Differential influence of asynchrony in early and late chronotypes on convergent thinking

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ABSTRACT
Eveningness preference (late chronotype) was previously associated with different personality dimensions and thinking styles that were linked to creativity, suggesting that evening-type individuals tend to be more creative than the morning-types. Nevertheless, empirical data on the association between chronotype and creative performance is scarce and inconclusive. Moreover, cognitive processes related to creative thinking are influenced by other factors such as sleep and the time of testing. Therefore, our aim was to examine convergent and divergent thinking abilities in late and early chronotypes, taking into consideration the influence of asynchrony (optimal versus nonoptimal testing times) and sleep quality. We analyzed the data of 36 evening-type and 36 morning-type young, healthy adults who completed the Compound Remote Associates (CRAs) as a convergent and the Just suppose subtest of the Torrance Tests of Creative Thinking as a divergent thinking task within a time interval that did (n = 32) or did not (n = 40) overlap with their individually defined peak times. Chronotype was not directly associated with creative performance, but in case of the convergent thinking task an interaction between chronotype and asynchrony emerged. Late chronotypes who completed the test at subjectively nonoptimal times showed better performance than late chronotypes tested during their "peak" and early chronotypes tested at their peak or off-peak times. Although insomniac symptoms predicted lower scores in the convergent thinking task, the interaction between chronotype and asynchrony was independent of the effects of sleep quality or the general testing time. Divergent thinking was not predicted by chronotype, asynchrony or their interaction. Our findings indicate that asynchrony might have a beneficial influence on convergent thinking, especially in late chronotypes.

Introduction
Circadian typology or chronotype represents interindividual variations in diurnal rhythmicity in relation to preferred sleep and wake times (Horne & Ostberg, 1977), fluctuations in cognitive performance, functional brain metabolism (Carrier & Monk, 2000; Schmidt et al., 2009) and the expression of physiological markers of endogenous rhythms (Randler & Schaal, 2010). Circadian preferences are usually defined along a continuum, with extreme morning- and evening-type individuals at the endpoints and moderate and intermediate types in between (Taillard et al., 2004). Morning-type (early chronotype) individuals prefer to wake up early in the morning and perform demanding daily activities during morning hours or early afternoon, in comparison to the evening-types (late chronotype), who usually report their peak times to extend from late afternoon until the evening (Horne & Ostberg, 1977; Taillard et al., 2004).

There is a growing interest regarding the differences in cognitive performance between early and late chronotypes (Preckel et al., 2011). The first meta-analyses on this topic pointed out to an apparently contradictory pattern of findings: evening-types seem to exhibit slightly superior cognitive abilities, but lower academic achievements (Preckel et al., 2011). Eveningness was positively associated with measures of working memory and processing speed (Roberts & Kyllonen, 1999) or verbal cognitive ability, although the latter was only evident in females (Killgore & Killgore, 2007). Superior performance associated with eveningness was found in more specific cognitive
domains such as emotional intelligence (Stolarski & Jankowski, 2015) or the processing of temporal information embedded in scripts (Nowack & van der Meer, 2014). Conversely, morningness is associated with better academic indicators (Preckel et al., 2011). Given that school lessons and examinations are usually scheduled in the morning hours, these findings seem to be related to circadian misalignment and “social jetlag” in the evening-types (Harasztî et al., 2014; van der Vinne et al., 2015).

The association between chronotype and academic achievements might also be related to differences in thinking styles. Evening-types seem to be characterized by a more holistic, intuitive and imaginative thinking style in comparison to morning-type individuals, who tend to prefer analytic and logical ways of thinking, the latter being more appreciated in education systems (Díaz-Morales & Escribano, 2013a, 2013b). Evening-types were also characterized by higher openness to experience (Tsaoûsis, 2010) and increased novelty and sensation seeking (Cimbalo & Hughey, 1986; Prat & Adan, 2013; Russo et al., 2012). Such personality factors may partly overlap with creativity (Díaz-Morales & Escribano, 2013a, 2013b); however, data about the association between chronotype and creative performance is scarce.

