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The effect of sleep in perceptual learning with complex objects

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A B S T R A C T

Recognition of objects improves with training, but task performance also improves between sessions without further training. This offline learning seems to be influenced by post-training sleep, as is evidenced in perceptual learning studies with simple stimuli. In this study we aim to investigate the role of sleep in perceptual learning with complex natural and man-made objects. Participants were trained with a backward masking task during four sessions with 12 h between each training session (morning-evening-morning-evening or evening-morning-evening-morning). A larger improvement on performance was found after a night's sleep, than when subjects performed the task without having slept between training sessions. This effect was not influenced by the participants' chronotype or non-verbal intelligence. In addition, we replicated some key characteristics of perceptual learning with complex objects. Participants were retested six days after the last training session with the previously trained stimulus and new stimuli. The performance gains were long-lasting and specific to the trained stimulus set.

1. Introduction

Perceptual learning refers to the improvement of the performance on a perceptual task. This type of learning is dependent on practice, as is evidenced by performance improvements during practice sessions (Fiorentini & Berardi, 1981; Poggio, Fahle, & Edelman, 1992). In addition to a fast learning component, task performance also improves between sessions (Karni et al., 1995), in the absence of any more training. This offline learning is often affected by sleep (Atienza, Cantero, & Stickgold, 2004; Fenn, Nusbaum, & Margoliash, 2003; Fischer et al., 2002; Gottselig et al., 2004; Mednick, Nakayama, & Stickgold, 2003; Stickgold, James, & Hobson, 2000a; Stickgold et al., 2000b; Walker et al., 2003; but see Aberg, Tartaglia, & Herzog, 2009; Censor, Karni, & Sagi, 2006). Sleep is thought to be important for the stimulus-specific benefits of perceptual learning (Karni & Bertini, 1997; Karni & Sagi, 1993; Stickgold et al., 2000b).

Most studies on the role of sleep in visual learning focused on perceptual learning paradigms with relatively simple stimuli such as texture patterns and oriented gratings (Karni et al., 1994; Matarazzo et al., 2008, but see Hussain, Sekuler, & Bennet, 2008). When studying perceptual learning with complex objects, studies have also observed improvements in discrimination and recognition performance, with a learning curve which spans multiple daily sessions (Baeck & Op de Beeck, 2010; Baeck, Windey, & Op de Beeck, 2012; Fine & Jacobs, 2002; Furmanski & Engel, 2000). But in addition to these similarities in the learning process, differences in perceptual learning with simple and complex stimuli have been found. For example, where the learning effects with simple stimuli are in general very specific to the trained stimulus characteristics (e.g. Ball & Sekuler, 1982, 1987; Crist et al., 1997; Fahle, 2004; Fiorentini & Berardi, 1981; Karni & Sagi, 1991; Schoups, Vogels, & Orban, 1995), more transfer to variations of the trained stimuli was found with more complex stimuli (e.g. Baeck, Windey, & Op de Beeck, 2012; Furmanski & Engel, 2000; Husk, Bennet, & Sekuler, 2007). As already extensively studied, selectivity for simple stimuli is found in earlier regions in the ventral visual stream than more complex stimuli like everyday objects and faces (Mishkin, Ungerleider, & Macko, 1983; Grill-Spector & Malach, 2004). This may cause a difference in learning effects between these types of stimuli and the role of sleep herein. Up to now no study has tested to what degree sleep might also have a role in learning to recognize objects. In this study we aim to investigate the role of sleep in perceptual learning with complex objects.

To fully characterize the role of sleep and how it affects learning, we also considered the possible effect of individual differences. Many individual differences, related to sleep characteristics or general abilities, can obscure the potential relationship between sleep and performance improvement. One example is the participant's "chronotype": the moment people go to bed is prone to individual

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differences, differentiating between so-called morning-types and evening types with a large intermediate group (Chokroverty, 2009). Research indicates that chronotype can significantly influence task performance through peaks in attention and memory functioning (Horne, Brass, & Petitt, 1980; Schmidt et al., 2007), potentially influencing the role of sleep in memory consolidation (Maquet, Smith, & Stickgold, 2003).

Another potential confounding factor when evaluating the role of sleep in procedural learning is intelligence, as suggested by Walker and Stickgold (2009). One of the many aspects of intelligence is the ability to learn from experience (Neisser et al., 1996). While it is as yet unclear whether intelligence has any influence on the efficacy of memory consolidation in perceptual learning, results from a recent exploratory study by Amitay et al. (2010) indicate that factors such as higher motivation and non-verbal intelligence play a role in more successful auditory perceptual learning.

