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Trains of thought on the tabletop: visualizing association of ideas improves creativity

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Abstract According to the Search for Ideas in Associative Memory theory, ideas in a brainstorming session do not come one by one but rather in "trains of thought," which are rapid accumulations of semantically related ideas. In order to visualize these trains of thought, we developed a brainwriting tabletop interface enabling users to link successive ideas together by means of graphical ropes. To test the effectiveness of this device, 48 participants (in groups of four) brainstormed for 20 min on the tabletop in one of two conditions: either with the train-of-thought interface (with graphical ropes), or without the ropes (control condition). The results show that visualizing the associations between ideas enabled the participants to produce longer trains of thought. We also assessed originality by collecting the unique ideas in the whole corpus of ideas produced by the different groups and observed that the train-of-thought condition produced more original ideas than the control one. One interpretation of this finding is that visualizing trains of thought increases cognitive stimulation, i.e., improves creativity by making others' ideas more intelligible to the brainstorming partners, in comparison with the classical visualization of ideas as independent items.

Keywords Train of thought · Brainstorming · Interactive tabletop system · SIAM theory

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1 Introduction

Tabletop systems are multi-user horizontal interfaces for interactive shared displays. They implement around-the-table interaction metaphors allowing colocated collaboration and face-to-face conversation in a social setting [1]. Tabletop devices have been developed for various application fields such as games, photo browsing, map exploration, planning tasks, classification tasks, interactive exhibit medium for museums, and drawing [1, 2]. Because tabletop systems provide sharing and visualization facilities (situation awareness) while emphasizing the social nature of collaboration (group awareness), they can also be expected to meet the requirements of creative problem-solving tasks. Indeed, creativity-supporting tools are another popular kind of application for tabletops [3–8].

One of the most classical creative problem-solving methods is group brainstorming [9]. This is a collective idea generation technique, which enables the group to benefit from many collective phenomena that promote creativity, but also suffers from several failings. Examples of positive effects associated with group brainstorming include *cognitive stimulation*: the exposure to other participants' ideas enhances idea generation [10–12]. *Social comparison* is another benefit of group brainstorming, since the possibility of comparing one's own performance to the others' was also shown to increase creative performance [10, 13–16]. However, a major shortcoming of "oral" brainstorming is the necessity of managing speech turns: each participant has to wait for his turn to give an idea, and only one idea can be given within a turn. This severely interferes with the idea generation process and results in *production blocking* [15, 17]. One simple solution is to use the written instead of the oral channel to record the ideas, which can be referred to as brainwriting [18, 19]. In this case, participants silently share written ideas, for example, on sticky notes. Finally, another key issue in brainstorming is *social loafing* [20–23]: in brainstorming groups, some participants tend to under-contribute in comparison with a situation where they would brainstorm alone.

Tabletop devices are particularly well suited for creativity because they support both cognitive stimulation (situation awareness) and social comparison (group awareness). Moreover, they have the potential to overcome the aforementioned limitations of group brainstorming. They generally implement brainwriting interfaces, in order to avoid production blocking. They are also likely to decrease social loafing in at least two ways. Firstly, the "around-the-table" form factor increases equity of collaboration [7]. Equity corresponds to the inverse of social loafing and correlates to the collective intelligence of a group, a factor that explains the group's performance on a wide variety of tasks [24]. Furthermore, the attractiveness of the tabletop device increases extrinsic motivation to engage in the task [7], which is also a moderating factor of social loafing [25, 26].

In the present study, our goal is to further improve idea generation in comparison with existing tabletop brainwriting tools. To this end, we implemented and tested a new interface based on the SIAM theory—Search for Ideas in Associative Memory [27–29], as explained below.

