Mixed Effects of Distractor Tasks on Incubation

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Abstract

Many experiments have tested the effect of distracting activities during an incubation period between a variety of main tasks, but no stable pattern of results has emerged. In the present paper, we propose a clarification and re-interpretation of the effect of distracting activities on incubation using a well-established cognitive model -- the CLARION cognitive architecture. The resulting predictions are tested in a human experiment. The results confirmed our predictions, which suggests that incubation is a diverse phenomenon, involving diverse cognitive processes. Hence, distracting activities can have different effects on incubation depending on the task used to assess the presence of incubation.

Keywords: Incubation, distracting activity, free recall, reminiscence, cognitive architecture, CLARION.

Introduction

Incubation can be defined as a period away from actively attempting to solve a difficult problem (Smith & Dodds, 1999). In a recent review of the experimental research on incubation, 29 out of 39 experiments have found a significant effect of incubation (Dodds, Ward, & Smith, 2003). More precisely, these authors investigated the effect of incubation length, preparatory activity, clues, distracting activity, expertise, and gender on participants' performances. This extensive review of the experimental literature suggested that performance is positively correlated with incubation length and that preparatory activities can increase the effect of incubation. Also, presenting a clue during the incubation period has a strong effect. If the clue is useful, the effect of incubation is increased; if the clue is misleading, incubation is inhibited. Moreover, the effect of clues is stronger when the participants are explicitly instructed to look for clues (Dodds, Smith, & Ward, 2002). The last three factors (distracting activity, expertise, gender) do not seem to yield stable patterns of results. In the present paper, we propose a clarification and re-interpretation of the effect of distracting activities on incubation using a well established cognitive model -- the CLARION cognitive architecture (Sun, Merrill, & Peterson, 2001; Sun, Slusarz, & Terry, 2005), in order to make sense of the seemingly inconsistent literature.

This paper is organized as follow. First, the experimental literature related to the effect of distracting activities on incubation is briefly reviewed. This review is followed by an overview of the CLARION cognitive architecture, along with some of the previous simulation results. Following this presentation, a classification of distracting tasks is provided within the CLARION framework and predictions about their effects are made. These predictions are then tested in an empirical investigation.

The Effect of Distracting Tasks on Incubation

The effect of distracting activities on incubation has been studied mostly using the remote association task and insight problem solving (Dodds et al., 2003). In the remote association task, the participants are shown three clue-words and their task is to find a fourth word that is associated with all three clue-words (e.g., "potato", "tooth", and "heart" are associated with "sweet"). In this task, the participants often reach an impasse and an incubation period ensues before returning to working on the initial problem. Results reviewed in Dodds et al. suggest that working continually on the problem is better than adding an incubation period that involves producing free associations or weighing objects. However, doing mental rotation during the incubation period improves performance. In addition, having a free conversation with the experimenter during the incubation period does not affect performance.

The effect of distracting activities on insight problem solving is different. For instance, results reviewed in Dodds et al. suggest that relaxing during the incubation period is more beneficial than doing other distracting tasks or working continuously on "insight problems". However, Olton and Johnson (1976) used seven different distracting activities (including those listed above) during the incubation period between solving the same insight problems as in the above mentioned review and found no incubation or distracting activity effect whatsoever (i.e., no improvement or decrement). This last experiment clearly highlights the disagreement on the effect of distracting activities on incubation.

An Overview of the CLARION Cognitive Architecture

CLARION is a cognitive architecture that is, in part, based on two basic assumptions: representational differences and learning differences of two different types of knowledge: implicit versus explicit (Sun et al., 2001, 2005). These two types of knowledge differ as to their accessibility and attentional requirements. The top level of CLARION (as in Figure 1) contains explicit knowledge (easily accessible, requiring more attentional resources) whereas the bottom level contains implicit knowledge (harder to access, mostly automatic). Because knowledge in the top and bottom levels is different, Sun et al. (2001, 2005) have shown that it is justified to integrate the results of top-level and bottom-level processing in order to model the interaction of implicit and explicit knowledge in humans.

