Impact and Sustainability of Creative Capacity Building: The Cognitive, Behavioral, and Neural Correlates of Increasing Creative Capacity

Grace Hawthorne, Eve Marie Quintin, Manish Saggar, Nick Bott, Eliza Keinitz, Ning Liu, Yin Hsuan Chien, Daniel Hong, Adam Royalty, and Allan L. Reiss

Abstract The impact and sustainability of creative capacity building over time is examined using both neural and psychological approaches. Our research proposes a unique experimental design to test whether creativity can be acquired or learned by an individual over time and how this relates to cognition, behavior, and the brain. In this chapter, we review the background work that focuses on specific cognitive, behavioral, and neural processes that may contribute to creative capacity building. We summarize key components of our experimental design, overview its implementation, and preview early outcomes of intervention research as it relates to the creative capacity building.

G. Hawthorne (✉) • A. Royalty
Hasso Plattner Institute of Design (d.school), Building 550, 416 Escondido Mall, Stanford, CA 94305-3086, USA
e-mail: grace@dschool.stanford.edu; aroyalty@stanford.edu

E.M. Quintin • M. Saggar • N. Bott • E. Keinitz • N. Liu • A.L. Reiss
Center for Interdisciplinary Brain Sciences Research, Stanford University School of Medicine, 401 Quarry Road, Stanford, CA 94305-5795, USA
e-mail: quintin@stanford.edu; saggar@stanford.edu; nbott@stanford.edu; ekienitz@stanford.edu; ningl@stanford.edu; reiss@stanford.edu

Y.H. Chien
Department of Pediatrics, Taipei City Hospital Zhong-Xing, Institute of Biomedical Electronics and Bioinformatics, National Taiwan University, No. 1, Sec. 4, Roosevelt Road, Taipei, 10617, Taiwan
e-mail: dtpedr81@gmail.com

D. Hong
Institute of Biomedical Engineering, National Taiwan University, No. 1, Sec. 4, Roosevelt Road, Taipei, 10617, Taiwan
e-mail: ddh0410@gmail.com

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1 Introduction

In the last 5 years there's been a seismic shift in what prized, must-have skill is needed to navigate a world of increasing complexity. IBM's Institute for Business Values asked 1,500 chief executives in 2010 what leadership competency they valued above all others to face these challenges (Kern 2010). Creativity topped their charts. In 2011, LinkedIn reported that "creative" was the most popular characteristic people used to describe themselves for professional profiles in the United States (Linked in 2011).

The enormous opportunity of creativity is also the underlying challenge because studying the creative process is not easy. As the cornerstone of innovation, creativity is an elusive human characteristic that can make one individual a better design thinker than another. Regardless if you believe that you were born with an endless supply of creativity or not, knowing that you can acquire it through practice has positive implications across all industries and areas of innovation.

Although there have been several recent studies focused on where creativity originates in the brain (Abraham et al. 2012; Aziz-Zadeh et al. 2013; Fink et al. 2012; Green et al. 2012; Jung et al. 2010a; Jung et al. 2010b; Takeuchi et al. 2012), none have focused on this construct as an acquired individual skill, in particular, assessing a person's capacity to become more creative over time, measuring an individual brain's acquisition of creativity, and determining if regular 'exercise' or practice is required to maintain it.

The Hasso Plattner Institute of Design at Stanford University (Stanford d.school) offers classes specifically aimed at enhancing creative capacity through design thinking skill building. As is custom in the academic tradition, instructors must come up with ways to evaluate their student's progression. Often, students are asked to produce deliverables that are then judged by the instructors and classmates. Although this method has academic value, its purely qualitative nature does not allow a formal assessment or measurement on whether the student's creative capacity has been enhanced. **Thus, our primary question is: Can creativity be acquired or learned by an individual over time and if so, does being more creative change an individual's patterns of thoughts and behaviors and even brain functioning?**

Setting out to tackle this question fueled other questions that will be addressed in this chapter. First, we defined a contemporary working definition of creativity as it is conceptualized by the Stanford d.school. Then we asked what human characteristics does creativity relate to on a psychological and biological level? Specifically, what are the cognitive, behavioral, and neural correlates of creative capacity? If creativity can be acquired or improved, does its maintenance require continuous conditioning (like sit-ups for your body) to be retained? What *new* brain and behavioral features are acquired/enhanced by an individual exposed to a creative capacity building instructional course? What *pre-existing* brain, cognitive, personality and behavioral features predict response to a creative capacity building instructional course?

