Identifying Divergent Design Thinking through the Observable Behavior of Service Design Novices

Abstract:

Design thinking holds the key to innovation processes, but is often difficult to detect because of its implicit nature. We undertook a study of novice designers engaged in team-based design exercises in order to explore the correlation between design thinking and designers' physical (observable) behavior and to identify new, objective, design thinking identification methods. Our study addresses the topic by using data collection method of "think aloud" and data analysis method of "protocol analysis" along with the unconstrained concept generation environment. Collected data from the participants without service design experience were analyzed by open and selective coding. Through the research, we found correlations between physical activity and divergent thinking, and also identified physical behaviors that predict a designer's transition to divergent thinking. We conclude that there are significant relations between designers' design thinking and the behavioral features of their body and face. This approach opens possible new ways to undertake design process research and also design capability evaluation.

Keywords: Design thinking; Behavior recognition; Novices; Service design; Concept generation

1. Introduction

Design involves some of the highest cognitive abilities of human beings, including creativity, synthesis and problem solving (Cross et al. 1996). Design thinking involves investigating and obtaining various kinds of information, and analyzing various factors of an ill-structured problem (Buchanan et al. 1992) to set up methods and processes for generating a solution in the field of design and planning.

Researchers explore the nature of the design thinking process in order to apply it to design teaching, design expertise evaluation, and so on. However, research in these areas has the following difficulties:

- **Implicit**. The designer's thinking activities are cognitive activities which cannot directly be observed and described;
- **Complexity**. Design thinking involves dynamic processes which overlap and interact in complex and inconsistent ways;
- **Fine grained**. The difference between different design thinking modes can be small and yet significant;
- **Expert experience is tacit**. An expert's design thinking is difficult to capture due to their decision-making agility, and their rapid and fluid movement between the problem domain and the solution domain.

Research on patterns of human limb and facial dynamic movement has identified correlations between physical movement and implicit thinking behavior (e.g. Xiao et al. 2015; Knight and Simmons 2013), indeed Mahmoud and Robinson (2011) argued that hand and face patterns largely reflect people's thinking which we suggest might provide some insight into people's design thinking. In this paper, we are specifically interested in the ideation period of design thinking which is the initial stage of structuring a complete design concept (Adams and Atman 1999), and whether extraction of human body and facial features could be used to understand features of design thinking and behavior.

2. Theoretical background

2.1 Divergent and convergent design thinking

Designers solve design problems and create specific designs by deconstructing design problems and extracting and restructuring design knowledge in specific contexts and design situations. There are many strategies for solving design problems especially since the problems designers encounter are usually not clearly defined. Although designers adopt different design strategies, diverging and converging processes are ubiquitous features of design strategies as outlined below - designers generate various ideas in divergent stages of the ideation process and select ideas in the convergent stages to identify the best result. Similarly, as described by Dubberly (2012), design strategies involve stages of decomposing and recombining. For Cross (2008), design processes iteratively involve divergent and convergent stages, though the design process is always convergent overall and as such design has to enter into a final stage of evaluation and detailing (Cross 2008) (Figure 1).

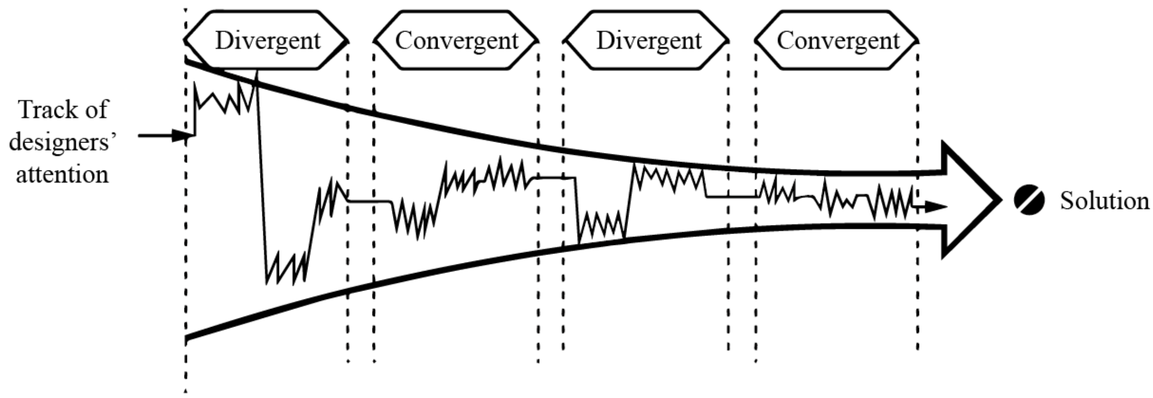

Fig. 1 Nigel Cross's divergence and convergence model of overall folding

For Cross (2008) random search strategies and prefabricated strategies represent two extreme forms of design strategies. The random search strategy represents a predominantly divergent design approach; the prefabricated strategy represents a predominantly convergent approach (Cross 2008). In practice, most design projects require a strategy that lies somewhere between these two extremes, and contains elements of both.