The bottom and top levels of CLARION are divided into two different subsystems (see Figure 1): the *Action-Centered Subsystem* and the *Non-Action-Centered Subsystem*. The Action-Centered Subsystem (with both levels) contains procedural knowledge concerning actions and procedures (i.e., it serves as the long-term procedural memory in CLARION), while the Non-Action-Centered Subsystem (with both levels) contains declarative knowledge (Sun et al., 2005). The Non-Action-Centered Subsystem is controlled by the Action-Centered Subsystem and constitutes another long-term memory (semantic or episodic) in CLARION. The Non-Action-Centered Subsystem is also used for reasoning (Sun & Zhang, 2006).

The second assumption in CLARION concerns the existence of different learning processes in the top and bottom levels (Sun et al., 2001, 2005). In the bottom level, implicit associations are learned through gradual trial-and-error learning. In contrast, learning of explicit knowledge is often one-shot and represents the abrupt availability of explicit knowledge following "explicitation" or newly acquired linguistic information in the top level. The inclusion and emphasis on bottom-up learning (i.e., the transformation of implicit knowledge into explicit knowledge) is, in part, what distinguishes CLARION from other cognitive models. Nevertheless, top-down learning is also included in CLARION (Sun & Zhang, 2004): Knowledge that is initially explicit can be assimilated and transformed into implicit knowledge to capture the proceduralization and automatization processes found in human data (Sun et al., 2001).

Previous Simulations

CLARION performs particularly well in sequence learning tasks. For example, the Action-Centered Subsystem of CLARION has been used to model navigation in mazes and mine fields (Sun et al., 2001; Sun & Peterson, 1998). CLARION quickly learned to achieve the task, and the performance of the complete model was always superior to the performance of its modules in isolation (synergy). This captured well the corresponding human data. In addition, the explicit rules developed in the top level were found to be similar in a sense to verbal reports produced by human participants in similar tasks (bottom-up learning). Moreover, because CLARION focuses on the dichotomy between explicit and implicit knowledge, benchmark psychological tasks that measure implicit learning were also successfully captured and explained (Sun et al., 2005).

The Non-Action-Centered Subsystem of CLARION has been used to simulate reasoning data (e.g., Sun & Zhang, 2006). In a series of experiments, human participants were asked to rate the relative strength of arguments of the form: "All flowers are susceptible to thrips → All roses are susceptible to thrips." The results in various experiments have shown a mixed effect of rule-based reasoning and similarity-based reasoning when judging the likelihood/strength of these statements. In the Non-Action-Centered Subsystem of CLARION, rule-based reasoning is captured by top-level processes (explicit) whereas similarity-based reasoning is captured using bottom-level processes (implicit). Both levels process the available information simultaneously and the results are integrated to produce a response. By varying the relative weights of the top and bottom levels in knowledge integration, the Non-Action-Centered Subsystem of CLARION was able to capture the data in four such experiments.

More recently, the Non-Action-Centered Subsystem of CLARION was used to model creative problem solving (by implementing the Explicit-Implicit Interaction theory, as in Hélie & Sun, submitted). More precisely, CLARION was able to capture data related to the effect of incubation in free recall and lexical decision tasks, as well as insight and overshadowing effects in problem solving. In these simulations, incubation was mostly explained by processing in the bottom level of the Non-Action-Centered Subsystem. However, alternative possibilities for incubation in other tasks and the effects of various distracting activities have not been investigated in previous work.

A New Interpretation of Incubation Effects Using CLARION

The four main modules in CLARION (i.e., the top level of the Action-Centered Subsystem, the bottom level of the Action-Centered Subsystem, the top level of the Non-Action-Centered Subsystem, the bottom level of the Non-Action-Centered Subsystem; Sun et al., 2005) might provide an intuitive explanation for the differential effects of different distracting tasks. In the CLARION framework, each task can be classified according to the modules that are involved in the processing, and incubation engages often the same modules as the main task. Hence, distracting tasks that involve mostly modules in CLARION that are needed for a task can disrupt incubation for that particular task. In contrast, distracting tasks involving modules that are less relevant to a task should not affect incubation of the task as much.