In the first part of this chapter, we review literature related to these questions as background for studying creativity. In the second part of this chapter, we propose an experimental design to study these questions.

This study involved a multidisciplinary team with representation from the fields of design, arts, cognitive and computational neuroscience, psychology, and psychiatry. These diverse perspectives shape the methodology and outcome value. We opted for an intervention aimed to increase creativity called Creative Capacity Building Program along with a control intervention (Language Capacity Building Program). Before and after the intervention, we collected structural and functional magnetic resonance imaging (MRI) brain scans and we administered neurocognitive, personality, and creativity assessments. This hybrid of neuro-imaging methods, neurocognitive assessments, psychological questionnaires and qualitative surveying will allow us to answer the questions stated above.

2 Creativity

Different fields define creativity in various ways. For the purpose of this study, our definition of creativity is inspired by the philosophy of the Stanford d.school while insuring translation to the field of cognitive neuroscience. We define creativity as "*a state of being and adaptation of personal skill sets that enables an individual to synthesize novel connections and express meaningful outcomes*". This definition captures the intersection of three different axes. To determine how creative a person, deliverable or process is, these components can be rated along three continuums from – (a) existing to new/novel, (b) linear to synthesizing, and (c) no value/meaning to meaningful. We propose a visual illustration of these continuums with three axes (Fig. 1a). A deliverable or process with high novelty, meaning, and synthesis is considered highly creative and so is the person responsible for this deliverable or process. This person, the deliverable, or the process falls within the upper right and back zone of the three-dimensional space created by these three axes (the zone in orange in Fig. 1b). This definition of creativity focuses attention to the person and their skills as opposed to process and outcomes as more traditionally defined. The intention of this focus is to better align the skill of creativity to indications that go beyond the possession of creativity into the ability to exercise/apply it.

2.1 Building Creative Capacity

The Hasso Plattner Institute of Design at Stanford University (the d.school) was founded in the School of Engineering in 2006 to prepare a generation of innovators to tackle the complex challenges facing the world today. Solutions won't come from any single field, but from collaboration between creative thinkers who can see beyond the way the world is, to the way it could be. The d.school brings together students and faculty from radically different backgrounds to develop innovative, human-centered solutions to real-world challenges. Design thinking is best learned

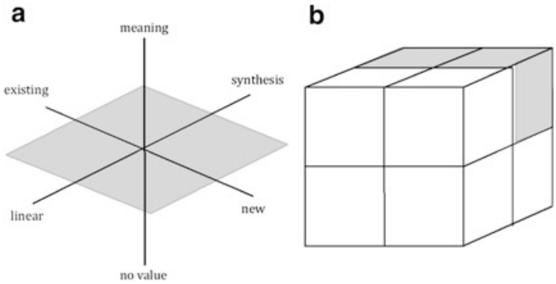

Fig. 1 Visual illustration of our working definition of creativity

by doing, and our classes immerse students in an experiential learning environment. Students cycle rapidly through a series of steps: observe, brainstorm, synthesize, prototype, and implement; repeating as necessary. We focus on the design process because we seek to equip our students with a methodology for producing reliably innovative results in any field. Our focus is on transformative experiences that create innovators rather than any particular innovation.

