Robust perceptual learning of faces in the absence of sleep

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ABSTRACT

This study examines the effects of sleep on learning in a face identification task. Five groups of subjects performed a 1-of-10 face identification task in two sessions separated by 3, 12, and 24 h. Session 1 consisted of four blocks of 105 trials each; Session 2 consisted of eight blocks of trials. All groups exhibited significant improvement in response accuracy within each session. Furthermore, between-session learning – defined as the difference in proportion correct between sessions 1 and 2 – was significant for all groups. Between-session learning was greater in groups that slept between sessions, but the effect was small and affected performance only in the first block of trials in Session 2. Overall, we find that sleep's contribution is a small proportion of the total amount learned in face identification, with improvements continuing to accrue in its absence.

1. Introduction

Perceptual and motor skills typically improve with practice over a time-course that consists of at least two components: a fast component in which performance improves during a practice session (Fiorentini & Berardi, 1981; Fahle, Edelman, & Poggio, 1995; Fahle, 1994; Karni et al., 1998; Karni & Sagi, 1993; Poggio, Fahle, & Edelman, 1992), and a slow component in which the benefits of practice accumulate across sessions (Brashers-Krug, Shadmehr, & Bizzi, 1996; Fahle, 1994; Karni et al., 1998; Karni & Sagi, 1993; McKee & Westheimer, 1978; Press, Casement, Pascual-Leone, & Robertson, 2005). This second, slow component, sometimes referred to as latent, or offline learning, is affected by sleep (Atienza, Cantero, & Stickgold, 2004; Fenn, Nusbaum, & Margoliash, 2003; Fischer, Hallschmid, Elsner, & Born, 2002; Gottselig et al., 2004; Karni, Tanne, Rubenstein, Askenasy, & Sagi, 1994; Stickgold, James, & Hobson, 2000a; Stickgold, Whidbee, Schirmer, Patel, & Hobson, 2000b; Walker et al., 2003). Results from Siegel (2001) and Walker and Stickgold (2004), for example, suggest that the REM and SWS stages of sleep are important for consolidating newly-acquired information into long-term memory (but see Song, Howard, & Howard, 2007; Vertes & Eastman, 2000; Vertes, 2004). Sleep is thought to be important for establishing the stimulus-specific benefits of perceptual learning (Karni & Bertini, 1997; Karni et al., 1998; Karni & Sagi, 1993), rather than general benefits that pre-

sumably can transfer across experimental conditions (but see Fenn et al., 2003). Sleep's distinct contribution to latent learning is supported by a study of motor learning, which found that the substantial improvement in performance that is observed across days of testing – i.e., after a night's sleep – is uncorrelated with within-session effects (Walker et al., 2003). However, sleep is not necessary for latent learning, which can occur in the absence of sleep if the gap between testing sessions exceeds 4–6 h (Fischer et al., 2002; Gottselig et al., 2004; Robertson, Pascual-Leone, & Press, 2004; Roth, Kishon-Rabin, Hildesheimer, & Karni, 2005).

In the visual domain, most demonstrations of sleep-related benefits have used a particular kind of texture discrimination task. For example, Karni and Sagi (1991) measured thresholds for discriminating peripherally-viewed horizontal and vertical textured targets, which were embedded in an array of short line segments, by varying the SOA between the offset of the target array and the onset of a mask. Using this task, Karni and Sagi (1993) found that sensitivity in a texture discrimination task increased only after at least 8 h elapsed after the initial training session. Subsequently, it was shown that the effects of practice were abolished by the interruption of sleep, with both REM and SWS contributing to the overall amount learned (Karni et al., 1994; Stickgold et al., 2000a; Stickgold et al., 2000b). Finally, a nap taken in-between successive practice sessions reverses the deterioration that otherwise occurs with repeated testing during the same day (Mednick, Nakayama, & Stickgold, 2003; Mednick et al., 2002; Mednick, Arman, & Boynton, 2005). Using a different task, Schoups, Vogels, and Orban (1995) reported that practice lowered orientation discrimination thresholds measured with circular noise fields rotated about the oblique axis, but only when subjects slept between

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sessions. Learning in both the texture discrimination task and the orientation discrimination task was specific to the trained location in the visual field and, in the orientation discrimination task, to the orientations used during training. For both tasks, within-session gains were only observed early within the first session, after which performance saturated. Further improvements in performance only occurred across sessions, i.e., the improvements were latent.

The role of sleep in consolidation is yet to be demonstrated for the remaining variety of visual tasks amenable to learning. We have previously shown that performance on a 1-of-10 forced choice face-identification task improves substantially across days (Gold, Bennett, & Sekuler, 1999b), and that the improvements are specific to the trained face exemplars and orientations (Hussain, Bennett, & Sekuler, 2005, 2006). Here we assess the contribution and sleep-dependence of latent learning to the overall improvement found with this task, and examine whether the amount of latent learning is associated with within-session learning.