Divergent design thinking, the process of generating various and differing ideas, is an important aspect of individual creativity in organizations (Williams 2004). In the context of design, divergent thinking is commonly defined as the ability to generate many alternative solutions and explore the design space (Shah et al. 2012). So, in the design process, divergent thinking is not only the most creative part, but also the part that is most influential on design result. Furthermore, convergent design thinking is more implicit (internalised) than divergent design thinking which involves more external and explicit action making it more readily observed through action and utterance. As such the primary focus of our research is on understanding divergent design thinking and how it might be observed.

2.2 Research on the design thinking and behavior feature extraction

Design activities include cognitive processes such as thinking, imaging and decision-making as well as practical and externally perceptible activities such as information gathering, drawing and model-making (Pedgley 2007). Implicit design thinking is mainly expressed through the designer's design activities themselves. Open questions remain on how the stages of a design strategy can be reliably identified without intruding into the design process itself. Specifically, how to identify divergent and convergent processes, which would allow us to study design strategies in more depth, and also to examine how support for design processes may change the design strategies employed by designers. In this section we review mechanisms for examining design processes and strategies.

The neurological basis of designers' thinking modes has been examined using functional magnetic resonance imaging (fMRI) and the findings suggest that (ill-structured) design thinking differs from well-structured problem solving in terms of overall levels of brain activity, but also in terms of patterns of functional interactions between brain regions (Alexiou 2011); Beaty also researched the dynamic interaction between different parts of the brain using neuroimaging to identify divergent design thinking activities (Beaty et al. 2016). Cash used the visual information analysis and temporal distribution methods to identify the design processes in complex design patterns (Cash et al. 2014); Behoora and Tucker (2015) used non-wearable sensors to capture and store skeletal joint data for specific individuals in the design team and to obtain human motion data in real time to further understand the interaction of the design team.

The spontaneous gestures we produce when we talk reflect our thoughts. The embodied perspective on cognition holds that all cognitive activities are ultimately grounded in actions of the body. Feature extraction of human behavior operationalizes this position and can be subdivided into *individual* behavior characteristics and *mutual* behavior characteristics. In this paper, behavior refers to the dynamic and static characteristics of the designer's body and face during the design process. Individual behavioral characteristics, such as gestures, head rotation, etc., have been used to analyze human emotions with a recognition accuracy of 94% (Gunes and Piccardi 2007). Behavioral psychology research has shown that in social interactions, communicating people match each other's behavior in various ways, often by behavioral matching, behavioral synchronization, behavioral imitation, etc (Louwerse et al. 2012). These mutual interactions, such as expression, tilt, stare, and head rotation, have been applied to automatically predicting human decision-making with a 76% accuracy rate (Park et al. 2013). Furthermore, it has been shown that gestures which may intuitively seem redundant, such as hand-over-face gestures, are in fact not redundant information but instead are used to emphasize the affective cues communicated through facial expressions and speech in order to communicate additional information (Mahmoud and Robinson 2011).

2.3 Novice's concept generation for reflective activities characteristics

Lawson and Dorset (2009) according to Dreyfus's (2003) generic models of expertise summarizes the definition of novices and experts: A novice will consider the objective features of a situation, as they are given by the experts, and will follow strict rules to deal with the problem. The expert responds to a specific situation intuitively, and performs the appropriate action straightaway. There is no problem solving and

Published 2018 in: *International Journal of Technology and Design Education*, Springer, 0957-7572 https://rdcu.be/9lZD

reasoning that can be distinguished at this level of working.

Novice and expert designers differ in their conceptual approach to early stages of the design process and how they take advantage of strategic design knowledge (Klein G 1998). In the process of solving design problems, novices find less information and tend to ignore concurrent factors in the design process. The reasons for this phenomenon can be summarized as follows: 1) lack of awareness of finding more varied and better information; 2) lack of ability to develop surface details (Christiaans and Dorst 1992). Novices eventually form their own modes of application of various design heuristics through individual learning strategies and their skillful mastering of design knowledge. We draw conclusions about the characteristics of novice concept generation for service design through a comprehensive qualitative and quantitative analysis of concept generation and reflective activities, including thinking modes of reflective activities, design strategies, types of design drive, and interaction mechanisms.

