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Dynamic tabletop interfaces for increasing creativity

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ABSTRACT

We designed a tabletop brainwriting interface to examine the effects of time pressure and social pressure on the creative performance. After positioning this study with regard to creativity research and human activity in dynamic environments, we present our interface and experiment. Thirty-two participants collaborated (by groups of four) on the tabletop brainwriting task under four conditions of time pressure and two conditions of social pressure. The results show that time pressure increased the quantity of ideas produced and, to some extent, increased the originality of ideas. However, it also deteriorated user experience. Besides, social pressure increased quantity of ideas as well as motivation, but decreased collaboration. We discuss the implications for creativity research and Human–Computer Interaction. Anyhow, our results suggest that the Press factor, operationalized by Time- or Social-pressure, should be considered as a powerful lever to enhance the effectiveness of creative problem solving methods.

1. Goal of the research

The Organisation for Economic Co-operation and Development (OECD) considers innovation as essential to economic growth and to competitiveness, particularly in western countries. Innovation can be defined as an invention, or a new product, that meets a commercial success (Perrin, 2001). To manage this combination of invention and adequacy to the market, the top five methods used in industrial companies include creativity techniques (invention) as well as market analysis, cost analysis and methods for comparing solutions (Geis, Bierhals, Schuster, Badke-Schaub, & Birkhofer, 2008). Hence the development of effective creativity techniques appears crucial for industrial innovation.

The general aim of our research is to improve such creativity techniques. For this purpose, we will present in this article three contributions. The first one is a conceptual contribution, focused on improving creativity through the Press factor. This is an original and challenging approach, which has been poorly investigated in the creativity literature. Hence we also refer to the domain of human performance in dynamic environments to better understand the effects of pressure. The second contribution is an operational one, taking the aforementioned conceptual elaboration as a basis for the design of a computer mediated tabletop interface for group creativity. This interface includes graphical artifacts implementing two kinds of pressures: time pressure and social pressure. This kind of contribution is also original in the creativity literature, which usually focuses on methods rather than on interactive tools to support groupwork. Finally, the third contribution is an experimental one, allowing us to quantify the effects of our implementation of pressure on three kinds of variables: in this respect we provide new knowledge about the potential impact of pressure on (1) performance to the creative task, (2) collaboration behavior, and (3) subjective experience of participants.

2. Overview on creativity

Creativity is the ability to produce work that is both novel and appropriate (Sternberg, 1998). As initially proposed by Rhodes (1961), creativity can be seen as a construct of four "Ps": Person, Process, Product, and Press. The Person component refers to the individual characteristics and personality traits correlating to creativity. Research on this component (see e.g. Bolin & Neuman, 2006; Feist, 1998) has shown that creativity can be influenced by certain personality traits such as psychoticism, social anxiety, openness, impulsivity, individualism, extroversion. The Process relates to the cognitive mechanisms of creativity. In this respect, the role of associative processes in divergent thinking and problem solving has been repeatedly emphasized (Nijstad & Stroebe, 2006; Runco, 2004), as well as the mechanisms related to group creativity, such as cognitive stimulation and social comparison (Dugosh & Paulus, 2005). The Product refers to the creativity outcomes and their evaluation criteria, with the assumption that studies of products like publications, paintings, poems, or designs are highly objective.

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Finally, Press corresponds to the contextual and environmental factors interacting with creativity. A broad overlook at the creativity literature suggests that this component was much less studied than the 3 other P-factors (see literature reviews from Runco, 2004; Zeng, Proctor, & Salvendy, 2010). According to Runco (2004), the concept of "Press" can be attributed to Murray (1938) and describes pressures on the creative process or on creative persons. Two types of pressures can be distinguished: alpha pressures which are the objective aspects of press, and beta pressures which correspond to people's subjective interpretations of contextual pressures. For example, competition, which is an objective contextual factor, may stimulate or inhibit creativity depending on individual's interpretation.

Amabile (1983) defends the general view that extrinsic constraints or pressures, by impairing intrinsic motivation, have a detrimental effect on creative performance. More specifically, Runco (2004) emphasizes that time pressure should be avoided when a creative outcome is expected: time is important for incubation, and for creative work. He cites the example of outstanding creative achievements like Darwin's theory of evolution which required sustained efforts and time to elaborate. Likewise, McFadzean (1998) reports that the development of post-it notes by 3M was possible only because the company allowed their inventor Arthur Fry to spend time working on the concept. However, Amabile herself (1983) observed inconsistent effects of extrinsic pressures on the outcomes of creative tasks. She hypothesized that extrinsic pressures have a negative impact on heuristic creative tasks (when it is not specified what should be done to produce a creative response) whereas they can have a positive impact on algorithmic creative tasks (when people know explicitly how to produce a creative response). The abovementioned examples of Darwin's theory of evolution or 3M's post-it notes, as well as employees' daily activity at work, all refer to heuristic tasks in which people are not told what to do to be creative. In contrast, we are interested in the present study to examine the effects of the Press factor on a brainstorming task, whose method attempts to render creativity more algorithmic.

Brainstorming in Osborn's seminal framework (1953) is a clearly-defined and structured task, with explicit rules, applied in a limited timeframe, within the scope of a designated paradigm. This active creative method was developed in order to help people overcome cognitive fixations. Indeed, the limited capacity of short-term memory and the automatic spreading activation mechanisms explain why people are often limited to a narrow, familiar, and bounded subset of the problem space. Cognitive fixations result in ignoring about 80% of potential solution space and being unaware of doing so (see review by Zeng et al. (2010)). Venturing beyond the highly familiar categories requires efforts and Osborn's brainstorming method was developed to support such process. It is a group method relying on two basic principles: deferment of judgment and quantity leads to quality. Deferment of judgment emphasizes the need for separating ideation and evaluation. Because original ideas may appear unusual or slightly bizarre, they might easily fall victim to self-censure and censure from others (Stroebe, Nijstad, & Rietzschel, 2010). Furthermore, emphasizing quantity of ideas as the desired outcome further reduces group members' tendency to be critical of the ideas produced. It was actually shown in experimental studies that quantity of ideas correlates to the number of high-quality ideas (e.g. $r = 0.69$ in Parnes and Meadow (1959); $r = 0.82$ in Diehl and Stroebe (1987)).

