BURN THE CHAIR, WE'RE WIRED TO MOVE:
TOWARDS DESIGN IMPLICATIONS FOR INNOVATION, CREATIVITY AND DISCOVERY IN HCI VIA NEURAL SCIENCE AND HUMAN PERFORMANCE STUDIES

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The following paper is meant as a starting exploration around the questions: if we know that our bodies' state has an impact on our cognitive performance, what are the implications for design and evaluation of design – particularly design to support creativity, innovation, discovery?

ABSTRACT

As per the Creativity Tools Report, 2005, a goal of Human Computer Interaction / Human Factors research with respect to creativity and cognition has been to develop principled heuristics that can both inform design of software, hardware and their environments, as well as offer a foundation for evaluation metrics [41]. As an approach towards developing such formalisms, we propose a novel combination of research from two domains not usually associated with HCI: (a) neuroscience for its mapping of creative acts to brain area and function, and (b) human performance for its research of physical activity's effects on cognition. We show how research in both these areas may be combined to inform new, neural based insights into design and evaluation. We suggest that working from this perspective may significantly reconfigure knowledge work software, hardware and work environment design and evaluation.

KEYWORDS

Neuroscience, creativity, cognition, human performance, hci, interaction design, evaluation.

INTRODUCTION

Creativity, usually understood to be a process that as Sternberg and Lubart put it in 1999, produces something both "novel and appropriate" [47], leads to discovery and innovation. As a culture, we therefore value creativity as a path towards improving our wellbeing aesthetically, socially and functionally via the expressions of creativity – our own or others – in sport, arts and science.

A particular challenge in Human Computer Interaction with respect to creativity is to be able to design tool- or process- interactions that support creativity for such innovation and discovery. A correlate challenge is to determine consistent methods of evaluation to assess whether and how the tools we develop enhance specific, repeatable attributes of creativity. The 2005 NSF Workshop Creativity Support Tools Report [41] is still the most thorough record of state-of-the-art discussions for C&C tool design. It proposes that extant HCI methods be used *concurrently* with the goal to "enhance the personal experience of the person who wants to be creative…to look for ways to improve the outcomes and artifacts [and] to support the improvement of process by providing tools that are designed with certain functional requirements in mind" (p14). These requirements are summarized as those of most HCI projects: to do the job better. The challenge from the workshop is to *deliberately* support the known attributes of creativity, such as its "social nature" (p17) in these designs.

As if in direct response, recent C&C papers have focused on the social creative environment, looking to derive attributes for example from theater improv [36] and architectural design [32] processes. The observations are rich, but necessarily course-grained: they do not tell us if these particular environments or processes are optimal or what particular quality or combination of components leads to the best opportunity for immediate, creative effect, such that these particular attributes can be replicated in other environments to produce the same effects: is the whole environment or interaction required, or is there one key component or combination that will do the job? We need processes to help refine the observations from these studies into such components.

Science, as we know, is all about reproducible phenomena. This repeatability is one of the goals of HCI and Human Factors: to find the algorithms – the elements of repeatability – that will ensure consistent results for optimal performance. We see this in the principles behind the design of an interface that disallows administration of an overdose [49], the representation of a bone relative to a tool in a 3D rendering in surgery to improve accuracy and reduce time for patient recovery [35], in tools to enhance search for drug discovery [42].

For many of us involved in creativity and cognition from such an HCI/Human Factors perspective, we are interested in the possibilities of such a science and engineering of optimized opportunities for creative performance. Here, we propose that two areas in particular may enable this more micro, repeatable approach to C&C oriented design and evaluation, methods that were not part of the 2005 report. These are studies in neural science and creativity, and human performance and cognition. In this paper, therefore, we have three goals:

- to review the state of the art in creativity and cognitive performance in brain science and human performance;
- from this consider design opportunities for spaces and tools,
- and likewise consider paths for same towards design and evaluation for creativity supporting tools.

With respect to the first goal to look at both neural science and human performance for creativity and cognition, we suggest that one informs the other. The focus of the first is largely creativity measurement; the focus of the second, largely cognition enhancement. Work in neuroscience, described below, also suggests that the same pathways for cognitive performance are used for creativity. As our work is to develop measures and enhancements of cognition and creativity, these seem logical areas to explore for principled creativity tool design and evaluation. To our knowledge, this is the first proposal to blend neuroscience and human performance research to inform creativity design.

Before detailing this approach, we situate our motivation and the consequent organization of this presentation.

MOTIVATION AND ORGANIZATION

Our research interest has been to investigate how it might be possible to formalize design and evaluation principles to support creativity for innovation and discovery. When this project started in the fall of 2008, we were not looking to neuroscience as a source for practical application, but were focused on the Creativity Tools report recommendations. Since then, however, neuroscience and human performance as a foundational approach for our challenge has become delightfully unavoidable. In the past few years, a number of books in the popular press have foregrounded work in neuroscience and human performance from sport to the arts to computer science. *The Brain that Changes Itself* by Norman Doige presents breakthrough work from the mid 80's to the present that has radically changed the neuroscience community's view around neural plasticity. Where previous models had said that our brains set after a certain age, the work reviewed by Doige shows the development of a new paradigm of neural plasticity: that we continually remodel our neural circuitry based on our need/use. Cases include remapping vision through the tongue and remapping neural processes from a stroke's paralysis back to movement. Plasticity is also a key component of creativity.

