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Investigating Triple Process Theory in Design Protocols

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Abstract

This study presents a coding scheme for design protocols that is derived from Triple Process Theory postulating the existence of three categories of cognitive processes: spontaneous, deliberate, and metacognitive. We applied the coding scheme to think-aloud protocols of designers engaged in an open design task. Results show that all three types occur during designing. The scheme we propose has the potential to ground accounts of Triple Process Theory for design in empirical studies. We explore the relation between design sessions outcomes and shifts between cognitive processes.

Keywords: process analysis, metacognition, design cognition, design theory, design protocols

1. Introduction

Testing cognitive processing theory in design research can shed new light on how cognitive activity unfolds while designing. Attempts have mostly focussed on interpreting models of dual process theory (Evans and Over, 1996; Sloman, 1996; Stanovich, 2004; Kahneman, 2003). The notion that cognitive processing is based on two concurrent major systems (Wason and Evans, 1974), has raised much discussion in the last 50 years (Evans, 2019; Goel, 2022), from Sloman's (1996) distinction between two types of cognitive processes to the critique of how dual process theory to some extent might have prevented scientific progress (Goel, 2022; De Neys, 2021). Still, it is widely accepted to distinguish between processes that are considered spontaneous and reflexive, and processes that are considered analytical and deliberate. For example, dual process models in the context of creativity research have explored how creative ideas arise from the interplay of spontaneous and deliberate thinking (Sowden, Pringle and Gabora, 2015; Benedek and Jauk, 2018). However, the various theories of dual processing (as reviewed by Evans and Stanovich, 2013a; Evans and Stanovich, 2013b) describe attributes that cannot easily be mapped onto just two categories of cognitive processing (Evans, 2018; 2019). Difficulties to accommodate findings of logical intuitions in dual process modes of reasoning have led to other theoretical approaches (Sowden, Pringle and Gabora, 2015; Benedek and Fink, 2019; Goel, 2022). Tripartite models of cognitive processing theory have been proposed (Evans, 2009, 2019; Thompson, 2009) on the assumptions that a third instance determines which of the two processes is to be used, a system that acts as referee (Evans, 2019). The literature suggestions span from the "idea monitor" (Nijstad et al., 2010) to the need to separate reasoning from monitoring and cognitive control (e.g. the ‘reflective mind’, Stanovich, 2009), or related to cognitive styles (Evans, 2009) or as a product of metacognitive processes (Thompson, 2009; Ackerman and Thompson, 2017), and further distinctive models are still being proposed (Goel, 2022).
In design research, models of dual process theory have been investigated through the analysis of the shifts between divergent and convergent thinking (Goldschmidt, 2016), the analysis of spoken language (Kannengiesser and Gero, 2019), design sketching and gesture (Cash and Maier, 2021), and ideation sketching cycle (Gonçalves and Cash, 2021). So far, models of dual process theory have been

separately investigated from metacognition in design research but have not yet been extended to tripartite models. Tripartite models, including metacognition, have yielded higher acceptance in the field of artificial intelligence (Sloman and Chrisley, 2003; Samuels, 2005). Still, design research has increasingly explored the role of metacognition, which can be viewed as a third category of cognitive processes, besides spontaneous, reflexive thinking and deliberate, analytical processing. The theoretical understanding of metacognition in design has focussed on strategic processing (Ball and Christensen, 2019; Hay et al., 2020), and has resulted in evidence for design strategies such as solution versus problem driven (Kruger and Cross, 2006), analogical reasoning (Ball and Christensen, 2009), mental simulation (Ball and Christensen, 2009), limited commitment mode (Kim et al., 2007), fixated solution generation (Crilly, 2019) and epistemic uncertainty in design teams (Christensen and Ball, 2018). Inherent to designing and common in reasoning theories is the metacognitive component of "satisficing" (Ackerman and Thompson, 2017), a mechanism of choice that would suffice when pursuing a path that will permit satisfaction at some specified level of all its needs (Simon, 1956). The role of metacognition and executive functions in monitoring and understanding knowledge, experiences and regulating behaviour (Roebers, 2017) and in monitoring the subjective feelings of certainty and uncertainty (Ackerman and Thompson, 2017) has led to further emerging themes in design research.