We suggest that novices' reflective activities focus on action activities. In the 'moving stage' (Dorst 1997), the most frequent activities are gathering information, generating analogies, and generating searches and relations. Novices switching among different activities and classes are the most low-frequency behaviour. Experts are more likely to maintain cognitive efficiency, but novices are more likely to cause cognitive costs and overload activities (Ball 1995). Overall, novices' design strategies can be characterized as "depth-first". One of the main differences between novices and experts is the interaction between people and objects (Popovic 2003). Due to a lack of convergence, novices' temporary integration of concepts is often too farfetched, rough and stiff. Novices mainly use a single demand-seeking approach in the design strategy, and are more inclined to focus on "self-demand" or known demand. In the design process, novices use a "trial and error" model to eliminate and replace needs.

2.4 Team-based design activity research

Most studies of design process to date have focused on individual designer's thinking, yet Bryan Lawson (2004) suggests that experienced designer practice is often done in teams. Whilst Valkenburg and Dorst (1998) explored design teamwork based on Schön's paradigm (Schön 1983), Lawson called for studying it in a real design environment, in which the task is studied in the context of a diverse set of real-world backgrounds. Therefore, in order to explore design processes, we undertook a study of pair design thinking, building on team-based design thinking research which focuses on information seeking, ideation and design review. In our case designers were empirically assessed on global and discipline-specific concept development.

This study through the observation of teamwork of pairs of designers, our study recorded their co-design processes and analyzed their interactive behavior as reported in the results section. A team was a set of two or more people who interact and adaptively toward a common and valued goal or mission (Tucker and Abbasi 2012; Convertino et al. 2005; Manhas and Bakhshi 2011). Unlike individual design exercises, the one plus one structure of team cooperation offers the opportunity for verbal discussion between the designers which provides a valuable source of data to understand the design process.

3. Aims of the study

In this study, we collected and analyzed behavior and dialogue fragments with divergent thinking attributes of novice designers in the process of design concept generation. Aims to analyze the correlations between divergent design thinking and physical behavior, and explore new methods of design thinking research. Specifically, the following research questions are posed:

1. Is there a fixed behavior in the design concept generation of novice designers?
2. Is there a strong correlation between one or more of these fixed behaviors and divergent thinking?
3. Whether explicit behavior provides a new way for the research of implicit design thinking?

4. Method

In this study we took "health" as the design task as "health" is closely related to our lives, and the experience of "health" has also been experienced by all people, and let participants design without enforcing any further sub requirements. Participants were instructed to produce a design concept, and had no limitations in terms of target users, context, touch points, and so on. Participants were asked to think aloud as they undertook their assigned tasks – to say as much as possible on the thoughts, actions and feelings, that came to them as undertook the design tasks. Each study generally lasted between 60 minutes and 90 minutes.

We used protocol analysis as the main method of analyzing our data – 3 researchers coded the voice, video, picture, and text content of the "think aloud" records. Researchers have more than 10 years of design research experience and more than 5 years of coding experience. The three researchers who performed the coding performed Kappa comparison of the coding results for many times, and finally achieved a high degree of fit (0.86), and the coding results were reliable. Protocol analysis was selected as it is one of the most popular and widely used methods of the research and analysis of design thinking in recent years (Gero and Neill 1998). However, it should be noted that it also has its limitations, as a method for investigating design thinking as it does not capture the non-linguistic aspects of the thinking process which is very important in the design part. Moreover, Dorst and Cross (2001) conclude that this is a very valuable research method but requires the analyst to have specific analytic skills. Whilst it can capture some of the details of design thinking, it cannot identify the more practical problem in the context of the design, but it is currently the most practical and pragmatic analytic method.

4.1 Participants

First-grade post-graduate students (N=28) took part in the study. The sample had a mean age of 23.56 years (SD=1.48), and 12 students (42.86%) were male. Participants in this study are designers who can express fluently, have good physical and mental health. All of these participants had 4-8 years design experience. However, they do not have relevant knowledge and experience in the field of service design, so they belong to novice level. As a freshman, the participants were unknown to each other and researchers. The experiment adopts the voluntary and unpaid participation mode, participants used their native language (mandarin) in the experiment.

4.2 Coding and data analysis

Published 2018 in: *International Journal of Technology and Design Education*, Springer, 0957-7572 https://rdcu.be/9lZD

The video and audio recordings from the studies were imported into the ATLAS.ti analysis software (from ATLAS.ti Scientific Software Development GmbH, Berlin, Germany) and coded using two classification schemes on the “timeline”: i) design thinking stage (as our focus is on divergent thinking) and ii) physical behavior as described below. The data analysis process was as follows:

(1) The three Researchers (who had expert design knowledge and experience) reviewed the video data which was collected in the studies and firstly identified all concept construction behavior (demonstrating divergent design thinking) and removed non-design behavior, such as daily life activities.