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A set of books – *the Talent Code, Talent is Overrated, Bounce,* and *Outliers* – all take their starting point from Anders Ericcson's work on the discovery that in all cases of human performance studied, from elite athletes to musicians to chess grand masters, all have put in a certain number of hours in the practice of their skill. The result of the work has been that "deliberate practice" rather than "talent" is a critical factor in each of these profiles' success [18]. (Of interest may be Ericcson's work with participants to excel well beyond the 7+/- 2 maximum for remembering numbers after one hearing [17]) An overview/ comparison of these books can be found here at begin2dig.

Developmental molecular biologist John Medina's *Brain Rules* foregrounds 12 key concepts about the brain based on current work in biology and neuroscience. Among these "rules" are: we are designed never to stop learning; stress changes the way we learn; memory is volatile, and exercise improves cognition. That last point becomes the entire thesis of cognitive scientist John Ratey's book *Spark* that brings together research on the effect of physical activity on cognitive performance.

[C]ould creativity be approached as a set of skills to be honed, and could design of tools for knowledge work be developed to deliberately support these practices?

With the evidence that our brains (and bodies) are plastic, constantly adapting to what we perform (as per Fitt's stages of learning models [20] blending with Erikson's deliberate practice) the question arises, if so much of what we have taken to be talent is actually, fundamentally, the practice of a skill, could creativity be approached as a set of skills to be honed, and could design of tools for knowledge work be developed to deliberately support these practices?

A second related question has been, since there is so much evidence that cognitive function is improved by physical performance, are there attributes of this action that we can distill to incorporate into design for creativity? Do we, for instance, need to burn our desk chairs?

In the following sections therefore we present research overviews of three related areas:

> *Directly related work*. We look for research in creativity and cognition work that is also investigating application of neuroscience of creativity and cognitive performance to design/evaluation.
>
> *Neuroscience and creativity measures.* We overview how creativity is assessed as well as how brain areas and brain functions have so far been mapped to creative processes in particular and cognitive task performance in general.
>
> *Cognitive performance and physical activity.* We overview work that shows how brain state as well as executive cognitive function is improved by physical practice, from brief bouts of aerobic work to long term practice. We also consider research that looks at sedentary effects on cognition.

We consider each of these topics in order, before presenting some formative explorations of our own in applying these findings to develop a design map towards enhanced creativity and cognitive performance tools.

Directly Related Research

In terms of work directly related to what we propose in this paper – that is, applying a synthesis of "creativity cognition research" [14] (the term we use throughout this paper) to deliberate tool design to support creativity, we have been able to find very little, suggesting that this idea to apply neurological understandings of creativity to tool design is still quite new, but is likely to evolve rapidly as "neuro" becomes the new black for domain prefixes. Indeed we propose NeuralHCI, neuralCHI and NeuralHumanFactors.

A recent paper by Chrysikou [12] applies mappings of the brain performing divergent thinking tasks as an explanation for why some people perform better in these standard creativity measure than others. The task will ask someone to come up with as many novel solutions as possible to an open problem like "design a survival pack for nuclear fall out." She describes patterns in MRI images of "design fixation," where a person fixates either on a new solution given or on previous strategies rather than innovating away from these. The paper does not offer strategies to address this block.

A fascinating study not on creativity explicitly, but on how we may measure cognitive load to better assess ubiquitous computing applications is proposed by Haapalainen and colleagues [25] to show how physiological measures, including brain wave and heart function, may be mapped to cognitive load. It would be interesting to compare measures of cognitive load with creative performance tasks, since of course, determining the right load for best creative performance may be a critical measure.

Work in [26] looks at efforts to integrate neurological work on creativity into pedagogy. Seeing no direct application, the authors investigate using it as an additional model to explain creativity in drama classes. Success seems to be that the approach informed discussions of generative vs analytical thinking.

The role of stress in creativity is reviewed by [7]. The synthesis here is that stress is a complex process: some level is effective for creative work, and that that the amount is related to the degree of evaluation that is part of the context. If that evaluative context is too high, creativity can be killed; if the evaluative context is perceived to be insignificant, there may be no motivation to engage, and so creativity is also dampened. The degree to which one feels out of control of a process produces stress that has a linear negative correlation with creative performance.

In sum, so far, to the best of our knowledge searching for published work using such terms as creativity, brain, cognition, insight, design, across a number of databases, we found little directly applying this work to design. What our searches have shown us, however, is that there is a smallish (and some argue[14] a disconnected) group of researchers who have been investigating mappings of brain area and creative function. The work is in large part driven by functional MRI work (fMRI), so is the product of relatively recent science (approx. 1994 to the present). The first synthesis of this work is from 2004 [15] with two more recent critiques appearing in 2010 [14][2].