Brainstorming is also meant to be a playful activity, which is likely to increase its effectiveness to free the group's creative potential (VanGundy, 1997). According to McFadzean (1998), research at the University of Michigan showed that laughter causes the release of endorphins, which in turn provide a burst of energy and an impetus to creativity. It can also help group members take things less seriously thus reducing self-censorship. In this respect, the Press-factor could also be seen as a potential lever to playfulness since challenges, rewards, or time pressure are classical workings of game design.

To summarize, we have seen in this section that although pressures are considered detrimental to heuristic creative tasks, it cannot be excluded that they could improve other tasks such as brainstorming. Indeed, because brainstorming in Osborn's framework tends to make creativity more algorithmic, it could respond positively to pressure. To further reason on the potential impact of pressure on creativity, we examined the literature related to the effects of pressures on different kinds of cognitive and collaborative activities. This research field, focusing on human activity in so-called "dynamic environments", proved fruitful to structure our study of creativity, as we will show in the next section.

3. Human activity in dynamic environments

Osman (2010) opens her literature review of human activity in dynamic environment by providing six examples of activities that seem eclectic at first sight: ecosystem control, automated pilot management, incineration plant monitoring, investment game, sugar factory plant control, and water purification system. However, these tasks all involve complex sequential decision making and occur in what she calls "complex dynamic environments". These are uncertain environments, changing either as a consequence of human actions, autonomously, or both (Osman, 2010). For this reason, complex dynamic environments bear the risk for the human operator of losing control. Task complexity is related to the characteristics and the number of elements and relations it is necessary to account for (Hoc, Amalberti, & Plee, 2000). Osman's (2010) unifying approach of economics, engineering, ergonomics, Human–Computer Interaction, management, and psychology, results in identifying four main sources of uncertainty in complex dynamic environments (see also Funke, 2001): (1) time pressure, (2) feedbacks, outcomes and reactions of the system to the operators' actions (positive, negative feedback, unpredictable, unreliable, invalid or invisible one...), (3) involvement of multiple actors and stakeholders, and (4) ill-structured problems with shifting, ill-defined, or competing goals.

Research on time pressure has identified many ways in which cognitive processes change with time pressure. In this respect, a number of contradictory findings were reported (see Maule, Robert, Hockey, & Bdzola, 2000): time pressure has sometimes been shown to increase the quality of decision-making, and sometimes to reduce it, to induce less extreme judgments, to reduce the propensity to take risks, etc. For example, Kersholt (1994) simulated a diagnosis task involving a virtual athlete running a race: subjects had to monitor the athlete's fitness level over time and react accordingly. Declines in fitness level could be caused either by dehydration, cardiac overload, overheating or a false alarm. The subjects had to diagnose the problem by consulting the athlete's physiological parameters and administer the adequate treatments (give water, rest or cool). In this study, the complex dynamic environment was characterized by: the autonomous evolution of the athlete's fitness level, time pressure (operationalized as speed of system decline), the diagnosis task which is ill-structured by nature, and the system feedback to the subject actions. The results show a general speedup of information processing as time pressure increases, up to a maximum where the strategy fails and leads to system collapse (inverted U-shaped relation between time pressure and performance).

Finance is another field in which decisions have often to be made under time pressure. Kocher and Sutter (2006) examined the influence of time pressure and time-dependent incentive schemes on decision making. The experimental task was a beauty-contest game designed with the same principles as financial tasks. The results are somewhat contradictory with those from Kerstholt (1994) since decision making was better under low time pressure, but time-dependent payoffs under high time pressure led to significantly quicker decision-making without reducing the quality of decisions (U-shaped relation).

Rogalski (1996) examines how humans collaborate under pressure, and more particularly how crew members in an aircraft cooperate in an incidental situation. To increase workload (and pressure), she used full-size simulation of an engine fire during takeoff and observed how experienced pilots cooperate on the main task (piloting) and on the incident (fire). Here, the complex dynamic environment involves the management of autonomous variables (external parameters for the piloting task, fire spreading), system feedbacks for both tasks, time pressure particularly emphasized by fire spreading, coordination of the crew, and competing goals (between the main task and the incident). The results show that explicit verbal cooperation (e.g. information sharing between crew members, situation awareness) decreased with pressure although distributed cooperation through action was maintained. Under pressure the pilots focused on the specific tasks they are assigned to in the distributed cooperation pattern, while explicit (verbal) cooperation was impaired. Rogalski explains that task complexity may interfere with explicit cooperation requirements: cooperation becomes a secondary task with respect to individual allocated task performance.

After this brief literature review, the relation between human performance and pressure remains unclear, between U-shaped and inverted U-shaped relation. If pressure could stimulate individual performance, or speed up individual cognitive processing, it could also impair collaboration and induce attentional filtering (Kelly & Loving, 2004). In other words, all hypotheses are left open regarding the effects of pressure in the creativity application framework. Nevertheless, this state of the art and particularly Osman's (2010) approach helped us operationalize the concept of dynamic environment (and pressure) into creativity research, as will be developed in the following section.

4. A tabletop interface for brainwriting

We have designed a tabletop platform for creativity, and first explain why it appears as a relevant medium for creative problem solving tasks.

Brainstorming in Osborn's framework is a collective idea generation technique which enables the group to benefit from many collective phenomena, but also suffers from several failings. Examples of positive effects associated to brainstorming include cognitive stimulation (the exposure to other participants' ideas enhances idea generation in individuals, see Dugosh & Paulus, 2005; Dugosh, Paulus, Roland, & Yang, 2000; Nijstad, Stroebe, & Lodewijkx, 2002) and social comparison (the possibility to compare one's own performance to the others' is a source of motivation, see Bartis, Szymanski, & Harkins, 1988; Dugosh & Paulus, 2005; Harkins & Jackson, 1985; Michinov & Primois, 2005; Paulus & Dzindolet, 1993).

However, a major shortcoming of classical "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 constraint severely interferes with idea generation process (Nijstad, Stroebe, & Lodewijkx, 2003) and results in "production blocking" (Diehl & Stroebe, 1987; Michinov & Primois, 2005). One simple way of counteracting production blocking is to use the written instead of the oral channel to record the ideas, which can be referred to as brainwriting (Heslin, 2009; Isaksen, Dorval, & Treffinger, 2000; Paulus & Yang, 2000; VanGundy, 2005). In this method, participants silently share written ideas, for example on sticky notes.

