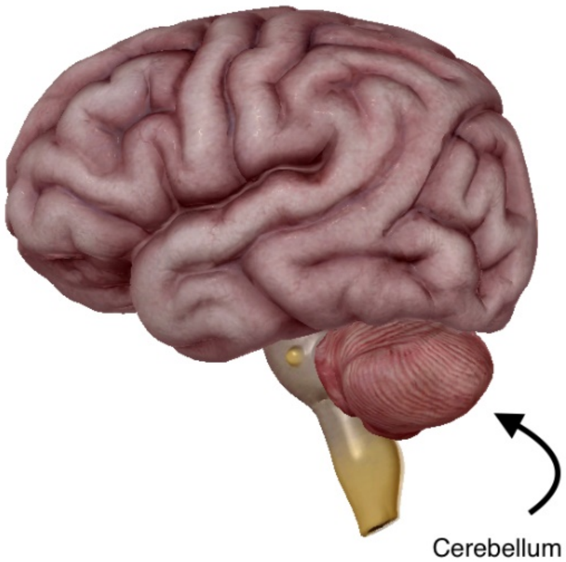

FIGURE 2. Cerebellum (Visible body human anatomy atlas, 2020).

The cerebellum is constantly repeating and confirming, re-learning and providing different output, when necessary. The cerebellum is also flexible, making it easy to adapt to new, short-term changes, such as if you need to carve with a band-aid on your thumb for a few days. The way the cerebellum can do this, and the reason for its importance to the woodcarver, is that it receives much of its information in neurological information language, electricity or action potentials. Through the distinctive purkinje cells in its outermost layer (Figure 3), it receives much more information than what it sends out, in a ratio of 40:1 (Mason, 2015). The ratio is due to several sources sending information to the cerebellum at the same time. The motor cortex sends a copy of what it intends to do to the cerebellum (afference), the muscle sends a copy of the message it receives to the cerebellum (efference) and the muscles and joints send information about what they have done (sensory reafference).

The cerebellum monitors whether all the input matches. If it does not match, the cerebellum varies the output, i.e. which type and strength of signals to send out (efference) to which muscles in the body. A mismatch of signals also triggers cerebellar learning. Neurobiologists call this associated learning, and movement might change slightly. When carving green wood, a carver engages in many repetitive movements, and each cut is slightly different (new angle, harder wood, a slip of the knife, etc). When learning to carve, the carver constantly repeats motor movements; after a movement is learned, the carver will remember it even if she/he does not practice it for a while.

As a part of the brain stem, the cerebellum does this all by itself without the conscious control of the forebrain. Thus, much of what is going on in our voluntary muscle movements is working automatically, as patterns, unavailable to our conscious thoughts or verbal concepts.

FIGURE 3. Bowl #3 in Purkinje-series, inspired by the Purkinje cells in the cerebellum, 44cmx12cmx6cm. Made by Gulliksen, 2018. Photo credit: Marek Podowski.

DISCUSSION: THE THEORY OF THE CEREBELLUM APPLIED TO CARVING SITUATIONS

Previously, this article described some of the key biological processes underlying the woodcarver’s experiences and actions during carving processes, focusing on neurons, their function and the neural circuits needed for moving and sensing, in particular the underlying sensorimotor modulation in the cerebellum. In this section, I return to the previous study on carving and discuss how these processes in the cerebellum possibly could be underlying these described experiences.

In the carving quote presented at the beginning of this article, the focus was on the shape of the object and how it was changed by moving the gouge. The perception focused on the somatosensory input on the wood’s shape, not on the visual input. The visual input was still there, but the somatosensations were more important for the experience right then. The process was described as an intense experience and a preconscious and conscious negotiation between the maker and the material (Gulliksen, 1997, 2001; Merleau-Ponty, 1962). In the neurosciences, new knowledge on the function of the cerebellum presents several possible angles for identifying a neurobiological basis for the described negotiation with the wood and the intense experience of the carver. Of these possible angles, at least three topics could be relevant to address in future explorations:

(1) Firstly, our nervous systems process a wide range of information about what is going on in the world and what we intend to do. This communication between muscle output and sensory input travels through our nervous system, and the cerebellum constantly monitors every small detail. The sheer overflow of the incoming information could be one possible reason for the reported experience of intensity and internal focus in the woodcarving process. Many signals are sent through our nervous systems, and our body is highly engaged in moving, sensing and perceiving.