2 Theoretical background

SIAM is an extension of the Search of Associative Memory (SAM theory [30]) and was created to account for the impact of production blocking on idea generation. SIAM theory proposes that the exposure to other group members' ideas improves individual's creative production and the quantity of ideas, but also the content of the ideas [12, 31]. This theory refers to the two memory systems known as working memory (WM) and long-term memory (LTM). The first is a limited-capacity memory where conscious operations are performed, and the second is an unlimited-capacity memory where previous experiences are stored, and most important for our topic, the LTM is partitioned into "images" (not necessarily visual or spatial), which are interconnected and semantically related (associative memory). So, when a person is performing a brainstorming (or brainwriting) task, the search in LTM results in an image activation, which is temporarily placed in the WM. When an image has been activated, its semantic relations in LTM can be used to generate other ideas [32]. In this case, as successive ideas generated are semantically related, the SIAM theory proposes the concept of "train of thought," which is a rapid accumulation of semantically related ideas [29]. During a brainstorming session, ideas are supposed to come in this form rather than one by one. When a train of thought is over, it takes some time to find a new idea: a new train of thought can be generated through the self-activation of a new semantic category or through stimulation from another participant's idea. But the same kind of process is involved in either case, with the activation of semantically related images in memory.

In this paper, we want to test whether visualizing trains of thought helps idea generation and improves group creativity (number and originality of ideas). We hypothesize that visualizing the semantic links between successive ideas will increase the length of trains of thought, by allowing participants not to lose the thread of their thought, and promote going further in idea generation. We also propose that this visualization will help participants better understand other participants' ideas by enabling them to track their semantic associations and so improve the stimulation mechanism.

In order to test this hypothesis, we compared the creative performance of groups using a "train of thought" tabletop interface (offering the possibility to visualize association of ideas) and groups using a tabletop brainwriting interface with no link between ideas that are successively generated.

3 Implementation

To operationalize these two conditions (train of thought and control), we developed two graphical user interfaces (GUIs) in JAVA for DiamondTouch [33] horizontal shared tabletop display. We used the DiamondSpin toolkit [34] to take advantage of the existing tabletop-specific features (menu bars on each side of the table, automatic orientation of graphical elements, and concurrent multi-user input). We also used the new multi-keyboard bindings to provide our users with the benefits of Bluetooth keyboards. Previous brainwriting experiments in which users had the possibility either to use soft keyboards or to write/sketch by direct finger input [7, 8, 35] had shown that users massively preferred soft keyboard to generate ideas. Indeed, current tabletop full HD resolutions being too limited for handwriting, users are required to write much bigger than they would normally on paper. Moreover, handwriting on a tabletop implies an unnatural position, keeping the hand in the air to prevent involuntary touch on the table. The same problem occurs when using a stylus (see hand position in [4]) or is handled by having users wear a glove [36] or by separating idea generation (on paper notes) from idea sharing (copying notes on the table) [37]. We considered these solutions as uncomfortable or time-consuming, and hence, we decided to provide keyboards to our users: we chose Bluetooth physical keyboards because they offer higher typing speed, lower typing errors, and lower cognitive load than soft keyboards, especially for users with few/no experience of tablets. They also save space on the tabletop and leave room for more ideas. Finally, physical keyboards are a very common input mode for brainstorming, as attested by the abundant literature on electronic brainstorming systems, which consists in brainstorming on computers networked together [38–41].

Train-of-thought and control GUIs display a 1-line text field on each side of the table (where the text of each participant is displayed as being typed). At startup, the 4 text fields display 4 different pin codes. If a user takes one of the Bluetooth keyboards and types the pin code in front of him/her, this keyboard is associated with the Diamondspin ID of this user. Each individual text field is augmented with a movable gray area so that users can move it to correspond to where they position their Bluetooth keyboard. On the left of each text field, a draggable menu bar recalls the topic of the session. Finally, a single "File" menu is displayed in a corner of the GUI (open, save, clean, etc.) to be used by the experimenter. The rest of the GUI differs in the train-of-thought and control conditions.