For instance, it was argued (see the previous subsection) that incubation in insight problem solving involves processes mostly located in the bottom level of the Non-

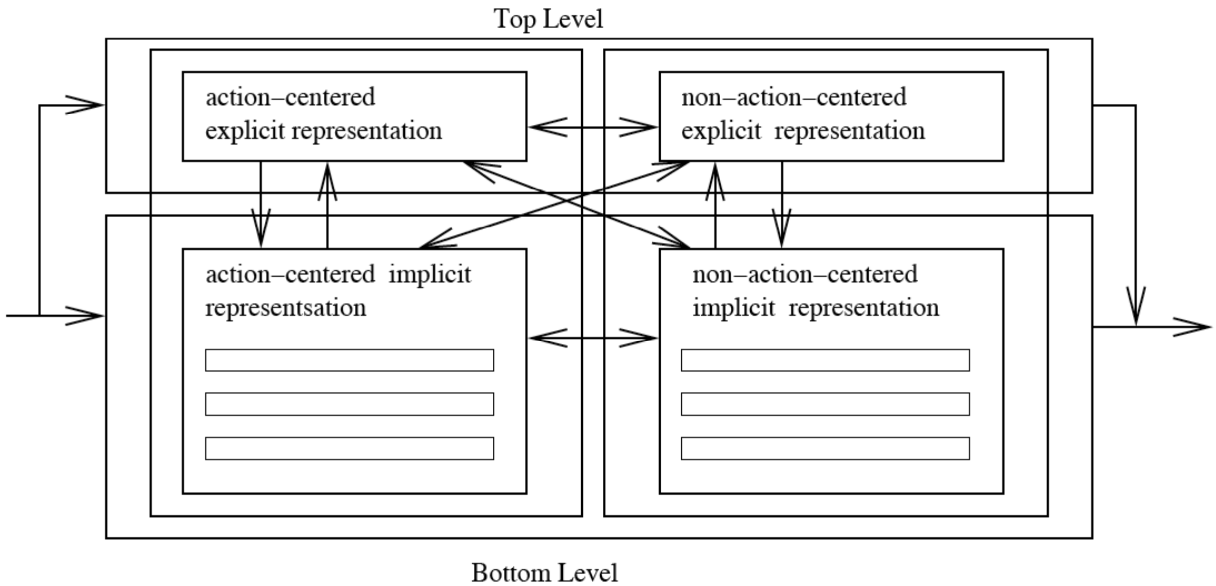

Figure 1: The architecture of CLARION.

Action-Centered Subsystem (Hélie & Sun, submitted; see also the "unconscious" work theory of incubation reviewed in Smith & Dodds, 1999). Hence, distracting tasks that disrupt the activity of the bottom level of the Non-Action-Centered Subsystem should disrupt incubation in creative problem solving. This explanation is consistent with previous interpretation and simulations of the overshadowing effect in 'insight' problem solving (Hélie & Sun, submitted; Schooler, Ohlsson, & Brooks, 1993).

In free recall tasks, however, incubation relies on both the Non-Action-Centered Subsystem and the Action-Centered Subsystem. The Non-Action-Centered Subsystem in CLARION serves as the long-term memory used to store the word list. However, the Action-Centered Subsystem is also heavily involved in free recall, because it controls the transfer of memory items from the working memory to the long-term memory (in the Non-Action-Centered Subsystem, for memory consolidation). Thus, distracting tasks that requires much top-level processing in the Action-Centered Subsystem may hamper the transfer of new memory items (because such top-level processing requires more attention), thus disrupting incubation in free recall (see the "conscious" work theory of incubation reviewed in Smith & Dodds, 1999). Distracting tasks that requires much top-level processing in the Non-Action-Centered Subsystem may also hamper the transfer of new memory items because such top-level processing requires more control by the Action-Centered subsystem, thus disrupting incubation.

Many tasks have been used to study incubation (e.g., remote association, free recall, lexical decision, problem solving; for a review, see Dodds et al., 2003), and their results are usually compared or pooled together. An important implication of this methodology is that incubation is assumed to be a unitary process that has the same effect on all tasks. Our new interpretation suggests otherwise. Because incubation can happen in different modules in CLARION, different distracting activities should have different effects depending on the processes involved.