The present study focuses on the influence of sleep on perceptual learning of natural and man-made objects using a backward masking paradigm. Participants were trained four times with 12 h between each session. They were asked only to sleep between each evening and morning session. We expected no or only small improvements between tests within the same day, whereas a larger improvement on performance was expected after a night's sleep. Two factors that potentially influence the performance of individual participants, namely sleep chronotype and non-verbal intelligence, were included in the study. We might predict that participants with higher non-verbal intelligence show better initial performance and a larger improvement between sessions. We also expected morning types to perform better in morning sessions than evening types, and vice versa.

In addition, we aimed to replicate some key characteristics of perceptual learning in this design using complex objects as stimuli. In a fifth session, six days after the previous training session, participants were tested with the previously trained stimuli and a new, untrained stimulus set. This enables us to test whether the performance gains are long-lasting (Karni & Sagi, 1993; Schoups, Vogels, & Orban, 1995) and whether they transfer to a completely new stimulus set. Based on previous research, we expected complete (Baeck & Op de Beeck, 2010; Baeck, Windey, & Op de Beeck, 2012) or at least partial object specificity (Furmanski & Engel, 2000; Grill-Spector et al., 2000), with better performance for the trained stimuli compared to the untrained objects.

2. Methods

2.1. Participants

Thirty-two students of the University of Leuven, aged between 18 and 24, took part in this study as paid volunteers. The participants, of whom 13 were male, had a normal or corrected-to-normal vision. None of them had previously participated in a study involving a visual learning task. Participants signed an informed consent prior to each session. The ethical committee of the Faculty of Psychology and Educational Sciences approved the study procedure.

2.2. Materials

The visual learning task was performed on a Dell desktop computer (GX-780) running Windows XP. Stimuli were presented using a Dell 16-in. monitor, with a 1024×768-pixels spatial resolution at 100 Hz. The experiment was programmed with Matlab 6.0 (Mathworks, Inc.) and Psychtoolbox 3 (Brainard, 1997). The task was carried out in a dimly lit room and viewing distance was approximately 90 cm.

Participants were asked to fill out the Horne and Östberg Morningness–Eveningness Questionnaire (MEQ) (Horne & Östberg, 1976) in order to determine their chronotype. The questionnaire not only distinguishes into definite and moderate morning and evening types, but also defines an intermediate type. In addition, the Raven Advanced Progressive Matrices (APM) (Raven, 1962) was used as a measure of non-verbal intelligence. It evaluates abstract reasoning and overall intellectual capacity in subjects with higher-level education.

2.3. Stimuli

We used 40 different gray-scale pictures of common manmade and natural objects from a previous study (Baeck, Windey, & Op de Beeck, 2012) assigned to two sets of 20, balancing the sets in difficulty level using data from the original study. The image size of all stimuli was 450 by 450 pixels (approximately 9 visual degrees). Mask patterns consisted of small fragments (70×70-pixels) of all different stimuli. To effectively mask the objects, stimulus contrast was reduced to 12.5% of the original contrast and three consecutive masking patterns were used. All stimuli were gamma corrected in order to create a linear luminescence range. Given that this correction reduced the overall contrast of the images (measurd as mean-squared energy), an inverse gamma-correction was applied to the masking stimuli in order to create a more robust masking effect.

2.4. Visual learning task

Each trial started with a fixation cross and subsequently the stimulus was presented for a variable time. Stimuli were presented at slightly different locations with a maximum deviation of 0.9° from the center of the screen. During the first trial of each block, the stimulus was shown for 120 ms. Two interleaved two-down, one-up staircase procedures were used to determine the exposure duration of the following trials. Upon two consecutive correct answers, the stimulus display time dropped by 10 ms (step size of 1 frame at a 100 Hz refresh rate). After one wrong answer, the stimulus in the next trial was presented for an additional 10 ms. Stimuli were followed by three consecutive masking patterns, each presented for 250 ms. The order of stimuli and masks was randomised independently. Participants were instructed to type the first 3 letters of the name of the presented object. After each response feedback was provided: the participants received a 'true' or 'false' message on the screen. In case of a wrong answer, the correct object name was presented.

2.5. Procedure

The study consisted of three parts: a preparatory phase, followed by a learning- and follow-up phase. Participants had to maintain a normal sleeping rhythm during the learning phase, with at least 7 h of sleep per night from one day before the first session until after the fourth, without taking naps between morning and evening sessions. In addition, they were instructed to wake up at least one and a half hours before their morning session started to prevent sleep inertia from influencing task performance.

2.5.1. Preparatory phase

During the preparatory phase, participants were asked to fill out the Morningness–Eveningness Questionnaire (MEQ) and the Raven Advanced Progressive Matrices (APM). Based on their scores on these tests, participants were divided into two equal groups, balancing them with respect to age, sex, chronotype and non-verbal intelligence (Table 1).