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Brief article

Sleep promotes analogical transfer in problem solving

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ABSTRACT

Analogical problem solving requires using a known solution from one problem to apply to a related problem. Sleep is known to have profound effects on memory and information restructuring, and so we tested whether sleep promoted such analogical transfer, determining whether improvement was due to subjective memory for problems, subjective recognition of similarity across related problems, or by abstract generalisation of structure. In Experiment 1, participants were exposed to a set of source problems. Then, after a 12-h period involving sleep or wake, they attempted target problems structurally related to the source problems but with different surface features. Experiment 2 controlled for time of day effects by testing participants either in the morning or the evening. Sleep improved analogical transfer, but effects were not due to improvements in subjective memory or similarity recognition, but rather effects of structural generalisation across problems.

1. Introduction

To be an effective problem solver, one must apply learning from previous experiences to new contexts. This application of knowledge is not simply a function of recalling previous information, because two situations are rarely identical. Consider the problems shown in Fig. 1. Applying the tree problem solution to the matchsticks problem requires remembering the initial solution, evaluating the similarity between the two problems, and restructuring the first solution to apply to the matchsticks (e.g., remapping trees to matchsticks, and the hill to constructing matches in a third dimension above the working surface). Thus, in addition to explicit information recall, one must identify the procedural steps that led to success in the previous event and adapt them to apply to the current context (Duncker, 1945; Gentner & Markman, 1997; Holyoak, 2012; Metcalfe & Weibe, 1987; Olton & Johnson, 1976; Scheerer, 1963). This process is referred to as analogical reasoning and has been considered as the major contributor to humans' mental agility (Gentner & Colhoun, 2010) and the bedrock of human cognition (Hofstadter, 2001).

Despite the importance of analogical reasoning to problem solving, people are notoriously poor at translating solutions from a previously attempted (source) problem to novel but structurally related (target) problems (Gick & Holyoak, 1980; Vendetti, Wu, & Holyoak, 2014). Unfortunately, people only effectively transfer if the source and target problems have a high degree of surface similarity (e.g., Bassock & Holyoak, 1989) or if attention is extensively and explicitly directed to the abstract schema underlying both the source and target problems' solutions (e.g., Catrambone & Holyoak, 1989). Consequently, discovering less intrusive means by which such transfer can be facilitated has become a major theoretical goal with important practical consequences.

There is good reason to believe that analogical transfer could benefit from something as simple as sleep. As analogical transfer depends in part on memory of the source problems, sleep can enhance transfer because sleep improves memory for previously experienced information (see Rasch & Born, 2013, for a review). Additionally, analogical transfer requires recognition of similarity between source and target problems, and sleep can assist in identifying similarities across experiences (Lewis & Durrant, 2011; Wagner, Gais, Haider, Verleger, & Born, 2004) subsequently creating a problem schema common to both source and target problems.

Here, we investigated whether sleep between exposure to source problems and related target problems improved analogical transfer. Previous studies of sleep have not tested transfer for complex problems with low surface similarities (e.g., Beijamini, Pereira, Cini, & Louzada, 2014; Cai, Mednick, Harrison, Kanady, & Mednick,

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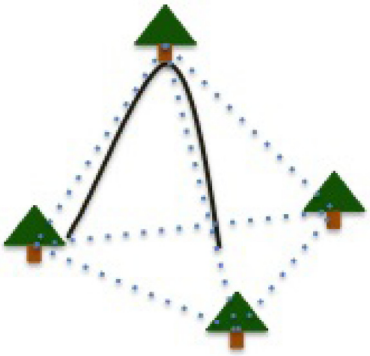
Source problem: How can a gardener plant four trees so that the trees are equidistant? (Metcalfe & Weibe, 1997).

Answer: plant one on a hill



Target problem: Assemble six matches to form four equilateral triangles, each side of which is equal to the length of one match (Scheerer, 1963).

Fig. 1. Example of a source and target problem in an analogical transfer task.

2009; Sio, Monaghan, & Ormerod, 2013; for review see Chatburn, Lushington, & Kohler, 2014). Further, we distinguished whether any facilitatory effects of sleep for problem solving were captured by subjective memory of the source problems or recognition of structural similarities between source and target problems (Experiment 1). We tested participants around their natural day-night sleep cycle which necessarily introduced a confound in time of day of testing. Experiment 2 ensured time of day was not driving the apparent effects of sleep from Experiment 1 (Fröberg, 1977).

2. Experiment 1: Effect of sleep on analogical transfer

2.1. Method

2.1.1. Participants

Sixty students at Lancaster University (17 males, 43 females) with mean age 20.1 (SD = 1.6) years volunteered to participate in the study. Participants were randomly allocated to a sleep (7 males, 23 females) or wake group (10 males, 20 females). Sample size was determined from a study by Payne et al. (2009), who tested effects of sleep on high-level memory processes with 30 participants in a sleep and a wake group (referred to in their paper as the "Merrimack" participants).

2.1.2. Materials

We selected 6 pairs of source and target problems from the analogical transfer literature (Gick & Holyoak, 1980; Gick & McGarry, 1992; Needham & Begg, 1991). Target and source problems had similar structural relations between problem information and solution, but different surface features (see Supplementary Materials for list of problems). An additional problem was used as a practice item.

We collected information on sleep habits and amount of sleep the night before the second session using a questionnaire, and also used the Stanford Sleepiness Scale (Hoddes, Zarcone, Smythe, Phillips, & Dement, 1973).

Subjective memory for source problems was measured using a questionnaire that asked participants how accurately they remembered the solution to each of the 6 source problems. Responses to each problem were on a 7-point Likert scale from 1 (don't remember) to 7 (remember accurately). We measured subjective recognition of similarity of source and target problems by asking participants the extent to which they noticed relations between pairs of problems, with a 7-point Likert scale from 1 (not similar) to 7 (very similar), adapted from Lockhart, Lamon, and Gick (1988). In both questionnaires, problems were referred to by very brief descriptions (e.g., referring to Fig. 1 problem: "the problem about planting trees"). Questionnaires are available in Supplementary Materials.

2.1.3. Procedure

There were two testing sessions, 12-h apart. Participants in the wake group were tested between 9 am and 10 am in the first session, and between 9 pm and 10 pm on the same day for the second session. Participants in the sleep group were tested between 9 pm and 10 pm in the first, and 9 am to 10 am the next day for the second session. The wake versus sleep manipulation was conducted around participants' diurnal cycle, such that they either stayed awake or slept according to their usual sleep routine.

In the first session, participants were instructed to try to remember the solution to the problems they were attempting, as they might be relevant to later problems. Expectation of future memory use has been shown to enhance memory consolidation associated with sleep (Wilhelm et al., 2011). Each source problem was presented for 3 min on a computer screen, during which time participants wrote their workings and solution on paper. Then, participants were shown the answer, which they studied for 1 min before the next problem was presented. Participants were asked to abstain from alcohol, caffeine and daytime naps during the course of the study, and to maintain their usual sleep and wake routine during the study. Participants then left the laboratory. All participants conformed to these requests, determined by self-report questionnaires at the second session.

In the second session, participants completed the sleep questionnaire, the Stanford Sleepiness Scale, and the memory for the source problems questionnaire. The 6 target problems were then presented on a computer screen for 3 min each, whilst participants