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A new dynamical model of brainstorming: Linear, nonlinear, continuous (simultaneous) and impulsive (sequential) cases

Hamit Coskun [a], Oguz Yilmaz [b,*]

[a] Abant Izzet Baysal University, Department of Psychology, Bolu, 14280, Turkey

[b] Izmir Institute of Technology, Department of Mathematics, Urla, Izmir, 35430, Turkey

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ABSTRACT

In this paper, we extended the linear dynamical model of [Brown, V., Paulus, P. B. (1996). A simple dynamic model of social factors in group brainstorming. *Small Group Research*, *27*, 91–114] on two accounts. First, we modelled the sequential type brainstorming using impulsive differential equations by treating each category as an impulse and tested its validity in the two experiments that investigated and demonstrated the beneficial effects of sequential priming and memory in individual brainstorming. Finally, we considered the nonlinear case of brainstorming in writing or brainwriting where dyads exchanged their ideas in a written format and that eliminated negative factors occurring in oral brainstorming (e.g., evaluation apprehension, free-riding, production blocking) and enhanced the upward performance matching, and conducted the second experiment in order to test its validity in this paradigm with the effects of sequential priming and memory. Comparisons showed good agreement between results of experiments and those of the mathematical model.

1. Introduction

Use of dynamical systems in areas like population dynamics and spread of an epidemic is well established (González, Huerta-Sánchez, Ortiz-Nieves, Vázquez-Alvarez, & Kribs-Zaleta, 2003). Other relatively new areas of research that are modeled through dynamical systems include attention and interference, non stationary versions of the random walk model of choice response time, models of human memory (Heath, 2000), perceptual segmentation (Van Leeuwen, Steyvers, & Nooter, 1997) and brainstorming (Brown & Paulus, 1996). Of these areas, Brown and Paulus (1996) have for the first time developed modeling brainstorming with dynamic systems. Obviously, despite this pioneering study, this modeling is not an end story for the future studies in the brainstorming area. Instead, some modifications or revisions for such modeling, in its content, should be required for scientific advancement because knowledge in modeling has rapidly progressed and changed from the first publication of brainstorming modeling, to now. From this standpoint, we tried to develop the model based on the impulsive differential equations, and nonlinear case of brainstorming in writing in which the previous modeling of brainstorming was not taken into consideration. Before giving detailed information about modeling in this paper, it would be better to give some ideas about brainstorming concepts, studies first, and then to demonstrate modeling with its validity by means of experimental studies.

Since the publication of Osborn's first influential book (Osborn, 1957), group brainstorming has become a widely used idea-generation method in many organizations in today's world (Parnes, 1992; Paulus, 2000; Paulus & Brown, 2003; Paulus, Dugosh, Dzindolet, Coskun, & Putman, 2002; Sutton & Hargadon, 1996). Osborn (1957) developed the four brainstorming rules as ways to improve group productivity or creativity: (1) criticism is ruled out; (2) freewheeling is welcome; (3) quantity is wanted over quality, and (4) improvement and combination of ideas are sought. Osborn claimed that an individual brainstorming in a group would produce almost twice as many ideas than brainstorming alone. His claim has led to an enormous number of experimental studies indicating robust evidence that interactive brainstorming groups tended to generate fewer ideas than nominal brainstorming groups (groups consisting of the same number of individuals working alone (Diehl & Stroebe, 1987; Mullen, Johnson, & Salas, 1991; Stroebe & Diehl, 1995)).

In the literature, four basic explanations have been offered for the productivity loss in interactive group brainstorming. These are evaluation apprehension or social anxiety (feeling of some fear in expressing the potential ideas in front of a group (Camacho & Paulus, 1995; Collaros & Anderson, 1969; Harari & Graham, 1975; Mullen et al., 1991)), free-riding or social loafing (the tendency to rely on the efforts of others to accomplish the task (Borgatta &

* Corresponding author.
E-mail addresses: hamitcoskun2000@hotmail.com (H. Coskun), oguzyilmaz@iyte.edu.tr (O. Yilmaz).

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Sales, 1953; Diehl & Stroebe, 1987; Karau & Williams, 1993; Kerr & Bruun, 1983; Paulus & Dzindolet, 1993)), production blocking (the inability to express the ideas because someone else is talking: (Diehl & Stroebe, 1991; Nijstad, Stroebe, & Lodewijkx, 2003)), and downward matching (the tendency for group members to match their performance to the least productive member (Paulus et al., 2002; Paulus & Dzindolet, 1993)).

In addition to these inhibitory factors, the two main tendencies occur in interactive brainstorming groups. The first tendency is that interactive groups as well as nominal groups typically tend to lower their idea generation performance over the later periods of the brainstorming session (Coskun, 2000; Nijstad et al., 2003; Paulus et al., 2002). This may reflect a reduced availability of ideas, a reduced motivation over time, or some degree of cognitive fixation (Smith, 1995). The second one is that groups have a tendency to converge on similar categories of ideas (Brown, Tumeo, Larey, & Paulus, 1998; Larey & Paulus, 1999; Paulus & Brown, 2003) and to scan only a small number of the ideas from available cognitive categories (Brown et al., 1998; Connolly, Routhieaux, & Schneider, 1993).

In an attempt to eliminate these inhibitory factors, researchers have been interested in techniques for improving the performance of brainstorming groups. For example, forming interactive groups with low anxious members was found to close the production gap between interactive and nominal brainstormers (Camacho & Paulus, 1995). The presentation of the facilitators or rules designed to improve group interaction and participation were suggested to eliminate the potential free-riding tendencies (Offner, Kramer, & Winter, 1996; Oxley, Dzindolet, & Paulus, 1996). Electronic versions of group brainstorming where participants generate their ideas simultaneously without blocking each other but seeing their ideas at the top of the screen have been suggested for eliminating the production blocking (Diehl & Stroebe, 1991; Gallupe, Bastianutti, & Cooper, 1991; Nijstad et al., 2003; Nunamaker, Briggs, & Mittleman, 1995; Valacich, Dennis, & Conoly, 1994). Downward matching, the tendency of group members to match their performance with the least productive member, which was also proposed to be a major factor in determining a relatively low performance of interactive groups (Borgatta & Sales, 1953; Camacho & Paulus, 1995; Collaros & Anderson, 1969; Harari & Graham, 1975; Karau & Williams, 1993; Kerr & Bruun, 1983), can be eliminated by the provision of comparison information or a high standard (Coskun, 2000; Paulus & Dzindolet, 1993).

The terminology specific to this paper is explained as follows: "Simultaneous brainstorming" is the case when all topics to be discussed are given at once at the beginning of the session; "Sequential brainstorming" is when each topic of discussion is given at a different time; "Memory condition" is an instruction on brainstormers to memorize the ideas; The manipulation of simultaneous versus sequential prompting of ideas is referred to as a type of 'priming'.

In this paper, we improve on the linear dynamic model of Brown and Paulus (1996). In their model, they assume that an individual's capacity to produce ideas would decay exponentially and that productivity of an individual would decrease as a function of total group output, known as blocking. Their final assumption is that if an individual's productivity were higher than the group average, he would decrease his output and vice versa (matching). Cognitive processes such as idea generation, storage of ideas in memory and idea output were included in the extended version of the linear model. Blocking and matching effects were studied in detail in the paper under hypothetical conditions. In this paper, we tried to improve the Brown and Paulus's model on several accounts. First, we modeled the sequential type (i.e., presenting each component of the problem one at a time) brainstorming using impulsive differential equations by treating each category as an impulse. Second, we considered the nonlinear case of brainstorming in writing. Finally, we modeled the memory effect in sequential and simultaneous cases (i.e., presenting all components of the problem at once). The last two cases are particularly interesting from a mathematical point of view. In dynamical systems it is desirable to have simple, linear models. But, in the case of brainstorming in writing, matching, inevitably, occurs in a nonlinear way. This is due to the fact that matching occurs only in the upward fashion (i.e., the individuals will try to increase their performance when their performance is lower than that of group's average and they will not try to reduce their performance when their performance is higher than the average). (Brown & Paulus, 1996; Camacho & Paulus, 1995; Paulus, 2000; Paulus et al., 2002). The memory condition, finally, gives some complexity to the system by the introduction of cognitive processes.