Previous Free Recall Experiment To test the effects of distracting activities on incubation, we used Smith and Vela's (1991) free recall experiment (as simulated in Hélie & Sun, submitted). In this experiment, the participants were asked to memorize a booklet of 50 line drawings. Following this initial study period, the booklets were removed and the participants were asked to write down the names of as many line drawings from the booklet as possible (i.e., a regular free recall task). Following the free recall task, an incubation interval ensued, followed by a second identical free recall task (which did not include a second study period). Smith and Vela found that the length of the incubation interval affects the reminiscence scores (i.e., the number of new words recalled in the second free recall task). In contrast, test length did not have a reliable effect on reminiscence.

In Smith and Vela's original study, different incubation intervals were compared, along with the absence of an incubation interval, but distracting tasks were not used during the incubation intervals. In the following studies, we reproduce Smith and Vela's original experiment and add four conditions, with each condition using a different distracting task (corresponding to different modules in different subsystems of CLARION).

New Free Recall Experiment Following Smith and Vela (1991), we used a test length of two minutes and an incubation interval of 10 minutes. (These experimental settings were chosen because they resulted in the strongest incubation effect in the original study.) Six conditions were tested by altering the distracting task during the incubation intervals: no incubation, do nothing, a dynamic control task (Berry & Broadbent, 1988), a remote association task (Dodds et al., 2002), a syllogistic reasoning task (Evans, 2007), and a perceptual-motor task.

Predictions Based on CLARION The free recall experiment is modeled the same way for all conditions. This task involves a memory consolidation process with (covert or overt) rehearsal of memory (Anderson & Milson, 1989), which is mainly responsible for the effect of incubation intervals (Roberts, 1972; Smith & Dodds, 1999). This rehearsal, which allows for transferring memory items from the working memory to the Non-Action-Centered Subsystem, is controlled by the Action-Centered Subsystem and can thus be disrupted by distracting activities that require processing in both of these subsystems (mostly in the top levels, because they require more attentional resources and/or control).

The first two conditions were a replication of Smith and Vela's (1991) study and were included to ensure that we could reproduce their results. Hence, the Do Nothing condition should have a higher reminiscence score than the No Incubation condition. The other conditions were designed to involve mostly one of the four main modules in CLARION (Sun et al., 2005).

In the dynamic control task (Berry & Broadbent, 1988), the participants were asked to control the production of a sugar factory by setting the number of workers. However, the sugar production was not only a function of the number of workers but also of the sugar production from the previous time step. This task is often performed using explicit hypothesis testing (especially by the engineering students at RPI), which is thought to be performed in CLARION by the top level of the Action-Centered Subsystem (because each hypothesis is a procedural rule describing the dynamics of the sugar factory). This module requires extensive attentional resources and thus this task can disrupt the memory consolidation and transfer of the main task (the free recall task), which requires control by the Action-Centered Subsystem. Hence, this distracting task should strongly interfere with incubation in the main task (and may even interfere with the main task itself).

The remote association task (explained earlier) can be viewed as an implicit, soft constraint-satisfaction process and is hypothesized to involve mostly implicit processing in the bottom level of the Non-Action-Centered Subsystem (Hélie & Sun, submitted). This module includes mostly automatic processes, but this task might still interfere with memory consolidation and transfer of the main task (the free recall task), because it may involve explicit processing by the Action-Centered Subsystem due to some attention devoted to the control of the task. [Also, some part of the long-term memory in the Non-Action-Centered Subsystem used by the main task (the free recall task) is implicit and possibly involves the same module used in the remote association task.] Still, the amount of explicit processing (and required attention and control) is substantially smaller in this condition. Thus, incubation in the free recall task should be inhibited to a lesser extent in this condition.

In the syllogistic reasoning task, the participants were asked to verify the validity of syllogisms that were presented using symbol representations. This task involves heavily explicit, symbolic, rule-based reasoning processes (Evans, 2007), which should engage mostly explicit, top-level processes (but also bottom-level processes) in the Non-Action-Centered Subsystem (Sun & Zhang, 2006). This attention demanding task requires much control (attention) by the Action-Centered Subsystem due to the heavy involvement of the top-level of the Non-Action-Centered Subsystem (which requires more step-by-step control). It may also use the modules where the working memory items are to be transferred by the main task (the free recall task). Thus, it should hamper memory consolidation and transfer of the main task (the free recall task) and strongly interfere with incubation in the task (as well as possibly the main task itself).

