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Abstract
The process of design is a complex, multifaceted activity that requires sophisticated professional thinking and competence, described as reflection in action and embodied process where hand, eye, and mind collaborate. We propose that cognitive neuroscience provide valuable tools for analysing processes of thinking and acting relevant to designing. This paper discusses the challenges and opportunities that use of brain imaging methods, especially, provides for understanding activities, skills, and cognition of design. We argue that cognitive neurosciences provide valuable instruments and methods complementing traditional design research.

Keywords
Design process; cognitive science; brain imaging methods; embodiment

Designing is a goal-directed, iterative, and creative activity that requires sustained cultivation of sophisticated cognitive competencies (Simon, 1977; Ralph & Wand, 2009). Cognitive neuroscience, in turn, represents a multidisciplinary effort to analyse neurobiological substrates underlying various cognitive processes using experimental methodology from physiology, psychophysics, electrophysiology, and functional neuroimaging. To what extent is cognitive neuroscience able to provide answers to scientific questions regarding the design process? Designing is a complex and multifaceted activity in nature, whereas typical cognitive neuroscience studies investigate very simple and repeatable cognitive processes. Can reliable experimental settings be created that allow detection of particular interrelations between design processes and functional activities of the brain and its subareas? Until recently, design researchers have not had research tools that would enable them to tackle the neural basis of designing (Alexiou & al., 2009).

Although the body and mind were traditionally studied separately, the research field of embodied cognition has emerged, integrating philosophy, psychology, and neuroscience (Varela & al.1991; Lakoff & Johnson, 1999). The research on embodied cognition has been conceptually elegant, but there have been very few associated empirical studies of design practice, where embodied knowing plays a crucial role. The neural basis of such practice has hardly been studied (see, however, Goel & Grafman, 2000; Alexiou & al., 2009). Yet current research on brain systems is deepening our understanding of the neural foundations of embodiment, skill learning, and social interaction relevant for design and craft (for a review, Hari & Kujala, 2009).

We understand design and craft as involving complex problem solving processes in the mind-body which are fundamentally creative in nature, and which implement conceptual ideas in the design of material artefacts (Keller & Keller, 1999). For us, craft and design represent similar processes and their enactments are both cognitive (ideation, problem solving) and embodied processes (experimenting, constructing and making) in nature although craft is more commonly related to learning traditional practices and motors skills. Design thinking is mediated by use of visual and material tools and artefacts (Goel, 1995; Perry & Sanderson, 1998). Drawing is generally the most important thinking tool for the designer, and sketching is an integral aspect of design (Goel, 1995; Seitamaa-Hakkarainen & Hakkarainen, 2004). In spite of intensive study of visualisation, the role of the material exploration and experimentations has not received much attention. Yet, the choice of materials and tools related to the specific context often alters sketches produced during the process (Mäkelä & Nimkulrat, 2011; Kosonen & Mäkelä, 2012). Designers appear to work in parallel processes of conceptual reflection and material experimentation (Ramduny-Ellis & al., 2010).

The present study is a part of the "*Handling Mind; Embodiment, Creativity and Design*" project integrating expertise in neuroscience, educational psychology, and design research; its goal was to develop and test novel neuroscientific methods for studying creative embodied processes and skill learning in the field of design. The present project aims at generating and testing hypotheses concerning design activity as well as the role and function of different brain areas in the design and craft process. Design research, at present, shows two broad areas of deficiency: 1) investigation of the brain basis of design practice and 2) empirical research of embodied aspects of design. Advances of neuroscience indicate that naturalistic settings for studying design cognition are feasible. We propose that cognitive neuroscience can be used to study 1) design activity and associated cognitive processes; 2) differences between design conditions and fields, and 3) between-group differences related to intensity and types of design training. We propose cognitive neuroscience as an alternative tool for design studies, to be accompanied with more traditional design research.