Before we continue, we propose a fast neuroscience knowledge check: on a map of the brain few of us in design or HCI can identify the location of the parietal lobe versus the occipital, or show which lobe is most strongly identified with working memory or what areas of the brain are activated when having an insight. And while we may be comfortable with Fitts's Law or even Ericcson's short term memory 5 +/- 2, we are also less likely to know how the emotional brain is connected to judgment, or how cortisol and other hormones that affect our cognitive performance respond to state. Having a sense of answers to these questions, we argue throughout this paper, and I hope you may agree by the end, is crucial for understanding how tools might be designed to optimize cognitive creative. Performance. Thus in the following sections, we go into some detail on these points.

Mapping Creativity in The Brain

Psychologists and neurologists have been interested for decades in determining the seat of creativity in the brain. According to Arne Dietrich, a pioneer in neuroscience and creativity, until 2004, work was largely focused on "hemispheric asymmetry" [5][8]. That is, there was assumed to be a single part of the brain responsible for creativity. Popular books like *Drawing on the Right Side of the Brain* with exercises to work the "creative" side of the brain were inspired by this early determination. Neural imaging with creativity assessments suggests, however, that creativity does not live in any one part of the brain, and that the term "creativity" itself may be too vague to identify the range of brain processes in creative thought.

> "Ordinary mental processes" map to the same activations in the brain as "creative" thought, and thus, creative thought reuses the same neural circuits as ordinary thought.

Dietrich's review from 2004 of brain areas and creativity also shows that "ordinary mental processes" map to the same activations in the brain as "creative" thought, and thus, creative thought reuses the same neural circuits as ordinary thought. This finding resonates as well with what we are learning about other multifaceted brain-based processes, such as pain [27]: they are complex, using multiple brain regions, where those same areas may be reused in different combinations for different processes (creativity, processing pain, sense making) or types of the same process (different kinds of creativity). That said, there are certain combinations of brain processes within creativity that seem agreed upon sufficiently that they may be used for design. We propose that Dietrich's framework of the various inputs and processes the brain uses to build up a creative product, presented below, offers a useful basis for such a strategy.

Before proceeding to that discussion, we offer an overview of the neuroscience perspective on creativity. For this review we largely follow Dietrich's excellent synthesis [15], updated in places where more current research is relevant. His complete review is strongly recommended.

The Cerebral Cortex

The cortex is the folding layers on top of the brain. The neural systems across the cortex lead into two types of information processing. In the first, information can be tagged in one's memory relative to its biological significance or saliency as LeDoux points out in the Emotional Brain [33]. The second type of processing is in the main, feature extraction. From these types of information we get emotion and cognition. It's important to note the significance of what is meant by "emotion" here. It is information leading to a survival response: fear at a predator; arousal; disgust at rotting food. It is this emotional brain that helps us understand what is important in social, survival contexts. A lack of this rationality has been hypothesized to be at play in autism, for instance: an inability to make rational judgments about the significance of information in a scene [30].

For our purposes, the key take away is that both these types of information processing draw on various parts of the brain, but they are integrated at the prefrontal cortex (PFC). The prefrontal cortex manages information from the rest of the cortex depending on information type being utilized. Because the PFC has such a key role in what might be seen as creativity integration and management, we review its involvement in the creative processes of the brain.

The Prefrontal Cortex and Creativity

The prefrontal cortex represents the largest area of the frontal lobe

Figure 1 images A and B). It has been found to be responsible for a suite of actions. Mainly, it takes information that has been processed by other parts of the brain for further abstraction into: self-construct, self reflexive consciousness, complex social functions, cognitive flexibility, planning. Other functions – working memory, temporal integration, sustained and direct attention are the workhorses of the PFC to enable the higher processes such as social function or cognitive flexibility, crucial in creativity, to occur. For detailed listing of the research behind each of these claims for PFC action, please see [15].

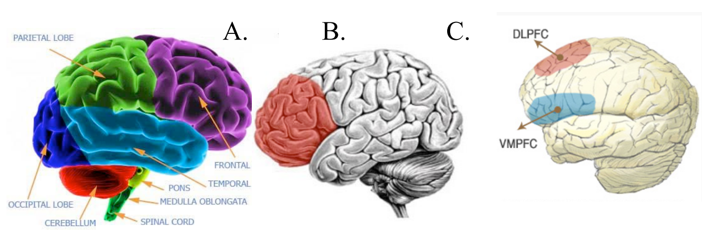


Figure 1 (A) Lobes (B) PFC (C) VM and DL PFC areas

Dietrich also draws attention to two other mappings: the ventromedial (VMPFC) and dorsolateral (DLPFC) PFC (

Figure 1,C). The DLFPC has been mapped with semantic memory retrieval (left DL) and sustained attention (right DL). Compromise of the VMPFC seems to result in an inability to sustain a plan of action or plan for the future or to abstract thought processes or judge consequences in part of logical, rational decision making. The DLFPC seems mainly connected to memory storage via the Temporal, Orbital and Parietal (TOP) area of the brain (

Figure 1, A) The VMFPC is more associated with the amygdala (emotional brain) and the cingulate cortex. The amygdala is part of the limbic system, and perhaps the oldest part of the brain, sometimes called the Lizard brain. The anterior area of the cingulate cortex in particular, also important in processing pain, [27] is critically used in conflict resolution (seeing a word blue written in red ink).