We conducted the two independent studies to test the fit of our model. Even though the effects of memory instruction (Dugosh, Paulus, Roland, & Yang, 2000) and sequential and simultaneous priming in oral brainstorming (Coskun, Paulus, Brown, & Sherwood, 2000) were investigated in the literature, the present study, consisting of the two experiments, has examined for the first time the combination of these variables in a single research paradigm (individual brainstorming and brainwriting paradigm). The findings of these studies, which would be mentioned later in a detailed way, did produce new outcomes that were mostly in line with the predictions of our model.

2. Modelling

Along these lines in the brainstorming literature, modeling interactive group brainstorming has become one popular field (Brown & Paulus, 1996; Brown et al., 1998; Coskun et al., 2000). A linear dynamic model of interactive brainstorming was initially developed by Brown and Paulus (1996) in order to account for some of these above mentioned mechanisms or processes. We should stress that the goal of the modeling we develop in this paper is qualitative mimicry of trends in the data, not quantitative data fitting.

First, we rewrite the model of Brown and Paulus (1) for convenience of the reader and then we model the sequential type brainstorming using impulsive differential equations by treating each category as an impulse (2). After that, we consider the nonlinear case of brainstorming in writing ((3) and (4)) and finally we present the cognitive processes ((5) and (6)).

Consider the following linear dynamical system, given by Brown and Paulus (1996), which linearly models decay, blocking and matching but ignores the cognitive processes,

$$\frac{\mathrm{d}x}{\mathrm{d}t} = -Ax - Bx + Mx \tag{1}$$

where x is a column vector in the n-dimensional real space (n represents the number of brainstormers), which represents the rate of idea generation, A, B and M are an $n \times n$ real matrices accounting for the effects of decay in output as the time progresses, for blocking effects and for matching respectively. The matrix A is diagonal, with entries of decay coefficients of individuals.

Matrix B is given in the following form,

$$B = \begin{bmatrix} 0 & b_1 & b_1 & \cdots & b_1 \\ b_2 & 0 & b_2 & \cdots & b_2 \\ b_3 & b_3 & 0 & \cdots & b_3 \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ b_n & b_n & b_n & \cdots & 0 \end{bmatrix}$$

where b_i is the blocking coefficient of each individual. Diagonal entries are zero, as an individual cannot block himself.

M is the matrix modeling matching effects given by,

$$M = \begin{bmatrix} -m_1 & \frac{m_1}{n-1} & \frac{m_1}{n-1} & \cdots & \frac{m_1}{n-1} \\ \frac{m_2}{n-1} & -m_2 & \frac{m_2}{n-1} & \cdots & \frac{m_2}{n-1} \\ \frac{m_3}{n-1} & \frac{m_3}{n-1} & -m_3 & \cdots & \frac{m_3}{n-1} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ \frac{m_n}{n-1} & \frac{m_n}{n-1} & \frac{m_n}{n-1} & \cdots & -m_n \end{bmatrix}$$

where m_i is the matching coefficient of each person, $\frac{m_i}{n-1}x_j$ represents the effect of the ouput of the jth person on the productivity of the ith person. Overall effect, given by $\sum_{\substack{j=1 \\ (j \neq i)}}^{n} \frac{m_i}{n-1}x_j - m_i x_i$ can be negative or positive depending on the relative productivity of the person concerned.

2.1. Sequential brainstorming using impulsive differential equations

Now, we introduce impulses at fixed moments of time, that is, the solution becomes piecewisely continuous. Consider the following linear impulsive equation,

$$\begin{aligned} \frac{dx}{dt} &= -Ax - Bx + Mx, \quad t \neq \theta_i \\ x(\theta_i^+) &= x(\theta_i^-) + d_i \end{aligned} \tag{2}$$

where θ_i are the fixed moments of time when a new category is introduced, the superscript $+(-)$ denotes the time just after (before) the impulse and d_i is a constant column vector which represents jumps in the solution (sudden increase in the rate of idea production).

2.2. Brainstorming in writing

Next, we consider brainstorming in writing, in which factors like social anxiety and blocking do not exist (cf. Paulus et al. (2002) and Paulus and Yang (2000)). In this case nonlinearity arises from the fact that matching occurs only in the positive sense, that is, when the individual's performance is lower than that of groups average he or she will try to increase his performance and when his or her performance is higher than the average he or she will not try to reduce his performance. In the simultaneous brainstorming, modeling is given as,

$$\frac{dx}{dt} = -Ax + M(x)x \tag{3}$$

where the matrix A represents the decay rate and the matrix $M(x)$ is the nonlinear matching matrix given by

$$M(x) = \begin{bmatrix} -m_1 & \frac{m_1}{n-1} & \frac{m_1}{n-1} & \cdots & \frac{m_1}{n-1} \\ \frac{m_2}{n-1} & -m_2 & \frac{m_2}{n-1} & \cdots & \frac{m_2}{n-1} \\ \frac{m_3}{n-1} & \frac{m_3}{n-1} & -m_3 & \cdots & \frac{m_3}{n-1} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ \frac{m_n}{n-1} & \frac{m_n}{n-1} & \frac{m_n}{n-1} & \cdots & -m_n \end{bmatrix} \times \begin{bmatrix} H(x_{r1}) & H(x_{r2}) & H(x_{r3}) & \cdots & H(x_{rn}) \\ H(x_{r1}) & H(x_{r2}) & H(x_{r3}) & \cdots & H(x_{rn}) \\ H(x_{r1}) & H(x_{r2}) & H(x_{r3}) & \cdots & H(x_{rn}) \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ H(x_{r1}) & H(x_{r2}) & H(x_{r3}) & \cdots & H(x_{rn}) \end{bmatrix}.$$

$H(x_{ri})$ is the Heaviside unit step function and x_{ri} is the relative value of x_i given by $x_{ri} = \sum_{\substack{j=1 \\ (j \neq i)}}^{N} \frac{x_j}{n-1} - x_i$. In the sequential case, the model is,

$$\begin{aligned} \frac{dx}{dt} &= -Ax + M(x)x, \quad t \neq \theta_i \\ x(\theta_i^+) &= x(\theta_i^-) + d_i. \end{aligned} \tag{4}$$

2.3. Cognitive processes

Cognitive processes include idea generation and storage of ideas in the short term memory. In Brown and Paulus (1996), decay coefficient was divided into three parts; decay of idea generation, decay in storage of ideas in the short term memory and decay in output. Similarly, blocking was represented in two stages; blocking at idea generation and blocking at output. However, some constraints should be imposed on the model of Brown and Paulus. First, at a fixed moment of time, rate of idea storage cannot exceed a certain value, for there is a capacity to store ideas. Second, it is necessary to rule out the possibility of a negative rate of ideas generated, stored or outputted. So the coupled model including cognitive processes for the simultaneous and oral brainstorming is,

$$\begin{aligned} \frac{dx}{dt} &= -Ax - Bx + Mx + Ry \\ \frac{dy}{dt} &= -Fy + z - x, \quad z(t) \geq 0, k \geq y(t) \geq 0, x(t) \geq 0 \\ \frac{dz}{dt} &= -Kz - Ex \end{aligned} \tag{5}$$

where k is a positive integer, x, y and z are n-dimensional vectors representing ideas per unit time at output, storage and generation stages respectively, matrices A, B, and M were described in Section 2, K and E are $n \times n$ matrices representing decay and blocking at idea generation stage. Ideas that are retrieved from the memory are modeled through the diagonal matrix R. Matrix E has the same shape as B.

The model presented in (5) may become nonlinear due to the physical and mathematical constraints placed on it. That is, when stored ideas grow out of its bound, then it will be forced back into its bound.

Next, we try to extend the model (5) into the sequential case by,

$$\begin{aligned} \frac{dx}{dt} &= -Ax - Bx + Mx + Ry \\ \frac{dy}{dt} &= -Fy + z - x, \quad z(t) \geq 0, k \geq y(t) \geq 0, x(t) \geq 0 \\ \frac{dz}{dt} &= -Kz - Ex \\ z(\theta_i^+) &= z(\theta_i^-) + g_i \end{aligned} \tag{6}$$

where the matrix g_i is a constant column vector which represents jumps in the solution. Here, the impulse is applied at the idea generation stage, and its effect on the output will be felt indirectly, with a time lapse. This is plausible, since when a new category is introduced, brainstormers first will contemplate for a few moments to generate ideas and then start outputting their ideas.