In the perceptual-motor task, a red square appeared in one of nine positions in a computer screen and the participants had to push a key on the numeric pad that corresponded to this position as quickly as possible. In CLARION, this task should involve mostly implicit, low-level, bottom-level processes in the Action-Centered Subsystem (because it involves mostly simple, senosory-motor, reactive behavior). Hence, this task does not require much attentional resources and should not interfere much with incubation in the free recall task. However, it may still slightly inhibit incubation due to some attention in the Action-Centered Subsystem being devoted to this task (as opposed to the control of the memory consolidation and transfer process in the main task).

Experiment

Methodology

Participants 114 undergraduate students from the Rensselaer Polytechnic Institute participated in this experiment for course credits. The participants where divided into six groups of equal size ($n = 19$).

Material The free recall task used the same stimuli as Smith and Vela's (1991) original experiment. The 50 line drawings were printed in a 10-page booklet, five drawings per page. No additional material was used in the No Incubation and Do Nothing conditions.

In the dynamic control task (Berry & Broadbent, 1988), the participants had to control the output of a sugar factory. The equation underlying the system was $O(t) = 20W - O(t-1)$, where $O(t)$ is the sugar output at time t and W is the number of workers (input). The sugar factory was simulated using a Windows-based computer, and the desired output was $O(t) = 6000$. The participants entered the number of workers by clicking on a number from a list at the bottom-left of the display. The selected number of workers was displayed in a graph in the top-left of the display, and the corresponding sugar output was displayed in a second graph in the top-right of the screen. The desired sugar output was represented by a straight line in the sugar output graph.

In the remote association task (Dodds et al., 2002), 20 problems were printed in a 20-page booklet (one problem per page). The problems used were the same as in Dodds et al.'s experiment (as listed in their Appendix). At the top of each page, three words were printed in large characters (i.e., the remote association problem), and a response box was printed at the bottom of each page. The remainder of each page was empty.

In the syllogistic reasoning task, 12 abstract syllogistic forms were printed in a 12-page booklet (one problem per page). On each page, a syllogism was printed at the top-left using letters alone (e.g., All As are Bs). All the syllogisms used allowed for a conclusion, and the participants had to choose between three responses: 'True', 'False', and 'Don't know'. A response box was printed in the top-right of each page, and the remainder of each page was labeled 'Workspace'.

In the motor control task, the participants had to press a key on the numerical keypad of a computer corresponding to the location of a square in the display. This task was controlled by a Windows-based computer. The display was similar to a 'Tic-Tac-Toe' grid with nine locations. At every trial, a large red square appeared at a random location and the participants had to press a key on the numerical keypad corresponding to the location of the square.[1] No sequence was used. The participants were asked to respond as quickly as possible without sacrificing accuracy.

Procedure The general procedure for the free recall task was the same in all conditions. First, the participants had 30 seconds to study each page of the free recall booklet, for a total of five minutes. To make sure that each page was given equal time, a signal from the experimenter was required before turning the pages. Following this study period, the booklets were removed from the participants and a two-minute free recall test was administered. During the free recall test, the participants were asked to write the names of as many items from the booklet as possible. Following the free recall test, the participants had a 10-minute interval to take part in a distracting task (incubation). After the incubation interval, the participants took part in a second, identical, free recall test (not including a second study period). Note that the participants were not informed ahead of the time of the existence of the second free recall test.

In the No Incubation condition, there was no incubation interval: the second free recall test immediately followed the first. In the Do Nothing condition, the participants were not given a distractor task: they were asked to remain seated and wait for 10 minutes. [Note that these two conditions were used to verify the accuracy of our results by trying to reproduce Smith and Vela's (1991) data.]

In the dynamic control task (Berry & Broadbent, 1988), the participants were seated in front of a computer and continuously entered the required work force of the sugar factory for 10 minutes. The number of trials was not controlled, and each participant could decide his/her own pace.

In the remote association task (Dodds et al., 2002), the participants had 30 seconds to work on each problem, for a total of 10 minutes. The participants were asked to wait for a signal from the experimenter before turning any of the pages to make sure that the same amount of time was spent on each problem.