Creative Gym is a course at the d.school that is devoted to individual skill building. Officially known as ME366, Creative Gym is a graduate level course that has been taught to students and industry executives across many disciplines. The class is an interactive studio where students can build their creative confidence and sharpen their individual design thinking skills through hands-on experiences. Participants engage in unconventional, simple exercises that take them far beyond their everyday experiences in order to train their intuition and push them to think without boundaries in the face of heavy constraints. The Creative Gym experience is an innovative regimen of hands-on exercises and an immersive and interactive experience that is organized around nine core themes that engage our human abilities in intersecting ways.

By introducing participants to fast-paced immersive exercises, the class encourages a potent bias towards action and a deeper understanding of their own personal skills as designers – it gives them a new way to approach life and experience the world that is truly transformative. The resulting bias towards action is their practiced activation of their individual creative capacity.

2.2 How Does Creativity Relate to Cognition, Behavior, and the Brain?

Research on creativity and cognitive processes has typically assessed the relationship between performance on neurocognitive tasks and the performance on measures of creativity. Unfortunately, this work gives us little information on the developmental nature of creativity and the factors that contribute to changes in creativity over time. Nonetheless, surveying the literature guides us in choosing which specific aspects of cognition, personality, and the associated neural correlates may contribute to changes in creativity through time.

Our definition of creativity fits with previous research that has described creativity as a human characteristic. Specific aspects of personality and cognition have been associated with creativity. One of the most renowned ways to characterize different personalities is to assert a value to each of five personality traits: the Big Five personality traits (Costa and McCrae 1992). They include openness, conscientiousness, extraversion, agreeableness, and neuroticism. People who obtain higher scores on standardized assessments of creativity, also score high on measures of openness-to-experience (Funrnham 1999; Jung et al. 2010b; Wolfradt and Pretz 2001). Using other classifications of personality, personality traits of efficacy, independence, cognitive control, tolerance and integrity-honesty were associated to being more creative while emotional stability, anxiety, dominance, aggressiveness, and leadership were associated to being less creative (Sanz de Acedo Baquedano and Sanz de Acedo Lizarraga 2012). Given that personality traits, specifically openness, are associated to differences in creativity between individuals, the same traits could also influence changes in creativity over time and are thus important to consider in our intervention study.

Similarly, factors associated to creativity at the cognitive level may influence response to creative capacity building. Cognitive inhibition, which includes the mental ability to focus attention while inhibiting a prepotent response, plays a role in ideational fluency or the ability to generate ideas quickly while intelligence impacts the originality of the ideas that are generated (Benedek et al. 2012). A cognitive strength of creative people is their ability to focus their attention in the most efficient way to respond to task demands indicating flexibility in adjusting focus of attention (Ansburg and Hill 2003). Vartanian et al. (2007) showed that creative potential is associated with an increase attention when no interference is present. For example, creative people respond faster when asked to press a button every time a stimulus appears on a screen and distractions are minimal. However, Vartanian et al. also showed that creative people respond slower on attention task where interference is present such as having to make decisions about a stimulus based on a set of conflicting rules. An oversimplification of these findings would be that creative people have a more flexible way of using their attentional resources. Fluency, flexibility, and originality are included within divergent thinking abilities, which are more related to creativity than general intelligence (Kim 2008). Thus, research has shown that attention, inhibition, fluency, flexibility are specific neurocognitive factors that influence creative capacity building. These factors are included within the broad concept of executive functions. Executive functions are higher-order cognitive processes required to organize thoughts and behavior. They include inhibition, attention, working memory, planning, organization, and verification. They impact general cognitive ability or general intelligence and divergent thinking, which are also important factors to consider as correlates of creativity.