In summary, there are three parameters in the non cognitive model; A (decay in output), B (blocking in output) and M (matching in output). In the cognitive model, seven parameters are used; A, B and M are the same as the ones in non cognitive case, F and K represent decay in storage and generation stages, R is the retrieval parameter and E is blocking at generation stage. In addition to these, initial rate of idea production for each member and the value of impulses for fixed moments of time (parameters d_i and g_i) could be considered as parameters.

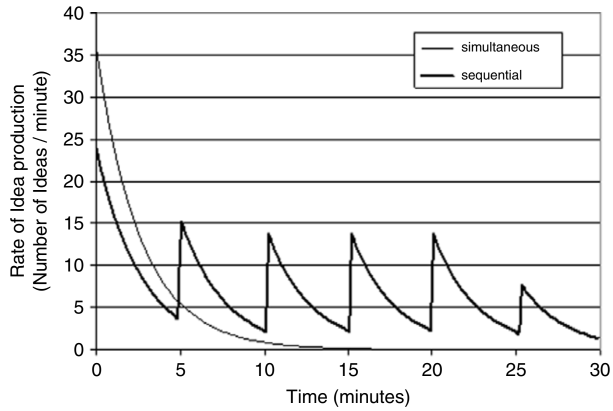

Fig. 1. Comparison of simultaneous and sequential cases.

2.4. Simulations with the mathematical model

Solution of the systems (1)–(6) is carried out using a classical Runge–Kutta algorithm. In most cases, due to nonlinearities and complexities of the equations, analytical solutions are not possible.

There are three different cases considered in simulations. In all of them, decay effects are exponential. In the first case, where blocking and matching are linearly modeled, simultaneous and sequential brainstorming concepts are compared with each other in terms of total rate of idea production. In both simultaneous and sequential cases, the decay coefficient was chosen to be 0.2 for each person, blocking coefficient to be 0.035 and matching coefficient to be 0.02. These coefficients are not based on the experiments and they were chosen this way to simplify the comparison of two different concepts. However, the rate of idea production at the beginning of the session for simultaneous and sequential simulations is chosen to be different and this is based on experimental evidence (see Fig. 5). Six brainstormers start with idea production rate of 36 in the simultaneous run and with idea production rate of 24 in the sequential run. In the sequential simulation, brainstormers are introduced to a new topic every five minutes, which results in an increase in idea generation rate, namely two ideas per minute per person at 5th and 10th min, two ideas per minute at 15th and 20th min and one idea per minute at 25th min.

This simulation (Fig. 1) supports the idea that sequential brainstorming is much better than the simultaneous one in terms of rate of idea production. This estimation will be verified by experimental results in Section 3.

The second simulation is about cognitive processes of individuals. The Eq. (5) is used to demonstrate the cognitive processes. In this simulation, the value of decay coefficient used in the first simulation is distributed among idea generation, storage and output stages equally, whereas the value of blocking coefficient is distributed equally among idea generation and output stages. According to Eq. (5), matching is done at the output level and its value is the same as the first simulation. The coefficient R in (5) was chosen such that the total number of ideas produced during 30 min is equal for sessions produced by cognitive and non-cognitive models and this value of R was found to be 0.075.

The rate of idea production at the idea generation stage for each individual is six ideas per minute initially. As time progresses, around $t = 11.4$ min there is a peak in the rate of idea production at the output stage. By comparing Figs. 1 and 2 one can notice that the simulation with cognitive processes gives a more realistic picture of brainstorming than the one with no cognitive processes. Certainly, at $t = 0$, the rate of idea production at the output stage should not be the maximum but zero.

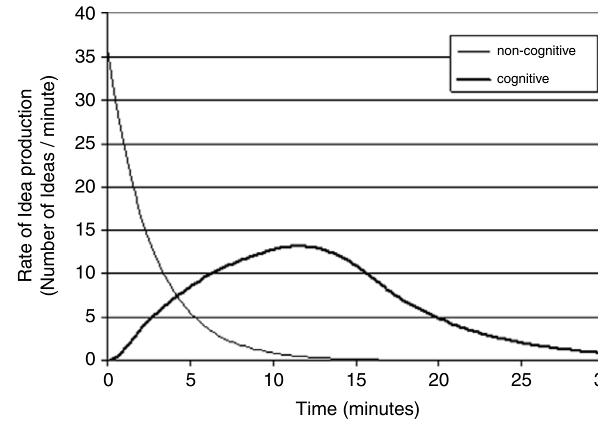

Fig. 2. Simulation with cognitive processes.

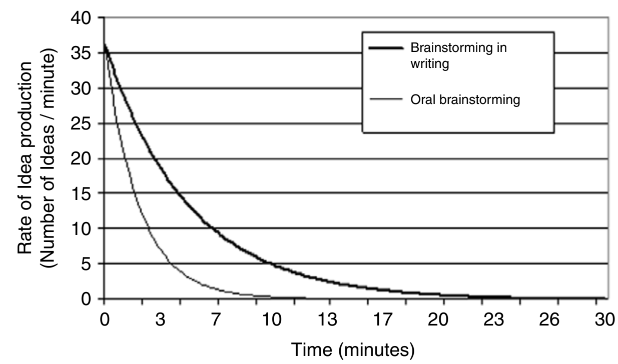

Fig. 3. Comparison of oral and written brainstormings in simultaneous case.

In the last simulation, brainstorming in writing, is the only nonlinear case. In this case, social anxiety, free riding and blocking do not exist, only nonlinear matching and linear decay effects are considered (Fig. 3).

This is the only case with nonlinear effects. Clearly, the brainstorming in writing format is superior to the oral brainstorming one. This outcome is due to the effects of upward matching, no blocking, and no social anxiety in brainwriting.

Table 1 gives the values for coefficients used in the simulations. Discussion about coefficients was given in the preceding paragraphs of this section.

Overall conclusions for the modeling of brainstorming are; first, in oral brainstorming, the model with cognitive processes gives a more realistic picture than the one without cognitive processes; second, nonlinear effects due to upward matching are the only interaction between the individuals in written brainstorming and give a clear advantage to it over oral brainstorming. In Section 3, experiments are explained in detail. The first experiment, carried out with nominal brainstormers, provides an average decay coefficient which will be used in simulations of modeling, whereas the second experiment allows us to compare the simulations with experimental results for the priming and memory conditions.

3. Experiments

In order to evaluate the effectiveness and validity of the last simulation, we tried to assess the effects of cognitive stimulation with memory and sequential priming in the following two experiments. The first study was conducted in individual (or nominal) brainstorming in a written format, whereas the second one was done in a brainwriting paradigm.

Table 1
Coefficients used in the simulations.

<table>
<tr><th>Simulations</th><th colspan="3">Decay coefficient (s)</th><th colspan="2">Blocking coefficient (s)</th><th>Matching coefficient</th><th>R</th><th>Initial values[a]</th><th>Value of jumps[b]</th></tr>
<tr><td>Simultaneous case (noncognitive), Figs. 1–3</td><td colspan="3">0.2</td><td colspan="2">0.035</td><td>0.02</td><td>–</td><td>36</td><td>–</td></tr>
<tr><td>Sequential case (noncognitive), Fig. 1</td><td colspan="3">0.2</td><td colspan="2">0.035</td><td>0.02</td><td>–</td><td>24</td><td>2
2
1
1
1</td></tr>
<tr><td>Brainstorming in writing (noncog.), Fig. 3</td><td colspan="3">0.2</td><td colspan="2">–</td><td>0.02 (nonlinear)</td><td>–</td><td>36</td><td>–</td></tr>
<tr><td>The case with cognitive processes, Fig. 2</td><td>0.067</td><td>0.067</td><td>0.067</td><td>0.0175</td><td>0.0175</td><td>0.02</td><td>0.075</td><td>36</td><td>–</td></tr>
</table>

[a] Rate of idea production for each member at $t = 0$.
[b] Increase in the value of rate of production at 5th, 10th, 15th, 20th and 25th min (value of increase is the same for each member).