Another key issue in brainstorming is social loafing (Harkins & Szymanski, 1988; Karau & Hart, 1998; Karau & Williams, 1993; Serva & Fuller, 1997): it was observed that in brainstorming groups, some participants tend to under-contribute with comparison to a situation where they would brainstorm alone. Hence the social nature of brainstorming can also impair the creative performance.

To overcome the aforementioned limitations of group brainstorming while maintaining its strengths, we have designed a creativity-supporting tabletop device (Fig. 1). Tabletop systems are multi-user horizontal interfaces for interactive shared displays. They implement around-the-table interaction metaphors allowing co-located collaboration and face-to-face conversation in a social setting (Shen et al., 2006). Because they emphasize both situation awareness (shared display) and group awareness (around-the-table configuration), they are expected to support both cognitive stimulation and social comparison processes. Moreover, to avoid production blocking, we developed an interface allowing idea collection in the form of virtual post-it notes (i.e. brainwriting). Finally, we have observed that our device was likely to decrease social loafing in at least two ways. In a previous series of experiments (Buisine, Besacier, Aoussat, & Vernier, 2012), we have compared the performance of 20 groups of four participants on creative problem solving tasks in four different media conditions: pen and paper tools on a flipchart, pen and paper tools around a table, and two versions of a digital tabletop interface with more or less advanced interaction styles (implementing two degrees of attractiveness). Firstly, the "around-the-table" form factor proved to increase equity of collaboration (balance in number of contributions from group members). 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 (Woolley, Chabris, Pentland, Hashmi, & Malone, 2010). Furthermore, our results showed that the attractiveness of the tabletop device increased extrinsic motivation to engage in the task, which is also a moderating factor of social loafing (Brickner, Harkins, & Ostrom, 1986; Shepperd, 1993).

For the present study the tabletop brainwriting tool was implemented using the DiamondSpin toolkit (Shen, Vernier, Forlines, & Ringel, 2004). Each participant creates his digital post-it notes using a push-up menu located on the edge of the table closest to him. Newly created notes can be edited (using handwriting, drawing, or typing in on a virtual keyboard), can be moved, or deleted. To illustrate an idea on a note, the system also provides the 20 first results of a Google Images search when a text is typed. An image

Fig. 1. Our tabletop brainwriting system.

can be chosen from a pie menu (Shen, Hancock, Forlines, & Vernier, 2005) to further appear in the note. When a note is completed, the user miniaturizes it: it consists in pressing a button to instantly shrink a note down to minimal size. It also represents a validation operation, since the note is no longer editable when shrunk down (this enables users to manipulate notes without writing on them). The default spatial orientation of notes is different according to their state: during idea generation, virtual notes cannot be moved out of each participant's personal area and their default orientation is centered on their author (i.e. on a virtual point located outside of the table); once a note is validated, it is automatically attracted in the collective space in the center area of the table. Notes are animated to help participants notice them and improve idea sharing. This animated movement brings the validated post-it note just beyond the center of the table, in the opposite quarter of the table. The animation is designed so as to bypass the geometric center of the table where the orientation suddenly flips 180°. The note path follows an arc of circle around the center as an invitation for other users to read it before it is piled on the opposite side. To make more notes visible we spread them randomly at two pre-defined distances of the center. An example of automatic arrangement of notes is visible on Fig. 1. However, notes in the collective space remain manually movable on the whole display area.

In the following section we describe how we implemented the Press factor into this tabletop brainwriting system.

5. Implementation of the Press factor

A first challenge of the present study was to operationalize the Press factor on our tabletop brainwriting system. To design the experiment we likened the Press factor to a complex dynamic environment, and relied on Osman's (2010) typology of dynamic variables to transfer this concept into a brainwriting task. We subsequently imagined more than a hundred ways of introducing dynamic variables into brainwriting (see Table 1).

Table 1
Examples of dynamic variables that could be introduced into a brainwriting activity (extract). The [∗] indicate the factors implemented in the present study.

Osman's categories of dynamic variables	Possible adaptations to brainwriting
A. Time pressure	• Limited time for editing an idea [∗] • Limited time for a session (display an hourglass) • Number and frequency of notes controlled by the system • Flashing notes (with flash rate gradually accelerating) • Play a music that gradually accelerates • ...
B. System feedbacks	• Automatic classification of ideas • Automatically display images in the table background • Random movements of blank and filled in notes • Reward certain ideas • Encouragements/comments from the system • ...
C. Involvement of multiple actors	• Display performance scores [∗] • Compete with the system • Competing subgroups • Obligation to develop the others' ideas • Inform the participants of the last ideas edited (with e.g. scrolltext) • ...
D. Shifting goals	• Trivial pursuit: switch between goals according to your position on a track • Free association from images (goal unknown) • The participants have different goals • Ideas are noted on their relevancy to the goal: you must generate ideas to guess the goal • Morphological matrix (forced combinations between unrelated concepts) • ...

As will be developed and described below, we chose to examine the effects of two factors: (1) time pressure in idea generation and (2) social pressure emphasized by the display of each participant's performance score.

5.1. Time pressure

As seen in Section 2 (state-of-the art on creativity research) and Section 3 (state-of-the-art on human performance in dynamic environments), the effects of time pressure on human cognition, and more specifically on creativity are unclear and we wish to contribute to this complex issue by examining its impact on a brainwriting task. For implementing time pressure we had several choices, for example (see Table 1): limiting the time for a whole session; limiting the time for generating each idea; setting participants a number of ideas to produce; designing flashing post-it notes (with flash rate gradually accelerating); playing music gradually accelerating throughout the task, etc. The two latter (flashing notes and music) are subjective rather than objective pressures because although flash rate or music accelerates, it does not necessarily imply that participants have more little time to be creative. Besides, the concept of forcing the participants to produce a certain number of ideas is only an indirect way of introducing time pressure and a more direct time pressure seems more appropriate to a controlled experiment. Finally, we considered that limiting the time for each idea constituted a more continuous time pressure than limiting the duration of the session. In the latter case, participants may feel the pressure only at the end of the session and this was likely to decrease the potential impact of the pressure.

This is why we decided to set a timeout for each post-it note. We designed a system to validate the post-it notes automatically after a given delay. Once the delay is expired, the note cannot be edited anymore, and is automatically dispatched in the collective space for sharing ideas. A new empty note is then automatically created in the participant's personal space. If the validated note is still empty, it is deleted. Users can also validate their notes before the end of the delay.