We designed the train-of-thought GUI with the rope metaphor (Fig. 1). In this GUI, a ring of rope is displayed in the center, and every user sees a personal roll of rope on the left of his/her text field. One end of this roll runs parallel with the text field. When an idea is typed in the text field and validated (with the ENTER key), the rope is extended along the text field, and a label (one or two lines according to the length of the text) is created and attached to the rope by its left side. This label is slightly colored with a random pastel color. As the text of the idea has been copied in a label, the text field is then cleared for the next idea. The following ideas produce labels of the same color bound up with the same rope. When the scissor button in the menu bar is touched, the newly constructed piece of rope is then detached from the roll, and a knot is attached to its two ends. The resulting decorated piece of rope represents a train of thought. This train of thought is then quickly animated toward the central ring of rope. The end of the rope holding the first idea of the train is attached to the central ring, and the rope is reoriented linearly outward the ring. If the user is not satisfied with the automatically chosen location in the central ring, the knot can be dragged with a finger and moved to a better location. When the knot is dropped near the central ring, it is snapped onto the closest free spot and the train of thought is automatically reoriented outward the central ring (with animation). For this automatic rearrangement, the quick animation and the drag action, we use a physics engine to animate the pieces of rope. Our model of rope consists of successive segments with angular and length constraints. When an end of the rope is moved, the constraints are recomputed along the successive segments. The last important feature for building the network of ideas is the branching feature. When a label holding an idea is touched by one of the four users,

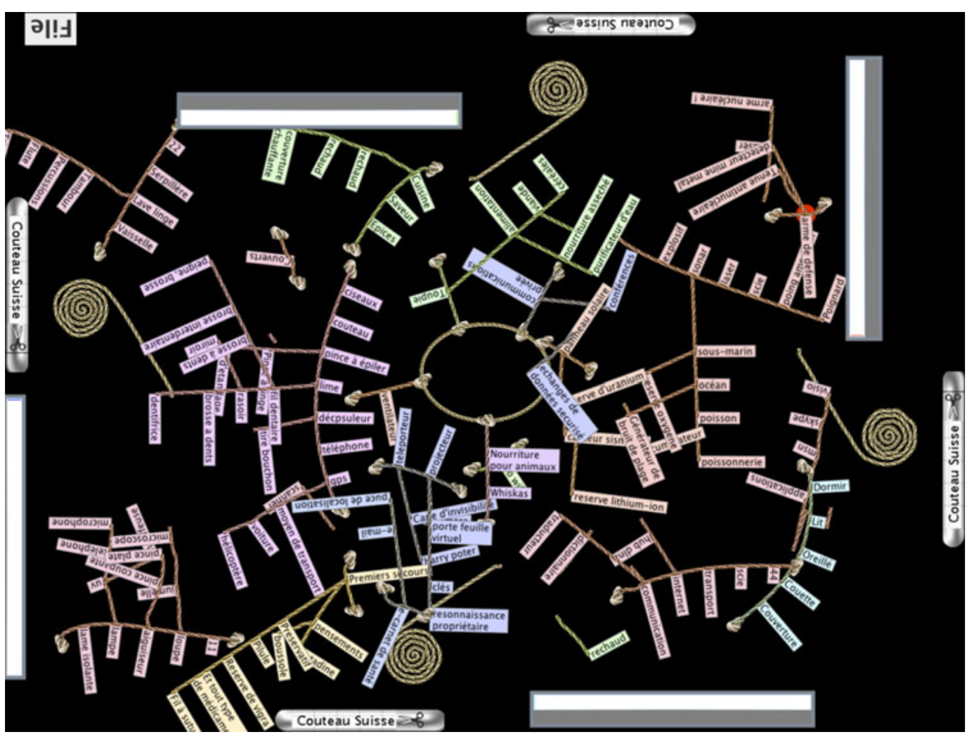

Fig. 1 The "train of thought" interface: semantically related ideas are written along a piece of rope