3.1. Experiment 1

In the first experiment nominal brainstormers (who brainstormed separately from each other or without any interaction) were included for at least three reasons. First, these individuals enable us to clearly evaluate cognitive influences without any external prevention such as group interaction. Second, so far, an evaluation for the effects of memory instruction (e.g., memory and no-memory conditions) has not been done in individual brainstorming. Previous research has demonstrated that the beneficial effect of memory instruction (e.g., an instruction for memorization of ideas during the idea generation process) was only evident in the later session of brainwriting groups rather than in the early session of it (Dugosh et al., 2000; Paulus & Yang, 2000). Paulus and Yang (2000) have compared interactive brainwriting groups, who were given memory instruction, with nominal groups without a memory instruction. In other words, they had no nominal groups with memory instruction so as to compare with those without memory instruction in their research paradigm. Third, the effect of memory instruction with the two types of priming (e.g., sequential or simultaneous priming) has not been assessed together yet, even though there was research evidence for the beneficial effect of sequential priming (e.g., priming a part of problem once at a time) over a simultaneous one (e.g., priming all part of problem at once: 30). In the view of associate memory, ideas or concepts are assumed to connect to each other in an organized fashion, called associative memory or a semantic network (Collins & Loftus, 1975). Similar or related ideas (e.g., apple–orange) have more connected bonds than dissimilar ones (e.g., apple–river). Thus when activated, the concepts that have strong connections with other concepts are more easily retrieved from memory than those that have weak connections (Brown et al., 1998). According to the associative memory perspective, memorization should lead participants to carefully attend or store ideas and retrieve more concepts from their memory, which in turn facilitates the generation of new or unique ideas. All subjects were randomly assigned to memory condition (memory and no-memory) and priming (sequential and simultaneous) conditions.

Method

Participants and design

One hundred-forty freshman students enrolled in Psychology Courses at the Abant Izzet Baysal University (AIBU), located in Bolu, Turkey, participated in the study in an exchange for experimental credit. The participants were randomly assigned to either priming (sequential and simultaneous) or memory (memory and no-memory) conditions. There were 35 participants in each condition.

Procedure

All participants, being sat apart from each other, were tested in a classroom setting. After the provision of an informed consent form and collection of it from participants, a second page, which included detailed instructions about the brainstorming procedure and its four rules, was given to the participants. A brief explanation for each rule was also provided and read aloud to all participants as they followed along. Upon the presentation of brainstorming rules, similar to the instructions used in the Paulus and Yang (2000) study, all participants were instructed to write their ideas on paper, not to talk each other during their idea generation session, and to just use simple sentences without worrying about grammar.

Then the participants were randomly assigned to priming conditions. The Thumbs Problem (generating ideas about difficulties or advantages of using an extra thumb on each hand) were given to the participants and divided into its four components (e.g., music, hygiene, clothing, and communication). This decomposition was made on the basis of a previously used data set in one piece of research (Dugosh et al., 2000) and the number of subcategories of these components (music (28), hygiene (24), clothing (20), and communication (19); $M = 22.75$, $S.D. = 4.11$). All participants were given a package that included sequential and simultaneous manipulations on it. The participants in the sequential priming condition were instructed to generate ideas for each given component every five minutes. However, those in the simultaneous priming condition were provided with all the components of the Thumbs Problem on the first page.

Prior to the start of the idea generation session, the participants were randomly assigned to the memory conditions. The participants in the memory condition were instructed to examine all of the ideas carefully and were provided with information that there would be a memory test at the end of the brainstorming session (Paulus & Yang, 2000). Those in the no-memory condition were given no such information. After these manipulations, all participants were led to brainstorm on the given problem for a five-minute session. At the end of this session, all participants were instructed to turn the next page (e.g., second, third, and fourth pages) at the end of five minutes and keep generating ideas. This procedure continued until the session was over. At the end of the session, the experimenter ended the brainstorming session and debriefed and thanked all participants for their participation.

Results

Coding

Two independent raters, one of whom repeated the coding for 40% of the transcripts and the other one for all of them, checked the transcripts for repetitive ideas and calculated a new total for nonrepetitive ideas. The interrater reliability coefficients (Cronbach's α) between these raters for both the nonrepetitive and repetitive ideas were 0.99. The number of nonrepetitive ideas was used as a productivity/performance index or dependent variable.

Performance

The data were analyzed by a means of 2 (the type of priming: sequential and simultaneous priming) $\times$ 2 (memory condition: memory and no memory conditions) between-subject ANOVA design. This analysis indicated a significant effect of memory condition on the idea generation performance, $F(1, 136) = 5.61$,

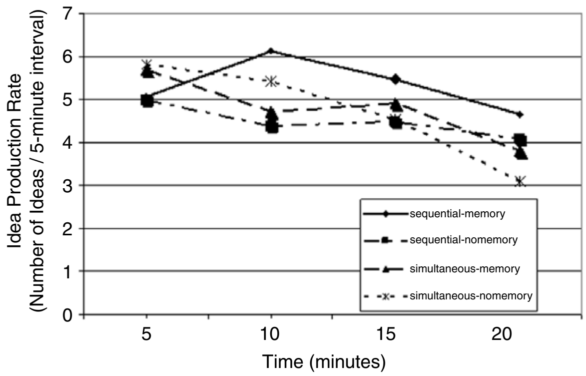

Fig. 4. Effect of memory instruction on productivity in individual brainstorming.

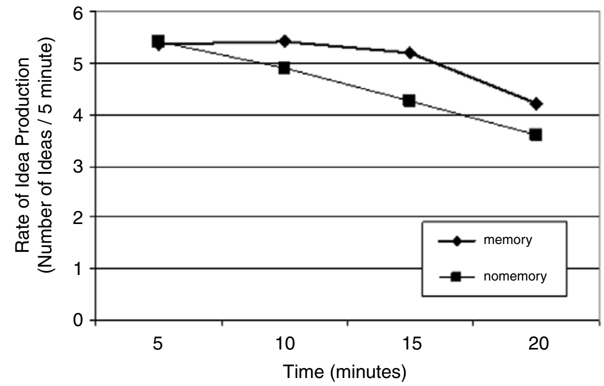

Fig. 6. Memory and time interaction on performance in experiment 1.

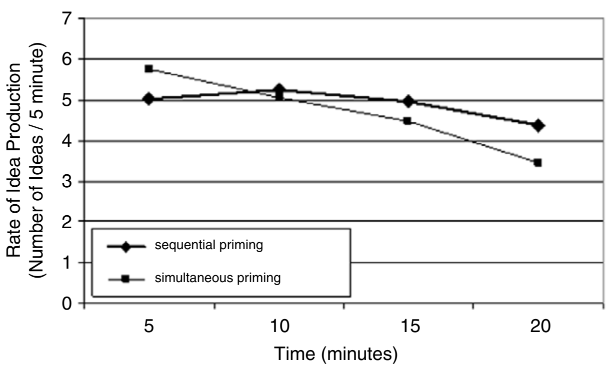

Fig. 5. Priming and time interaction on performance in experiment 1.

$p < .03$. The participants in the memory condition ($M = 20.13$) generated more ideas than those in the no-memory condition ($M = 18.17$). However, priming effect ($F(1, 136) = 1.04, p > .31$) and the interaction effect between memory and priming ($F(1, 136) = 2.26, p > .14$) were not significant (Fig. 4).

We also analyzed the idea generation performance over five minute time periods by $2 \times 2 \times 4$ (time periods: 0–5 min, 5–10 min, 10–15 min, and 15–20 min periods) analysis of variance (ANOVA), with the last factor as a within subject design. Time periods had a significant effect on performance, $F(3, 408) = 43.63, p < .0001$. As can be seen in Fig. 5, the idea generation performance linearly decreased over time periods, $F(1, 136) = 89.38, p < .0001$. Time period *x* priming interaction was also significant, $F(3, 408) = 12.65, p < .0001$, indicating a sharper decline of the idea-generation performance in the simultaneous priming condition than sequential priming condition (Fig. 5). In addition, time period *x* memory interaction was significant, $F(3, 408) = 4.05, p < .008$. This interaction reflected a sharper decline in the no-memory condition than memory condition over the later time periods of brainstorming session (Fig. 6). Moreover, time period *x* priming *x* memory interaction effect was significant, $F(3, 408) = 9.15, p < .0001$, indicating the best performance in the sequential priming and memory condition and the worst performance in the simultaneous priming and no-memory condition towards the end of brainstorming session.