During edition, time pressure is visible through two visual feedbacks (Fig. 2). The top right corner of the note displays a rotating clock. The corner becomes transparent as time elapses, with a movement referring to the hand of a clock. However, pilot tests revealed that this signal was not pro-eminent enough, hence we added a vertical gauge on each side of the note. The color[1] of these feedbacks simultaneously turns green to red to enforce user perception of time pressure.

5.2. Social pressure

The second kind of pressure we decided to address is social pressure. The benefits of social comparison are well-known. They can be observed for example when individual outputs are identifiable (with comparison to a situation where outputs are pooled, see Harkins & Jackson, 1985), when participants believe that their output will be evaluated (Bartis et al., 1988), when they are given a performance standard for their task (Paulus & Dzindolet, 1993; Shepherd, Briggs, Reinig, & Yen, 1995), when they are exposed to the ideas of other participants (with comparison to a situation where they think the ideas come from a computer, see Dugosh &

[1] For interpretation of color in Figs. 1–3, the reader is referred to the web version of this article.

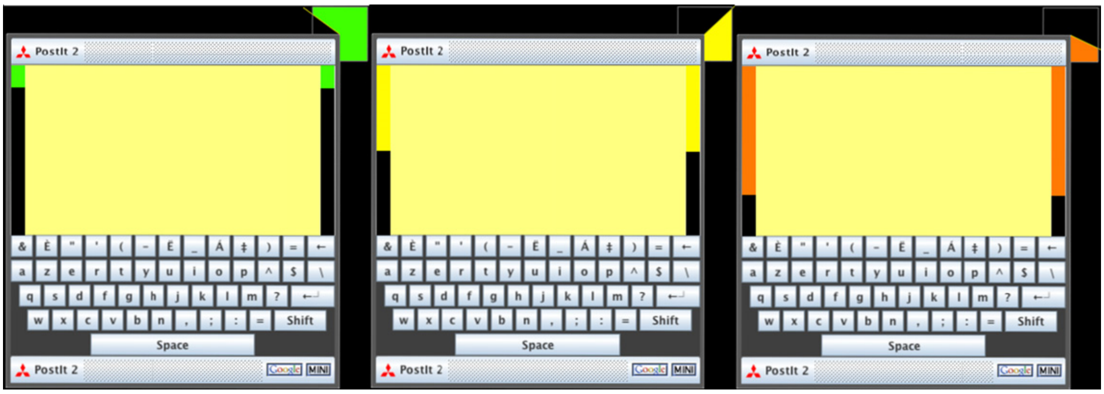

Fig. 2. Different states of time pressure feedbacks.

Paulus, 2005), or when they are periodically informed of each one's performance level (Michinov & Primois, 2005; Paulus, Nakui, Putman, & Brown, 2006). In all these experiments, social comparison was created by means of direct and explicit information (a group performance standard, individual performance levels) in the absence of implicit contextual information (group awareness, situation awareness, or performance perception). Indeed in these experiments, the participants' challengers were always physically absent (Dugosh & Paulus, 2005; Michinov & Primois, 2005; Paulus & Dzindolet, 1993; Shepherd et al., 1995) or they were present but worked on separate computers and had no clue to the others' performance level (Paulus et al., 2006). In other words, these experiments simulated social comparison in order to better control it. In contrast, we wish to test the effects of a specific pressure *in addition to* the contextual and environmental information (group and situation awareness) already available to a group working in presence (co-located participants around a table who share their post-it notes). Can social comparison be further emphasized in this case? Does the performance continue to increase or does it reach a maximum (inverted U-shaped relation)?

To answer these questions, we decided to provide real-time explicit feedback on individual performance and display it on the table background the group is working on. Similar feedback signals intended for visualizing individual performance in group situations can be found in the literature (DiMicco, Pandolfo, & Bender, 2004; Rashid et al., 2006; Ringel Morris et al., 2006) but they were not used in the context of creative tasks. A notable exception is the study from Kim, Chang, Holland, and Sandy Pentland (2008), in which group members of a brainstorming task were provided with sociometric badges and mobile phones facing them on a table. The sociometric badges recorded their participation level to the task (e.g. speaking time, speaking energy...) and the mobile phone displayed a visualization of the balance and interactivity level between group members. This device proved to influence group interactivity towards a more equitable collaboration pattern, but had no effect on the number of ideas generated. Actually the fact that the feedback accounted for verbal participation but not for the number of ideas may explain the lack of effect on the latter. Hence in the present study we will test whether a feedback regarding directly the *number of ideas* generated by each member will influence the creative performance of groups working on a digital tabletop device, a system that already favors group awareness and situation awareness by nature. It should be noted that such real-time feedback is possible only because we use a fully-digital environment and could hardly be tested with pen and paper tools.

Social pressure was set by counting the number of valid (non empty) notes for each user and display a real-time performance feedback. Usually this kind of feedback is displayed through histograms, either on a wall display (DiMicco et al., 2004) or on a table-

Fig. 3. Performance feedback used to create social pressure. In addition to the number of notes generated, the rank of each participant is graphically represented by the size and color of his portion.

top interface (Ringel Morris et al., 2006): in the latter case, the histogram was duplicated in front of each participant highlighting his own score. In order to strengthen the comparison between participants, we designed a unique feedback to be placed in the center of the table, ensuring intuitive visualization of performance as well as facilitating the attribution of the scores to the participants. This feedback is a circular histogram, looking like a pie chart divided into four portions, one in front of each user, displaying his particular score (Fig. 3). Each portion prints the number of valid post-its and highlights the rank of the user. The rank is represented by the size of the portion (bigger is better) and the color (greener is better). The original design of the circular histogram was guided by the goal of having a single artifact, located at equal distance of all users. This design implies to have a very noticeable view of the scores at all time by all the participants. We relied on the redundancy of three graphical features (large numeric labels, ordered colors and size of the histogram portions). A more subtle design could be achieved (for screen real estate saving for instance) but the need for measurable effects in the experiment played in favor of a strong representation.

6. Experiment

6.1. Participants

Eight groups of four subjects (32 users in total) participated in the experiment. This sample included 22 students, six teachers and four staff members from two research institutes, 19 men and 13 women, aged 27.7 years on average (SD = 6.7).