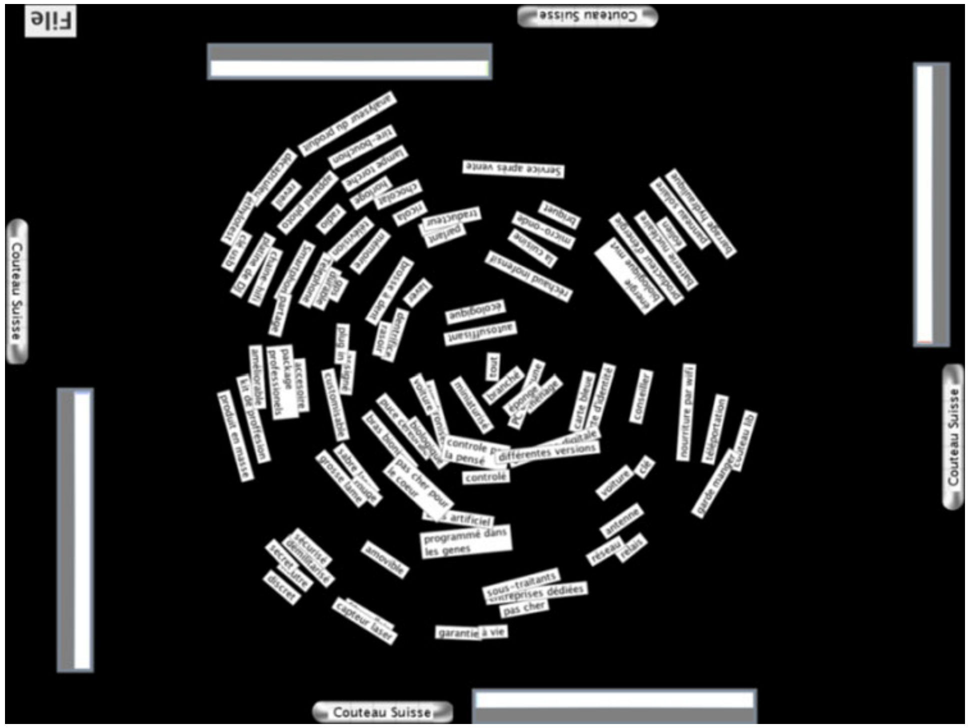

Fig. 2 The control interface: ideas are written on independent labels

the intersection between the rope and the label is highlighted with a colored disk (like the red disk behind the label “arme de defense” in Fig. 1). All the subsequent ideas, until the label is deselected by touching the background, are then bound up with a new rope growing at the perpendicular of the selected label. This new portion of rope is not ended with knots and remains perpendicularly attached when the holding rope is manipulated or animated. A train of thought can also be built just in front of the text field and later attached to an idea/label if this idea is not reachable when the train of ideas starts (idea just orally discussed, idea being written in another text field, etc.).

The GUI for the control condition was later written. The goal was to be as similar as possible to the previous one without exposing any grouping mechanism. When a typed idea is validated in the text field, a label with the same size as in the previous GUI is created and displayed on the table. The label is randomly positioned on the surface and rotated outward (Fig. 2). All the labels can be freely moved by drag and drop. The system automatically maintains the outward facing direction of these labels.

4 Experimental protocol

4.1 Participants

Twelve groups of four participants (48 users in total) were involved in the experiment. All of them were students or staff members from our school, and they were not familiar with each other. They were 42 men and 6 women, aged 18–60 years (mean = 21, SD = 5.94). The participants were not paid for their participation.

5 Material

We used a 107-cm Circle Twelve DiamondTouch device [33] with a 1,400 × 1,050 projected display. Participants worked in groups of four seated around the tabletop, interacting with finger input on the display and typing their ideas by means of wireless keyboards (Fig. 3).

5.1 Procedure

Each session began with a presentation of the tabletop system and the brainwriting method. The participants were invited to familiarize themselves with the interactive tabletop and have a practice session. After that, the goal of the session was presented: the participants had to imagine the “Swiss Army knife” (a multi-function multi-tool pocket knife) of the future. They were then explained the four brainstorming rules [9]: focus on quantity, withhold criticism, welcome unusual ideas, combine and improve ideas.

The type of brainwriting interface was a between-subject variable: half of the groups (control groups) had to write their ideas on independent virtual labels (one idea per label, see Fig. 2). In the other half of the groups (train-of-thought groups), participants were invited to write their

Fig. 3 The experimental setup

ideas on similar virtual labels, which were linked successively along a graphical rope. When the participants decided that they had finished an association of ideas, they could cut the rope and were then ready to start a new one. All the participants were free to examine all the ideas displayed on the table, and add new ideas or new pieces of rope to those that had been generated by their partners (Fig. 1).

In both conditions, participants were allowed to manipulate the ideas (or the ropes) from anywhere in the interface and place them wherever they wanted. They were encouraged to react on all these ideas in order to generate as many ideas as possible. The experimenter played the role of session facilitator. In both condition, participants brainstormed for 20 min on what could be the Swiss Army knife of the future.