Discussion

The findings of Experiment 1 indicated that memory instruction enhanced the idea generation performance. This gain was almost 11% when compared to the no-memory condition. This finding is consistent with the findings of previous research (Paulus & Yang, 2000), indicating the beneficial effect of memory especially in the later periods of brainstorming. The present study employed 20-min sessions in contrast to 15-min sessions in the previous research (Paulus & Yang, 2000). Longer time periods may be one appropriate strategy for assessing the effects of memory instruction on the idea generation performance because it may help the idea generation process when participants are about to run out of their potential ideas. In such a time period, participants may easily retrieve their ideas from their memory on which they build with the help of memory instruction. At the beginning of the session, memory instruction may lead participants to store more ideas in their memory, which later facilitate the retrieval of potential ideas when they get exhausted or have no additional ideas.

According to the associate memory perspective, memory instruction may especially enhance one's span of attention to the ideas generated by others, and the capacity of short-term memory. Since there is no other person in the nominal situation to be paid attention, memory instruction should lead one individual to focus on his or her ideas. An elevated attention should enhance one's memory capacity or idea storage as well. This standpoint suggests that the effect of memory instruction should be stronger in interactive conditions than nominal conditions. This is because brainstormers may get more benefit from paying attention to the ideas of others than focusing on their own ideas. Ideas generated by others should be more stimulating and diverse than those generated by one's own standing. This suggestion was assessed in Experiment 2 by a means of having brainstormers brainstorm either in a group or alone.

It should be kept in mind that the beneficial effect of memory instruction was not evident in the first session of the Paulus and Yang (2000) study, but evident in that of Experiment 1. This difference may be due to the methodological difference between Experiment 1 and the Paulus and Yang (2000) study in a way that the former study used an individual brainstorming paradigm, whereas the latter one used a brainwriting paradigm. Keeping track of ideas and paying attention to the ideas of a partner in a brainwriting paradigm is a difficult process in the early session of brainstorming. Such a procedure with a shorter time period may hinder the difference in performance between nominal and interactive groups with memory instruction at the first session in the Paulus and Yang's (2000) study. With a longer time period, subjects become familiar with the procedures of brainwriting and thereby the beneficial effect of memory may occur in the later session, as was the case in Paulus and Yang (2000) study. Paulus and Yang (2000) have compared the performance of interactive groups with memory instruction with that of nominal groups without memory instruction. However, such a research design lacked a condition of interactive groups with memory instruction. These possibilities or methodological concerns were assessed in Experiment 2.

Experiment 1 showed no significant main effect for priming on performance. This is inconsistent with the finding of the first experiment but consistent with that of the second experiment in Coskun et al. (2000) study. This outcome comes from the fact that all participants were stopped every five minutes and instructed to turn their page and continue generating ideas. Such a procedure makes the simultaneous priming similar to the sequential priming in terms of timing and pauses despite the fact that the participants in the simultaneous priming condition viewed all categories of the problem in contrast to those in the sequential priming. Previous research (Coskun et al., 2000) used 3-min time intervals or segmentation, whereas Experiment 1 did use 5-min time intervals. In contrast to longer time intervals or periods, shorter time intervals (both 3 min and 5 min intervals) may have motivational as well as cognitive consequences on performance, thus closing the performance gap between sequential and simultaneous priming. Another difference between the former study (Coskun et al., 2000) and Experiment 1 is that the former one used 10 categories of the University problem, ranging from broad categories (e.g., campus life) to narrow ones (e.g., athletic teams), whereas the latter one had 4 categories of the Thumbs problem, having almost homogeneous categories in depth. Despite this relative difference, the findings were robust across these studies.

On the other hand, an interaction between priming and time periods or intervals indicated that the participants in the sequential priming were successful at keeping their initial performance up over sessions, while those in the simultaneous priming condition lowered their performance level as the brainstorming session went on. This outcome mimics the finding of the first experiment (interactive and nominal brainstorming with an oral format) and the second experiment (nominal brainstorming with a written format) of the previous research (Coskun et al., 2000), both of which indicated the performance difference between the simultaneous and sequential priming was greater in the later periods than in the early periods. In other words, the idea generation performance declined more over time with simultaneous priming than that with sequential priming.

From this experiment, decay coefficient at the output stage can be obtained and used in Experiment 2. By exponential curve fitting in Figs. 5 and 6, decay coefficients are found to be 0.03 ideas/min and 0.015 ideas/min for the simultaneous cases with no memory and with memory respectively. Also, we notice from the figures that, at $t = 0$, brainstormers in simultaneous and sequential sessions had a different number of ideas on average; 7 ideas for the former and 5.5 ideas for the latter. In this sense, such a modeling was in line with the outcomes (i.e. both experimental results and model's outcomes) of the Coskun et al. study (2000) but with a different assumption (i.e., impulsive differential equations) underlying modeling.

3.2. Experiment 2

In Experiment 2 we investigated the effects of priming and memory condition in both interactive and nominal brainwriting conditions, on which no empirical research had been conducted earlier. Brainwriting procedure, initially developed by Paulus and Yang (2000), includes exchanging ideas in a small group with a writing format. Such a procedure is assumed to eliminate evaluation apprehension, free-riding, and blocking (Coskun, 2000; Paulus & Yang, 2000) because it relies on simultaneous writing or idea generation and identifiable group members. It also enhances upward matching or competition and cognitive stimulation because it includes both a procedural pressure for generating more ideas and paying attention to ideas generated by other group members. In the literature, interactive brainwriting groups or dyads were found to perform better than nominal brainwriting ones (Coskun, 2000, 2005a; Paulus & Yang, 2000). However, the beneficial effect of its cognitive stimulation did not appear in the early sessions as expected, but it occurred in the later time periods. Given these considerations, we examined the effects of memory instruction and priming type in nominal and interactive dyads with a longer time period (e.g., 20 min time period). It was hypothesized that interactive brainwriting dyads would generate more ideas than nominal ones. The individuals with memory instruction were also considered to generate more ideas than those without memory instruction. Sequential priming would be similar to simultaneous priming if shorter pauses and timing were present in both the two types of priming.

Method

Participants and design

Ninety-eight freshmen students enrolled in Psychology courses at the AIBU, participated in the study in exchange for experimental credit, and were randomly assigned to either priming conditions (sequential and simultaneous), memory (memory and no-memory) or social context (interactive and nominal contexts) conditions. There were 49 participants in the sequential priming condition, 49 in the simultaneous priming condition, 50 in the interactive group condition, 48 in the nominal group condition, 49 in the memory, and 49 in the no memory condition. The participants in Experiment 2 did not participate in Experiment 1.

Procedure

Experiment 2 was similar to Experiment 1 in all respects except for social context manipulations. After the presentation of brainstorming rules, the participants were randomly assigned to either nominal or interactive dyad conditions. Interactive dyads were seated in a rectangular table with two chairs. Nominal dyads were led to sit apart from each other and provided the four type of numbered (e.g., the papers numbered with 1, 2, 3, and 4) A4 paper. Each of the interactive dyads was provided with the four types of numbered slips with a total of five slips (one-fourth of A4 paper) and different color pens (black and blue) in order to generate their ideas.

The participants in the interactive brainwriting condition were instructed by a means of a brainwriting procedure similar to those used in the Coskun (2000, 2005a,b) and Paulus and Yang (2000) study. The procedural instructions for all interactive dyads were detailed as follows:

> "You will write your ideas on paper slips and share these with your partner. Do not talk to each other while you are doing this. You will each use a different color pen to write down one idea on the paper slips and pass it to your partner. You will then receive the paper slip from your partner. Read the idea on the slip, add your own idea, and pass it on. If you finish before receiving your next slip, you may use another blank slip until one is passed to you. If you can't think of any ideas to put on a slip, read the idea and pass it on. When a slip you started returns to you, read it and place it in the center of table. This process will continue until the session is over. You do not need to make complete sentences when writing the ideas. Just use simple phrases. Don't worry about grammar".

The nominal dyads were instructed as follows:

> "You will need to write down your ideas on a paper sheet. When you complete writing them, you should use another blank slip. Do not talk to each other while you are doing this. You do not need to make complete sentences when writing the ideas. Just use simple phrases. Don't worry about grammar".

Then the participants were randomly assigned to either the sequential priming condition where they were instructed to generate ideas for each given component of the Thumbs problem (e.g., music, hygiene, clothing, and communication) at very five minutes or the simultaneous condition where they were provided with all components of the problem on the first page.