In order to examine the challenges of conducting neuroscientific studies of design, we will review, in the first section, studies of design cognition. We will cover studies of expertise, reasoning, and visualisation as well as address the relevance of distributed and embodied cognition for design. The second section provides a concise description of the methods of cognitive neuroscience relevant to design research.

I Previous research on design cognition and embodiment

Expertise in designing

Studies of design expertise indicate that design thinking is a distinct mode of knowing (Cross, 2004, 2006; Lawson & Dorst, 2009). Design tasks require complicated processes of searching for workable, aesthetic and functional solutions; such tasks are commonly viewed as prototypical cases of complex and ill-defined problems (Goel & Pirolli, 1992; Goel, 1995) without unique or predetermined solutions (Simon, 1969, 1977; Akin, 1986). Design problems are also considered to be wicked problems in nature (Rittel & Weber, 1984). In order to manage the infinite possibilities, the designer has to limit the design space by using external and internal constraints (Goel, 1995). The design process involves successive reframing of the design space; the process advances iteratively through cycles of ideation, testing, and modification (Goel & Pirolli, 1922; Goel, 1995; Seitamaa-Hakkarainen & Hakkarainen, 2001).

Research on expert/novice differences in problem-solving performance, starting from architectural design (Akin, 1986; Suwa & Tversky, 1997) and expanding toward product design (Goel and Pirolli, 1992; Eisentraunt & Günther, 1997), played an important role in establishing the field of design research. Design studies have examined knowledge, strategies, and methods designers use in solving design problems (Akin, 1986; Goel & Pirolli, 1992). Most of these design studies relied on the empirical investigations tracing design processes by thinking-aloud protocols and described design activity as movements through problem space (Akin, 1986; Goel, 1995; Seitamaa-Hakkarainen & Hakkarainen, 2001). Dorst and Cross (2001) proposed that the space of proposed solutions and the space of structuring problem co-evolve by moving between these two spaces and by creating matching problem-solution pairs. Along similar lines, Seitamaa-Hakkarainen and

Hakkarainen (2001) have proposed that designers are iteratively moving between composition (i.e., visual design) and construction design (technical) spaces. According to Cross (2004) considerable work remains to be done to adequately understand design expertise.

Visual analogy

Analogical thinking and reasoning are cognitive processes important for creativity (Boden, 1992) and designing (Ball & Christensen, 2009; Ozkan & Dogan, 2013). Analogy is defined as a process of mapping and transferring from one situation to another based on similarities between stimulus and target (Goldschmidt, 2001). Analogical reasoning moves from a known example to abstraction, and from abstraction to a new idea to solve the problem (Casakin & Goldschmidt, 1999). Visual analogy is considered to be a central strategy in solving design problems for both novices and expert designers (Casakin & Goldschmidt, 1999). They concluded that visual analogy improves the quality of designs and that it is especially important for students to learn the uses of analogies for improving their problem solving processes (Casakin & Goldschmidt, 1999).

When abstract or unusual representations are used as possible source analogues, designers invoke more analogies and they are better in analogizing (Perttula & Sipilä, 2007). Visual displays act as stimuli and either expand the space of creative solutions (Goldschmidt & Smolkov, 2006; Goldschmidt & Sever, 2010) or constrain and recycle old ideas (Purcell & Gero, 1996). To boost the use of analogies and avoid cognitive fixation many design studies have manipulated the given examples or the instructions of analogical thinking (for review see Ozkan & Dogan, 2013).