(2) Key points of physical movement related to “divergence” thinking in the study’s video recordings were identified, and coded with descriptions of both spatial and temporal movement around body-related key points (palms, elbows, head, eyeballs, lips, etc.). These were then analyzed to identify kinds of physical behavious in the video recordings. For example, where we observed the designer's limbs and facial features changed as the designer was "looking around", we coded this as "look around" behavior.

(3) The start and end time of points of divergent design thinking were recorded in the timeline.

(4) Correlations between divergent design thinking and physical behavior were analysed using ATLAS.ti to identify the frequency and degree of occurrence, and Pearson Correlation Coefficient to quantitatively measure the degree of correlation and the relative direction.

The design thinking stage was coded based on the "divergent / convergent / N.A" model (Cross 2008). Typical divergent design thinking occurs when designers try to find similar information in existing data or material libraries, thus constructing their own design proposals. Designers search for information and connection is the preparation for constructing concepts. During divergent thinking designers try their best to conduct information retrieval, and their analysis will be from different angles, in different directions, ways or means. The following two fragments of talk aloud transcript exemplify divergent thinking discussion and would be coded as such in the timeline

Like other websites or apps that I use, they all refer to the existing information to the patient for reference, or let the patient describe his symptoms and let the doctor diagnose them online. (Participant 2)

I used an app, which allows patients to register online for an appointment, and also upload the sick condition and let the doctor know about you in advance. (Participant 9)

5. Results

5.1 Behavior extracted

By coding and analyzing the collected video and audio data, a total of seven frequently occurring physical behaviors were identified as illustrated in figure 2 and described below:

(1) Touch lips (2.28%): touch lips by hand (left or right hand).

(2) Hand waving (10.91%): fast moved hand(s) in the air (left hand, right hand, or both)

(3) Look around (34.52%): eye deviation from orbital centre, not stopping rotation

(4) Hold neck (2.86%): hold neck by hand (left or right hand).

(5) Hold cheek (10.76%): hold cheek by hand (left or right hand).

(6) Hold chin (6.46%): hold chin by hand (left or right hand).

(7) Write (32.21%): hold the pen on the paper (left or right hand).

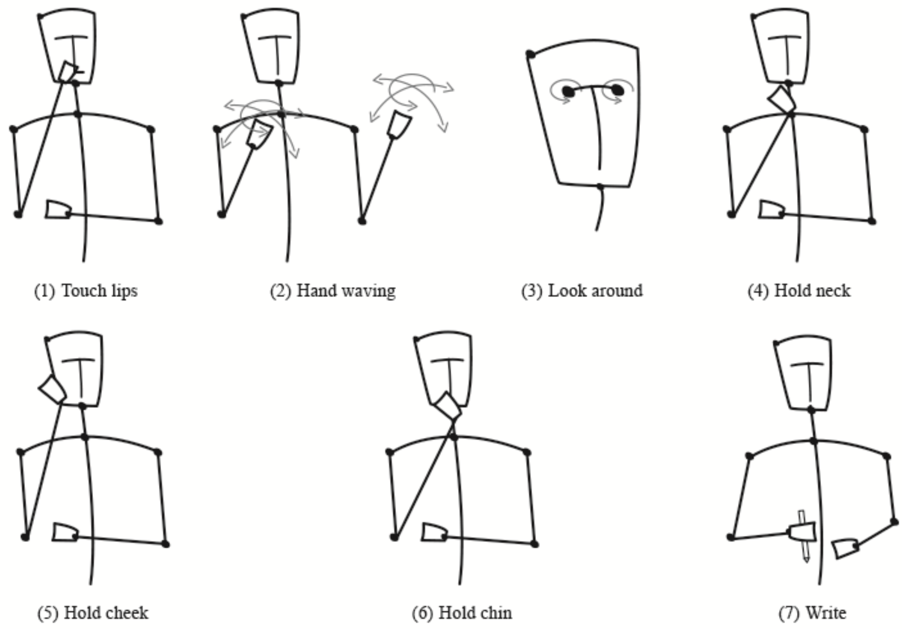

Fig. 2 Behavior schematic diagram

5.2 Concurrency relation of divergent design thinking and behavior

In order to explore the relationship between divergent design thinking and physical behavior, we used ATLAS.ti to examine the concurrency relations between divergent design thinking and behavior. We define "concurrency relations" as temporal relationships between overlapping divergent design thinking and behavior codes, divided into the following five sub-relations (figure 3):

- (1) Coincide: divergent design thinking fragments and behavior fragments begin and end at the same time, that is begin simultaneously and end simultaneously.
- (2) Begin simultaneously: divergent design thinking and behavior fragments begin simultaneously, but not at the same time end.
- (3) End simultaneously: divergent design thinking and behavior fragments end simultaneously, but not at the same time begin.
- (4) Include: divergent design thinking and behavior fragments do not start at the same time, nor at the same time end, and one fragment is included in another fragment.
- (5) Overlap: divergent design thinking and behavior fragments do not start at the same time, nor at the same time end, and the overlap is greater than or equal to 0.