A 2010 overview of the neurochemistry of stress, [4] maps these same regions involved in the planning/assessment part of creative work as those involved in stress: the amygdala and the prefrontal cortex. This mapping may be particularly relevant when considering the following section's connections between physical and cognitive performance. Dietrich notes that the primary input for the DLPFC comes from the TOP (stored memory) for sustained attention, but its primary output is the motor cortexes. This observation as well will be key for our discussion of physical interaction design for creative support. Indeed a key test of the DLPFC is for cognitive flexibility: the ability to adapt to new conditions as rules change by being able to compare previous context against the current context. As Dietrich sums up, "Creativity is the epitome of cognitive flexibility."

Spontaneous vs Deliberate

Beyond this mapping of cognitive processes that contribute to our recognition of what we identify as the fruits of creative endeavor is the question about inspiration vs perspiration. There is in the creativity literature evidence that creative products come as much from a state of defocused attention, the inspiration of dreams as it seems there is of creativity being the result of deliberate effort – the 10% inspiration 90% perspiration.

One suggestion for this seeming split between kinds of inspiration is that working memory (conscious mind) is limited to processing a reduced set of contexts in active attention (the limit seems to be four); the unconscious mind however apparently parallel processes and so takes on more information, without the conscious mind attending to it. The shifting between whether the conscious or unconscious mind is feeding active attention at any particular moment has implications for tool design. As we will see, different states of consciousness can be practiced, and such tuning within an application may help optimize its potential to support creativity.

It's not JUST the PFC

While Dietrich's work foregrounds the PFC as the path for accessing and integrating information from the rest of the brain for creativity, this is not to say that "creativity happens in the PFC."

Echoing Dietrich's observations that people who have had PFC damage sometimes appear to have more effective divergent thinking, Chrysikou suggests that divergent thinking tasks require a similar kind of "hypofrontality" [12] that is, they are more data driven or bottom up approach from the "posterior brain area" rather than from the more judging side of the PFC. The hypothesis is that prefrontal cortex activity (the VMPFC) may censor possibilities for novel solutions in the process of candidate evaluation.

Certainly there are famous examples of people training themselves to wake up as they start to fall asleep to note their insights. Edison is reputed to have napped with ball bearings in his hands so that when he started to drift off and his hands relaxes, the bearings hit a plate, waking him, and he would record his ideas. Recent work on PFC damage in at least dementia suggests that greater divergent thinking does not always occur [45]. That said, work by Fink and colleagues [19] shows that a simple timing modification to exposure to an open ended problem seems to have a profound effect on replicating similar performance: that people who were encouraged simply to reflect upon an idea they came up with (incubate) before moving onto the next suggestion generated more ideas than those who were not asked to reflect, and that, in particular, people who first came up with their own ideas, and *then* were told of other people's solutions generated far more ideas again. From the fMRI, Fink and colleagues show more temporal-parietal cortex involvement when shown others' ideas as stimulus for new solutions, more of the back end firing pattern that Chrysikou suggests is best for open ended task performance, but not necessarily less of the PFC.

Timing – here a pause – is an interesting dimension to consider for creativity when so much of our design work seems to be to make things turn over faster.

Assessing Creativity

Beyond concern for too much or too little PFC, recent reviews of creativity cognition research have begun to challenge the accepted measures for both validity and completeness. Provocatively, in their 2010 review of measures of creativity [14], Dietrich and Kanso question the ubiquitous divergent thinking tasks as often the sole qualifier of creative performance. They suggest that, when it comes to measuring creativity in a lab rather than a case study, psychology has hit "a *cul du sac*," and is "stuck in a rut" reusing variants of the 1976 "divergent thinking" tests (DTT) for generating numbers of unique "creative" solutions to open problems. As Dietrich and Kanso put it,

from this rather promising beginning [of having one assessment measure for creativity in the DTT], in a development that even Guilford did not intend, this idea morphed from a first crack at this hard-to-pin down phenomenon into the standard conception of creativity, dominating theoretical and empirical work ever since. Once established, tests of divergent thinking became, for the sake of convenience, tests of creativity; and findings using these scales were often discussed, without badly needed qualifying remarks, as if applicable to creativity in general [14]

Arden and colleagues note as well in their review of metrics used in studies of creativity and the brain[2], that measures across studies range too broadly to make specific statements about particular brain processes. They suggest that the measures themselves need to be better validated and propose a range of steps from exploratory factor analysis of creative cognition measures, to use of larger sample sizes, to adding in IQ and personality test data to provide a more robust and fine-grained set of metrics. Despite these suggestions, a recent fMRI study boldly titled "Neuroanatomy of Creativity" [29] reuses DTTs to show how a new measure of cortical thickness in areas of activation augments previous views of DTT.

As an antidote, Deitrich and Kanso foreground new approaches to creativity assessment being explored in EEG and MRI studies' comparing artists' and non-artists brain patterns when asked to do what we normally construe to be creative tasks. In one case, visual artists and non-experts are asked to imagine drawing a picture. Not only are the patterns between them different, but neither maps to familiar DTT responses. When musicians and non-experts are asked to imagine composing, the DTT pattern seems to reemerge, while differences between expert and non-expert disappear. These results would suggest that rather than generalize, we may need to consider domain type for creativity tool design.