(2) Secondly, only some of this massive amount of information that is processed is perceived. The carver does not need to be aware of something to react to it. The cerebellum monitors this information and helps us make deliberate actions without our conscious self necessarily being engaged. In this context, our carving activity can be explained as the cerebellar controlled and monitored action led by general guidelines originating in intentions and thoughts in the forebrain, sent and filtered by the cerebellum. The carving activity could be compatible with such generated patterns (the CPG), somewhat similar to the pattern resulting in our individual gait. This description bears similarities to, and is compatible with, prior phenomenological descriptions of the preconscious state of mind of the carver in the negotiations between the maker and the material, as exemplified in the text quote presented at the beginning of this article (Gulliksen, 1997, 2001).

(3) Thirdly, in the text referred to, the woodcarver's experience was described as a negotiation, or overcoming of resistance, between the maker and the material. This could be compatible with knowledge in which the neurons are 'in the loop' or included in the active or functional circuits in the CPG. When carving wood, the functional circuits of active neurons were dominated by the circuit between the sensory input from the material and the muscle output, guided by general guidelines of the idea about the wanted shape as well as what possible forms the material could offer. The aware, or conscious, self is somewhat distant in these circuits, monitoring but not necessarily guiding. In particular, self-reflection, a result of the processes situated in the pre-frontal cortex, is not necessary in this activity. Rather, as many practitioners have experienced, deliberately thinking about certain motor activities, such as walking, makes it more difficult to do them. This could be one possible reason for the maker's experience of being tightly interwoven with the material, as the reflective and self-questioning awareness that provides possibilities to distance oneself from the situation is less included in the loop.

To explore how these three topics could be used to understand another issue, we must look at another example from a carving situation:

> As the tools perform the tasks they were constructed for, they gradually grow into extensions of my body. The gouge is hot from the work it does, and my hand is a willing participant. Through the shaft, I feel whether the edge glides with or against the fibres, whether it is sooth or rough wood. I hear the sound of cuts gradually getting deeper, while the other hand is resting underneath the bowl, telling how thick the walls are and where to remove wood to make them even. The tool has become part of an extended arm that performs my will before I am even able to formulate my ideas.
>
> Not until my concentration breaks, I realise that the gouge is not my arm. Now, all of a sudden, the gouge slipped, and uncontrollably flies directly into my thumb. I let out a small scream. Why did I scream? Not from pain that's for sure: cuts from sharp tools rarely hurt much. Neither because the flooding blood frightened me; I have cut myself more times than I care to remember. No, the reason why I screamed was because I was so surprised that the gouge was a sharp tool actually able to hurt. In the process of working, the gouge had been materialising the edge of my will. It was a part of me and represented my own opportunities to shape the wood.
>
> The moment the gouge turns against me and cuts my finger, the situation represents an immediate contrast to the way I just worked. Now when I look back on it, I can still picture my left hand

> running over the wood, holding it, searching it, looking for yet undiscovered shapes, while the right hand was just a vague shadow behind the edge of the gouge. The prompt disruption makes me remember it like if it was happening right now. The cut is there, like a glass-wall through which I can peek into my own subconsciously conscious work. If I had stopped working any other way, to take a break or to change tools, I would not have been able to remember it this way because my concentration would have been focused elsewhere (Gulliksen, 1997, p. 67).

Using cellular and organ level terminology, this excerpt describes a situation where the cerebellum suddenly receives a significant dissonance in afference, efference and re-efference, or between intended motor action and received sensory input. The pattern created by the CPG, allowing the cerebellum to generate deliberate actions (topic 2), is disrupted and conscious control of muscles is needed. This abruptly ends the repetitive intense overflow of information between the sensory input and the motor output (topic 1). The carver undergoes an acute experience of becoming aware, bringing in the cerebral cortex's monitoring and self-reflection, thus ending the feeling of being close to the material (topic 3). The description of being surprised and the sudden feeling of being distanced by the material is caused by the sudden engagement of pre-frontal self-awareness.

This description supports the idea that the cerebellum, at least to some degree, could be the key to understanding the carver's experience. In particular, this indicates that the carver's experience is not 'preconscious' in a perception-phenomenological sense (Merleau-Ponty, 1962). It is not necessarily *pre*ceding a conscious experience or waiting for the experience to become conscious. The function of the cerebellum operates without any conscious experience. As the above example suggests, the conscious intervention disturbs this function, the same way as deliberately thinking about how we walk makes us walk ungainly. However, the making process coordinated by the cerebellum is not 'unconscious' in the layman's sense of that term either. It is a part of our deliberate actions, and it engages large areas of the brain, the sensory perception cortex and the motor cortex; it does so automatically, as patterns, not necessarily coming to our conscious attention, or having to be put into words, or be explained.