Published 2018 in: *International Journal of Technology and Design Education*, Springer, 0957-7572 https://rdcu.be/9lZD

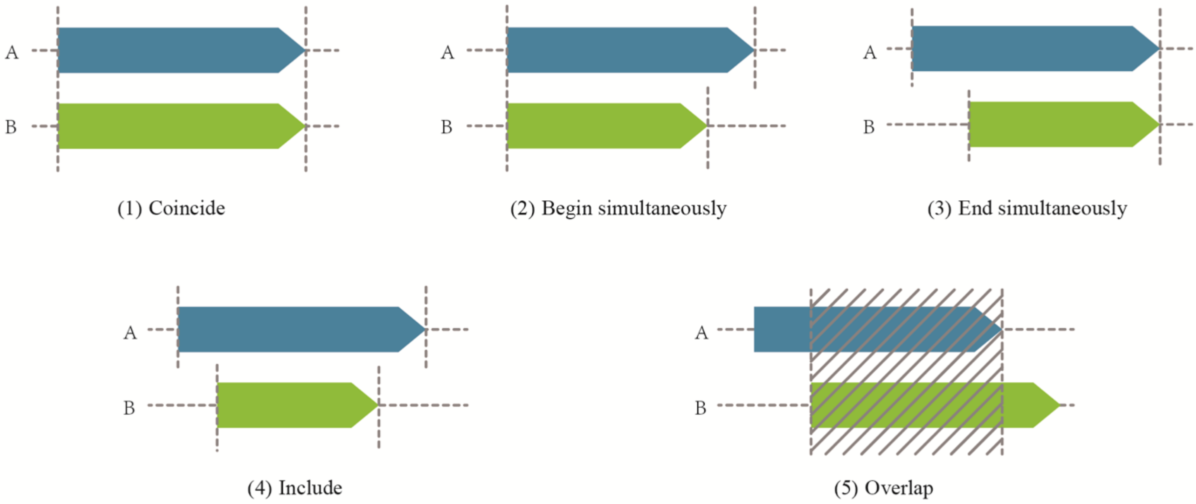

Fig.3 Concurrency relation of divergent design thinking and behavior

We identified two groups of concurrency relations: ThinkBehave and BehaveThink defined as below and illustrated in figure 2:

- ThinkBehave: Divergent thinking which precedes or starts at the same time as physical behavior. In figure 2, A is divergent design thinking and B is behavior for (3), (4), (5).
- BehaveThink: Physical behavior which precedes or starts at the same time as divergent thinking. In figure 2, A is behavior and B is divergent design thinking for (3), (4), (5).

All (1) "coincide" and (2) "begin simultaneously" relations are classified as both BehaveThink and ThinkBehave at the same time as it is not possible to determine whether the behavior of the divergent thinking started first.

5.3 Concurrency relationship analysis

In statistical analysis, the correlation coefficient quantitatively describes the closeness of the linear relationship between the two variables. In a large number of literatures, Pearson's correlation coefficient, Kendall′tau and spearman rho′s are probably the most widely used (Mari and Kotz 2001). The Pearson's correlation coefficient is different from the other two, it is a parametric statistic and requires interval data for both variables (Field 2013). It is widely used in various research fields (Wang and Zheng 2013; Wu and Xu 2010; Tomasi and Volkow 2010; Fisher et al. 2010). Therefore, we used the Pearson correlation coefficient to calculate the correlation between the divergent design thinking and behavior in terms of the concurrency relationships ThinkBehave (Table 1) and BehaveThink (Table 2) in order to identify whether certain bodily movements correlated with divergent thinking e.g. whether looking around would predict that divergent thinking would happen, or whether people hold their necks once they started divergent thinking.

Table1- Pearson Correlation Coefficient with ThinkBehave

	Touch lips	Hand waving	Look around	Hold neck	Hold cheek	Hold chin	Write

Published 2018 in: *International Journal of Technology and Design Education*, Springer, 0957-7572 https://rdcu.be/9lZD

Frequency	Pearson correlation	-0.227	-0.039	0.801**	0.046	0.410	-0.259	0.355
	Sig.	0.558	0.844	0.001	0.900	0.078	0.258	0.069
Degree	Pearson correlation	0.303	0.003	0.680**	0.615	0.231	-0.076	0.494
	Sig.	0.428	0.988	0.007	0.058	0.278	0.712	0.056

Note. *p < 0.05, **p < 0.01.