Visualisation

The role of visualisation during the design process has attracted interest among design researchers (Goel, 1995; Perry & Sanderson, 1998; Seitamaa-Hakkarainen & Hakkarainen, 2004). Goel (1995, 87) investigated kinds of visual representations designers generate, especially what kinds of sketches they create to transform design tasks into desired artefacts. Various visual and concrete materials, three dimensional models, and abstract concepts are used (Goldschmidt & Sever, 2010; Goncalves, Cardoso & Badke-Schaub, 2013) and designers reasoning and decision making is carried out through the construction and manipulation of the models of various sorts (Goel, 1995, 128; Perry & Sanderson, 1998). Goel (1995) has stated that designers produce and manipulate representations of the artefacts rather than the artefacts themselves and designers are aware of the ways various systems of representation affect their thought processes. Goel (1995; Perry and Sanderson, 1998) maintained that freehand sketches play an important role in the creative, explorative, open-ended phase of problem solving. Further, the designing requires abilities in spatial relations, orientation, and mental rotation i.e. learning to mentally manipulate the elements of complex spatial shapes. A designer needs these kinds of visual spatial abilities, for example, to perceive how a sketched drawing would look from behind or from the side (Kavakli & Gero, 2001; Silvestri, Motro, Maurin, & Dresp-Langley, 2010).

Embodiment

Empirical research on embodied cognition has only recently emerged, focusing on the human body and associated embodied knowing. 'Embodiment' refers to the fact that a great deal of human thinking takes place at subconscious, implicit, and non-linguistic levels (Lakoff and Johnson, 1999; Pfeifer & Bongard, 2006; Gibbs, 2005) and we should not study the mind in isolation from the situated body. The mind and body is bound to a material world and bodily experience (Varela et al., 1991; Lakoff and Johnson, 1999). Embodied-cognition studies aim to understand how the body and mind interact in the process of thinking, i.e., how artisans relate their bodies, tools, materials, and space in their work setting (Patel, 2008). Investigation of such processes is important because design activities are both materially and socially distributed (Hutchins, 1995) across environment, tools and artefacts supporting the designing. The socially distributed cognition refers to cognitive processes that are distributed across the members of a social group, for example, between members of design team. Further, physically distributed cognition refers to cognitive processes that are distributed on material environment, concrete tools, and physical artefacts that help one to solve more complicated tasks. Social neuroscience is emerging as a research field highlighting interaction between tools, physical environment, and embodied activities in cognitive processes (Hari & Kujala, 2009).

Skills of design and craft are based on the extensive use of various embodied senses, tactual, and sensor-motoric operations. The design process, as a multi-modal process, involves tactile attention and tactile processing; studies indicate that a designer's senses never operate on their own, but always inter-related and embodied in one another (Spence & Gallace, 2007; Gallace, 2012). Skilled activity involves practitioners attuning to working with a material, action or movement that a person has performed, encountered and handled countless times; without conscious effort, he or she is able to imagine and predict the perceptual consequences of actions. The human brain is a super-plastic entity that is constantly reorganizing itself according to emerging and changing needs of activity (Hari & Kujala, 2009). When a particular activity is intensively practiced, the brain changes so as to facilitate performance of this activity; as in skill learning. Investigations have revealed activation on the sensor motor areas of the brain as a response to using hand-related action verbs (Candidi, 2010; Borghia, & Cimattic, 2010), seeing other people working (Borghia, & Cimattic, 2010) or seeing hand-held tools (Jessica, 2010). Moreover, the brain and muscles become activated in synchrony with a visual stimulus describing movement. When following another person's work the motor reflection of mirror neuron system is activated (Borghia, & Cimattic, 2010). Hence, analysing changes in neural activity associated with learning new craft skills appears to be important for expanding our knowledge of design cognition.

To conclude, design cognition has been extensively investigated whereas the study of neural basis of this design is still lacking. Only recently, have researchers started to tackle problem-solving processes using functional magnetic resonance imaging (fMRI) and focused on analysing differences in pursuit of (ill-defined) design and well-defined problem-solving tasks (Goel & Grafman, 2000; Alexiou & al., 2009; Gilbert, & al., 2010). Cognitive neuroscience does not tell us what or how designers think but can be used to analyse designers' activities in specific situations and trace brain activity associated with their problem solving. The challenge is to develop reliable experimental settings and define specific hypotheses for examining cognitive processes relevant to examining interrelations between brain activity and design process. Next, we briefly describe some methodologies of neuroscience and highlight challenges of studying designing, visual thinking, visualisation and skill learning.