Recently, a series of neuroimaging studies have focused on the neural correlates of creativity in the brain (Abraham et al. 2012; Aziz-Zadeh et al. 2013; Fink et al. 2012; Green et al. 2012; Jung et al. 2010a; Takeuchi et al. 2010). Although limited to a static view of creativity at one fixed point in time, these studies provide a starting point for our research. In one of the first studies linking neuroanatomy and creativity, Jung et al. (2010b) established a link between cortical thickness in different areas of the brain and creativity. They operationalized creativity using pre-established Creativity Achievement Questionnaire (CAQ; Carson et al. 2005) and divergent thinking tasks and found that thickness of posterior cingulate, left orbitofrontal, and right angular gyrus was related with scores on these measures of creativity. In another similar study, Diffusion Tensor Imaging (DTI) was used to examine the relation between creativity (operationalized using divergent thinking tasks) and white matter integrity in the brain (Jung et al. 2010a). The authors reported that fractional anisotropy (FA) values were inversely related to creativity in the left inferior frontal white matter, which plays a role in executive functioning. FA values are measures of axonal coherence and myelination. Thus, an inverse relation between FA values and creativity suggests decreased myelination in participants scoring higher on creativity. Based on these and other anatomical correlates of creativity, we also plan to obtain DTI scans and assess whether DTI metrics including FA are associated with creative capacity building.

Apart from structural predictors of creativity, researchers have also investigated brain connectivity predictors for creativity. For example, a recent study by Takeuchi et al. (2012) examined the brain's functional connectivity while participants are at rest (i.e. not involved in any active task; a.k.a. rFC) to find out which neural circuits of the resting brain are related with creativity (operationalized using divergent thinking tasks). They found that higher scores on creativity tasks were associated with higher connectivity between medial prefrontal cortex (mPFC) and posterior cingulate cortex (PCC) in the brain. The mPFC and PCC regions are usually considered to be key components of default mode network (DMN), which deactivates as soon as a participant actively performs a task requiring significant cognitive processing. The authors suggest that participants achieve higher creativity through increased interaction within DMN, thereby combining ideas represented in different regions in the network. Thus, the DMN is also important to consider in our study of creative capacity building.

In search of neural correlates of creativity, researchers have also examined functional activity in the brain while participants were performing tasks that required creative solutions (Arden et al. 2010; Dietrich and Kanso 2010 for review). Most researchers have mainly focused on divergent thinking aspect of creativity. However, a few have also attempted to find neural correlates of creative problem solving in real world-like situation. For example, Fink et al. (2012) tested whether the exposure to other people's ideas would impact the creativity of participants engaged in a divergent thinking task. The authors simulated brainstorming sessions and found that cognitive stimulation by exposing common or moderately creative ideas improved the participants' creativity. Temporo-parietal brain regions (in right hemisphere) were found to be sensitive to such cognitive stimulation, by possibly playing the role of integrating new information and previous knowledge.

Altogether, neuroimaging research suggests that many brain regions are associated with creativity, many of which are in frontal brain regions. This has been demonstrated by examining brain structure, the DMN, anatomical connectivity within the brain (via DTI techniques), or brain activation associated with performance on divergent thinking tasks. Our study will include these techniques to identify neural correlates of creative capacity building.

3 Experimental Design

Using a scientific method to approach the question of creative capacity building, we propose a unique and novel experimental design (see Fig. 2), where we collected data related to creativity, cognition, behavior, and the brain before (time 1 or T1) and after (time 2 or T2) a creative capacity building program based on the Creative Gym class offered at the d.school. We also included a control group receiving a Chinese language and character drawing learning intervention (or Language Capacity Building Program). Both interventions lasted 5 weeks with weekly meetings of 2 h per week. Participants were randomly assigned to either intervention. Thus, there were two groups of participants. The groups were matched on age, gender, and IQ. Following the intervention and time 2 data collection, the groups crossed-over to receive the other intervention, i.e. participants in the creative capacity building group were assigned to the Chinese language and character drawing learning intervention and vice versa. The second set of interventions was followed by assessments and brain scans at time 3 (or T3). This experimental design allows us to compare changes in cognition, behavior, and brain function from time 1 to time 2 between groups (creative capacity building program vs. control) and assess whether these changes are maintained over time (from time 2 to time 3). Thirty-six people completed our first testing point (T1 in Fig. 2). Participants were randomly divided into two groups of 18. Figure 2 shows how many participants completed each portion of the experimental design.