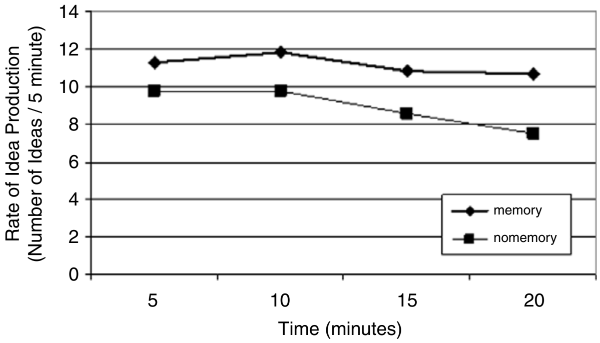

Fig. 7. The effect of memory on the idea generation performance in experiment 2.

Prior to the brainstorming session, they were also randomly assigned to the memory conditions similar to those in Experiment 1. After these manipulations, all participants were instructed to brainstorm on the given problem for five-minute sessions, turn to the next page (e.g., second, third, and fourth pages) at the end of this session and keep generating ideas. At the end of the brainstorming session, the experimenter debriefed and thanked all participants for their participation.

Results

Coding

The interrater reliability coefficients between two independent raters, one of whom repeated the coding for 40% of the transcripts and the other all of them, for the nonrepetitive and repetitive ideas were 0.99 and 0.98, respectively. We also calculated each participant's recall accuracy by comparing the number of ideas generated in the session and the number of ideas remembered. The interrater reliability calculated by Cronbach alpha was .95 for this measure.

Performance

The data were analyzed by a means of 2 (social context: interactive and nominal context) $\times$ 2 (priming: sequential and simultaneous priming) $\times$ 2 (memory condition: memory and no memory conditions) between-subject or dyad ANOVA design. This analysis indicated a significant effect of social context on the idea generation performance, $F(1, 90) = 18.14, p < .0001$. Interactive dyads ($M = 49.24$) generated more ideas than nominal ones ($M = 32.54$: Fig. 7). Memory instruction also had a significant effect on performance, $F(1, 90) = 6.48, p < .01$. The dyads ($M = 45.48$) in the memory condition generated more ideas than those ($M = 35.63$) in the no-memory condition (Fig. 7). Neither other main nor interaction effects except for these mentioned above were found to be significant. Though not being significant, interactive dyads seemed to benefit more from memory instruction than nominal ones (The means of interactive dyads for memory is 13.85 and no-memory is 10.04; whereas those of nominal ones for memory is 8.45 and no-memory is 7.73.), $F(1, 90) = 2.74, p > .10$.

Further analysis was made over five-minute sessions by a means of 2 $\times$ 2 $\times$ 2 $\times$ 4 (time periods; 0–5 min, 5–10 min, 10–15 min, and 25–20 min) ANOVA with the last factor (time periods) as a within-subject (dyad) design. Time had a significant effect on performance, $F(3, 89) = 5.06, p < .002$. Trend analysis indicated that performance linearly decreased over time, $F(1, 90) = 9.57, p < .004$, form a mean of 8.33 at the end of five minute to a mean of 6.79 at the end of twenty minute.

Time *x* priming interaction also had a significant effect on performance, $F(3, 89) = 4.10, p < .008$. This interaction reflected the fact that dyads in the sequential priming condition maintained almost the same level of idea generation performance over sessions, whereas those in the simultaneous priming condition experienced a sharp decrease in performance, especially after the end of a ten-minute session, and maintained this low performance towards the end of the session (Fig. 8). No other significant effects were found to be significant on performance.

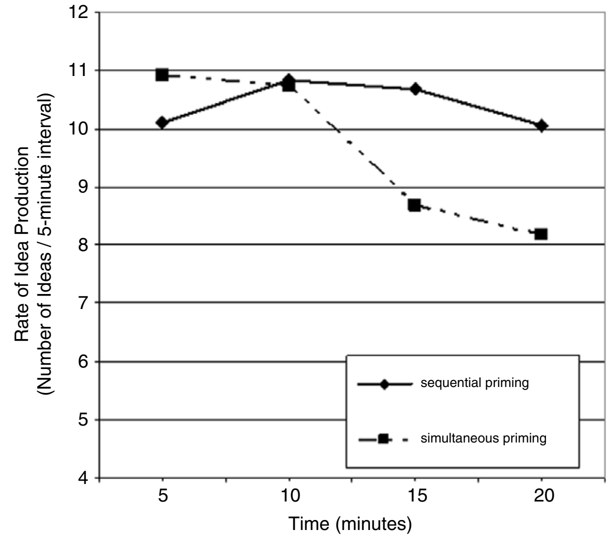

Fig. 8. Comparison of simultaneous and sequential cases.

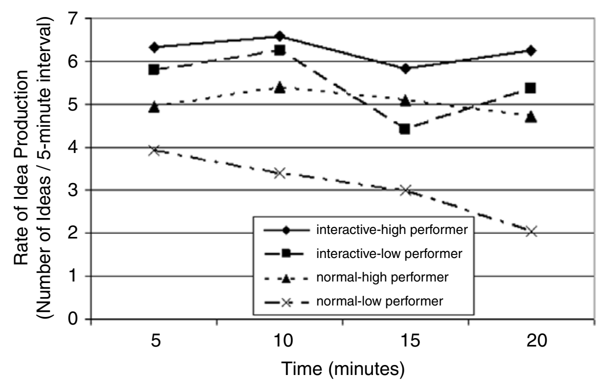

Fig. 9. Performances of high performers and low performers in social context.

In addition, we examined the performance of an average high performing member and a low performing member of the dyads for each experimental condition, in order to obtain a clear picture of how interactions between two brainstormers differ as a function of the experimental condition. On the basis of average performance of each dyad, the participants showing above average performance were defined as high performers, whereas those below average were defined as low performers. Then analysis was made over five-minute sessions by a means of 2 $\times$ 2 $\times$ 2 $\times$ 2 $\times$ 4 (time periods; 0–5 min, 5–10 min, 10–15 min, and 25–20 min) ANOVA with the last factor (time periods) as a within-subject design. High performers ($M = 23.10$) outperformed low performers ($M = 18.04$), $F(1, 82) = 14.32, p < .0001$. An interaction effect between social context and low/high performers showed a sharper performance decrement in nominal condition ($M = 12.50$) than interactive condition ($M = 22.82$) for low performers but a weaker performance decrement in nominal condition ($M = 20.19$) than interactive condition ($M = 24.96$) for high performers, $F(1, 82) = 4.56, p < .03$ (Fig. 9).

Moreover, analysis showed a main effect of social context ($F(1, 82) = 33.67, p < .0001$), memory ($F(1, 82) = 11.50, p < .001$), time ($F(3, 80) = 33.67, p < .0001$) as well as memory *x* social context ($F(1, 82) = 5.97, p < .02$), time *x* priming ($F(3, 80) = 5.88, p < .001$) interactions were found to be significant, which were in line with those mentioned above. The time

x social context x priming x memory ($F(3, 80) = 2.92, p < .04$) interaction reflected the fact that the best performance occurred and was maintained in interactive dyads with sequential priming across time period, while the worst performance was more evident in nominal dyads with simultaneous priming, especially in the middle and later period of brainstorming. In addition to these analyses, we calculated correlations between dyads in interactive and nominal conditions. There was a significantly high correlation ($r = .94, p < .00001$) in idea generation performance between dyads for the interactive group condition but a nonsignificant correlation ($r = .07, p > .97$) between dyads for the nominal group condition.

Lastly, there was a positive correlation ($r = .74, p < .0001$) between the number of ideas and that of recalled ideas. This outcome provided additional evidence for the attention-enhancing effects of the memory instruction.

Discussion

Consistent with the finding of Experiment 1, Experiment 2 indicated beneficial effect of memory instruction on the idea generation performance. Additional evidence for the attention-enhancing effects of the memory instruction was also found by a means of a positive correlation between the number of ideas and that of recalled ideas. It increased the idea generation performance by almost 29% as compared to the no-memory instruction. The gain due to the memory instruction for the nominal group condition was about 17%, whereas that for the interactive group condition was about 39%. This outcome is also in line with the findings of the previous research, indicating the beneficial effect of memory in electronic brainstorming groups (see Experiment 3: Dugosh et al. (2000)). From the associative memory or cognitive stimulation perspective, memory instruction may facilitate the associations of unique or new ideas in the memory since it may enhance both storage and retrieval of ideas.