Creative thinking skills are typically assessed with open- or close-ended problem-solving tasks, assumed to tap divergent and convergent thinking, respectively (Arden et al., 2010; Lee & Therriault, 2013). Performance on divergent thinking tasks is considered to be an indicator of creative potential, that is, a necessary but insufficient correlate of real-life creative achievement (Batey & Furnham, 2006). Convergent thinking, that is, the process of finding a single correct solution, plays a key role in the evaluation and implementation of novel ideas (Cropley, 2006); therefore, it can also be expected to contribute to creative achievements. For example, tests of fluid intelligence probe convergent thinking, as they require participants to work out a single correct answer, and indeed, a recent study has demonstrated that fluid intelligence is a necessary but not sufficient condition of real-life indicators of creativity (Karwowski et al., 2016).

Giampietro and Cavallera (2007) reported a positive association between eveningness preference and originality scores in a (visual) divergent thinking task, corroborating other studies that showed superior cognitive abilities in evening-types (Preckel et al., 2011). In contrast, a more recent study found a weak positive correlation between morningness and fluency on another divergent thinking task, regardless of the confounding effects of testing time (Roerse et al., 2015). Testing time seems to be an important variable that might influence the association between chronotype and cognitive processes. Performance during optimal testing-times (that overlap with subjectively defined peak times) is enhanced in a variety of cognitive tasks, involving measurements of executive functions, working memory (Schmidt et al., 2007), fluid intelligence (Goldstein et al., 2007) or inhibitory processes (Pica et al., 2014). In contrast, a positive effect of “asynchrony” has also been reported: in tasks that do not require (or even might benefit from the reduction of) inhibitory processes, performance was reported to be better in nonoptimal testing times (May, 1999).

Although Roers and colleagues (Roers et al., 2015) found no significant effect of asynchrony on divergent thinking, their results might be limited by some methodological drawbacks. For instance, divergent thinking tasks were not administered separately for each subject in standardized laboratory conditions, but in a natural classroom setting that might have introduced several nonspecific (social, emotional and motivational) confounding factors. Moreover, the authors simply applied an interaction term between morningness scores and time of testing (beginning versus end of lectures) instead of individually determining peak times. Since peak times can show considerable variability in evening, morning and, more importantly, within intermediate chronotypes, optimal versus nonoptimal testing times require more stringent quantification. Additionally, given that impaired sleep quality and insomniac symptoms have a detrimental effect on cognitive functions (Van Someren et al., 2015), and evening-type individuals were consistently characterized by impaired sleep quality (Roers et al., 2012; Simor et al., 2015; Tavernier & Willoughby, 2013), disrupted sleep in evening-types may also influence creative problem solving. Given the paucity and inconclusiveness of previous studies, our aim was to examine creative thinking abilities in evening versus morning-type
participants, taking into consideration the influence of asynchrony (peak versus off-peak times) and sleep quality.

**Methods**

**Participants and procedure**

Participants were recruited via advertisements and word of mouth from two Hungarian Universities (Budapest University of Technology and Economics and Eötvös Lóránd University). A total of 183 undergraduate and graduate students (all native Hungarian speakers) were tested at the laboratory of the Cognitive Science Department of the Budapest University of Technology and Economics. Participants (n = 183) signed up for the experiment through an online platform where they could choose between time slots provided by the experimenters. A convergent and a divergent thinking task as well as an online questionnaire that included scales measuring sleep quality, chronotype (see below) and different factors of personality were administered. Participants after completing the tasks at the laboratory were provided a granted access to the online questionnaire, and were asked to complete it in the following days. Laboratory testing lasted approximately 50 minutes. The beginning of laboratory testing ranged between 8.00 AM and 6.15 PM (First quantile: 10.00 AM; Median: 12:10; third quantile: 2.30 PM. See Supplementary Figure S1.). After the creative thinking tasks, a part of the sample also completed a semantic and a letter fluency task. The analyses of the fluency tasks as well as of the personality scales will be reported elsewhere. The data of participants reporting prior history or current psychiatric, neurological or chronic somatic symptoms (n = 13), or excessive alcohol consumption (n = 6) were excluded from subsequent analyses. Participants (n = 8) reporting the use of medication (except contraceptives) were also excluded. Additionally, extreme sleep duration (less than 5 or more than 10.5 hours) in the night before testing also pertained to exclusion criteria (n = 8). We decided to exclude five subjects, who were older than 30 years (age range: 36–50) in order to examine a sample that was more homogeneous with respect to age. The data of 143 individuals (mean age: 21.57, sd: 2.35; age range: 18–30; 58 males) remained in the sample. From this pool, we selected a set of evening- and morning-type participants based on the first and last quartiles of the Morningness-Eveningness Scores in the current sample (MEQ-H; Zavecz et al., 2015, see description below). This way, the data of 72 individuals, including 36 evening-types (15 males) and 36 morning-types (12 males) was used in the subsequent analyses. The study was approved by a local ethical review board and was conducted in accordance with the policies of international chronobiological standards (Portaluppi et al., 2010). Written informed consents were obtained.