In the frequency dimension (table1), the correlation coefficient of divergent thinking and look around (r=0.801, p=0.001) has a high degree of linear correlation in ThinkBehave.

Touch lips (r=-0.227, p=0.558), hand waving (r=-0.039, p=0.844), hold neck (r=0.046, p=0.900), hold cheek (r=0.410, p=0.078), hold chin (r=-0.259, p=0.258) and write (r=0.355, p=0.069), have no significant correlation with divergent thinking in Think Behave.

In the degree dimension (table1), the correlation coefficients of divergent thinking and look around (r=0.680, p=0.007) have a notable linear correlation and they were significantly positive relationship for ThinkBehave.

Touch lips (r=0.303, p=0.428), hand waving (r=0.003, p=0.988), Hold neck (r=0.615, p=0.058), hold cheek (r=0.231, p=0.278), hold chin (r=-0.076, p=0.712) and write (r=0.494, p=0.056), have no significant correlation with divergent thinking in the degree dimension for ThinkBehave.

Table2- Pearson Correlation Coefficient with BehaveThink

		Touch lips	Hand waving	Look around	Hold neck	Hold cheek	Hold chin	Write
Frequency	Pearson correlation	0.958**	0.514	0.786**	0.625*	0.830**	0.599**	0.769**
	Sig.	< 0.001	0.078	< 0.001	0.022	< 0.001	0.002	< 0.001
Degree	Pearson correlation	0.937**	0.455	0.798**	0.957**	0.678**	0.723**	0.807**
	Sig.	< 0.001	0.091	< 0.001	< 0.001	< 0.001	0.008	< 0.001

Note. *p < 0.05, **p < 0.01.

In the frequency dimension (Table 2), the correlation coefficient between divergent thinking and touch lips (r=0.958, p<0.001), look around (r=0.786, p<0.001), hold neck (r=0.625, p=0.022), hold cheek (r=0.830, p<0.001), hold chin (r=0.599, p=0.002) and write (r=0.769, p<0.001) was significant for BehaveThink.

There were no significant correlations with divergent thinking for hand waving (r=0.514, p=0.078) and hold neck for BehaveThink.

In the degree dimension (Table 2), There is a significant correlation coefficient between divergent thinking with touch lips (r=0.937, p<0.001), look around (r=0.798, p<0.001), hold neck (r=0.957, p<0.001), hold cheek ($r=0.678$, $p<0.001$), hold chin ($r=0.723$, $p=0.008$) and write ($r=0.807$, $p<0.001$) for BehaveThink.

The correlation between the divergent thinking and hand waving ($r=0.455$, $p=0.091$) is not significant for BehaveThink.

We analyzed the correlations between the convergent thinking and physical behavior, but there were no correlations found. Maybe the small amount of data for convergent thinking did not provide enough data for the correlation tests. Therefore, we do not consider convergent thinking, nor compare it with divergent thinking.

6. Discussion

In this study, we examined the generation of design concepts by analyzing qualitative and quantitative data to identify correlations between designers' divergent design thinking and their physical behavior. Because of the breadth of divergent thinking activities, we limited our study to focus on the concurrency relations between divergent design thinking and physical behavior, which we characterized as two relationships: BehaveThink and ThinkBehave.

ThinkBehave and BehaveThink showed different degrees of correlation with physical behaviors except for "look around" which showed a strong correlation with both ThinkBehave and BehaveThink on the frequency and degree dimensions. Therefore, we suggest that "look around" behavior is a reliable indicator of divergent thinking. In contrast, we observed that "hand waving" behavior that was not significantly correlated with divergent design thinking. These two findings suggest that divergent design thinking can be readily observed through objective observation of bodily movement rather than through personal and subjective analysis: i.e. "look around" indicates divergent thinking is probably happening; "hand waving" indicates that divergent thinking is probably not happening.

The results show that there is a concurrent relationship between divergent design thinking and behavior. According to this relationship, in addition to relying on personal experience, subjective analysis and judgment, we may also be able to identify divergent design thinking through more easily observed and defined behavior. Furthermore, the significant correlation of BehaveThink with touch lips, hold neck, hold cheek, indicates that these behaviors are predictors of an imminent transition to divergent thinking. When observing designers these observable physical movements could be used to predict designers' behavior more easily and reliably than talk-aloud or introspective protocols. Such predictions could be used in the design of pro-active creativity support tools which may help to more responsively scaffold the design process.