Creativity Model

Despite the limitations and critiques of extant neural mappings of some types of creativity in the brain, there does seem to be some consensus around kinds of information flow that can inform tool design. In the last part of this review of the brain and creativity, we present a summary of Dietrich's framework for understanding the ebb and flow of information types in the brain that become creative output.

Dietrich first summarizes the role of the PFC in creativity as a three part process:

Becoming conscious of a novel thought in order to evaluate it. Hence the important of working memory. "A novel thought becomes an insight when it is represented in working memory."

Processing insight into a creative product. Hence from working memory, the other attributes of higher consciousness of the PFC can be brought to bear upon them: are they interesting, trivial, correct, etc.

Implemented or expressing the new work according to the appropriate framing/goal: an artistic, scientific – or, we would argue – athletic production – requiring usually a high level of skill and knowledge.

Dietrich then proposes that this three stage translation occurs within a particular kind of creative thinking. Which kind is informed by type of information (emotional or cognitive) as well as type of process (deliberate or spontaneous) as shown in Figure 2.

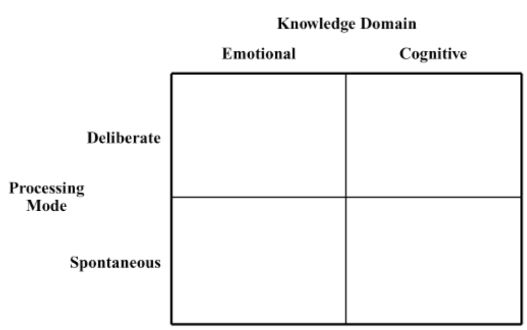


Figure 2 Dietrich's Framework for Creativity

We describe the attributes of the resulting quad below.

Deliberate mode, cognitive structures. This quad engages the active attention, and pulls information from stored memory. Creativity here draws on domain knowledge, and enables working memory to manipulate more possibilities. Creative production here means agile reconfiguration of existing knowledge towards the novel.

Deliberate mode, emotional structures. Again, we have active attention, but this time drawing more from the VMPFC to foreground affective memory. Lessons learned, we might say, come into play here: fire is hot; it burns. The DLPFC comes into play as well where such innovations may be brokered against one's norms and values such as insights around one's past against new ideas: *aha*, that's why I keep hurting myself cooking; I can use an implement to remove the meat from the fire next time.

Spontaneous mode, cognitive structures. Access to stored memories (TOP) during "associative, unconscious thinking." These generally map to light bulb moments that may come after what is referred to as incubation where a solution to the problem appears while doing something unrelated. Again, however, expertise is of critical importance [31] to be able to make the connections between an impression (an apple falling) and an abstraction (gravity).

Spontaneous mode, emotional structures. Emotional information makes its way spontaneously into working memory. Since emotional information is tied to biologically significant events (falling from a tree; breaking one's heart), these make a substantial bid, when cued, to enter active attention. Creative expression is an obvious result that literally (ironically) seeks to re-present this experience for attention and sense-making.

A 3D Creativity Model

We suggest that Dietrich's model can be read three dimensionally. The Z axis represents the translation of the PFC three stage refinement of information into creative product that will operate anywhere over (or through) any of the quads described about. Whether spontaneous/emotional or deliberate/cognitive, the PFC enables information to come into attention, become processed into a creative (novel and appropriate) mental artifact, and from there expressed.

Design Opportunities from the Framework

While there are many opportunities for tool intervention informed by the above framework, we offer 3 examples for approach, and related design challenges:

Example: Spontaneous Mode, Cognitive Structures: Research in neurofeedback fits well into Dietrich's Spontaneous/Cognitive quad because of its deliberate practice of relaxed mental state for performance. Neurofeedback participants spend multiple sessions over a period of weeks with electroencephalogram (EEG) visualizations in a game environment to practice often one of two types of brain wave state control SMR or A-T. In sensorimotor rhythm (SMR) one works to bring low beta frequencies (12-15 Hz) up, while bringing theta (4-7Hz) down. In Alpha-Theta, one works to raise the ratio of theta (5-8Hz) over alpha (8-11Hz). The effects of these manipulations is to improve general neural plasticity (opportunities to form new patterns), improve long term memory and improve speed and accuracy in tasks [24]. One study with surgeons doing micro-surgery work (in simulation) [40] showed that while both SMR and A-T were effective, SMR had the greatest significance in error free practice and speed to completion compared with control over an 8 week course. In another study with actors, performance quality was assessed by experts to be better in the participants who had trained using neurofeedback [23].

Challenge: Might some of this deliberate practice approach from neurofeedback be used more deliberately for in-application use to enhance creativity in knowledge work?

Example: Deliberate Cognitive Creativity Active attention has a limit of what can be brought into working memory at any one time. Given this limit it seems critical not only to have expert domain knowledge ready to draw upon to improve the possibilities of candidates to be available to repurpose in new ways as part of actionable insight as per work by André and colleagues on serendipity [1] but also to have the space and nimbleness to maintain these multiple options in play.

Challenge: How might our tools support extending the working memory active attention space while enhancing nimbleness of option interrogation (part 2 of the Z axis), and ultimately capture or embodying these new representations (part 3 of the Z axis)?