2. Methods

2.1. Subjects

One hundred and three McMaster University undergraduate students participated in this experiment. All subjects had normal or corrected-to-normal Snellen visual acuity. The mean age and years of education were, respectively, 20.9 (SD = 3.31) and 16.9 (SD = 2.30). All subjects received a small fee ($10/h) or partial course credit for participating in the experiment, and were naïve with respect to the task. All subjects provided informed consent prior to the start of the experiment. Seventy-four of the subjects were female; the remaining 29 were male.

2.2. Apparatus and stimuli

Stimuli were generated in Matlab (The Mathworks, v. 5.2) using the Psychophysics and Video Toolboxes (Brainard, 1997; Pelli, 1997). Stimuli were displayed on a 21" Sony Trinitron monitor at a resolution of 1024 × 768 pixels, which at the viewing distance of 114 cm translated to 26.7 pixels per cm. Frame rate was 85 Hz. Average luminance was 62.51 cd/m^2. The monitor calibration data were used to build a 1779-element lookup table (Tyler, Liu, McBride, & Kontsevich, 1992) and customized computer software constructed the stimuli on each trial by selecting the appropriate luminance values from the calibrated lookup table and storing them in the display's eight-bit lookup table.

The stimuli were faces of five males and five female faces cropped to show only internal features and equated for spatial frequency content. The methods used to create the stimuli have been described previously (Gold, Bennett, & Sekuler, 1999a; Gold et al., 1999b). Stimulus size was 256 × 256 pixels, subtending 4.8 × 4.8° of visual angle from the viewing distance of 114 cm. During the experiment, stimulus contrast was varied across trials using the method of constant stimuli. The seven levels of contrast were spaced equally on a logarithmic scale, and spanned a range that was sufficient to produce significant changes in performance in virtually all subjects. The images were shown in three levels (low, medium and high) of static two-dimensional Gaussian noise, created by sampling from distributions with variances of 0.001, 0.01, and 0.1. Hence, there were a total of 21 stimulus conditions (seven contrast levels × three external noise levels) that allowed subjects to view each face at a variety of signal-to-noise ratios.

2.3. Procedure

All subjects performed a face identification task in two sessions (Fig. 1). Subjects in the 12HR-Sleep group (n = 24) performed Session 1 at 9pm and Session 2 at 9am the next day. Subjects in the 12HR-No-Sleep group (n = 24) performed Session 1 at 9am and Session 2 at 9pm on the same day. Thus, there was a 12-hour interval between sessions in both the 12HR-Sleep and 12HR-No-Sleep groups. In the 9AM-Sleep group (n = 24), subjects performed Sessions 1 and 2 at 9am on Days 1 and 2. In the 9PM-Sleep group (n = 24), subjects performed Sessions 1 and 2 at 9pm on Days 1 and 2. Therefore, there was a 24-hour interval between sessions in both the 9am-Sleep and 9pm-Sleep groups. Subjects in the sleep groups were instructed to sleep normally overnight (between sessions), whereas subjects in the 12HR-No-Sleep group were instructed to not sleep or nap between sessions. An additional

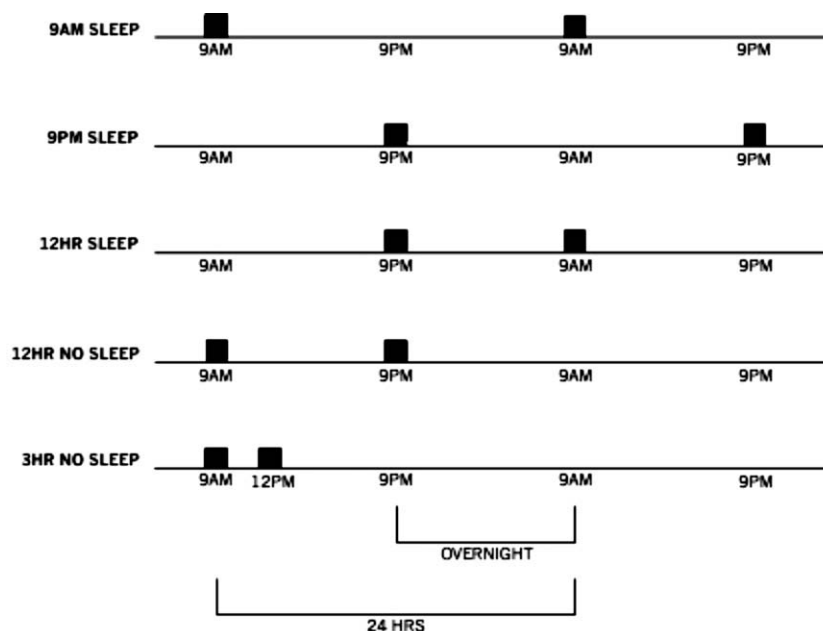**Fig. 1.** Illustration of the experimental design. Placeholders indicate the time of testing for each group across two consecutive days.