Interactive dyads were found to generate more ideas than nominal dyads. Such a finding was consistent with the previous research finding (Coskun, 2005a), It was also consistent with the findings of studies which used either three person (Coskun, 2000), four person (Paulus & Yang, 2000) groups, or dyads (Coskun, 2005a). This indicated that the beneficial effect of brainwriting (e.g., its eliminative power of evaluation apprehension, social loafing, blocking, and downward matching) was evident at a dyadic interaction level. Here, however, it should be noted that smaller time periods (e.g., 5 min) were found to close the gap in performance between interactive and nominal dyads when provided the same number of paper slips (Coskun, 2005b). The findings of Experiment 2 once again provided evidence for the presence of cognitive stimulation in interactive brainwriting paradigm.

One could argue that in the second experiment, the dyadic interaction could introduce some of the self-presentation effects that are argued to be removed in written format—essentially making predictions quite different from those found in the results (e.g. evaluation apprehension because my partner will be reading my silly ideas). Evaluation apprehension is not a problem in the second experiment using the brainwriting technique for at least three reasons. First, some scholars have argued that evaluation apprehension was more evident in oral brainstorming than written (electronic or brainwriting paradigm: see also Gallupe et al. (1991), Nunamaker et al. (1995), Paulus and Yang (2000) and Valacich et al. (1994)). Despite the fact that any subject in electronic brainstorming or brainwriting condition may have a chance to evaluate his or her partner's ideas, expressing ideas with the written format under high idea flow does not provide one enough mental time to wonder off or criticize someone's or partner's ideas. Second, when we examined this evaluation apprehension possibility by calculating the sentences or words that mention any criticism or agree/disagree statements, we found that the rate of these sentences to the whole sentences or the percentage of these sentences implying social anxiety was less than one percent (0.66%). In one of our previous studies done in oral brainstorming, this ratio was almost 20%. Third, even though verbal messages are perceived to be different depending on the nonverbal behavior (e.g., voice tone, quality, pitch, gestures, and mimics), written messages do not provide such salient clues to the perceiver or partner. Given these considerations, evaluation apprehension is minimal or absent in the brainwriting context compared with the oral or face-to-face brainstorming context.

Though not being significant, interactive dyads seemed to have a greater benefit from memory instruction than nominal ones while generating their ideas. However, the power for this interaction effect (.07) was small in the second experiment. The estimated effect size for this interaction could be .11 in order to reject the null hypothesis. According to the associate memory perspective, memory instruction may especially enhance one's span of attention to the ideas generated by others, and capacity of short-term memory. Consistent with this, it was found that performance gain due to the memory instruction was greater with brainwriting (29% gain: Experiment 2) than the nominal condition (11% gain: Experiment 1). This may be due to the fact that nominal brainstormers have to pay attention to their own ideas since there is no other person or external stimulation in the nominal situation to be paid attention. A lack of external stimulation or the ideas generated by others (which is often more diverse than one's own ideas) may decrease one's memory capacity or idea storage and thereby the rate of idea generation. Despite of a lack of any significant finding, brainstormers seemed to get more benefit from paying attention to the ideas of others than focusing on their own ideas. From this standpoint, it is obvious that future research should be done with a greater sample size in order to evaluate this possibility for an interaction effect.

Interaction effect between time and priming reflected the fact that sequential priming led participants to successfully maintain their initial performance level over sessions, whereas simultaneous priming led to a performance decrement over the session, especially after the end of the 10 min session. This finding is in line with the finding of Experiment 1. This suggests that the detrimental effect of simultaneous priming becomes evident in the later session of brainstorming. Almost the same type of pattern occurred in a previous piece of research, in a way that participants decreased their performance level after 12 min time periods. Successful continuation of initial performance over a session in sequential priming was also observed in oral or conventional brainstorming (Experiment 1: Coskun et al. (2000)) and nominal brainstorming with writing format (Experiment 2: Coskun et al. (2000)).

An interaction effect between a social context and low/high performers showed a sharper performance decrement in a nominal condition than an interactive condition for low performers but a weaker performance decrement in a nominal condition than an interactive condition for high performers. In other words, low performers tended to match the performance of high performers in the interactive group condition but this trend was absent in the nominal group condition. Interactive dyads also showed a greater degree of convergence over time than the nominal dyads. Taken together, these findings mean that upward matching is more evident in interactive brainwriting than nominal one. These outcomes were in line with the findings of the Coskun et al. (2000) study and modeling of Brown and Paulus (1996).

In Experiment 2, in contrast to Experiment 1, no significant interaction effect between time and memory (the effect size was .04) was found ($p > .10$). Despite this non significance level, as with Experiment 1, there seemed to be the trend for a sharper decline in the no-memory condition than the memory condition over the later time periods of the brainstorming session. This may be due

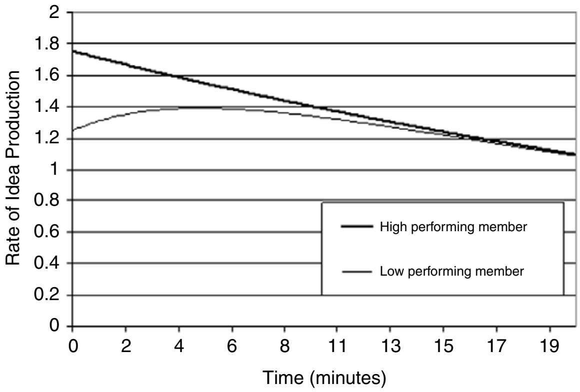

Fig. 10. High and low performing members for the simultaneous case (non cognitive).

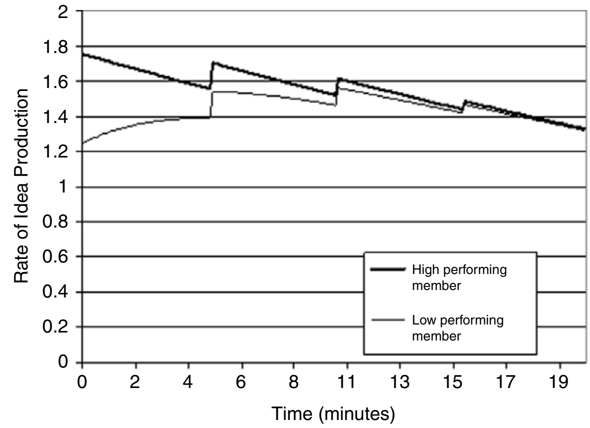

Fig. 11. High and low performing members for the sequential case (non cognitive).

to the fact that the strong or very constructed situation brainwriting (keeping track of ideas by others, paying attention, and generating ideas, and etc.) may override this interaction effect. Since paying attention to the ideas of others is also present in interactive brainwriting, such an extra component may make this potential interaction very weak. Since the number of observations is lower in Experiment 2 than Experiment 1, this may contribute to this outcome. Thus the future research should examine this possibility.

4. Comparison of experimental results with mathematical modelling

Tables 2 and 3 show some comparisons between the results of the experiments and those of the mathematical model for memory conditions. In the simulations, decay and matching coefficients have been chosen to be 0.0235 and 0.2 respectively. The former was determined from Experiment 1. For the simultaneous and sequential cases, initially it is assumed that the rates of idea generation are 1.75 and 1.25 for different members of the group. We assume that the initial number of ideas for each person should be different; otherwise there would be no matching, which results in underestimation of the total number of ideas outputted by the group. Another key assumption in the sequential case is that at the fifth minute, the rate of idea generation is increased by 0.15 ideas/min for each member, at the tenth minute by 0.1 ideas/min and at the fifteenth minute by 0.05 ideas/min. The freely estimated parameter in this case is the matching coefficient and its best fitting value is 0.2. The number of starting rates of idea production can also be regarded as freely estimated parameters, and their best fitting values are given as above.

The general trend of the simulations agrees quite well with the experimental results. There are small discrepancies between the results of experiments and simulations, which are normal, considering the assumptions made by the model and statistical deviations of the experimental results.

We think it is necessary to consider cognitive processes of each individual to model the effects of the memory condition. The memory condition will change the cognitive processes of individuals, possibly causing a decrease in the decay coefficient of idea generation, storage and output stages. Thereby it will increase the number of ideas outputted, whereas in non cognitive modeling there is no such mechanism to account for these effects. As suggested by Experiment 1, in order to account for the memory condition, the decay coefficient was chosen to be 0.0235 which is smaller than the number (0.03) used for no memory condition. The freely estimated parameters in this case are the matching coefficient and the coefficient R, and their best fitting values are 0.2 and 1.0. Figs. 10 and 11 show the rate of idea production for high and low performing members for the simultaneous and sequential cases respectively (non cognitive case).