At the end of the 20 min, they had to fill out a questionnaire to assess how they perceived the device, the interface, and their performance (see below the list of items). Finally, they were invited to give us their opinion about the experiment.

5.2 Data collection and analysis

We used the same variables as Nijstad et al. [28] in order to characterize idea generation:

- Number of ideas generated by each participant (*N*), after cleaning the corpus from incomprehensible notes and from duplicates in each user's production.
- Length of trains of thought for each participant ($N/(N - R)$), with *R* the number of ideas from the same semantic category: each idea was manually classified as "same" versus "new" category with regard to the preceding idea. This analysis was based on log files only, with timecodes and ideas of all participants. To ensure a similar analysis to the control condition, we disregarded the graphical ropes that had been inserted by users in the train-of-thought condition.
- Number of trains of thought for each participant ($N - R$).
- Diversity (*D*), i.e., the number of semantic categories in each participant's production.
- Within-category fluency (N/D).

We added to this set of variables another variable to assess the originality of ideas (*O*). Although originality was not examined by Nijstad, it is considered as the most widely acknowledged requisite for creativity [42]. We assessed it by collecting the number of unique ideas [43] with regard to all the ideas proposed by all the groups.

We also analyzed the following subjective data (ratings on 7-point Likert scales): suitability of the tabletop device for this creative task, suitability of the interface, ease of use of the interface, ease of entering ideas, ease of reading other participants' ideas, self-assessment of the quantity of ideas generated, self-assessment of the quality of ideas, self-assessment of the degree of collaboration, usefulness of others' ideas to be creative,

Table 1 Examples of unique ideas (extracted from the set of 96 ideas)

Examples of unique ideas: *A knife that would…*
Be a jewel
Cut everything but human skin
Cut the hair by itself
Detect my car in the parking lot
Detect rifts
Identify plants
Include a breathalyzer
Include a protection bubble for the rain
Include a radar for visually disabled people
Record what I eat during the day

Unique ideas are those that appear only once in the whole corpus of 998 ideas (aggregation of all groups' productions)

enjoyability of the session, fun, and effectiveness of the session.

6 Results

The whole corpus contained 1,025 ideas. After cleaning incomprehensible notes and duplicates in each participant's production, we retained 998 ideas, which corresponds to 20.8 ideas per participant. In this corpus, semantic categories were manually annotated by a single judge. In order to test the reliability of this classification, a second independent judge performed the same annotation on a sample of the corpus. Inter-judge agreement on this sample amounted to $K = 0.652$. We followed the same procedure to assess the reliability of the selection of unique ideas. Uniqueness of ideas was decided with regard to the whole corpus, forming a database of answers to the Swiss Army knife problem. In this corpus, a single judge identified the ideas appearing only once and considered them as unique ideas. A second independent judge analyzed a sample of the corpus and inter-judge agreement amounted to $K = 0.631$. The judges agreed on a set of 96 unique ideas (i.e., 9.62 % of the corpus), examples of which being presented in Table 1.

The differences between control and train-of-thought conditions were analyzed by means of *t* tests (Table 2). Only three variables showed significant differences between conditions. The train-of-thought condition yielded significantly longer trains of thought ($t(46) = -2.35$; $p = 0.023$) and more original ideas ($t(10) = -3.676$; $p = 0.004$). However, the control interface was judged as significantly easier to use than the train-of-thought interface ($t(46) = 2.38$; $p = 0.022$). The other variables showed no significant difference. In particular, the train-of-thought interface did not result in more ideas, more diversity, or more fluency, and participants did not feel more effective.