II Brain research methodologies and their relation to design research

Although neuroscientific research is rapidly developing, the challenge is to develop experimental settings that allow examination of interrelations between brain activity and design cognition, especially in more naturalistic settings. All neuroscience methods, however, have restrictions that affect the feasibility of types of investigation and research questions posed.

Functional magnetic resonance imaging: a full picture of complex tasks

Functional magnetic resonance imaging (fMRI) utilizes the blood–oxygenation-level-dependent (BOLD) signal that shows changes in different brain areas according to the changes of use of oxygen in the task. With this method, a full image of brain areas and their use of oxygen in a task can be obtained. The most traditional questions in fMRI answer these questions: 1) Which brain areas are activated in task A compared to task B? 2) Are there differences between individuals in group X compared to group Y in the brain areas activated in task A compared to task B? Such questions are of great importance in comparing professionals to novices in design, and in assessing different types of design tasks and their neural correlates.

Many researchers argue that it is important to distinguish problem solving tasks from design tasks (Goel & Pirolli, 1992; Cross 2004). The prefrontal cortex represents the neural basis of higher-order cognitive functions; it is involved in complex planning, creative thinking, and problem solving (Goel & Grafman, 2000). In order to examine the neural basis of planning, problem solving, and creative thinking in design, Alexiou and colleagues (2009) used fMRI for analysing differences between ill-defined design and well-defined problem-solving tasks. Their study revealed different patterns of brain activation between the study phase (learning to know the task) from the performance phase (moving objects). The region of right dorsolateral prefrontal cortex showed greater activity in design than problem-solving tasks (Gilbert et al., 2010). Overall, design tasks recruited a more extensive network of brain areas compared to well–defined tasks. Different parts of the premotor cortex activated when moving from the learning phase to moving objects. It was confirmed also that motor and premotor areas of the brain are activated not only when performing particular movements, but also while observing them. It appears important to better understand the role of doing in designing and its relation to visual, spatial and verbal reasoning (Alexious et al., 2009).

However, in fMRI experiments the participants are usually restricted in a recumbent position on the cylindrical tube of an fMRI scanner, unable to move. A head coil is usually placed on the top of the participant’s head and a mirror is attached to the head coil. In the experiment, the stimulus is projected onto a screen hanging outside of the scanner but within participants’ visual field (Alexiou et al., 2009; see also Gilbert, & al, 2010). To move objects, participants have to use a mouse to click-and-drag objects displayed on the screen. A challenge for fMRI studies is to design valid experiments that can be accomplished without extensive movements or drawings. Such studies have to be complex enough to qualify as ‘prototypical’ design tasks, but simple enough to be solved within the time constraint imposed by the brain imaging methodology.

The fMRI can be utilized to study the neural basis of visual analogical thinking by comparing experts and novices and/or comparing participants from different design field. First-year students who do not have previous design experience may assist in determining a baseline. Design tasks and visual analogy categories should be carefully selected (see for example those of Ozkan and Dogan, 2013). Such investigation could focus on assessing the impact of the level of expertise or design field for the preferred distance of source analogues (see Ozkan and Dogan 2013). The fMRI experiment could consist of two tasks 1) evaluating the usefulness of each of the 80 examples as a source domain for designing a field-specific object (for example a lamp etc.) and 2) choosing one analogy category (architecture, artefact, nature, lamps) that will best fit as an analogical source domain for designing particular object. The analogies are projected onto the computer screen and experts/novices identify and rate them by clicking a mouse.