**Instruments**

**MEQ-H**

We applied the shortened (13 itemed), Hungarian version of the Horne-Östberg Morningness-Eveningness Questionnaire (Horne & Ostberg, 1976; Zavecz et al., 2015). The original scale is a widely used and reliable measure focusing on individual differences in morningness-eveningness preference. The items concern subjective preferences of sleep-wake schedules as well as optimal time for intellectually or physically demanding activities. Higher scores indicate increased morningness. The 13-item-long Hungarian version of the questionnaire showed excellent internal consistency (Cronbach’s α above 0.8), test-retest reliability ($r = 0.89; p < 0.001$) and adequate validity indices in previous studies (Simor et al., 2015; Zavecz et al., 2015). The MEQ-H can be used as a continuous measure, but it is also applicable for the differentiation of early and late chronotypes based on the first and last quartiles of the MEQ-H scores, respectively (Simor et al., 2015; Zavecz et al., 2015). The internal consistency of the scale in the present study was excellent (Cronbach’s α = 0.81).

**Athens insomnia scale (AIS)**

The AIS is a reliable and valid instrument that can be used in epidemiological studies for the measurement of insomnia (Soldatos et al., 2000). The first five items cover nighttime symptoms (e.g. increased sleep latency, nocturnal awakenings, perceived sleep duration), whereas the last three items refer to daytime dysfunctions (mood, performance and fatigue). The AIS showed acceptable sensitivity and specificity in order to identify possible cases of
insomnia (Soldatos et al., 2000). The Hungarian adaptation of the questionnaire (based on data from a large epidemiological study enrolling more than 12,000 individuals) proved to be a reliable and valid tool for the assessment of disrupted sleep in the adult population (Novak et al., 2004). The scale showed good internal consistency in the present study (Cronbach’s $\alpha = 0.77$).

**Measure of asynchrony**

In order to examine the influence of optimal versus nonoptimal times of testing (effect of asynchrony), we inspected individually defined peak times in each participant based on the 12th item of the MEQ-H (At what time of the day do you think that you reach your “feeling best” peak?). In case of this item participants can select one out of five time intervals (5.00–8.00; 8.00–10.00; 10.00–17.00; 17.00–22.00; 22.00–5.00). If the individually defined peak time overlapped with the time of laboratory testing (e.g. participants indicated his/her peak between 8.00 and 17.00 with laboratory testing starting at 8.00), the participant obtained a score of 0 (no asynchrony), otherwise (e.g. peak between 10.00 and 17.00 with laboratory testing starting at 8.00) the participant obtained a score of 1 (asynchrony). Off-peak times did not necessarily mean earlier than optimal testing times for evening, and later than optimal testing times for morning chronotypes, respectively. According to this coding, 32 individuals (15 evening- and 17 morning-types) were tested at their peak times and 40 participants (21 evening- and 19 morning-types) during their off-peak times. Additionally, we computed a continuous measure of asynchrony based on the mismatch between real testing times and individually defined peak times. Given that the MEQ-H item assessing the subjective peak times provides relatively long time ranges, we have computed the absolute difference (in minutes) between the midpoint of the reported peak times (e.g. 19.30 for the response 17.00–22.00) and the beginning of the actual testing times. Values were square root transformed in order to normalize their distribution before statistical analyses.

**Previous night’s sleep quality and quantity**

Additionally, participants responded to items regarding previous night’s sleep. Sleep quality was assessed by a single item rating previous night’s sleep quality with a 4-level Likert scale and sleep quantity was covered with a question concerning the duration of previous night’s sleep.