Table 2 Detailed results: mean, standard deviation, and *t* test for each variable

Variable	Condition	Mean	SD	*t* test
Quantity of ideas (*N*)	Control	20.33	12.994	$t(46) = -0.336$; $p = 0.739$
	Train of thought	21.33	6.644	
Length of trains of thought ($N/(N - R)$)	Control	**1.26**	**0.1981**	$\mathbf{t(46) = -2.35}$; $\mathbf{p = 0.023}$
	Train of thought	**1.497**	**0.4574**	
Number of trains of thought ($N - R$)	Control	15.88	9.181	$t(46) = 0.342$; $p = 0.734$
	Train of thought	15.13	5.605	
Diversity (*D*)	Control	9.13	3.055	$t(46) = 0$; $p = 1$
	Train of thought	9.13	2.675	
Within-category fluency (*N*/*D*)	Control	2.11	0.8436	$t(46) = -1.44$; $p = 0.157$
	Train of thought	2.46	0.8381	
Number of original ideas (*O*)	Control	**4.67**	**2.944**	$\mathbf{t(10) = -3.676}$; $\mathbf{p = 0.004}$
	Train of thought	**11.33**	**3.327**	
Suitability of the device	Control	5.54	1.215	$t(46) = -0.957$; $p = 0.344$
	Train of thought	5.83	0.868	
Suitability of the interface	Control	5.54	0.884	$t(46) = -0.834$; $p = 0.409$
	Train of thought	5.75	0.847	
Ease of use of the interface	Control	**6.42**	**0.776**	$\mathbf{t(46) = 2.38}$; $\mathbf{p = 0.022}$
	Train of thought	**5.83**	**0.917**	
Ease of entering ideas	Control	6.63	0.576	$t(46) = 0.202$; $p = 0.841$
	Train of thought	6.58	0.830	
Ease of reading ideas	Control	5.08	1.381	$t(46) = 0.957$; $p = 0.344$
	Train of thought	4.71	1.334	
Self-assessed quantity of ideas	Control	4.438	1.262	$t(46) = -0.824$; $p = 0.414$
	Train of thought	4.708	0.9991	
Self-assessed quality of ideas	Control	4.42	0.830	$t(46) = 0.708$; $p = 0.482$
	Train of thought	4.21	1.179	
Self-assessed collaboration	Control	4.71	1.197	$t(46) = 0.708$; $p = 0.483$
	Train of thought	4.46	1.250	
Usefulness of others' ideas	Control	5.33	1.373	$t(46) = -1.644$; $p = 0.107$
	Train of thought	5.88	0.850	
Enjoyability	Control	6.04	0.955	$t(46) = 0.153$; $p = 0.879$
	Train of thought	6.00	0.933	
Fun	Control	6.00	0.978	$t(46) = 0.39$; $p = 0.698$
	Train of thought	5.88	1.227	
Effectiveness	Control	5.00	1.651	$t(46) = 0.639$; $p = 0.526$
	Train of thought	4.74	1.054	

Bold font indicates significant differences

7 Discussion

We observed a highly significant difference between the control and the train-of-thought conditions regarding the number of original (unique) ideas produced: on average, participants generated more than twice as many unique ideas in the train-of-thought condition. This result suggests that visualizing the association of ideas enabled the participants to go further in the association and therefore reach more original ideas. In the associative creativity theory [32], the semantic distance in association of ideas is considered as favoring originality and creativity. The graphical artifact we used (a rope between labels) proved very effective in increasing originality. To obtain this result, we collected unique, i.e., statistically rare ideas [43]. To complement this result, we could perform new analyses on the corpus, for example, make a sample of potential users (of Swiss Army knives) rate the originality, usefulness, or relevance of each idea, in order to decide whether the train-of-thought condition yielded more original, more useful, or more high-quality ideas (from the users' viewpoint).

As hypothesized, the train-of-thought interface with its ability to track associations between ideas during the brainwriting session enabled the participants to produce longer trains of thought. The difference in length was significant although it seems minor (1.5 vs. 1.3 ideas, see Table 2) and corresponds to very short trains of thought. In contrast, the look of the interface at the end of the session (Figs. 1, 3) shows quite long ropes of ideas. Here, it should be reminded that only ideas that were *successively* generated *by the same user* and *in the same semantic category* can be considered a train of thought [27–29]. For example, we observed in our experiment the following succession of ideas: "Magnifying glass—Sharpener—Lamp—Isolated blade," which was represented on a single thread by the user. However, it was recorded as a succession of four trains of thought of only one idea each because it alternates two semantic categories (stationery and tools). It seems that this participant was actually following two associations of ideas at the same time, which is contradictory to the principle that only one image should be activated in WM at a time [29]. Likewise, the following ideas "Clothesline—Dental floss" were successively generated by the same user and added to different ropes. Consistently, they were classified in our analysis in different semantic categories and therefore in different trains of thought. However, they may actually come from the same association of ideas, because there is a clear formal and lexical (in French: "Fil à linge—Fil dentaire") similarity between them. There are many examples of this kind, emphasizing the limitations of our analysis of idea generation mechanisms. In this study, we chose to follow Nijstad's [28] analysis method, in order to be consistent with the SIAM theoretical framework, but these examples call for new and more accurate analysis methods to better account for the effects of our train-of-thought interface on idea generation.