The making process is our embodied self-enacting. Discussing this process through the lens of how the cerebellum functions, it becomes clear how the direct modulation between the senses and the muscles also engages a significant amount of neural signalling in sensory motor areas in the cortex without asking the forebrain or executive functions for permission or advice. These sensory motor areas of the cortex are active when processing abstract thoughts, such as space, distance, resistance, closeness, joy, etc. (Groh, 2014). Seen through this lens, the similarities in previous experiential descriptions of the making process could be explained more fully; the neural activity generated by the making process and coordinated by the cerebellum as semiautomatic patterns engages areas that generate experiences of being active and being connected. This provides a possible explanation for the maker's experience of closely interacting with the material and the surroundings while simultaneously having an intense internal experience. Therefore, future studies should explore these three topics further, and continue to expand our current understanding of the maker's experience. An example of this type of research is the ongoing study, Mental Rotation Tasks in Three-Dimensional Materials (see e.g. Gulliksen, forthcoming), which discusses a case where an experienced wood-crafter lost and later regained her sense of space due to a brain tumour.

CONCLUSION

The first aim of this article was to describe some biological processes at the cellular and organ layers of complexity underlying the woodcarver's experiences and actions when engaged in carving processes. I have described neurons, their function and the neural circuits needed for moving and sensing, targeting in particular the underlying sensorimotor modulation in the cerebellum. Three directions (topics) for further exploration were presented and discussed: 1) the overflow of information in cerebellum, and the maker's experience of intensity and internal focus; 2) the function of the cerebellum as generator of deliberate actions without the conscious self necessarily being aware of it, and the preconscious element in the maker's negotiation; and 3) the importance of the neural circuit between sensory input and motor output at the cost of the neural circuits between the cerebral cortex's monitoring and self-reflection and the maker's experience as being close to the material.

A problem with the deductions in these three topics is that, in this initial state, they are only tentative ideas. As such, they could be regarded as 'new, modern gloss on some very old ideas' (Wall, 2014, 12th paragraph). A rigorous study is needed for us to know how deductions such as these hold up when analysed and translated between the layers of complexity and between disciplines (Donoghue & Horvath, 2016). In the terminology of Donoghue and Horvath (2016), it is possible to argue that the deductions in the current article indicate a *downward compatibility* between the layers: that the individual carvers' experience, as presented in the introduction, is compatible with the aspect at the organ- and cell layers of complexity that were described. However, it is necessary to emphasise that the processes described at the organ and cellular levels are only a small part of an individual's complex experience. Therefore, from such a lower level, it is impossible to predict what would happen on the higher individual and sociocultural levels if more processes in the interwoven nervous system were described.

FIGURE 4. Carving purkinje #4, April 2018.

This article addressed green woodcarving in particular (Figure 4); however, it is to be assumed that the points that were discussed can be relevant for manual practices in other materials. Previous articles by Gulliksen (2016a, 2016b, 2017) have similarly addressed green woodcarving, highlighting the role of the hippocampus in working memory and long-term memory storage and retrieval. Together, these articles have formed an initial starting point for the theoretical foundations for future studies. This present article has taken some small new steps towards a future study where reconciliation of the terminological differences between the layers of complexity could be developed further (Donoghue & Horvath, 2016). For example, giving examples of described experiences, the article indicates the terminological problems with using the term preconscious in phenomenological descriptions of the maker's experience; hence, addressing the second aim of the article. However, the present discussion is too narrow to capture a translational contiguity between the different layers of complexity. In the future, several methodological challenges linked to these and other issues need to be addressed, given the complex nature of the topic (Mason, 2011, pp. 22–23). Addressing them will generate a line of knowledge-based questions and hypotheses that could be used as an entry point for new targeted studies. For example, all three of the tentative topics discussed in this present article indicate that it could be relevant to look for possible neuroplasticity-related changes in the cerebellum, in carvers vs non-carvers.

The examples discussed in this article demonstrate that embodied making experiences, such as carving, can be studied through a variety of methods ranging from the descriptive, experiential or phenomenological perspectives to neurobiological perspectives, and studies that combine these perspectives. A methodological framework of an integrated applied research approach (Bammer, 2013) with an innovative and stringent research design and a team of experts collaborating on the different layers of complexity could make such studies possible. Providing researchers and teachers within arts and crafts science and the making disciplines with knowledge about the neurobiological basis of making and experiencing can inform and support their knowledge about what underlies the carver's or the maker's experience. In the future, knowledge generated from such studies could contribute to further advancing the field of design and craft research, as well as design and craft education.

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