Our recruitment surpassed what we had initially proposed in the grant. To recruit participants, we sent out advertisements for our study to family and friends and listservs for groups on Stanford University's campus and in the area. Ninety-two people replied with an interest for the study. We then contacted each of these 92 people to verify if they met inclusion criteria for the study. Thirty-six of the 92 people met the criteria for inclusion in the study. Participants were not eligible if they were fluent in Chinese and knew how to write Chinese characters. Exclusion criteria also included left-handedness, non-removable metallic devices, a history of neurological or serious psychiatric disorder, pregnancy, and some types of medications. Participants were aged between 18 to 39 years old and were available for the entire study, which included two 5-weeks trainings sessions and MRI brain scans, neurocognitive, and behavioral assessments at three time points. In total, this represents a 30–35 hour time commitment for each participant over approximately 15 weeks. In total, 6 (of the initial 36) participants did not complete the entire research protocol for personal reasons. Each participant terminating their participation was debriefed by one of the experimenters.

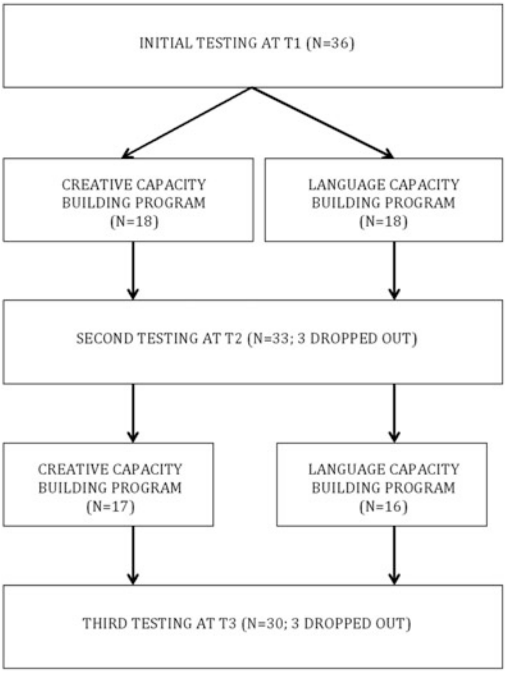

Fig. 2 Visual overview of our experiment design

4 Interventions

All participants underwent both training sessions during the study, what differed between groups was the order they received the interventions.

4.1 Creative Capacity Building Program

For this study, we created a short version of the d.school “Creative Gym” class. The adaptation of the class engaged participants in best of breed, fast-paced immersive exercises from each of the original course’s nine themes. In an open design studio setting, participants worked individually on unconventional, fast-paced immersive exercises. The hands-on activities used everyday office supplies as materials. Participants were able to reflect on their exercises through post-activity reflections and viewing other participants’ work. Each training session was comprised of a diverse variety of activities that were made known to the participants as they were assigned to them.

4.2 Language Capacity Building Program

In this intervention, participants learned how to pronounce some basic Chinese words and the general rule of writing Chinese characters. This was done in a group setting to recreate the shared environment atmosphere of the design studio. Participants copied and practiced Chinese characters with regular pens and by using traditional Chinese brush and ink (calligraphy) on tracing books. This part of the intervention gave an opportunity for hands on exercise while minimizing creative generation of ideas. To motivate participants, the instructor briefly introduced Chinese history and Chinese calligraphic history.

5 Assessments and Data Collection

To provide a glimpse of the richness of multiple dimensions of the collected data, we provide a brief introduction to the most important measures that were used at various time points (Fig. 3).