Example: Emotional Deliberate Creativity. Stress in the wrong amount negatively impacts on creative performance [7] As many people may refer to themselves as "stressed out" reducing stress helps performance. Many people hire therapists to help us work through emotional issues in the same way we hire a trainer to improve physical wellbeing.

Challenge. Just as there is a growing field of health and fitness applications – and as we shall see below, physical wellbeing is a key marker for cognitive performance – how could we design tools to help identify stress responses – physiological markers as per [25] on cognitive load - and tie these to cues towards reflections on emotional information behavior in order to get the *aha!* about self necessary to get back to one's task at hand?

HUMAN (PHYSICAL) PERFORMANCE AND CREATIVITY

The previous section has been designed to present a map of the brain's processes for the attributes of creativity that have been mapped to date. If creativity is a particular demonstration as Dietrich and other suggest of "ordinary mental processes" such as those used in executive cognitive functions (planning, scheduling, and working memory), then work that enhances the performance of these components must be of interest for our design goals in creativity. Thus we turn to human performance. Indeed, we suggest that some of the most relevant work for design and evaluation measures is in physical performance studies of cognition.

Relationship to Design

For years various health professionals have been saying that we are, as a culture, too sedentary and that we must move to be well. Resistance training fends off osteoporosis and heart attack. Improved cardiovascular capacity from working out helps to reduce stress. More recently, the act of sitting has come under the microscope as a contributor to disease. In a 2010 study, Stephens considered how one day of sitting affects insulin performance [46]. The results show that compared with not sitting, insulin's ability to clear blood down to normal blood glucose levels was affected from 11% for when one's calories were reduced to compensate for the lack of activity, to 39% when no such compensation in regular diet was made. Without going into detail about insulin's role in obesity and Type II diabetes, suffice it to say, this is not a good result [48], as it means most knowledge workers will have sub par insulin sensitivity. This effect does not seem to be well offset by going for a 60 minute workout every other day after work. JA Levine, a researcher in obesity, has found that a key differentiator between people who ate the same amount of food but either lost or gained weight was their degree of movement *during the day* [34].

Levine's response has been to build the treadmill desk so one could keep walking while working. The approach is perhaps a partial solution: it does up the caloric expenditure of a person by 100kcals an hour [34] and may therefore help bring insulin levels back up to a level closer to a no-sit optimum. In the one study of the apparatus to date for cognitive performance, however, researchers found that fine motor skills and math performance went *down* by 6-11% for participants, but reading comprehension and selective attention remained the same [28].

The walking desk is an intriguing intervention to try to make perhaps an unnatural environment – working at a computer – more effective for at least part of our performance – in this case improving caloric efficiency. We might also speculate that since "going for a walk" (in a forest [37]) is familiar advice to help blow off the hormonal response to stress, walking at a desk may help. Part of the research challenge of looking at creativity and cognitive performance in design suggests a more creative intervention may need to be explored if the goal is to improve cognitive and not just physiological performance.

Physical and Cognitive Performance Blends

Research over the past decade with the human genome has stirred numerous researchers to suggest that there is a strong link between movement and cognition and that it is wired into us [6][9]. The right moves made the difference between starvation and survival. As neurologist John Ratey summarizes [39]:

Physical activity improves cognitive performance by increasing neuroelectric activity, brain volume, and blood flow in brain networks that mediate attention, learning, and memory. At the molecular level, physical activity increases the availability of neurotrophins and growth factors in the brain... Many studies have shown that physical activity influences neural systems involved in attention, learning, and memory.

The simple consensus of the growing research on physical activity, brain health and cognitive function is that physical activity is a key component in better and lasting cognitive performance. The great potential of this work is that it has benefit it seems throughout life, from looking at activity levels and children's performance [11] to interventions with the elderly. While longer practice seems to have greater benefit [39], intervention at any time, and in potentially small doses, seems to provide an immediate improvement.

Several studies have shown now that a single dose of aerobic activity has both immediate and lasting effect on improving cognitive performance from college age to elders [26]. Most of these evaluations consider effect on "executive cognitive function" such as planning, scheduling, inhibition and working memory. Reducing inhibition means accelerating accuracy of selection. For instance, in a Stroop test with word, color and word/color conflict one reads words shown then names colors shown for speed of response; the last set may have the word green printed in red and one is asked either to name the color or read the word. The conflict tests attention in filtering information [10].

The simple consensus of the growing research on physical activity, brain health and cognitive function is that physical activity is a key component in better and lasting cognitive performance.

Of note, a related single dose study [38] compares single bouts of aerobic activity, exergaming and videogaming on cognitive control. While aerobic treadmill activity for 20 minutes at 60% of maximum heart rate (max HR) produced improved cognitive control (including improved attention performance, a vaunted attribute of video gaming), neither seated video gaming *nor* exergaming using a WiiFit at a similar 60% of max HR had any effect. An interesting additional factor in this study is that it used a 20 minute bout rather than the previous one hour session. A little bit of off-the-screen physical activity seems to go a long way.

Research shows that the inverse is also true [44]. A large prospective study that followed people from 35-55 over 11 years showed that a low level of physical activity in later life correlated to lower mental fluidity and creative flexibility .