Investigating and understanding how the metacognitive processes play a role in designing has the potential to add explanatory power beyond dual process theory, of relevance to design research. To this end, we propose a triple process model for design cognition and we outline a coding scheme that can be applied to the study of think-aloud design protocols. Besides this methodological development, we provide a first empirical test of the model by analysing available think-aloud data during a design task. The proposed model has the potential to ground accounts of Triple Process Theory for design in empirical studies. The operationalization of metacognitive processes in design research can open avenues for the development of explanatory models of higher predictive power. We investigate the following research questions: (RQ1) What is the reliability of the coding scheme on *spontaneous, deliberate* and *metacognitive* processes of spoken language in an open design task? (RQ2) What and how do shifts occur between *spontaneous, deliberate* and *metacognitive* processes while designing?

2. Triple Process Theory in Design

We propose a model of Triple Process Theory in design (Figure 1), resulting from the analysis of literature on concurrent cognitive processing (Thompson, 2009; Sowden, Pringle and Gabora, 2015; Ackerman and Thompson, 2017; Benedek and Jauk, 2018; Evans, 2019; Gilhooly et al., 2007; Stanovich, 2009), which assumes three categories of cognitive processes that can be identified from designers' verbalizations while designing:

- *Spontaneous*: design-related thinking of reflexive and automatic nature, namely *task reiteration,* repeating words and phrases from the task instruction, or *spontaneous generation,* generative processes that add elements to producing solutions and sub-solutions, or self-related thinking such as *self-questioning*.
- *Deliberate*: design-related thinking of deliberate nature, namely, *deliberate generation,* articulated development of the idea, the design or solutions, or *analysis,* manifested in the appraisal of appropriateness or approval of the design.
- *Metacognitive*: task-related or process-related thinking of reflective and evaluative nature, namely, *thinking about thinking,* or task-progress related, self-related and non-design related thinking of reflective and evaluative nature namely, *task progress assessment*. From the two sub-categories of processes underlying metacognitive judgments, *thinking about thinking* is information-based, *task progress assessment* is experience-based (Koriat and Levy-Sadot, 1999). These metacognitive processes reflect the monitoring of one's own knowledge whether conscious or yet unknown.

The designers' thoughts and inner speech reveals connections between spontaneous, deliberate and metacognitive processes. These connections are supported by spontaneous or articulated language when making sense of information, knowledge and experience while pursuing to accomplish a design. The present Triple Process Theory model assumes dynamic shifts and halts within and between the

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three main categories of processes (Figure 1), which define the progression of the design process and determining the design outcome. The literature suggests that shifting between the concurring cognitive processes can be conducive to providing means to escape impasses of thought (Benedek and Jauk 2018), and to generate candidate solutions that subsequently get elaborated and evaluated for appropriateness in an iterative manner (Finke et al., 1992). Dual-process models (Finke et al. 1992; Goldschmidt, 2016) and the theory of the emergence of a creative insight (Gabora and Ranjan, 2013) suggest shifting between types of thinking occurs repeatedly (Sowden, Pringle and Gabora 2015), as top-down and automatic bottom-up shifting processes are supposed to drive adjustments in the focus of attention (Vartanian, Martindale and Matthews, 2009). Whether these mechanisms are dominant might depend on the task and design stage (Nijstad et al., 2010; Sowden, Pringle and Gabora 2015).

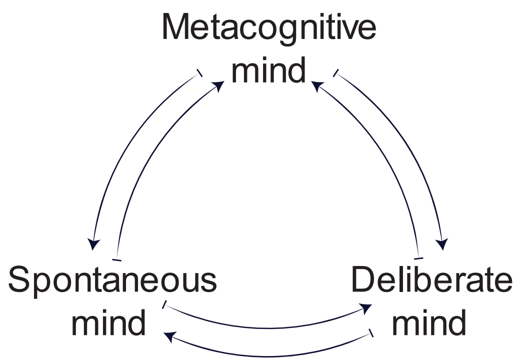

Figure 1. Illustration of the Triple Process Theory model based on the analysis of spoken language, which assumes three categories of cognitive processes during designing, Spontaneous, Deliberate, and Metacognitive and the shifts between them.

With this initial study we aim at testing the coding scheme and explore the feasibility of identifying processes of shifting between them from think-aloud protocols during designing.