**Convergent thinking**

Convergent thinking was examined with a Hungarian version of the Compound Remote Associate (CRA) problems (Bowden & Jung-Beeman, 2003), which is a revised version of Mednick's classical Remote Associates Task (Mednick, 1962). In the CRA, participants are shown three problem words and are asked to come up with a fourth word, that, when combined with each of the three problem words, makes up a valid compound word (e.g. AGE/MILE/SAND form the compounds STONEAGE, MILESTONE and SANDSTONE with the solution word STONE, Bowden & Jung-Beeman, 2003 (p. 635)). The task was presented on a laptop with PsychoPy2 (Peirce, 2007). First, participants practiced with five (filler) items. Then, they were given 50 Hungarian CRA items, one after the other. Each trial began with a fixation cross. When the participants fixated on the screen, the experimenter pressed the spacebar and three problem words appeared simultaneously above, at and below the center of the screen. Participants were asked to report the solution as soon as they thought they had it. If they were correct, the experimenter pressed the spacebar; otherwise no feedback was given and participants could carry on with their attempts to solve the item in the remaining time. Thirty seconds were available to answer each item, after which the program stepped to the next trial. The reliability of the CRA was good in our sample (ordinal $\alpha = 0.73$).

**Divergent thinking**

We examined divergent thinking in the verbal domain with the “Just suppose” subtest of the Torrance Tests of Creative Thinking (Torrance, 1974; Hungarian validation by Kéri, 2009). In this task, participants are asked to imagine fictive scenarios and list their ideas about what would happen (e.g. “Just suppose clouds had strings attached to them which hang down to earth.”). We asked participants to try to be original and creative and also to come up with as many ideas as they could. We administered two forms of the test. In both, participants had 3 minutes to write down their ideas. Creativity of the
ideas was evaluated with the subjective scoring protocol described in detail by Silvia et al. (2008). Three university students were recruited to rate the creativity of the ideas. We used PsychoPy2 (Peirce, 2007) to present the ideas and to obtain ratings. First, in order to improve agreement between raters, a detailed description of creativity was provided (see Silvia et al., 2008). Then, a randomly selected 10% of the ideas on both forms of the task were shown separately, so that raters could gain a general impression about the ideas provided by the sample. Finally, raters were asked to judge the creativity of all the ideas one after the other on a 5-level Likert scale (ranging from 1: not at all creative to 5: highly creative). Interrater agreement was good (Cronbach’s $\alpha = 0.78$) and acceptable (Cronbach’s $\alpha = 0.64$), for ratings of ideas on the first and the second form, respectively. The “Just suppose” test yielded two dependent variables: the average creativity score mirrors the average rated creativity of a participant’s ideas on both forms of the task, and the fluency score reflects the number of ideas a participant generated.

**Data analyses**

Statistical analyses were carried out with R (Team, 2012). Normality of data was verified by the skewness and kurtosis indices as well as by histograms of data distribution. Separate linear regressions were performed in order to examine creative thinking (dependent variables) indexed by scores on the CRA and the Just Suppose task as a function of chronotype (0: evening-type; 1: morning-type), asynchrony (0: peak time; 1: off-peak time or measured as a continuous variable) as well as their interaction (predictor variables). Bonferroni-corrected post hoc $t$-tests were computed to contrast different creativity scores between the subgroups (morning versus evening/tested at peak versus off-peak times). Additionally, to rule out the possible confounding effects of persistent and/or transient sleep disruption, as well as of a general daytime effect, we included AIS scores, previous night’s sleep duration/quality and the time of testing separately, as covariates in further regression models.

**Results**

Table 1 summarizes the age, distribution of gender and measures of sleep quality in the evening- and morning-type group. The age of the participants and the distribution of males and females did not significantly differ across the evening- and the morning-type groups. Insomniac symptoms based on AIS scores, as well as the quality and duration of sleep the night before testing were not statistically different between the two groups.

**Convergent thinking**

Performance in the CRA Test was not associated with chronotype (Std. Beta = 0.2, $p = 0.23$), but asynchrony (measured as a binary variable) (Std. Beta = 0.49, $p = 0.003$) as well as the interaction between chronotype and asynchrony (Std. Beta = $-0.68$, $p = 0.003$) significantly predicted the CRA scores. This pattern implicates that asynchrony had a differential influence on CRA scores in the evening- and morning-types. These effects remained significant irrespective of the confounding factors of insomniac symptoms (indexed by AIS scores) or previous night’s sleep quality and duration or the time of testing. Asynchrony (assessment during individually defined off-peak times) showed a positive and insomniac symptoms yielded a weak negative association (Std. Beta = $-0.22$, $p = 0.04$) with performance on the CRA. The parameters of the tested models are detailed in Table 2. Parsing out the interaction term between chronotype and asynchrony (see Figure 1), post hoc tests revealed that evening-type individuals tested at nonoptimal times showed better performance in comparison to evening-types tested at their peak times ($t(34) = 3.23$, $p = 0.008$, Cohen’s $d = 1.11$). In contrast, CRA scores of morning-type participants tested at nonoptimal time periods were descriptively lower than those of morning-types tested at optimal times, but the
The difference was not statistically significant ($t(33) = -1.15, p = 0.25, \text{Cohen's } d = -0.4$). Moreover, the evening subgroup tested at off-peak times scored higher than the morning group tested at off-peak times ($t(37) = 2.97, p = 0.02, \text{Cohen's } d = 0.97$), whereas no significant differences emerged between the evening- and the morning-type group that were assessed at their optimal time periods ($t(30) = -1.34, p = 0.18, \text{Cohen's } d = -0.49$).