6.2. Material

We used a 107-cm Circle Twelve DiamondTouch device (Dietz & Leigh, 2001) with a 1400 × 1050 projected display. Participants were seated around the table and interacted with finger-input on the display. A video camera placed above the table recorded the sessions.

6.3. Procedure

The session began with a presentation of the tabletop brainwriting method and a familiarization with the interactive device. The interface's functionalities as well as the experimental conditions (time pressure, social pressure) were explained and demonstrated to the participants. The goal of the session was then presented: participants had to imagine the "Swiss Army knife" (a multi-function multi-tool pocket knife) of the future. Before starting the idea generation, Osborn's rules (1953) were delivered: Focus on quantity, Withhold criticism, Welcome unusual ideas, Combine and improve ideas. A key principle in Osborn's brainstorming method is to unleash creativity by deferring judgment (divergent thinking). The three first rules all refer to this principle of separating idea generation and evaluation. Another principle of brainstorming is to favor associative creativity from others' ideas (cognitive stimulation). The fourth rule then encourages participants to appropriate others' ideas and transform them. These rules need to be formalized and periodically reminded to the brainstorming participants because such attitudes are not spontaneous. However, it was repeatedly shown that brainstorming with Osborn's rules is more efficient than brainstorming without the rules (Parnes & Meadow, 1959; Paulus et al., 2006; Turner & Rains, 1965; Weisskopf-Joelson & Eliseo, 1961).

Time pressure, which was a within-subject variable, included four conditions: P0 (no time limit to edit a post-it note), P1 (edition time limited to 60 s), P2 (30 s) and P3 (15 s). These values were chosen after a pretest session which had determined an average spontaneous edition time of 15.3 s (SD = 4.8) – a value which does not include the time for searching ideas. The 20-min brainwriting session was divided into four 5-min stages of these different time pressure levels. The order of conditions was counterbalanced across the sample: two groups experienced increasing time pressure all along the session (P0–P1–P2–P3), two groups experienced decreasing time pressure (P3–P2–P1–P0), and four groups experienced uneven succession of conditions (P1–P0–P3–P2 and P2–P3–P0–P1). Between two stages the participants were offered a few minutes to read and discuss the ideas on the table. Such breaks appeared necessary to better share ideas, particularly in high levels of time pressure in which the participants could not take the time to read all ideas on the fly. Moreover, breaks in a brainstorming have a number of benefits (Paulus et al., 2006): they allow for incubation-like processes, they stop the decline in number of ideas generated over time and contribute to re-motivate the participants for the following stage. After the break the table was cleared and the participants had to start again generating ideas on the same topic, but in a new condition.

Social pressure was a between-subject variable: the performance feedback was displayed on the table background for half of the groups. For the other half the table background was empty. The performance scores were reset at the beginning of each 5-min stage in order to give participants more opportunities to "win" a stage.

At the end of the experiment, users had to fill in a questionnaire (see Appendix A) to assess several subjective variables with Likert-type items (ordinal response format contrasting two semantic ends along a continuum). The whole experiment lasted about 1 h for each group.

6.4. Data collection and analysis

6.4.1. Performance criteria

As it was shown that quantity of ideas correlates to the number of high-quality ideas (e.g. linear correlation coefficient $r = 0.69$ in Parnes and Meadow (1959); $r = 0.82$ in Diehl and Stroebe (1987)), we considered the quantity of ideas as a first performance measure. To collect it in an unbiased way we had to clean the idea corpus from incomprehensible notes and from duplicates in each user's production. To complement this metric, we also assessed the originality by collecting the number of unique ideas (in Torrance's (1966) sense): uniqueness is decided with regard to normative data (typically: a database of the most frequent answers to the same problem). For this purpose we created our own database of answers to our "Swiss Army knife" problem by aggregating all groups' ideas. In this corpus we identified the ideas appearing only once and considered them as unique ideas. Note should be taken that uniqueness or originality are different from relevance and some unique ideas may well appear as irrelevant. Relevance could be assessed with regard either to users' needs or to a market strategy. We did not have sufficient information to assess relevance of each idea and were not in contact with any Swiss Knife manufacturer. Therefore in this study we focused only on originality as an evaluation criterion for ideas, considering also that it is the most widely acknowledged requisite for creativity (Runco, 2004).

6.4.2. Collaborative behaviors

We annotated the collaborative behaviors from the video-recordings of the sessions in order to quantify each participant's contributions and calculate an inequity index. Equity in collaboration refers to "democracy", as a set of ways to ensure the information communicated by the various participants is done so with minimal distortion, as opposed to a repressive communicational framework (Habermas, 1984). Equity in conversational turns is also correlated to the Collective Intelligence of the group (Woolley et al., 2010). Hence we assessed collaboration through the following inequity index I, where N = size of the group, $1/N$ = the expected proportion of collaborative behaviors if each participant contributes equally, and O_i = the observed number of collaborative behaviors for each individual.

$$I = \left| \frac{1}{N} - \frac{O_i}{\sum_{i=1}^{N} O_i} \right| \times 100$$

Similar quantification of participants' contributions can be automated by logging interface actions made by individuals (Ringel Morris et al., 2006; Wigdor, Jiang, Forlines, Borkin, & Shen, 2009) but we applied our inequity index to a more complete set of behavioral variables. Indeed we consider that task completion cannot be reduced to interface actions, and we wished particularly to account for spoken contributions. Hence we collected conversational turns (e.g. reading an idea, asking a question, answering, etc.) and communicative gestures (e.g. pointing to an item, moving a note, requesting speech turn by a gesture). Gesture input for note edition was not collected since it was not considered as communicative or collaborative gestures. The whole video corpus (160 min) was annotated by a single coder but in order to assess the reliability of annotation a second coder independently annotated a 20-min extract (i.e. 12.5% of the corpus). Inter-judge agreement (Cronbach's alpha) amounted to 0.876 on this extract, which means that the two coders obtained very close results with regard to the number of conversational turns and communicative gestures per participant, and that the annotation can be considered as reliable (Cronbach's alpha above 0.7).

