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# Implicit learning is better at subjectively defined non-optimal time of day

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ABSTRACT

Individual preferences in morningness–eveningness rhythms modulate temporal fluctuations of cognitive performance over a normal day. Besides enhanced cognitive performance at individual's peak time as derived from morningness–eveningness questionnaires, a few studies have shown increased implicit memory abilities at a non-optimal (NOP) time of day. Various subjective factors might also determine the clock time for high or low cognitive efficiency. Using an artificial grammar learning (AGL) task, we show enhanced implicit learning of high-order information at NOP [*vs* optimal (OP)] time of day as subjectively defined by participants, irrespective of morningness–eveningness scores. Our results suggest that subjectively defined efficiency periods are a modulating factor in the testing of cognitive functions.





## 1. Introduction

Circadian and homeostatic processes regulate the timing and structure of sleep and neurobehavioral performance (Borbely, 1982; Wyatt, Ritz-De Cecco, Czeiler, & Dijk, 1999) over the 24-h cycle. Individual chronotype that reflects interindividual differences in circadian preference additionally modulates the sleep–wake schedule and temporal fluctuations of cognitive performance over a normal working day (Roenneberg, Wirz-Justice, & Merrow, 2003; Schmidt et al. 2007). Enhanced cognitive efficiency at peak time of day (i.e., *synchrony effects*) – as derived from morningness–eveningness questionnaires – has been reported in various cognitive domains including executive and alerting components of attention (Matchock & Mordkoff, 2009), inhibitory control (May & Hasher, 1998), visuospatial working memory (Rowe, Hasher, & Turcotte, 2009) and long-term declarative memory (May, Hasher, & Foong, 2005). However, May et al. (2005) found better performance on perceptual and conceptual priming tasks at off-peak than at peak times of day. Similarly, Rowe, Valderrama, Hasher, and Lenartowicz (2006) showed, by superimposing irrelevant

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distractors on target items in a judgment task, that irrelevant elements are better implicitly memorized during non-optimal (NOP) periods. Hence, these reports suggest that high-demanding attentional tasks are better performed at peak times of day whereas performance on more automatic tasks would improve at off-peak times. At NOP time of day indeed, attentional control decreases and may less efficiently oppose automatic processes (May et al., 2005). In all of these prior studies, the optimal (OP)/NOP clock time for testing was defined according to morningness–eveningness scores, which may actually not fully match OP/NOP moments for performance as subjectively experienced by some participants. Indeed, a wide variety of factors (from biological to social) may determine the best and worst moments for a particular type of cognitive performance in an individual. It is therefore of interest to explore cognitive performance based on the individual's subjective feeling about its peak/off-peak time for cognitive performance, rather than derived from a chronotype compound score built considering a variety of different domains (e.g., appetite, physical and cognitive performance, time for sleep and wakefulness periods, easiness to wake up, …). In the present study, participants learned abstract high-order information using an artificial grammar learning (AGL) task (Meulemans & Van Der Linden, 1997), an implicit learning paradigm relying on automatic processes. Participants were tested at their subjectively self-defined peak versus off-peak time of day irrespective of morningness–eveningness scores.

## 2. Methods

### 2.1. *Population and context of testing*

Thirty-six university students (10 males; mean age = 25.08, range = 20–30 years) participated in this study approved by the local Ethics Committee. Sleep quality for the month prior to the experiment was assessed using the Pittsburgh Sleep Quality Index (PSQI; Buysse, Reynolds, Monk, Berman, & Kupfer, 1989). Use of sleeping pills and bad sleep quality (PSQI global score > 6) were exclusion criteria. Sleep quality during the night preceding the experiment was assessed using an adapted version of the St. Mary's Hospital Sleep Questionnaire (Ellis et al., 1981). Participants had neutral to moderate chronotypes [range 30–70 on the Morningness–Eveningness Questionnaire – MEQ; Horne & Ostberg, 1976]. At the recruitment phase, subjects had to indicate at what time of day they usually felt at their best (or their worst) to perform on cognitive tasks. The experimental session was then defined at the participant's self-defined OP or NOP moment. Participants were randomly allocated to the NOP or the OP condition.

### 2.2. *Experimental material and procedure*

#### 2.2.1. *AGL task*

The AGL task is described elsewhere (Peigneux, Meulemans, Van Der Linden, Salmon, & Petit, 1999). The material consisted of 63 letter strings (length 4–7 consonants) generated using the transitional rules of a finite-state grammar. The grammar comprised six different consonants (F, V, M, T, R, X) distributed across fourteen positions between nine nodes, in such a way that it does not produce meaningful strings or acronyms, for instance "TV". Fifty-one grammatical (G) strings were used for the incidental learning phase, the 12 other G strings for the testing phase. Additionally, 12 nongrammatical (NG) strings were constructed for the testing phase (see below). In NG strings, the transitional rules of the grammar were violated at one or two positions within the letter string (except in the first or in the last position). G and NG strings were also constructed in such a way that grammaticality judgments could not be based on a simple knowledge of pairs or triplets (chunks) of letters. Amongst others, chunk strength and novelty parameters were controlled, and G and NG strings were matched for the frequency of the possible triplets in the initial position (for a complete presentation of controlled parameters, see Meulemans & Van Der Linden, 1997). For instance, whereas "TXRMXV" was a G string, "TXFRMXV" was a NG item because "TXFR" could not be followed by "M" in the finite-state grammar.

During the *incidental learning* phase, participants were informed that they would be administered an immediate memory test. Each G string was presented on a computer screen for 3 sec; afterward, the participant had to repeat the letters of the G strings in the same order as presented. If the recall was correct, the following item was presented; if not, the item was shown again. A learning score was computed as the total number of presentations needed to correctly repeat the 51 sequences.

During the *classification* (testing) phase, participants were informed that the previously presented letter strings were constructed according to a complex system of rules, so difficult that it was impossible to unravel them. They were then asked to classify the 24 G and NG test items as being G or not based on their intuition. No feedback was given as to the correctness of the judgments. At the end of the session, participants were asked to verbally report whether they detected regularities within the G material, and if yes to explain what were these regularities.

#### 2.2.2. *Additional measurements*

A digit span task and a 10-min version of the Psychomotor Vigilance Task (PVT; Dinges & Powell, 1985) were administered before the AGL task. Participants' sleepiness was also self-rated using the Karolinska Sleepiness Scale (KSS; Akerstedt & Gillberg, 1990) before study, between the learning and testing phases, and immediately after testing.

## 3. Results

### 3.1. *Characteristics of the participants and vigilance scores*

As shown in Table 1, OP and NOP groups did not differ significantly according to chronotype (MEQ score), sleep quality and sleep latency during the previous night (St. Mary questionnaire). Although sleep duration for the previous night was marginally longer in the OP ($8.6 \pm 1.2$ h) than in the NOP group ($7.7 \pm 1.5$ h; $p = .07$), means were normal and above 7 h in both conditions. Conversely, sleep quality during the previous



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