Asynchrony as a continuous variable, as well as the interaction between asynchrony and chronotype predicted the CRA scores (Std. Beta = 0.39, $p = 0.02$, partial eta squared = 0.03; and Std. Beta = $-0.51, p = 0.04$, partial eta squared = 0.06, respectively), whereas the effect of chronotype was not significant (Std. Beta = 0.2, $p = 0.2$). These effects remained significant after controlling for insomniac symptoms (asynchrony: Std. Beta = 0.43, $p = 0.006$, partial eta squared = 0.05; asynchrony x chronotype: Std. Beta = $-0.52, p = 0.03$, partial eta squared = 0.07; AIS: Std. Beta = $-0.27, p = 0.02$, partial eta squared = 0.08), previous night’s sleep quality and duration (asynchrony: Std. Beta = 0.43, $p = 0.01$, partial eta squared = 0.04; asynchrony x chronotype: Std. Beta = $-0.62, p = 0.01$, partial eta squared = 0.09). Parsing out the interaction between asynchrony and chronotype, we correlated (by Pearson’s coefficients) the continuous measure of asynchrony with CRA scores within the evening- and morning-type subgroups. As Figure 2 shows, asynchrony positively correlated ($r = 0.39, p = 0.02$) with task performance within the evening group, whereas no such association was evidenced within the morning-types ($r = -0.11, p = 0.5$).

**Divergent thinking**

Regarding the average creativity score of the divergent thinking task, the main effect of chronotype

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**Table 2.** Linear regression models with CRA score as the dependent variable.

<table>
<thead>
<tr>
<th>Entered variables in linear regression models</th>
<th>Std. Beta</th>
<th>t - Value</th>
<th>p Value</th>
<th>Partial Eta Squared</th>
<th>Model Summary</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chronotype</td>
<td>0.2</td>
<td>1.21</td>
<td>0.23</td>
<td>0.03</td>
<td>Adj. $R^2 = 0.14, p = 0.005$</td>
</tr>
<tr>
<td>Asynchrony</td>
<td>0.49</td>
<td>3.10</td>
<td>0.003</td>
<td>0.12</td>
<td></td>
</tr>
<tr>
<td>Chronotype $\times$ Asynchrony</td>
<td>$-0.68$</td>
<td>$-3.05$</td>
<td>0.003</td>
<td>0.12</td>
<td></td>
</tr>
<tr>
<td>Chronotype</td>
<td>0.16</td>
<td>1.03</td>
<td>0.3</td>
<td>0.04</td>
<td>Adj. $R^2 = 0.18, p = 0.002$</td>
</tr>
<tr>
<td>Asynchrony</td>
<td>0.49</td>
<td>3.18</td>
<td>0.002</td>
<td>0.11</td>
<td></td>
</tr>
<tr>
<td>Chronotype $\times$ Asynchrony</td>
<td>$-0.64$</td>
<td>$-2.92$</td>
<td>0.004</td>
<td>0.11</td>
<td></td>
</tr>
<tr>
<td>AIS</td>
<td>$-0.22$</td>
<td>$-2.08$</td>
<td>0.04</td>
<td>0.06</td>
<td></td>
</tr>
<tr>
<td>Chronotype</td>
<td>0.22</td>
<td>1.29</td>
<td>0.20</td>
<td>0.03</td>
<td>Adj. $R^2 = 0.12, p = 0.01$</td>
</tr>
<tr>
<td>Asynchrony</td>
<td>0.51</td>
<td>3.15</td>
<td>0.002</td>
<td>0.03</td>
<td></td>
</tr>
<tr>
<td>Chronotype $\times$ Asynchrony</td>
<td>$-0.70$</td>
<td>$-3.06$</td>
<td>0.003</td>
<td>0.12</td>
<td></td>
</tr>
<tr>
<td>Previous night’s sleep quality</td>
<td>0.12</td>
<td>1.08</td>
<td>0.28</td>
<td>0.01</td>
<td></td>
</tr>
<tr>
<td>Previous night’s sleep duration</td>
<td>$-0.02$</td>
<td>$-0.17$</td>
<td>0.86</td>
<td>0.001</td>
<td></td>
</tr>
<tr>
<td>Chronotype</td>
<td>0.22</td>
<td>1.29</td>
<td>0.19</td>
<td>0.03</td>
<td></td>
</tr>
<tr>
<td>Asynchrony</td>
<td>0.50</td>
<td>3.17</td>
<td>0.002</td>
<td>0.03</td>
<td></td>
</tr>
<tr>
<td>Chronotype $\times$ Asynchrony</td>
<td>$-0.70$</td>
<td>$-2.94$</td>
<td>0.002</td>
<td>0.13</td>
<td></td>
</tr>
<tr>
<td>Testing time</td>
<td>0.12</td>
<td>$-1.51$</td>
<td>0.13</td>
<td>0.01</td>
<td></td>
</tr>
</tbody>
</table>