6.4.3. Subjective data

In the questionnaire (see Appendix A), the participants had to compare the four successive conditions they had seen on 25 criteria: for each criterion, the participant had four scales to complete, one for each time pressure condition. The evaluation criteria were distributed in three sections. The first section was dedicated to usability criteria (easiness, fun, agreeableness, satisfaction, self-assessed level of collaboration with the other participants, self-assessed quantity and quality of ideas generated). The second section was a customized motivation questionnaire inspired by existing scales (Chow & Law, 2005; Pelletier, Vallerand, Green-Demers, Blais, & Brière, 1996; Rubin & Hernandez, 1988; Zaharias, 2006). The following items were used: "I was motivated to do well, the results are important to me, I tried to do my best, I would like to know my performance, I would like to know the others' performance." A global motivation score for each condition is obtained by averaging the answers to these five items. Finally the third section of the questionnaire was a self-evaluation of the affects and emotions experienced during the four conditions. This part was adapted from Maule et al.'s (2000) evaluation scale of the impact of time pressure: 12 items were used to assess three dimensions, namely happiness, anxiety, and energy. In addition to these 24 questions, users were also particularly prompted to make qualitative comments at their leisure.

6.5. Results

The dataset was analyzed by means of ANOVAs with Time-pressure as within-subject factor (P0, P1, P2, P3) and Social-pressure (performance feedback, no feedback) as between-subject factor. Fisher's LSD was used for post-hoc tests; all the analyses were performed with SPSS v18.

6.5.1. Performance criteria

The corpus of ideas generated by all groups initially contained 1483 ideas. After incomprehensible notes or duplicates (within a user's production) were removed, the corpus comprised 1450 ideas. This represents a global rate of 11.3 ideas per participant for a 5-min session (SD = 5.2), and we checked that there was no ordering effect in the number of ideas produced in the four successive sessions ($F(3/90) = 0.145$; NS). However, we observed a main effect of Time-pressure on the number of ideas ($F(3/90) = 29.45$; $p < 0.001$; see Fig. 4): in P0 condition participants generated significantly less ideas ($m = 8.38$ ideas) than in the other conditions ($p < 0.019$). In P1 condition they tended to generate less ideas ($m = 10.1$) than in P2 ($m = 11.41$; $p = 0.068$). And P3 condition yielded significantly more ideas ($m = 15.44$) than all other conditions ($p < 0.001$).

A main effect of Social-pressure also appeared ($F(1/30) = 6.55$; $p = 0.016$; see Fig. 5), showing that significantly more ideas were generated in the presence of the performance feedback ($m = 12.83$) than in the absence of feedback ($m = 9.83$).

Out of 1450 ideas in the whole corpus, only 110 met the uniqueness criterion, which represents 7.6% of the corpus. Examples of unique ideas for the "Swiss Army knife" problem are listed in Table 2. On this idea sample ANOVA was run at the group level (1 value by group). We obtained a main effect of Time-pressure ($F(3/18) = 3.46$; $p = 0.038$; see Fig. 6) showing that groups produced more unique ideas in P2 condition than in P0 ($p = 0.033$), P1 ($p = 0.007$) and P3 (marginally, $p = 0.079$). Other pairwise comparisons were not significant. Besides, there was no effect of Social-pressure on the number of unique ideas ($F(1/6) = 0.082$; NS).

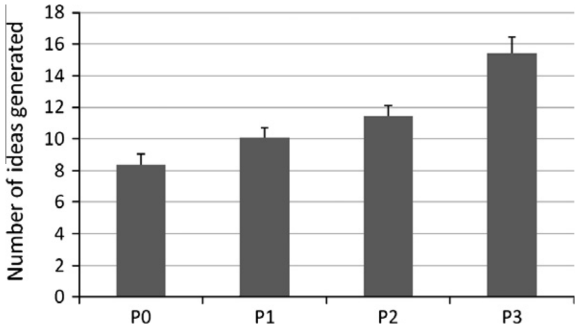

Fig. 4. Effect of Time-pressure (P0–P3) on the number of ideas generated by each participant in a 5-min session.

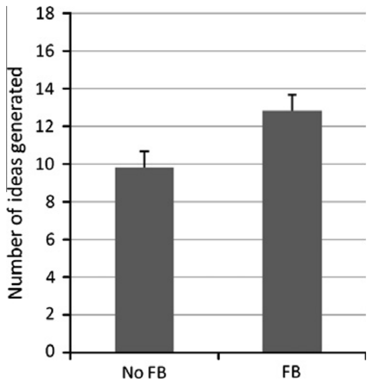

Fig. 5. Effect of Social-pressure (No FeedBack; Performance FeedBack) on the number of ideas generated by each participant in a 5-min session.

6.5.2. Collaborative behaviors

The number of conversational turn was not significantly influenced by Time-pressure ($F(3/90) = 2.35$; NS), but it decreased with Social-pressure ($F(1/30) = 7.54$; $p = 0.01$). The number of collaborative gestures was influenced neither by Time-pressure ($F(3/90) = 1.46$; NS) nor by Social-pressure ($F(1/30) = 2.68$; NS).

Equity in turn-taking was impacted neither by Time-pressure ($F(3/90) = 2.26$; NS) nor by Social-pressure ($F(1/30) = 3.67$; NS). Likewise, equity of collaborative gestures showed no effect of Time-pressure ($F(3/66) = 0.38$; NS) nor of Social-pressure ($F(1/22) = 0.12$; NS).

6.5.3. Subjective data

A main effect of Time-pressure on easiness was observed ($F(3/90) = 44.41$; $p < 0.001$): P0 condition was judged marginally easier ($m = 6.47$) than P1 ($m = 6.31$; $p = 0.056$), itself easier than P2 ($m = 5.38$; $p < 0.001$) and P2 easier than P3 ($m = 4.16$; $p < 0.001$). The Social-pressure had no effect on easiness ($F(1/30) = 2.74$; NS).

Table 2
Examples of unique ideas (extract from a corpus of 110 ideas). Unique ideas are those which appear only once in the database of 1450 ideas (aggregation of all groups' productions).