5.1 Assessing Creativity

As an index of creativity, we used the Figural Torrance test of creativity thinking (fTTCT), the Design Thinking Creativity Test (DTCT), the Creative Agency and Confidence Questionnaire (CACQ), and the Creative Achievement Questionnaire (CAQ). The fTTCT, CTCT, and CACQ were administered at each time point (T1, T2, T3) while the CAQ was only administered at the first time point. The fTTCT includes three picture-based exercises to assess five mental characteristics: fluency, resistance to premature closure, elaboration, abstractness of titles, and originality. It also provides scoring for the following creative strengths: emotional expressiveness, internal visualization, storytelling articulateness, extending or breaking boundaries, movement or action, humor, expressiveness of titles, richness of imagery, synthesis of incomplete figures, colorfulness of imagery, synthesis of lines or circles, fantasy, and unusual visualization (Torrance 1974). The DTCT, developed at d.school by Hawthorne et al., is a companion assessment to the TTCT that reflects problem solving needs in the twenty-first century by testing an individual's ability to exercise their creativity effectively in real world scenarios. The CACQ, also developed at d.school by Royalty et al., is a self-reported scale to evaluate subjects' creative self-efficacy and perception of their own creative capacity. Finally, the CAQ is a reliable and valid measure of creative productivity across ten domains including visual arts, music, creative writing, dance, drama, architecture, humor, scientific discovery, invention, and culinary arts (Carson et al. 2005).

AREA ASSESSED	NAME OF MEASURE	DESCRIPTION	TIME POINT T1	T2	T3
General intelligence	Wechsler Abbreviated Scale of Intelligence (WASI)	This test measures verbal knowledge, reasoning ability, concept formation, visuospatial problem solving, and abstract reasoning	X		
Executive function	Delis-Kaplan Executive Function System (D-KEFS)	This test is used to measure a variety of verbal and nonverbal executive functions including attention, inhibition, and flexibility	X	X	X
Creativity	Figural Torrance Test of Creativity Thinking (TTCT)	Uses picture-based exercises to assess: fluency, resistance to premature closure, elaboration, abstractness of titles, and originality	X	X	X
Creativity	Design Thinking Creativity Test (DTCT)	Uses a scenario-based activity to assess application of creative characteristics	X	X	X
Creativity	Creative Confidence Questionnaire	Self-assessment to capture creative self-efficacy and agency	X	X	X
Creativity	Creativity Achievement Questionnaire (CAQ)	Measures creative productivity across ten domains including visual arts, music, creative writing, dance, drama, architecture, humor, scientific discovery, invention, culinary arts	X		
Personality	NEO-FFI-3	NEO-Five Factor Inventory (NEO-FFI) was used to assess the personality types for each participant	X		
Neuroimaging	Structural Brain Imaging (MRI)	Provides information about the anatomy of the brain: volume, thickness, and surface area of different brain structures	X	X	X
Neuroimaging	Functional Brain Imaging (fMRI)	Provides dynamic information about the functioning of the brain while the participant is performing a task	X	X	X
Neuroimaging	Resting State Brain Imaging (fcMRI)	Method for evaluating regional interactions that occur when a participant is not performing any explicit task (a.k.a. Default-Mode-Network)	X	X	X
Neuroimaging	Diffusion Tensor Imaging (DTI)	Used to infer connectivity amongst brain regions	X	X	X

Fig. 3 Summary table of assessments

5.2 *Assessing Cognition and Behavior*

Given previous evidence of personality traits, specifically openness, on creativity, we used the NEO-Five Factor Inventory (NEO-FFI-3, Costa and McCrae 2010) to assess the personality traits for each participant. It has 60 questions (12 per domain) evaluating the following personality traits: extraversion, agreeableness, conscientiousness, neuroticism, and openness to experience. This measure was only administered at the first time point because personality traits are thought not to vary through time.

We administered an IQ test to verify that groups did not differ on this factor to ensure that potential group differences in creative capacity would not be attributable to an IQ difference between the groups. IQ is also stable through time and was thus only assessed at the first time point. We used the Wechsler Abbreviated Scale of Intelligence (WASI-II, Wechsler 2011). This test includes two subtests of verbal knowledge, reasoning ability, and concept formation and two subtests of visuospatial problem solving and abstract reasoning.