Smaller Movements' effects on Cognitive Performance

While most work on cognitive performance and the physical focuses on the effects of large-scale movements like lifting a weight or running on a treadmill, some work focuses on much smaller perturbations, from hand gestures to eye movement. Goldin-Meadow's work on physical gestures shows the use of hands in making or conveying meaning is a key part of problem solving. Gesturing is not a complement to spoken language; it is a language. When children use their hands in ways that complement what they are learning, they learn better than when not using gestures [22]. These physical gestures also speak knowledge that is not in the verbal expression and sometimes does not bridge immediately to the verbal. This dual channel may remind us of the unconscious mind as a parallel processor in Dietrich's model, and the conscious mind limited in what it can attend to at once: both channels are still on, enriching each other.

When working at a keyboard, and attempting to be creative on a screen typing, we are restricting that manual channel for richer sense-making, knowledge building and perhaps creative discovery. How might we liberate our hands?

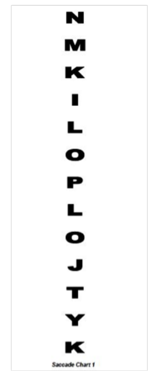
The Eyes Have It

To look at even smaller physical actions, research by Shobe considering eye movement and creativity has shown that inducing bilateral eye movement with the goal of stimulating inter-hemispheric interaction can contribute to improving creativity measures in people with strong handed preferences. The thinking is that strong handers are more hemispheric-specific than more ambidextrous, and that eye movements back and forth, following a target will enhance creative performance by enhancing inter-hemispheric interaction [43] As predicted, the trials did increase originality and fluidity in strong handers, but did not affect mixed handers. The outcome suggests that knowing one's handedness may be a factor in application use of screen space or screen positions.

In a recently completed formative study, our group looked at how using self-paced saccade drills and focal accommodation work might improve cognitive performance measured with simple reading speed and reading comprehension performance [21]. These drills are frequently used for vision training for sports performance [50]. In saccades, rather than follow a target a person reads a letter on a chart on the left, then one on the right, back and forth across two lists. Participants have three trials to read as many letters as they can in thirty seconds (**Figure**). Focal accommodation has the eyes follow a pencil, converging to focus in close as the pencil nears ones nose, and diverging to focus out on the pencil at arm's length. The task is to move the pencil in from arms length to as close to the nose as possible before the image of the pencil splits in two. Unlike the Shobe study participants did work standing, and the participant, not the system, sets the pace.

Figure 3 Testing saccades, showing example saccade charts for reading comprehension performance

Our goal in using these drills was to find a physical performance intervention that was quick, easy, repeatable and assessable in a measure that would matter to the target population of computer screen knowledge workers: beat back fatigue; improve screen performance. Based on the above work in creativity and eye movement, the eyes seemed the smallest muscular target that might have a considerable effect. Our reasoning was not only that the eye muscles can be worked without leaving one's desk but based on two notes from the research above. First is the body-brain connection that Dietrich highlights in stating that while the DLFPC receives its information from the TOP, it manifests it in the motor cortex. There may be a loop that our eye muscles can tap in cognitive performance like reading comprehension and express physically in movement. Likewise our visual system is the primary way we process information from our environment (then the vestibular, then, the proprioceptive – all part of the somatosensory hierarchy [16]). If our eyes are not processing information optimally, we do not perform optimally; our nervous system via our emotional brain has a kind of threat/flinch response [13] and performance shuts down. Our focus was not inter-hemispheric interaction, though that may be a factor, but cognitive refreshment with the smallest effective physical dose: helping the eyes relearn their full range of motion with their 6 muscles, we hypothesized, would offer a reset, and if effective, would register in reading speed and comprehension improvements.



Eight graduate students (6 men, 2 women) participated. After one session of three thirty second saccades, and one focal accommodation drill, 6 people had noticeable improvements. What was perhaps more interesting, is that after the three weeks of the trial, participants reported that they would use the drills during the day as a break at work and that there work on the screen felt easier from doing the drills. More particularly, their work felt better.

We are not going into the details of this study as it was informal, and run simply to see if testing an even smaller dose of movement than the 20 minute aerobic interventions detailed above can have a positive effect on cognitive performance. Based on these results we will be running a more formal study. A design question from this work is if such eye work is helpful, how might it be utilized in tool design, to let the eyes move in a more complete natural range of motion? What kinds of screen repositionings, for instance or new screen technologies might we consider?

Move it Move It

The fundamental observation from these studies on cognitive performance and physical movement is that physical action improves cognition performance, an "ordinary mental process" strongly tied to factors measured in neural imaging of creativity. Significantly, in published studies, as little as a single bout of aerobic activity has benefit; longer-term action shows greater benefit. The inverse is also true: being sedentary makes us dumber over time; sitting all day is performance debilitating for our health, including our cognitive wellbeing.

What if, however, a change as simple as getting out of our chairs in and of itself improves our creative capacity?

A critical question regarding our goal in design to enhance creativity, innovation and discovery comes from this synthesis: given the negative effects of sedentary living on cognitive performance, and that our knowledge work environments are largely sedentary, and given that physical activity in even it seems the smallest doses has immediate cognitive benefit, how could we ever produce any but suboptimal creativity results if our work only augments standard, sedentary work environment?