Examples of unique ideas: "*A knife that would…*"
Be allowed in aircrafts
Include a GPS projecting arrows on the ground
Have a weather-sensitive color
Include a food analyzer detecting sugar rate
Include a battery charger for mobile phones
Include a seismograph
Float when falls down in the water
Include a mushroom detector
Include a vase
Include a bird singing analyzer
Include an invisibility cloak
Include a mosquito net
Include a baby monitor
Not harm users' nails to open
Include an instantaneous rest dispenser
…

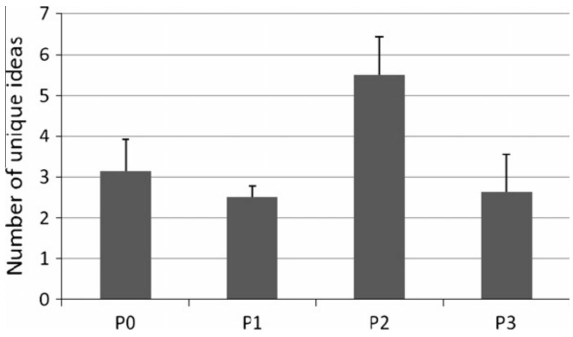

Fig. 6. Effect of Time-pressure level (P0–P3) on the number of unique ideas generated by a group in a 5-min session.

There was also a main effect of Time-pressure ($F(3/90) = 5.67$; $p = 0.001$) on agreeableness, showing that P3 condition was judged as significantly less agreeable than all other conditions ($p < 0.033$). The other pairwise comparisons were not significant. Besides, there was no effect of Social-pressure on agreeableness ($F(1/30) = 2.21$; NS).

No effect of Time-pressure ($F(3/90) = 0.52$; NS) nor Social-pressure ($F(1/30) = 0.37$; NS) was found on the fun criterion. Likewise, satisfaction level was not influenced by Time-pressure ($F(3/90) = 1.99$; NS) nor by Social-pressure ($F(1/30) = 0.31$; NS). Self-assessment of collaboration showed the same pattern ($F(3/90) = 1.55$; NS for Time-pressure and $F(1/30) = 3.78$; $p = 0.061$ for Social-pressure), and self-assessed quantity of ideas generated also ($F(3/90) = 0.86$; NS for Time-pressure and $F(1/30) = 0.28$; NS for Social-pressure). However, Time-pressure had a main effect on self-assessed quality of ideas generated ($F(3/90) = 3.48$; $p = 0.019$): participants thought they have produced better ideas in P0 ($m = 4.78$) than in P3 condition ($m = 3.94$; $p = 0.028$). The other pairwise comparisons were not significant. Social-pressure had no influence on self-assessed quality of ideas ($F(1/30) = 1.39$; NS).

Regarding motivation, we observed no significant effect of Time-pressure ($F(3/90) = 0.17$; NS), but we found a main effect of Social-pressure ($F(1/30) = 6.6$; $p = 0.015$) showing that participants submitted to the performance feedback were more motivated ($m = 5.28$) than those who worked without performance feedback ($m = 4.47$).

Finally, the emotions and affects experienced during the session proved to be impacted by Time-pressure ($F(3/90) = 5$; $p = 0.003$ for the Energy, $F(3/90) = 13.66$; $p < 0.001$ for Anxiety and $F(3/90) = 3.44$; $p = 0.020$ for Happiness). Energy proved to be higher in P3 condition than in all other conditions ($p = 0.005$), Anxiety level was similar in P0 and P1, significantly higher in P2 ($p < 0.036$) and highest in P3 ($p < 0.001$). Finally, Happiness was significantly higher in P1 than in P2 ($p = 0.031$) and P3 ($p = 0.025$). There was no effect of Social-pressure on Energy ($F(1/30) = 2.07$; NS), Anxiety ($F(1/30) = 0.04$; NS) or Happiness ($F(1/30) = 0.06$; NS).

6.6. Discussion

6.6.1. Effects of time pressure

Our results show that time pressure successfully impacted the creative performance of brainstorming groups. This is a totally novel result in the field of creativity. We expected that it would stimulate idea generation and speed up idea search, but we actually thought we would obtain an inverted U-shaped curve, with idea generation reaching a maximum and decreasing under highest time pressure level(s). Surprisingly, the quantity of ideas increased linearly with time pressure, and we could not identify any ceiling. In the highest Time-pressure condition P3, participants produced nearly twice as more ideas ($m = 15.44$ ideas) than in the no-Time-pressure condition P0 ($m = 8.38$ ideas). Strikingly, self-assessed quantity of ideas did not vary with time pressure, which suggests that the participants did not realize that they generated more ideas under time pressure.

Contrary to quantity of ideas, our second performance criterion, namely uniqueness of ideas, highlighted a ceiling: the number of unique ideas was highest in P2 condition (edition time limited to 30 s), with sufficient but not-too-high time pressure to speed up idea generation without impairing idea search, note edition, or both. This is also a highly original result that, to our knowledge, cannot be found in earlier literature. In P3 condition (edition time limited to 15 s), participants kept editing more and more ideas but "getting nowhere" since they did not manage to produce unique (or original) ideas. Participants may have partly perceived this result because they rated the quality of their ideas lowest for P3 condition ($m = 3.94/7$). However, they did not realize that their ideas in P2 ($m = 4.38$) could be better than those from P0 ($m = 4.78$).

The behavioral analysis performed on the video-recordings revealed no effect of Time-pressure on collaboration. Consistently, participants reported a constant level of collaboration across conditions. Our informal observations of the sessions led us to think that under high time pressure they clearly had *no time* to collaborate, but did it anyway. We felt that it was a way to cope with pressure, to show a kind of solidarity. Fun, satisfaction and motivation were also preserved in spite of time pressure and showed constant intermediate-to-high levels (respectively $m = 5.87$; $m = 5.38$ and $m = 4.88/7$).

However, time pressure severely impacted easiness: as time pressure increased, easiness fell from a very high level ($m = 6.47/7$ in P0 condition) to an intermediate one ($m = 4.16/7$ in P3 condition). Agreeableness also significantly decreased in P3. Finally, emotional pattern significantly deteriorated under time pressure, with increasing energy and anxiety, and decreasing happiness.

6.6.2. Effects of social pressure

Social pressure proved to influence idea generation as well: the mere presence of the performance feedback on the table background led to significantly more ideas produced. With comparison to the effects of time pressure, it should be emphasized that social pressure increased idea generation *without* impairing user experience: easiness level, fun, satisfaction, agreeableness, emotional pattern, self-assessment of collaboration, of quantity and quality of ideas all remained constant in spite of the increase in social pressure. It even had a positive impact on motivation.