Other neurocognitive factors that may influence creative capacity building include attention, inhibition, fluency, and flexibility. These factors can be included within the broad concept of executive functions. We hypothesized that some components of executive functioning may change as creative capacity changes and we thus assessed these functions at each time point (T1, T2, T3). We used three subtests of the Dellis-Kaplan Executive Functions Systems Test (DKEFS, Delis et al. 2001). The verbal fluency and design fluency subtests measure fluency, flexibility, executive memory, and inhibition. The color-word interference test measures inhibition and flexibility.

5.3 Assessing the Neural Correlates of Creativity

In order to find the neural correlates of creativity, we employed a series of neuroimaging techniques and collected data at all the three time points. Starting with the anatomical correlates of creativity, we acquired structural MRI data that will allow us to measure changes (if any) in brain structure associated with creativity training. We also plan to use the anatomical data (at T1) to predict improvements in creativity after training (at T3). Second, using High Angular Resolution Diffusion Imaging (HARDI) technique we also acquired anatomical connectivity information. Using anatomical correlates we plan to not only identify the regions associated with creative capacity, but also to use these correlates in conjunction with other assessments for predicting and understanding subject-to-subject variability in the dataset. For example, we can find out whether certain brain areas or networks are correlated with increased creative capacity and how they change over time.

To find the functional correlates of creativity, we used functional brain imaging (fMRI). This method provides dynamic information about the functioning of the brain while the participant is performing a task in the scanner. In our case we used the following two tasks to investigate neural correlates of increased creative capacity. Both of these tasks were implemented using a novel MRI-safe drawing tablet that was designed especially for our project by Dr. Bob Dougherty (Director, Center for Cognitive and Neurobiological Imaging, Stanford University).

The first task, the trail-making test, is an fMRI adaptation of a neurocognitive assessment commonly used outside the scanner to measure visual attention and flexibility or shifting, which have been associated with creative capacity. The task consists of two parts in which the participant is instructed to connect a set of 12 dots as fast as possible while still maintaining accuracy. It can provide information about visual search speed, scanning and speed of processing, mental flexibility, and executive functioning. In part A, participants connected numbers in sequential order (1, 2, 3, etc.). In part B, participant connected an alternating sequence of numbers and letters (1, A, 2, B, etc.). Participants used the MR-safe drawing tablet to complete this task.

The second fMRI task is a novel task that was designed specifically to measure the participant's creative capacity. Saggar et al. created an experimental task inspired by the Pictionary™ game (Designers: Angel and Everson 1985) and adapted to imaging constraints. In condition A, participants were shown a word (usually a verb) and were asked to draw it using the MR-safe drawing tablet so that the word/action can be recognized. This is an open-ended task where participants can draw as much or as little as they deem appropriate. This task involved several components of the creative capacity building intervention implicitly, for example, it involved building, synthesis, navigation, etc. In condition B of the task, participants were asked to draw a control word, "zig-zag".

Altogether, using a myriad of behavioral and neuroimaging tests we planned to explore the correlates of creativity capacity building in an exhaustive manner.

6 Implications

Preliminary findings have been generated, that we invite the reader to interpret with caution until the findings are published in a peer-reviewed scientific article. The results comparing group performance on neurocognitive and behavioral tasks suggest that the creativity training intervention did successfully improve some aspects of creativity and had an impact on some components of executive functioning (Bott et al. 2013; Kienitz et al. 2013). Changes in creativity and executive functioning do not seem to be dependent on personality types. Preliminary findings from our imaging tasks also indicate that the creativity training intervention was associated with changes in the neural resources associated with executive functioning and imagination.

7 Looking Ahead

New findings on the brain basis and sustainability of creative capacity and design thinking skills will provide completely unique information to the field. This information has the potential to profoundly influence our understanding of human brain and behavior links underlying design thinking during the phenomenon of innovation.

By understanding if a person can improve their creative capacity and whether it is retained, metrics and method of increasing creative and instructional effectiveness can be improved. By diving deeper into the question of individual skill building and creativity retention over time, we can discover the true value of design thinking during the phenomenon of innovation and know better how to teach it.

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