Burning Down The Chair

As a very preliminary consideration of the cognitive performance potential of getting away from the chair, we ran a very simple exploratory protocol: sit in a chair in a relaxed manner for three minutes and then stand in a relaxed manner for three minutes. We used an EEG headset by NeuroSky (as per [25]) to track brainwave function. We were shocked at how immediately upon standing brain wave activity changed. Using the A-T protocol goal to increase the theta over alpha ratio, just by standing up the ratio changed from 1:3.3 to 1:4.

This test was obviously not a formal study. We make no claims for these results other than that they are sufficiently intriguing to warrant further consideration. To our knowledge, no one else has considered simple position or movement in assessing creativity with neural performance. What if, however, a change as simple as getting out of our chairs in and of itself improves our creative capacity? The implications of this one environments change may have substantial effects (and opportunities) for design. What does an office look like that privileges non-seated interaction as well as movement? What is an alternative to a chair that supports periods of incubation and then active work? Should mobile applications literally be focused on maintaining more movement while cogitating? While these remain open questions, we increasingly have the tools at our disposal to begin to measure the effects of our interventions formally. Consumer devices to monitor sleep quality, EEG, ECG, blood oxidation, steps taken, location, all open up new ways to measure "is this thing working?" Likewise, we may find that as we look at cognitive/movement interventions, we will collaborate with colleagues in human performance labs to begin to investigate muscle tone, hormone levels, oxygen exchange performance. We may draw blood. For analysis.

CONCLUSION AND FUTURE WORK

In this paper, we have contributed both an overview and integration of neural science work on creativity mappings to the brain and studies in human performance to enhance cognition. We suggest that the creativity and cognition community is ideally placed to extend "creativity cognition research" and have proposed what we believe to be a novel approach integrating these two strands of work to motivate, situate and evaluate design for creativity, innovation and discovery. We propose there are at least four areas for taking this approach forward:

1. Implicit Use of Neural Knowledge for Design and Evaluation. As per the Creativity Tools Report [41] creativity design is to make being creative easier, more cognitively potent within our regular work practices. With the neural assessments of creativity, we have strategies to think about situating and evaluating our designs. Work from 1999 [3], for instance, demonstrated that simply encouraging a positive affect improved creative function, just by looking at a picture that made one happy. Similarly bilateral eye movement work shows that small-dose movement of even a few muscles enhances creative function. How might we use these findings of what does cognitively improve creativity within a search engine?

2. Monitoring the Quantified Self for Peripheral Awareness. Since we can monitor now so many attributes of personal state as the work on cognitive load shows, an interim contribution to our work environments may be to show us our state so that we can be proactive about taking time to incubate or get cracking. How to present these views on the self is another open question.

What does an office look like that privileges non-seated interaction as well as movement? What is an alternative to a chair that supports periods of incubation and then active work? Should mobile applications literally be focused on maintaining more movement while cogitating?

3. Explicit Tools for Deliberate Practice. There may be new areas of application, beyond neurofeedback, that can deliberately use software and information technology to enhance creative/cognitive performance skills

4. Evaluation. Dietrich's framing of types of knowledge domains, information processes, and creative product evolution offers a space to test creativity design goals. Combined with affordable EEG and related monitoring tools, and the metrics of cognitive/creative assessment, our community has new, vetted tools, whatever their limitations, to at least explore how these metrics may enhance our designs for creativity and cognition.

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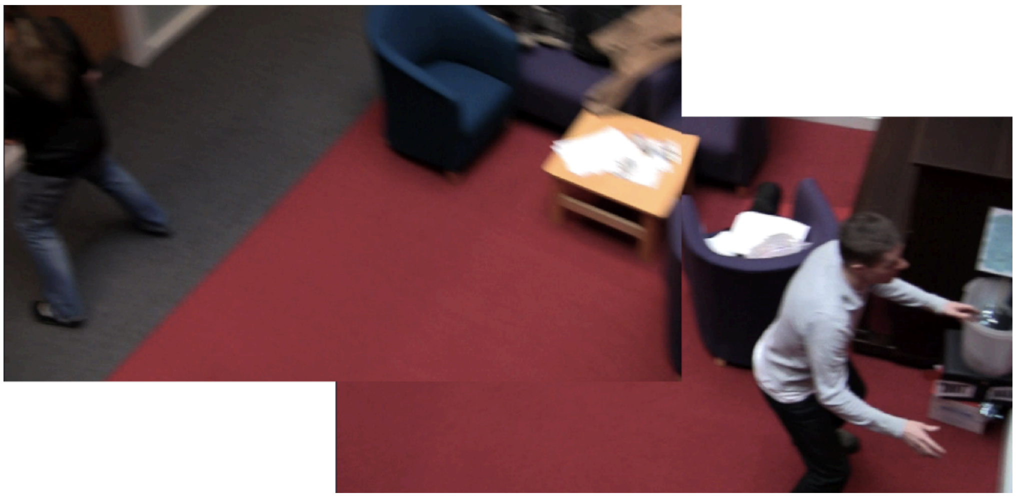

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