However, we observed two limitations of social pressure: firstly, the number of unique ideas stagnated although the total number of ideas had increased under social pressure. Secondly, it led the participants to reduce the quantity of collaborative verbal behaviors. These two limitations might be linked to one another. Indeed social pressure, by intensifying competition between participants, impaired collaboration (which, in brainwriting, mainly consists in sharing ideas). Hence, lower collaboration may have resulted in reduced cognitive stimulation and disrupted divergence and generation of unique ideas. This body of results, including performance, subjective and behavioral impacts of social pressure is unique in the literature: usually social comparison is studied with regard to performance (Bartis et al., 1988; Dugosh & Paulus, 2005; Michinov & Primois, 2005; Paulus et al., 2006; Shepherd et al., 1995), sometimes conjointly with subjective experience (Harkins & Jackson, 1985; Paulus & Dzindolet, 1993), but the possible drawbacks of social comparison on collaboration were not previously identified as they are in our experiment.

7. Conclusion

We showed that to some extent, explicit time pressure can stimulate creativity: in a brainwriting task, time pressure can help increase quantity of ideas, and enhance originality (number of unique ideas). We are not suggesting that time pressure stimulates *all kinds* of creativity: designers, scientists, and everyone expected to be creative, should not be placed under time pressure in their everyday work, of course. But the possibility that time pressure could speed up the creative process like it was shown to speed up other cognitive mechanisms should not always be ruled out in the literature. In this respect, our experiment provides a new viewpoint on creative process.

Our results concern algorithmic creative tasks only, in Amabile's (1983) sense: algorithmic tasks include methods from the creative problem solving toolbox used in a time- and sequence-structured group format (Isaksen et al., 2000; VanGundy, 2005). In this specific context, time pressure clearly proved to speed up information processing, or idea search, but reached a maximum since under highest time pressure uniqueness of ideas decreased. Although with an accelerated process, too-high time pressure may shorten the exploration *space* in associative memory. The fact that the creative performance decreased beyond a given Time-pressure level tends to support Kerstholt's (1994) results (inverted U-shaped relation between time pressure and human performance) better than those from Kocher and Sutter (2006 – U-shaped relation). Regarding collaboration under time pressure, our results appear inconsistent with Rogalski's (1996) observations since collaboration remained stable across Time-pressure conditions. We feel that this result can be attributed to the tabletop device: the conviviality of spatial arrangement around the table may have compensated for the decrease in collaboration that should normally be observed under time pressure. The relation between conviviality, or group cohesiveness, and collaboration is also supported by the fact that collaboration decreased under social pressure. Therefore we may have found with the tabletop system a solution to favor collaboration even in highly demanding situations such as time pressure.

In addition to the speedup of idea search process, the positive effect of time pressure on creative performance can be explained by a better compliance with Osborn's (1953) rules (time pressure may have forced the participants to give up self-censorship). However, it cannot really be attributed to an increase in playfulness: although fun, satisfaction and motivation were not *impaired* by Time-pressure, they were not *improved* either. Besides, time pressure clearly deteriorated other aspects of user experience (easiness, agreeableness and emotional patterns). Therefore we recommend that each group finds its own acceptable Time-pressure level for optimizing both performance level and subjective experience. This level might depend on the individuals forming the group and their capacity to cope with pressure.

Beyond social comparison, which was repeatedly shown to increase idea production (Bartis et al., 1988; Dugosh & Paulus, 2005; Harkins & Jackson, 1985; Michinov & Primois, 2005; Paulus & Dzindolet, 1993; Paulus et al., 2006; Shepherd et al., 1995), our study showed that an additional social pressure further enhances its benefits. At first sight, this kind of pressure seems easier to handle than time pressure, since our results showed that it improved performance (quantity of ideas) and user experience (motivation) at the same time. However, the detrimental effect of social pressure on collaboration and its lack of effect on the number of unique ideas are of serious concern. One way to further emphasize the benefits of social pressure could be for example to design new interaction techniques forcing the participants to share their ideas or to work on others' ideas. Such adaptations of the brainwriting method could increase cognitive stimulation without relying on spontaneous collaboration, given that competitiveness resulting from social pressure is likely to impair this collaboration.

Time pressure has not been studied a lot in Human–Computer Interaction although computers manage time very well and offer the possibility to study it very accurately. It is also a challenging issue since time pressure effects are not straightforward. This study explored two new tools (time and social pressure) to enhance tabletop experience when faster pace is desirable. Current research is exploring many application domains for tabletop systems (games, monitoring, military, sale, etc.) but it is too early to decide if the pace of such activities will always fit expectations. When multiple users sit around a tabletop interface we cannot expect the global pace to always satisfy every user but we can expect that the UI designer studied the target activity and identified pitfalls of certain paces. For example slow paces can be a problem for monitoring activity where a constant attention is necessary and fast paces can be a problem for strategic games where acting too fast is inefficient. Due to the novelty of the setting, tabletop experiments often reveal user prudency (tending to slow down the pace) and excitement (tending to speed up the pace). When novelty effect will fade out, interaction pace will be socially moderated and politeness may promote the pace of the slowest user. In critical applications (e.g. military) a leader remains necessary to manage the pace and makes the tabletop system a real competitor to the non-electronic counterpart. At least for non-critical activity like brainstorming this study shows pace management can be provided by the system. However, it also showed that pace management must be carefully designed since it remains a critical aspect of users' individual and collective experience. Real-time tabletop user interfaces require more experiments in order to better understand which tools can be used and how, and how effectiveness and acceptability can be optimized.

Several limitations of this study draw avenues for future research. First, we used ad hoc groups composed of students and university staff. Future research should extend our findings using groups of co-workers such as design teams, or ad hoc creative problem solving groups with real expectations regarding the outcome of the session. Such populations will not necessarily be subject to pressure in the same way as our users were. In this respect the literature on knowledge management, organizational learning and leadership strategies may provide a useful framework to draw a more complete picture of our conceptual elaboration on the Press factor. A second major shortcoming of our study is its timeframe. Longitudinal research should investigate whether our results endure over longer periods of time, whether individual and collective strategies emerge regarding the way participants cope with pressure, whether social pressure evolves with the history of the group, etc. Despite the limitations of our study, we believe that it provided new knowledge on the influence of the Press factor on creativity and will give rise to new kinds of research implementing tabletop-supported creativity.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.chb.2012.05.007.

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