The final display of ropes on our interface shows associations of ideas that were completed in one or several steps by a single participant and also associations of ideas that were collectively completed: one participant generated a piece of rope, another one extended it, etc. The form of the interface encouraged the participants to do so, and this became a real strategy for some users: for example, we observed some of them thinking in a loud voice "how can we extend this rope?" In this respect, representing associations of ideas through ropes seems more effective than simply pooling ideas together since it was recently shown that idea pooling does not increase cognitive stimulation in comparison with an unstructured list of ideas [44]. Participants' strategies as well as the whole phenomenon of stimulation (using others' ideas to find new ideas) are not accounted for in the variables we collected. Moreover, even if we want to, we cannot measure this phenomenon in the control condition. When there is no visual link between ideas, how can we detect where the stimulation comes from? Which idea the user drew inspiration from at a particular moment? Such implicit activation mechanisms could not be captured in this experiment. What we observed in the control condition mainly consisted in participants manipulating ideas one by one when looking for inspiration, dragging ideas to them in order to read them more easily, and finally generating new ideas. Only one group out of the twelve control groups spontaneously started to sort the ideas into clusters, and this group did not produce more original ideas ($O = 6$) than the other control groups.

Finally, the third significant result we obtained concerned the ease of use of the interface. Our train-of-thought interface proved to be more difficult to use than the control interface. This may be due to the differences in functionality between the two interfaces. However, it also prompts us to improve our design. Some of our users suggested improving the way to move ropes (e.g., catch a rope by the labels and not necessarily by the knots) and to tie them together (e.g., tie existing ropes together and connect knots), and automatically arranging the threads so that all the ideas are always readable (no overlap).

8 Conclusion

By simply providing graphical ropes to link together successive ideas, we managed to increase the number of original ideas in a group brainwriting session. Graphical ropes may have helped each participant to go further in his/her own associations of ideas (i.e., produce longer trains of thought), and they may also have helped brainwriting partners to gain higher stimulation from sharing ideas together. We believe that this second effect was a key factor to increase originality, even if we cannot confirm it with the data collected in this study. Further experiments will be necessary to better understand the role of graphical ropes in cognitive stimulation. In particular, we intend to compare the train-of-thought interface to a new one, which would cluster together ideas successively generated by a participant, but without the graphical ropes. This new condition should help us understand whether idea generation and cognitive stimulation are influenced by the links or by the arrangement of ideas.

Our initial intuition of implementing a brainwriting tabletop interface based on the principles of the SIAM theory proved fruitful, even if our results do not exactly match the predictions of the theory. In particular, we believe that the concept of train of thought should not be limited to the initial association of ideas occurring in one's mind, and that a train of thought can be extended by the same or by another participant. Also, can several trains of thought be concurrently activated in one's mind? Future work should include several refinements of the protocol to answer such questions, as well as several refinements of the analysis methods to better account for the complex mechanisms of associative memory activation and cognitive stimulation.

Other limitations of the present study should also be addressed in future works. The population we observed was composed of students and university staff, and we used quite an artificial brainwriting subject (Swiss Army knife of the future). It would be interesting to replicate this study with groups of coworkers such as design teams on real design problems or ad hoc creative groups with real expectations, regarding the outcome of the session. We believe that the effects we observed may even be emphasized in a more realistic context. Therefore, despite the limitations of our study, we think that it provided new insight into brainwriting effectiveness, and hope it will stimulate further research about tabletop-supported creativity.

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