Another possibility is to compare analogies related to conceptual (words) and visual (pictures) problems. In study of Green et al., (2012) participants completed 80 analogy trials and in each trial, participants viewed an analogy problem comprising three words and a question covertly generated a solution (word) to complete the analogy. A similar setting could be developed in which the participants see both word problems and visual problems. Since, designers have experiences with visual world, it could be expected that they would work better with visual analogy problems than do novices, and there might be detectable differences in brain activities.

The fMRI setting can also be used to examine skills of 2D and 3D spatial reasoning. Most designers are trained to be 'visualizers' so that they have acquired specific skills and competencies related to visualisation and model making. Novice and expert designers are likely to respond differently to diverse stimuli (keyword, diagram, plan, sketch rendering, and precedent photos) modalities. The differences between different design professions (architecture, industrial design, and graphic design) may be associated working with two or three dimensional representations. The stimuli might impact designers' subsequent designs and particularly on their design fixation.

Optical imaging provides, further, new possibilities for studying visual reasoning outside the laboratory. Optical imaging, or near infra-red spectroscopy (NIRS) utilizes changes in the absorption and scattering properties of light when it travels in brain tissue. When brain tissue is active, more oxygenated blood travels to the area, and the properties of light absorption and scattering change. With event-related optical signals (EROS), these properties change due to changes in chemicals and liquid in the brain due to brain activity. According to some scientists, optical imaging may thus provide a possibility to combine measurements of BOLD-type signals and direct neuronal measures (Gratton et al., 2001). In addition, optical imaging is portable and does not require a laboratory facility but can be used in natural working environments. For this reason, optical imaging is a promising area of advancing design-related brain studies. For example, as stated earlier, 2D and 3D as well as spatial reasoning skills can be seen as a core of professional training in many design fields (e.g. product design, architecture and fashion design to name a few). Designers are manipulating various 2D- (drawings, cloth patterns) and 3D-representations (physical mock-ups, clothing), and they exercise mathematical relations, such as proportions (Ho, Eastman & Catrambon, 2006). There is extensive research of mental rotation of 3D-objects that might provide a model experimental setting to study expert/novice and design-field related differences between 2D-, 3D and spatial reasoning skills by utilizing optical imaging (Kavakli & Gero, 2001; Silvestri, & al., 2010).

Electroencephalography and event-related potentials: fast and not limited to the laboratory

Electroencephalography (EEG) is the oldest brain research method and provides millisecond-scale temporal accuracy. EEG signal is the result of synchronous activity of neuronal assemblies that can be recorded from the surface of the scalp. Expert/novice differences in design-related brain activity may be traced through EEG (Alexiou et al., 2009); because portable and lightweight EEG instruments have become available, such investigations can be done in natural working environments of designers. Event-related potentials (ERPs) are averaged fragments of EEG, indicating brain activity that is temporally related to such event as the presentation of an image, the beginning of a sound, or starting a task or attempt. Several visual, somatosensory and auditory components (peaks) of ERPs have been observed and some features of their relationship to the cognitive functions of perception, memory or attention, have been identified. The long tradition of ERP research provides a good basis for applying it to design research. Pursuit of design tasks may, however, pose challenge for the ERP method due to the different time courses of the consecutive sub-tasks of the process. A clear down-side of EEG measurements compared to fMRI is the difficulty in identifying the brain areas that have contributed to the elicitation of the responses, especially from deeper brain areas. Thus, the methods can complement each other in terms of pros and cons.

Figure 1: EEG equipment used in research on skill learning.

We have currently conducted an EEG study regarding how specific craft skills are learned. Modelling, coaching, and scaffolding are traditional ways of learning specific craft skills through traditional apprenticeship. In the process, observation and guided practice (Wood et al., 1976; Collins, 2006) as well as careful imitation and deliberate practice (Ericsson & al., 1993) play a crucial role. Our laboratory experiment focused on examining the neural foundations of novices' process of acquiring new skills: 1) Which brain areas activate when participants look at instructions of crafts? 2) How does skill learning change this activation pattern? 3) Does skill learning change the timing of the brain activity? We are especially interested in the role of motoric training on the skill learning process and its neural basis as well as brain organization and large-scale memory systems of self-paced, intensive skill learning.