2.1. Identifying cognitive processes through Verbalizations

Verbalizations of thoughts provide the means to assess the outcome of the person's cognitive processes and whether further action to be taken is determined (Thompson, 2009). This is recurrent in designing as designers observe and interpret the results of their actions and sketching and decide on new actions to be executed (Schön, 1992). Conceptualisation and abstract, meta-representational thought are supported by language. Spontaneous verbalizations are characterized by having little chance for reflection, thought, or fabrication (Ward, 1989) conceived and perceived during their utterance. Spontaneous verbalizations are identified by: repeating words or phrases, complete or truncated preceding a restart; missing, unknown or mispronounced words as a possible gap in the semantics; spurious words or phrases leaving part of the input unaccounted, but the utterance is semantically complete; grammatical misconstructions such as errors of agreement, verb, number. Deliberate verbalizations are characterized by utterances that show deliberate constraints that serve to limit, frame or filter the contents of thought and how these contents change over time, in each mental state and between mental state transitions. Metacognition, defined as the cognition about cognitive phenomena (Flavell, 1976), is described as the awareness of one's own thinking and content of conception, and active monitoring of cognitive processes. Metacognition is also considered to support the conscious and the unconscious minds. The conscious mind is language-dependent, as conscious reasoning involves producing and monitoring sentences of inner speech and other forms of mental imagery, preceding strategies motivated by nonconscious metacognition (Evans, 2009).

2.2. Coding Scheme

We propose a Triple Process Theory coding scheme that distinguishes different cognitive processes for each category, which will now be further described and supported with definition, identification criteria

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(some adapted from Gilhooly et al., 2007) and examples. In a first step, a grounded theory approach to identify the main categories of cognitive processing from the data was taken while available literature guided the development of the scheme (Creswell, 2014) as further detailed in section 3.1.

2.2.1. Spontaneous

- *Task reiteration,* repeating or evoking words from the task request in a design problem-related manner.
- *Self-questioning,* queries about the design, or the self. Example: *"More? What else can I have here?"*
- *Spontaneous generation,* verbalized thoughts about the idea, the design, or solutions described in an automatic, rapid, effortless manner (Benedek and Jauk, 2018). These thoughts can be information from memory not necessarily complete and represent possible starting points to facilitate generating characteristics of the design (Ward and Kolomyts, 2010), for which reduced control might even be beneficial for creativity (Chrysikou et al., 2014).

Identification criteria: statements without explanation, of possible characteristics with reference to a specific memory (episodic memory), dominant feature, use, or function, repeating function or other characteristics, properties of the design, impasse indicating the participant cannot report any further features (Gilhooly et al., 2007), reconstructive interference, where contextual interference during recall can foster creative associations (Gabora and Ranjan, 2013). Examples: *"and it would be an object, it would be a spherical object"*, *"and will have a semi-high-tech form, we might say"*, *"to empower actions, mechanics, makers"*.

2.2.2. Deliberate

- *Deliberate generation,* verbalized thoughts while producing or elaborating the idea, the design or solutions, in a controlled, and analytic manner often including details and explanations (Benedek and Jauk, 2018). These thoughts include processing of various types of information (Ward and Kolomyts, 2010) and may generate new ideas and insights (Finke, 1996).

Identification criteria: statements of specific category exemplars, mentioning justifications and context in which the design or feature is often or can be found, restructuring based on information gained during failed efforts, decomposing the design or feature, and using the resulting components, general knowledge, application of knowledge (Gilhooly et al., 2007). Examples: *"even for example, sometimes immaterial memory", "these stories would appear on the scene", "would be an object that potentialized communication between people".*

- *Analysis*, verbalized deliberate thoughts while examining the esthetical, functional, structural, material, economic characteristics of the design, solutions, sub-solutions or production, in isolation or in context.

Identification criteria: assessment of utility, structural, user, economic and esthetical performance. Examples: *"It does not have great validity from the point of view of its aesthetics"*, *"but it is a notoriety so superfluous"*, *"it is not very representative"*, *"which is to be balanced and pleasant to the eye. Symmetrical"*.

2.2.3. Metacognitive

- *Thinking about thinking,* showing thinking about the task, the process or judgment of ideas in a reflective, or evaluative manner.

Identification criteria: conscious, goal-directed strategies, conscious monitoring of the task and process, revising the strategy, judgment of solvability (Ackerman and Thompson, 2017; Thompson, 2009). Examples: *"The first issue is the difficulty of interpreting the object itself, and the visual coding of the object itself"*, *"Now establishing a better view of how this could work"*, *"I'm having some ideas here"*, *"I will try to reinforce what are the determining elements"*.

- *Task progress assessment,* assessing and monitoring the progress and success with the task and global judgment of ideas.