However, it should be noted that a key limitation of this work is that we observed a short-term ideation process with a small number of designers. Despite the small sample size it was still is a huge challenge to understand the details of divergent design thinking and behavior in our study. Also, there were clearly problems of precision and standardization in the behavior capture due to manual extraction of markers and manual assignment of codes. Finally, this study only studied divergent design thinking and did not compare the result to other types of design thinking. Whilst divergent design thinking is regarded as the most creative activity in design, future studies would need to undertake long-term tracking and research including other forms of design thinking in order to provide more reliable and informative results. For example, identified behaviors may belong to divergent design thinking as we identified, but may, of course, also belong to

Published 2018 in: *International Journal of Technology and Design Education*, Springer, 0957-7572 https://rdcu.be/9lZD

convergent design thinking. Writing is a good example of this potential paradox: it could be that writing it is more likely to be happening in divergent design thinking when participants draw sketches, but designers might be writing down their partner's words as some sort of summary which would be regarded as convergent design thinking. In this case our analysis would need to include capture of the content of the writing or drawing in order to attempt to classify the content as convergent or divergent design work.

The findings of our study may also have implications for service design education including students, team leaders and teachers:

1. One way to analyze the gap of design thinking between novices and experts is to undertake an in-depth analysis of their divergent design thinking which is inherently hard for educators. Whether novice or expert, it has been demonstrated in our studies and others reported earlier that there is a relationship between divergent design thinking and behavior. Therefore, in the design of teaching, we could develop observational methods based on our findings to more reliably identify divergent thinking and enable educators to better observe and identify transitions to and from divergent design thinking. This method might help educators become more objective and scientific in their judgement of students' divergent design thinking, and may also enable educators to observe and guide students' divergent design thinking in real time.

2. Novices and experts have different mechanisms to solve design problems. Enhancing the transition between convergence and divergence could be a method for educators to promote students' growth. Students' observed behavior could be used to determine their divergent design thinking processes, and infer their design patterns. This could be used in design education to make education more responsive to students' design aptitudes and learning style.

7. Conclusion and future work

Our study shows that in the design process there is a correlation between divergent design thinking and certain physical behaviors of designers. In order to improve the quality of the analysis of design thinking from objective and observable measures we would suggest the following improvements to carry out detailed design thinking tracking:

1. At the behavior level, 1) Before the formal experiment, the behavior characteristics of participants in the daily life situation were recorded, so as to classify the different participants from the behavior level, such as the active behavior participants and the inactive behavior participants. 2) Capture the interaction between members of the design group. This provides us with another basis for judging the design thinking to which the behavior belongs, thus improving the accuracy. 3) Observe and analyze the results of behavior, such as writing.

2. At the design thinking level, because some behaviors may belong to both convergent and divergent design thinking, the coding scheme of design needs to be refined to improve the accuracy of behavior classification.

3. At the team work level, organizing experiments of various cooperation modes. For example, the design team of more than two-member mode, and the repeated experiment of participants with different behavioral characteristics categories, that is, a participant collaborates with participants with different

Published 2018 in: *International Journal of Technology and Design Education*, Springer, 0957-7572 https://rdcu.be/9lZD

behavioral characteristics, to study the correlation between thinking and behavior in this case, and to explore the similarities and differences of thinking and behavioral characteristics of the participant.

Besides these suggestions for further work we will also feasibility of machine recognition of design behavior based on the data extracted from the observations of team design activities. Finally, we believe that our findings could be used to develop guidelines for educators or companies to use in their design education, design capability evaluation and improvement.

References

Alexiou, K., Zamenopoulos, T., & Gilbert, S. (2011). Imaging the designing brain: a neurocognitive exploration of design thinking. Design Computing & Cognition, 489-504.

Adams, R., & Atman, C. (1999). Cognitive processes in iterative design behavior. Frontiers in Education Conference, 1999. FIE '99. 29th Annual, 1, 11A6/13-11A6/18.

Ball, L. J., & Ormerod, T. C. (1995). Structured and opportunistic processing in design: a critical discussion. International Journal of Human-Computer Studies, 43(1), 131-151.

Beaty, R. E., Benedek, M., Silvia, P. J., & Schacter, D. L. (2016). Creative cognition and brain network dynamics. Trends in Cognitive Sciences, 20(2), 87-95.

Behoora, I., & Tucker, C. S. (2015). Machine learning classification of design team members' body language patterns for real time emotional state detection. Design Studies, 39, 100-127.

Cash, P., Stanković, T., & Štorga, M. (2014). Using visual information analysis to explore complex patterns in the activity of designers. Design Studies, 35(1), 1-28.

Christiaans, H., & Dorst, K. (1992) Cognitive models in industrial design engineering: a protocol study. Design theory and methodology, 42(2), 131-140.

Convertino, G., Ganoe, C. H., Schafer, W. A., Yost, B., & Carroll, J. M. (2005). A Multiple View Approach to Support Common Ground in Distributed and Synchronous Geo-Collaboration. Coordinated and Multiple Views in Exploratory Visualization, 121-132.