Brain responses of participants were recorded by using a NeurOne EEG-instrument (Mega Electronics Ltd, Finland) with 32 channels of EEG and EOG while they see 120 instructional photographs (i.e., working instructions) showing various textile techniques (for example macramé, tatting, braiding, crochet stitches) that are previously unknown or very little known to the participants. The brain responses to the photographs were averaged together across the session and across the participants. During a break of 4 weeks, the two groups of participants learnt two specific craft techniques either tatting or filet lace. After an expert has taught these techniques in one session, participants practiced the skill independently, and later taught these skills to other students. The participants kept a diary of their own learning during the practice period. Thereafter, the EEG recording was repeated and the results from the first and the second session were compared. We have just completed this experiment and, therefore, the results are not yet available. The expectation is that the motor or somatosensory areas are activated while looking at the photographs; this involvement is likely to change and some of the brain responses to become faster after learning of the skill.

We are also pursuing another experiment in which the Neurone EEG-instruments will be used to test hypotheses about the neural activity associated with producing visual representations (i.e., replication of drawings versus creating new designs) as well as producing material representation (i.e., replication of model versus creating new designs). The participants are 8 first-year and 8 master-students who are, respectively, considered to represent novices and experts. The question addressed is whether the brain responses working with visual (drawing) or material (mould clay) representation differ between tasks of 1) copying, 2) creating novel designs or 3) freely improvising. In order to document participants' frustration related to copying, designing and free improvisation tasks, we will record their heart-rate variability (HRV) through the FirstBeat (www.firstbeat.com) instrument. In the Drawing experiment, the participants will individually construct three types of drawings: 1) a copy of a line drawing of a cup (i.e., copying task) 2) a creative design of a cup (i.e., design task) and 3) a creative drawing of a self-chosen topic (i.e., free improvisation task). Prior to drawing, the students have 10 seconds to look at the drawing or plan their work. The time for drawing is restricted to 30 seconds. Each of the three tasks is done 10 times. In the moulding-clay-task participants work with materials; it is otherwise similar. Using a NeurOne EEG-instrument with 32 channels of EEG we will record participants' brain activity, trace their gaze with eye-tracking instruments, and track heart-rate variability (HRV)--all of these recorded in time synchrony with the tasks. We expect that the brain responses during the 10-second period of getting ready to perform the task will differ according to the task. We expect that the visual areas are mainly activated in task 1 (visible through the suppression of the alpha rhythm) whereas motor areas may be more active in tasks 2 and 3, visible through the suppression of the mu-rhythm. Further, the activity in the frontal areas may differ between tasks 2 and 3 with respect to the level of creativity required by the tasks. We expect that the two groups will differ with respect to having differential amounts of experience in working with clay. The experiments will provide a novel understanding of the creative process compared to a copying task.

III Conclusion

We have reviewed research on design cognition, expertise, and embodiment related to skill learning. The present examination reveals that the methods of neuroscience may open many interesting lines of design research. On one hand, a limitation of the traditional cognitive research on design was to overemphasize deliberate within-mind processing of conceptual or visual information. On the other hand, practitioners' accounts of their design experiences tended to be subjective descriptions of their practices that were hard to systematize so as to make design research cumulate.

The methods of neuroscience are advancing rapidly and providing new possibilities of experimentally tracing interrelations between brain activity and design cognition. The brain changes and forms according to the physical and mental activities. An exciting new trend in neuroscience is, further, to compare the brain structures of different professionals. It is an inspiring challenge to design an experimental setting for studying functional and structural changes of the brain related to learning and practicing special skills of designing.