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Identification criteria: feeling of rightness without explicit argument (Ackerman and Thompson, 2017; Thompson, 2009), modulating cognitive inhibition (Sowden, Pringle and Gabora, 2015), a few minutes of task-unrelated thought leading to more remote associations and creative solutions (Dijsterhuis and Meurs, 2006), perception of the self, as subjective feelings of certainty and uncertainty (Ackerman and Thompson, 2017). Examples: *"I have no idea", "I do not know what I'm going to do", "And that's it, that's it", "I think I'm done", "I think the time is running fast".*

3. Methods

The development of the coding scheme followed methodological recommendations (Creswell, 2014) as described in sections 2.1 and 3.1. The research questions are investigated by implementing the coding scheme for the analysis of *spontaneous, deliberate* and *metacognitive* processes in the think-aloud protocols of designers while performing an open design sketching task (Ericsson and Simon, 1993). This study extends from a research project previously reported (Vieira et al., 2020; 2022). The full experimental design included four different tasks proposed to the subjects from which we selected the open design sketching task for testing the coding scheme of the Triple Process Theory, because it is arguably the least restrictive with respect to cognitive processes in design. As participants propose and develop one concept, we started by testing our coding scheme with this elemental unit of analysis. By temporally segmenting verbalizations for each participant, it is possible to distinguish the three categories of cognitive processes across design sessions. The analyses focus on time and frequency observed along the three categories of cognitive processes and the occurrence of shifts between them. The task and experimental procedure were piloted prior to the full study (Vieira et al., 2020).

3.1. Data Processing and Coding Procedures

We examined the time-course of the verbalizations of the designers while performing the task. The data sources were synchronized by time-locking the verbalization concurrent with the observation of the videos. The participants' verbalizations during the task were first transcribed and then translated from Portuguese to English language. The transcripts were analysed, segmented and coded by two coders and then arbitrated by a third researcher. A code book was elaborated on the structure of the categorization system supported by examples from the literature (Creswell, 2014) shared and honed among the authors. The codebook entails the definition of categories and sub-categories, criteria of analysis, identification criteria and examples (see section 2.2). The first coding stage was based on a grounded theory approach to identify possible categories of cognitive processes from the data in parallel with constant updating of the literature. The second coding stage was based on a semantic analysis, line by line, identifying spontaneous, deliberate, and metacognitive verbalizations (as described in 2.1). The third coding stage was based on statements identified according to the coding scheme categories' and sub-categories' identification criteria (as described in 2.2).

3.2. Participants

We invited designers demographically having the same characteristics, such as language and culture, to the experiment. Participants chose whether to perform the experiment in silence (n=108) or think-aloud (n=18). Information on the 18 volunteers' demographics was gathered beforehand. Results are based on 15 right-handed designers, healthy individuals with no pragmatic disorders, aged 21-50 (M = 31.1, SD = 9.0), 10 men (age M = 30.4, SD = 7.7) and 5 women (age M = 32.6, SD = 12.2). The participants are all professionals (experience: M = 8.1 years, SD = 8.6). The volunteers are designers from the domains of industrial design, architecture, and mechanical engineering. This study was approved by the local ethics committee of the university that the lead author of this paper was affiliated with.

3.3. Experiment Design

The participants were asked to propose and represent an outline design for a future personal entertainment system. The task included free-hand sketching and notations. This task is an ill-defined and unconstrained task. The experimental design, setup and complete procedure has been previously reported (Vieira et al., 2020). One researcher was present in each experiment session to instruct the participant and to check for

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recording issues. A period of 10 minutes for setting up and a few minutes for a short introduction were necessary for informing each participant, reading and signing of the consent agreement and to set the room temperature. The researcher followed a script to conduct the experiment so that each participant was presented with the same information and stimuli. The participants were asked to start by reading the task request. Each participant was given two sheets of paper (A3 size) and three instruments, a pencil, graphite and a pen. Participants took an average of 13:12 minutes (SD = 4:45 min) for the total task, 7.7 seconds (SD = 2.9) for reading the task, 13:04 minutes (SD = 4:44 min) for sketching which included notations. Most participants generated one design solution or sub-solutions. We examined the verbalisations after the reading of the task request.

3.4. Data collection

The participants performed the task, with two video cameras capturing the participants' face, posture, gesture and sketch development, and an audio recorder to record verbalizations via microphone. All the data captures were streamed using Panopto software (https://www.panopto.com/). The experiment sessions took place at the university that the first author was affiliated with, between March and July of 2017 between 9:00 and 15:00.