Table 2
Comparison of number of outputted ideas for 5 min-intervals and relative errors for the simultaneous case.

	5th min	10th min	15th min	20th min
Experiments	14	16	11	13
Model-cognitive	10.7	16.0	14.5	13.3
Relative error	%24	%0	%32	%2.3
Model-non cognitive	14.5	14.4	12.8	11.7
Relative error	%3.5	%10.0	%16.4	%10.0

Table 3
Comparison of number of outputted ideas for 5 min-intervals and relative errors for the sequential case.

	5th min	10th min	15th min	20th min
Experiments	13	15	15	15
Model-cognitive	10.7	16.0	14.8	14.8
Relative error	%17.7	%6.7	%1.3	%1.3
Model-non cognitive	14.5	15.7	14.9	14.1
Relative error	%11.5	%4.7	%0.7	%6.0

The Tables 2 and 3 show that the non cognitive model does better in the first half of the simulation and the cognitive model does better in the second half. This is explained by the fact that in cognitive modeling, an idea starts in the generation stage and then moves to the storage and output stages. The whole process takes time and the cognitive model underestimates the actual output during the first 5–10 min.

The rates of idea production for high and low performing members for the simultaneous and sequential cases with cognitive processes are shown in Figs. 12 and 13.

We also notice that non-cognitive models fair better in fitting the sequential priming data than they do in fitting the simultaneous priming data. A possible reason for this is that, in the former case, a sudden increase in outputted ideas at fixed moments of time somewhat counteracts the possible defects of the model. This outcome is similar to the findings of Coskun et al. (2000) study where simulations of the model described in that paper showed that the capacity of short-term memory had no effect on idea generation when categories were sequentially primed, since sequentially-presented primes did not need to be maintained in short-term memory.

Table 4 gives the values for coefficients used in the simulations. Discussion about coefficients was given in the preceding paragraphs of this section.

For Figs. 10–13, quantitative comparison with experiments is not possible. The reason for this is that there are two freely estimated parameters in the simulations – matching coefficient

Table 4
Coefficients used in the simulations of experiments.

Simulations	Decay coefficient (s)			Blocking coefficient (s)	Matching coefficient	R	Initial values[a]	Values of jumps[b]
Simultaneous case (noncognitive with memory), Table 3	0.0235			–	0.2	–	1.75 1.25	
Sequential case (noncognitive with memory), Table 4	0.0235			–	0.2	–	1.75 1.25	0.15 0.1 0.05
Simultaneous case (cognitive with memory), Table 3	0.0235	0.0235	0.0235	– –	0.2	1.0	1.0 0.7	
Sequential case (cognitive with memory), Table 4	0.0235	0.0235	0.0235	– –	0.2	1.0	1.0 0.7	0.6 0.3 0.15

[a] Rate of idea production for each member at $t = 0$.
[b] Increase in the value of rate of production at 5th, 10th and 15th min (value of increase is the same for each member).

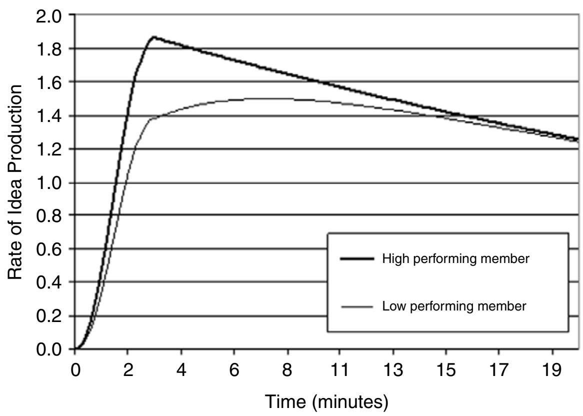

Fig. 12. High and low performing members for the simultaneous case (with cognitive processes).

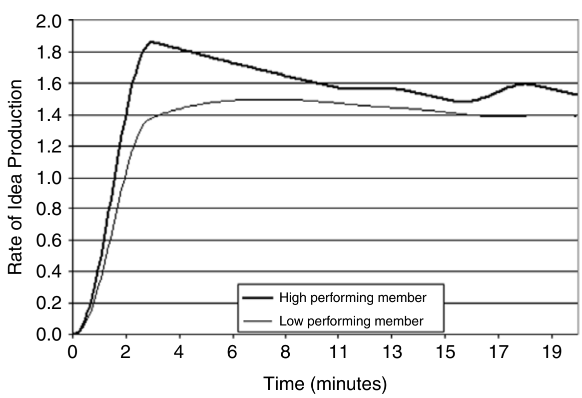

Fig. 13. High and low performing members for the sequential case (with cognitive processes).

and the number of starting ideas – and these parameters are varied to fit the total number of outputted ideas of the group, not the rate of idea production of each member. But qualitative comparison with experiments can be done and we can see that in both cases that the low performing member is trying to match his/her performance to that of the high performing member.

5. Conclusions

In this paper, we tried to provide an alternative account for the model developed by Brown and Paulus (1996). The simulations produced a reasonable and good fit to the existing data in the literature (Brown & Paulus, 1996; Camacho & Paulus, 1995) as well as interesting outcomes for future studies. However, the verification of such a modeling obviously requires more studies and experimental manipulations.

In addition to this modeling effort, we developed a modeling that treated the sequential type brainstorming with impulsive differential equations by assuming each category as an impulse. We conducted the two experiments in order to assess the verification of sequential and simultaneous priming with a different paradigm that consisted of memory instruction and brainwriting as compared to the previous studies (Brown & Paulus, 1996; Coskun et al., 2000). Taken together, experimental studies suggest that memory instruction had a beneficial effect on the idea generation performance. However, presenting all categories of the problem at every five minutes, regardless of presenting them either at once or one at a time, eliminated the potential difference between simultaneous and sequential priming. However, consistent with the findings of the previous experiments (Coskun et al., 2000), in both Experiment 1 and 2 the time and priming interaction reflected the fact that the performance declined more with the simultaneous priming than that with sequential priming over time. Consistent with these outcomes but being different from the model of Brown and Paulus (1996), our model considered a different number of ideas for each person at the onset of the session, and treated these ideas as an impulse to the system. The general trend of the simulations based on these considerations seemed to fit quite well with the experimental results.

The mathematical model produces quite good results based on the input obtained from Experiment 1. We learn that the initial number of ideas for each person should be different, so as to have a positive effect of matching in brainstorming, in writing. (This is almost always the case for laboratory groups, since people are randomly selected.) Otherwise there would be no matching, which results in underestimation of the total number of ideas outputted by the group. Also, based on the assumptions of the sequential modeling, new categories introduced at the fifth, tenth and fifteenth minutes have the impulsive effect of an increase on the rate of idea generation for each person. Our assumption that in sequential cases each new category can be treated as an impulse to the dynamical system is verified by these two experiments (Tables 2 and 3). Cognitive processes were modeled in the hypothetical simulations and gave results that are more realistic than the non cognitive cases do. Cognitive modeling is also necessary to account for the memory condition. The simulations (Tables 2 and 3) verified that the memory condition decreases decay, therefore making a positive impact on the result. Overall conclusions are that the non cognitive model does better in the first half of the simulation and the cognitive model does better in the second half.

From an application point of view, organizations or companies may benefit from sequential priming and memory instruction in their idea generation sessions by keeping the performance level alive over long idea generation sessions. For example, coworkers may be instructed to pay close attention to the ideas generated in the brainstorming sessions. However, it should be kept in mind that a strong emphasis on the memory test at the end of a team or group meeting may lead to an increase in one's evaluative concerns in corporate or industrial settings. Thus the team leader should be aware of this possibility and should not place more emphasis on the memory test for it especially in the case of individuals working alone. The findings of the current two studies suggest that providing memory instruction may not much help one person who works alone. Coworkers in industrial settings may benefit from sequential priming when considering too many different aspects of the same topic or problem. Before giving the cases where a group considers a problem for the first time, it would be beneficial to have a meeting to identify the components of the problem. Alternatively, the team leader may discuss the characteristics of the problem and then subdivide those into smaller segments before the brainstorming session starts.

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