Chronotype (Evening = 1, Morning = 2) and Asynchrony (Peak time: 0, Off-peak time = 1) are used as binary variables. AIS (Athens Insomnia Scale) scores, previous night’s sleep quality, sleep duration and testing time are entered as covariates in separate models.
Figure 2. The association between asynchrony and performance in the Compound Remote Associates (CRA) Task within morning- and evening-types.

was not significant (Std. Beta = 0.02, p = 0.89). Asynchrony yielded a trend (Std. Beta = 0.28, p = 0.1, partial eta squared = 0.03), indicating higher average creativity scores in participants assessed at their nonoptimal time periods. The interaction between chronotype and asynchrony was not significant (Std. Beta = −0.27, p = 0.3) and the linear model could not account for a significant proportion of the variance (Adj. $R^2$ = −0.02, p = 0.66). None of the predictor variables turned significant after the inclusion of AIS scores, previous night’s sleep quality and duration or time of testing as covariates in separate regression models. Similarly, no significant effects of asynchrony and chronotype x asynchrony were detected when asynchrony was measured as a continuous variable.

Discussion

A large body of data has accumulated regarding the association between eveningness and poor psychosocial functioning (Chan et al., 2014; Fabbian et al., 2016; Merikanto et al., 2013). On the other hand, another line of research indicates that eveningness might additionally have a “bright side”, since evening-type individuals exhibit slightly better cognitive abilities (Preckel et al., 2011) than morning-types, including working memory, processing speed (Roberts & Kyllonen, 1999), performance-based emotional intelligence (Stolarski & Jankowski, 2015) or temporal processing of event sequences (Nowack & van der Meer, 2014). Eveningness was also linked to intuitive-imaginative thinking styles (Díaz-Morales & Escribano, 2013a, 2013b), suggesting that evening-types might have an advantage when it comes to thinking creatively, relative to morning-type individuals. Our preliminary findings, however, show that the relationship between chronotype and creative performance might be more complex.

First of all, chronotype was not associated with convergent and divergent thinking, that is, a direct relationship between chronotype and indicators of creative thinking was not supported. Nevertheless, in case of a convergent thinking task, the CRA task, an interaction between chronotype and asynchrony emerged. Evening-type participants who completed the test out of their individually defined peak times showed better performance than evening-types tested during their “peak” and morning-type participants tested at their peak or off-peak time periods. Furthermore, in the evening-types, the extent of asynchrony was associated with better performance in the CRA task, whereas no such relationship
emerged within the morning subgroup. Although insomniac symptoms predicted lower scores on the CRA, the interaction between chronotype and asynchrony was significant over and above the confounding effects of chronic or temporary sleep disruption. In contrast, performance in a divergent thinking task was not significantly predicted by chronotype, asynchrony or their interaction.