All neuroscience methods have, however, their own limitations constraining research questions that can be addressed. The limitations are related to the fact that most of the neuroscientific equipment cannot be removed from laboratory and measuring brain activities requires expertise in neuroscience. Further, typical neuroscience studies investigate very simple and repeatable cognitive processes, whereas designing in nature represent a complicated and multi-faceted activity. Thus, it is very demanding to create reliable and valid experimental settings that allow identifying and determining specific interrelations between design cognition and brain activities. Although we recognize the limitations of the methods of cognitive neuroscience, we suggest that it can be seen as an alternative tool for design studies, to be accompanied with more traditional design research.

In Table 1 we summarize the pros and cons of the methods of neuroscience in the context of design studies. Starting from the right column there is name of the method, parameters measured, temporal resolution (accuracy in time) and spatial resolution (i.e., how well active brain areas are located). The strengths and weaknesses of the methods are described. As indicated by Table 1, some methods (fMRI) the sequence of design activities is difficult to study whereas in EEG there is long tradition of well-controlled experiments that can be applied for design studies. NIRS (near-infra-red spectroscopy) is portable instrument but not yet widely used for cognitive studies.

Table 1: The pros and cons of neuroscientific methods for design studies.

Neuroscientific method	**Parameters measured with this method**	**Temporal resolution (accuracy in time)**	**Spatial resolution (accuracy of locating active brain areas)**	**Pros for design studies**	**Cons for design studies**
fMRI (functional magnetic resonance imaging)	BOLD-signal (blood-oxygenation-level-dependent signal), changes in blood flow after increased neuronal activity	Block design studies: several seconds to minutes Event-related studies: hundreds of milliseconds	From several millimeters to sub-millimeter accuracy	Some fMRI study protocols are quite well suited for design studies	Equipment cannot be removed from the laboratory; sequence of activities is difficult to study
EEG (electro-encephalo-graphy)	Electric potentials from scalp, directly resulting from neuronal activity	Less than a millisecond	Problematic due to distortion of electric potentials, less than 1 cm in good conditions	Portable instruments, natural environments, some EEG study protocols are quite well suited for design studies, long tradition of well-controlled experiments, measurements of several hours are practically possible	Location of brain activity is difficult to determine
MEG (magneto-encephalo-graphy)	Magnetic fields outside the head, directly resulting from neuronal activity	Less than a millisecond	Less problematic than EEG, in good conditions clearly less than 1 cm	Some MEG study protocols are quite well suited for design studies, long tradition of well-controlled experiments stemming from EEG, optimal time-space-resolution	Equipment cannot be removed from the laboratory; location of brain activity is quite difficult to determine
MRI (magnetic resonance imaging)	Structures of the brain (structural MRI), neural tracts (DTI, diffusion tensor imaging)	no accuracy in time	Less than 1 mm	Good for studies comparing groups of people	Equipment cannot be removed from the laboratory
PET (positron emission tomography)	Structural image of concentration of metabolically active tracer, usually oxygen	Contrast of two conditions: no accuracy in time	Less than 1 cm	Good for comparing groups of people or natural tasks	Radioactive tracer is injected into participants; equipment cannot be removed from the laboratory
NIRS (near-infra-red spectroscopy)	Diffusion and absorption of near-infra-red light in tissues, depending on hemodynamic and electromagnetic changes in brain tissue	hemodynamic NIRS: hundreds of milliseconds, electromagneti c NIRS: millisecond (according to some researchers)	Theoretically less than 1 cm	Portable instruments, natural environments, some NIRS study protocols are quite well suited for design studies, measurements of several hours are practically possible	Difficulties in determining the location of brain activity, not many groups yet using NIRS for cognitive studies

To conclude, research on distributed and embodied cognition assists in expanding design research beyond focus on mind to consider bodily, materially, and socially distributed processes critical in design. As revealed by the present paper, neuroscience is, moreover, providing instruments and methods that make many phenomena of the design cognition, subject to rigorous scientific scrutiny.

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