4. Analysis of Results

4.1. Triple Process Theory Coding-scheme Reliability

All 15 protocols were coded, with an inter-coder agreement of 84% and an inter-coder reliability (Cohen's kappa) of .83. Using the interpretation of Cohen's kappa from Fleiss (2003) and Landis and Koch (1977) the agreement is considered *"excellent"* or *"almost perfect"* and answers RQ1.

4.2. Shifts between Spontaneous, Deliberate and Metacognitive processes

We examined the time spent in each category of cognitive process across the 15 protocols. The results are based on the verbalizations that constitute 91% of the total time (the remaining 9% include modes of design representation such as gesture and sketching). Results reveal the average percentage of time spent in each category, across the protocols. On average, most time was spent in *deliberate* processes, 48%, followed by 31% in *spontaneous* and 21% in *metacognitive* processes. Shifts between the three categories unfold in three kinds: Dual shifts, between *spontaneous* and *deliberate* cognitive processes, and two categories of metacognition-mediated shifts, namely, Meta 1, between *metacognitive* and *spontaneous*, and Meta 2, between *metacognitive* and *deliberate* processes. The designers performed an average of 13,2 Dual shifts, and 17 Meta shifts (Meta 1= 9,4; Meta 2=7,6) while designing for an average of 13:04 minutes. Although less frequent than *spontaneous* and *deliberate*, the 20% of time spent in metacognitive processes play a prevalent role mediating the shifting between them and answer RQ2.

4.3. Qualitative Analysis of Shifts: Dual, Meta 1 and Meta 2

The illustrative results from the qualitative analysis of the shifts occurring during the course of a design session reveal similarities and differences across the 15 protocols. We explored the relation between individual design outcomes and shifts between cognitive processes. Cumulative occurrence graphs were used for representing the temporal development of Dual, Meta 1 and Meta 2 shifts per design protocol. From selected exemplary protocols (Figure 2), we present how the cumulative occurrence of the three kinds of shifts translate into design issues identified in the design protocols by the authors such as fixation (Crilly, 2019) or primary generator (Darke, 1979). These qualitative results also answer RQ2.
Meta 1 shifts appear at the very beginning of the tasks, intertwined with Meta 2 shifts for introducing the first ideas (two examples, Figure 2), followed by the start of sketching, sometimes prompted by Dual shifts (highlighted in the second example of Figure 2). We first divided the protocols in two groups, as four protocols (group 1) revealed less successful performance due to fixation from the previous task (Crilly, 2019) or stuckness (Sachs, 1999), while the remaining 11 protocols (group 2) revealed better performance. The results of the unpaired t-test comparing the frequency of each kind of shift between the two groups revealed statistically significant difference, $t(13)=2.27$, $p=.040$, for the Dual shifts, more frequent in the second group (example of primary generator, Figure 2).

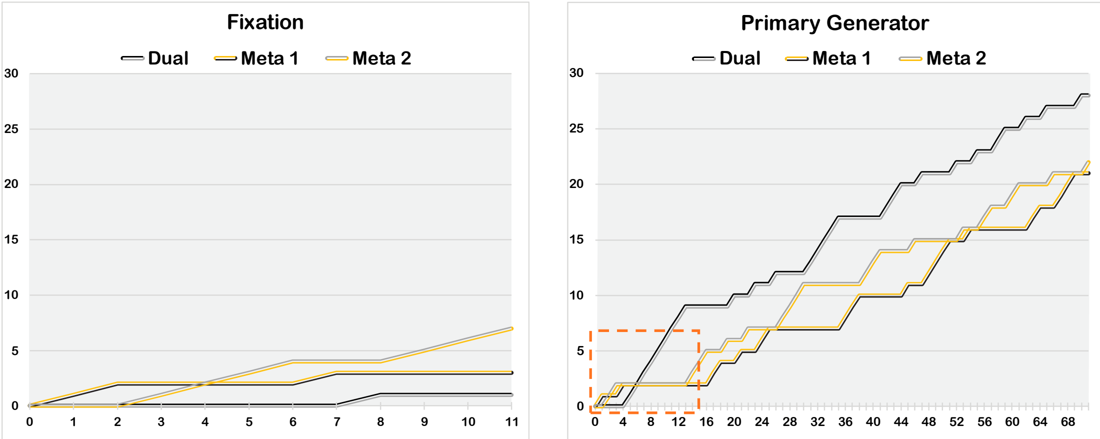

Figure 2. Examples of Dual, Meta 1 and Meta 2 cumulative shifts in the open design sketching task from two exemplary protocols.