In the syllogistic reasoning task, the participants had 50 seconds to work on each problem for a total of 10 minutes. As in the remote association task, the participants were asked to wait for a signal from the experimenter before turning any of the pages.

In the motor control task, the participants were seated in front of a computer and asked to press a key on the numerical keypad corresponding to the position of a large red square on the display. As in the dynamic control task, the number of trials was not controlled, and each participant could follow his/her own pace for 10 minutes.

Results

The results are shown in Figure 2. The first thing to notice is that we were able to reproduce Smith and Vela's (1991) results: the Do Nothing condition had a higher reminiscence score than the No Incubation condition. This was confirmed by an ANOVA, which showed a statistically significant effect of condition $F(5, 108) = 10.65$, $p < .001$. Precisely, Tukey posthoc analyses ($\alpha = .05$) confirmed that participants in the Do Nothing condition had a mean reminiscence score (7.26) higher than the participants in all the other conditions. Furthermore, the participants in the No Incubation (4.9), the Remote Association (4.84), and the Perceptual-Motor (4.84) conditions, had higher mean reminiscence scores than the participants in the Syllogistic Reasoning (2.47) and the Dynamic Control (2.26) conditions. (Statistically, Do Nothing > No Incubation = Remote Association = Perceptual-Motor > Syllogistic Reasoning = Dynamic Control.)

Discussion

The preceding results showed that the experiment was sufficient to elicit incubation effects in the free recall task. Also, the empirical results are consistent with the predictions made by CLARION concerning the effects of distracting activities on incubation in a free recall task. As predicted, the main factor predicting the effect of incubation seemed to be the amount explicit processing involved in the distracting task: tasks that were assumed to be performed by top-level, explicit processes produced more interferences on the main task (i.e., Dynamic Control and Syllogistic Reasoning) whereas tasks that were assumed to engage

[1] The mapping between the numerical keypad and the locations of the squares in the display was intentionally made to be intuitive. For instance, the top-left corner of the display was mapped to the '7' on the numerical pad, the center of the display was mapped to the '5' on the numerical pad, and so on.

bottom-level, implicit processes (e.g., Perceptual-Motor and Remote Association) did not affect the main task as much (although incubation was still inhibited).

This finding is very interesting and could be a function of the task used to study incubation: free recall. Many psychological theories assume that the performance in free recall is affected by some kind of mental rehearsal in memory consolidation (e.g., Anderson & Milson, 1989). This rehearsal requires control (hence, it competes with other top-level processes, which either require control or are needed for carrying out control) and can be inhibited by a distracting task involving top-level processes.

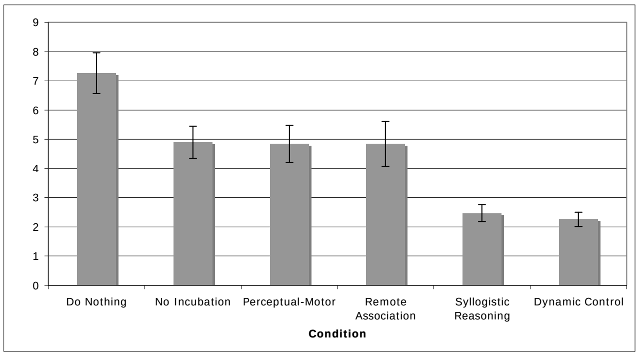

Figure 2: Reminiscence scores in the free recall experiment.

Conclusion

To our knowledge, the cognitive processes involved in incubation have never been systematically studied. The results of several incubation tasks (e.g., remote association, free recall, lexical decision, problem solving; for a review, see Dodds et al., 2003), and several distracting activities, have been compared as if the processes involved in the incubation task and the distracting activity were independent. As a consequence, incubation was assumed to be a unitary process that has the same effect on all tasks. The above analysis based on CLARION and the subsequent experimental results suggest otherwise. Hence, our future research should focus on testing these six conditions with other main tasks, e.g., problem solving, to verify if similar predictions based on CLARION can be made and if a corresponding pattern of results would emerge. As research on incubation starts to accumulate a larger set of data, process-based theories (e.g., based on cognitive architectures) will be needed to make sense of the data. The present CLARION-cognitive-architecture-based work is a first attempt at such analysis and theorizing.

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