Cross, N., Christiaans, H., & Dorst, K. (1996). Analysing design activity. Materials & Design, 16(2), 122-123.

Cross, N. (2008). Engineering design methods. Wiley.

Cross, N. (2011). Design thinking: understanding how designers think and work. Berg.

Dreyfus, H. L. (2003). The Spinoza Lectures, University of Amsterdam.

Dorst, C. H. (1997). Describing design: a comparison of paradigms. Industrial Design Engineering.

Dorst, K., & Cross, N. (2001). Creativity in the design process: co-evolution of problem–solution. Design Studies, 22(5), 425-437.

Dubberly, H. (2012) How do you design? A Compendium of Models. Dubberly Design Office, 10(8).

Field, A. (2013). Discovering Statistics using IBM SPSS Statistics. Sage Publications Ltd, 397-423.

Fisher, J. A., Jacob, D. J., Purdy, M. T., Kopacz, M., Sager, P. L., & Carouge, C., et al. (2010). Source attribution and interannual variability of arctic pollution in spring constrained by aircraft (arctas, arcpac) and satellite (airs) observations of carbon monoxide. Atmospheric Chemistry and Physics,10,3(2010-02-01), 10(3), 977-996.

Gero, J. S., & Neill, T. M. (1998). An approach to the analysis of design protocols. Design Studies, 19(1), 21-61.

Gunes, H., & Piccardi, M. (2007). Bi-modal emotion recognition from expressive face and body gestures. Journal of Network & Computer Applications, 30(4), 1334-1345.

Klein, G. (1998) Sources of Power: How people make Decisions. Cambridge, MA: MIT Press, 1-323

Knight, H., & Simmons, R. (2013). Estimating human interest and attention via gaze analysis. IEEE International Conference on Robotics and Automation, 4350-4355.

Lawson, B. (2004). Schemata, gambits and precedent: some factors in design expertise. Design Studies, 25(5), 443-457.

Lawson, B., & Dorst, K. (2009). Design expertise. Design Expertise, 98-99.

Louwerse, M. M., Dale, R., Bard, E. G., & Jeuniaux, P. (2012). Behavior matching in multimodal communication is synchronized. Cognitive Science, 36(8), 1404-1426.

Mahmoud, M., & Robinson, P. (2011). Interpreting Hand-Over-Face Gestures. International Conference on Affective Computing and Intelligent Interaction, 6975, 248-255.

Manhas, C., & Bakhshi, A. (2011). Relating occupational self efficacy to team effectiveness. European Journal of Business & Management, 3(2).

Mari, D. D., & Kotz, S. (2001). Correlation and Dependence. Correlation and dependence. Imperial College Press.

Park, S., Scherer, S., Gratch, J., Carnevale, P., & Morency, L. P. (2013). Mutual behaviors during dyadic negotiation: automatic prediction of respondent reactions, 7971, 423-428.

Pedgley, O. (2007). Capturing and analysing own design activity. Design Studies, 28(5), 463-483.

Popovic, V. (2003) Expert and Novice Users Model and their Application to the Design Process. Journal of the Asian Design International Conference, Japan: University of Tsukuba.

Schön, D. (1983). The reflective practitioner: How professionals think in action. New York: Basic Books.

Shah, J. J., Millsap, R. E., Woodward, J., & Smith, S. M. (2012). Applied tests of design skills—part 1: divergent thinking. Journal of Mechanical Design, 134(2), 689-698.

Tomasi, D., & Volkow, N. D. (2010). Functional connectivity density mapping. Proceedings of the National Academy of Sciences of the United States of America, 107(21), 9885-9890.

Tucker, R., & Abbasi, N. (2012). Conceptualizing teamwork and group-work in architecture and related design disciplines.

Valkenburg, R., & Dorst, K. (1998). The reflective practice of design teams. Design Studies, 19(3), 249-271.

Williams, S. D. (2004). Personality, attitude, and leader influences on divergent thinking and creativity in organizations. European Journal of Innovation Management, 7(3), 187-204.

Wang, J., & Zheng, N. (2013). A novel fractal image compression scheme with block classification and sorting based on pearson's correlation coefficient. IEEE Transactions on Image Processing, 22(9), 3690-3702.

Wu, W., & Xu, Y. (2010). Correlation analysis of visual verbs' subcategorization based on pearson's correlation coefficient, 4, 2042-2046.

Xiao, B., Georgiou, P., Baucom, B., & Narayanan, S. S. (2015). Head motion modeling for human behavior analysis in dyadic interaction. IEEE Transactions on Multimedia, 17(7), 1107-1119. Buchanan, R. (1992), Wicked Problems in Design Thinking. Design Issues, vol.8, no.2, pp. 5-21