The 11 protocols of group 2 were divided in two groups, as five elaborated and detailed the designs and six stayed with the concepts. The results of the unpaired t-test comparing the frequency of each kind of shift between these two groups revealed statistically significant difference, $t(9)=3.01$, $p=.014$, for Meta 2 shifts, more frequent in the sessions of more elaborated and detailed designs. The 11 protocols were regrouped, as six mostly sketched designs from previous knowledge while five remained open to newness while designing. The results of the unpaired t-test comparing the frequency of each kind of shift between these two groups revealed statistically significant difference, $t(9)=2.46$, $p=.035$, for Meta 1 shifts, more frequent in the protocols of designers that remained open to newness. The plots illustrating the cumulative occurrence of the three kinds of shifts have the potential to characterise the core design issue inherent to each protocol, such as periods of fixation versus fluent generation (Figure 2). These examples illustrate the potential of the coding scheme to ground accounts of Triple Process Theory for empirical studies in design research.

5. Discussion and Conclusion

With this study, we extended from the literature on concurrent cognitive processing and proposed a methodological development by presenting a Triple Process Theory model and implemented its coding scheme for the analysis of think-aloud design protocols of designers while designing one single concept for an open design task. Results provide initial answers to the research questions:

a) From the methodological implementation of the coding scheme on *Spontaneous*, *Deliberate* and *Metacognitive*, we found that cognitive processes can be derived from spoken language with high reliability. Results reveal prevailing frequency and timing for all the three categories of cognitive processes. Think aloud protocols of open design tasks thus seem an adequate source for identifying the three types of cognitive processes during designing which offers valuable process data to study complex design cognition in greater detail.

b) Three kinds of shifts can be observed to occur between the three categories of cognitive processes: Dual, Meta 1, and Meta 2, with prevailing frequency for all. Patterns between shifts can illustrate and exemplify known phenomena such as fixation or primary generator.

The three kinds of shifts occur with higher frequency in more successful protocols and can play decisive or constraining roles where well-founded or premature decisions are made on the path to follow, where change or the exponential development of the design and closing remarks announcing the conclusion of the designing process can happen. Shifts mediated by metacognitive processes play a role in designing and its investigation has the potential to add explanatory power (Gilhooly et al., 2007) beyond dual process theory, of relevance to design research. Neuroscientific evidence suggests a correspondence between triple process theory and the triple network model (Menon, 2011). The salience network (SN) is involved in modulating the switching between the default (DN) and executive control networks (ECN; Menon and Uddin, 2010) and in detecting the integration of sensory and emotional stimuli (Downar et al., 2000). Activity of the salience network has been positively correlated with metacognitive abilities (Quattrini et al., 2019). Importantly, higher connectivity

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between core nodes of the DN, ECN, and SN predicts more creative performance (Beaty et al., 2016, 2018). Although preliminary, these results shed some light on neural correlates of Triple Process Theory. In future papers we will explore EEG frequency band power associated with the three categories of cognitive processes. We will also investigate how the present results relate to the data on sketching and gesture of the same protocols. Future studies can provide means to advance the investigation of the direction of the shifting between the three categories, augment the analysis between specific processes and stages, how it can be used to inform designers to flexibly modulate cognitive control and enhance creative thinking. This paper is a first step focused on the methodological development of the coding scheme, which requires further validation in future research based on larger samples that aim to predict outcomes such as design quality based on dynamics of involved processes. As limitations of this approach, we acknowledge that people have limited insights in their mental processes as reflected in verbalizations, especially the *spontaneous* ones. The think-aloud method may further affect cognitive processes (i.e., verbal overshadowing); yet, we still observed verbalizations associated with all three processing categories, and effects of verbal overshadowing are usually very limited (e.g. Gilhooly et al., 2007). This study shows that the mapping of the proposed Triple Process Theory can further advance the analysis of think-aloud protocols through a more complete understanding of the role of metacognition in designing. The Triple Process Theory is a macro perspective of single or joint application with other theoretical models (i.e. Kannengiesser & Gero 2019; Hatchuel and Weil, 2009). The preliminary results of this study are relevant to inspire further developments that support the advance of neurocognitive feedback systems and inspire methodological improvements.

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