Earlier studies provided inconsistent results on the relationship between chronotype and creative thinking (Giampietro & Cavallera, 2007; Roeser et al., 2015); however, these studies did not appropriately control for the confounding effects of sleep quality and testing time. We suggest that disrupted sleep and, more importantly, optimal versus nonoptimal testing times might differently influence performance in early and late chronotypes. Therefore, studies focusing on the cognitive differences between evening- and morning-type individuals should include the assessment of sleep quality as well as the stringent verification of peak and/or off-peak times. Here, instead of testing participants in two different time points (morning versus evening), we defined peak times by the responses to a specific item of the MEQ. Based on the overlap (or misalignment) between individually reported peak times and the time of testing, we determined whether the participants were tested at optimal or nonoptimal times.

The beneficial impact of asynchrony on convergent thinking is in line with the finding of a previous study that reported better performance in off-peak periods in case of an insight-based problem-solving task (Wieth & Zacks, 2011). Nevertheless, it is important to note that in our sample, only the evening-type group benefited from nonoptimal testing times. This pattern coheres with the findings of Wieth and Zacks’ (2011), since their study mostly included evening-type individuals tested during the morning (nonoptimal testing time) or the evening (optimal testing time). Nonoptimal testing times seem to facilitate performance in tasks that demand less-controlled cognitive processing (e.g. executive functions) but rather rely on automatic (Delpouve et al., 2014) or associative (May et al., 2005) mechanisms. May and colleagues proposed (May et al., 2005) that the beneficial influence of asynchrony on such domains is subtended by reduced inhibitory control during nonoptimal times, the latter being evidenced by other studies (Manly et al., 2002). Accordingly, a more recent study (Pica et al., 2014) showed that retrieval-induced forgetting was attenuated during nonoptimal testing times, presumably due to the reduced inhibition of interfering semantic memory elements. Therefore, we may assume that during off-peak times, reduced inhibitory control over semantic associations might have facilitated the access to a broader associative network when confronted with the words of the CRA.

Nevertheless, we can only speculate why only evening-type participants benefited from asynchrony. One may argue that the interaction between asynchrony and chronotype could reflect a morning effect, that is, better performance in participants tested at morning hours. (Nonoptimal testing times in the evening-types were mostly scheduled in the morning, such as optimal testing times in the morning-types.) Testing time included as a covariate, however, was not a significant predictor in the regression model, arguing against a plain morning effect. The only association between time of testing and performance was evidenced in relation to average creativity scores of the divergent thinking task; however, in this case later times predicted higher creativity scores. Moreover, the lack of influence of testing time on convergent and divergent thinking was also verified in an additional analysis that included the data of intermediate chronotypes (n = 143): time of testing was not a significant predictor of convergent or divergent task performance. And in a final set of analyses, we excluded the data of those evening-types (n = 4) that were tested after their peak as well as the data of those morning-types (n = 5) that were tested before their peak, but the exclusion of these participants did not modify our findings. These analyses indicate that not testing time per se, but the mismatch between peak times and testing times was the factor that had contributed to the observed findings.

Another alternative is that asynchrony exerted a stronger influence on cognitive processes within the evening-type subgroup. More specifically, evening-types, who are characterized by increased intuitive-imaginative thinking styles (Díaz-Morales & Escribano, 2013a, 2013b) (trait effect), could have benefited more from disinhibition (state effect), which in turn might have facilitated the access to
weak and distant associations (trait x state interaction). Moreover, due to societal demands, the evening-types are more accustomed to be challenged at nonoptimal times than the morning-types and might have learned to invest more cognitive resources to face the adverse effects of asynchrony. This assumption coheres with the result of a recent study showing that evening-types allocate more cognitive resources in response to demanding tasks (Nowack & van der Meer, 2014). Nevertheless, further investigations might explore whether asynchrony has a differential impact on specific cognitive processes in late and early chronotypes.

Although we observed an apparently similar pattern in the divergent thinking task compared to convergent thinking, the effects were not statistically significant. Although both support creativity, divergent and convergent thinking were classically considered to be independent and complementary processes (Cropley, 2006), and in general, negligible correlations are reported between measurements of the two constructs (Akbari Chermahini et al., 2012; Lee & Therriault, 2013). Divergent and convergent thought both rely on reaching semantically distant associations; however, a key difference is that convergent creative thought involves the evaluation of associations and finding a single correct answer, while divergent thinking does not comprise arriving at a single correct solution. Different trait-like and state-like factors that influence, or cognitive processes that operate during convergent and divergent thinking are far from being clarified and warrant further investigations (Lee and Therriault, 2013). Furthermore, it should be noted that although divergent and convergent thinking are both necessary, they are not sufficient prerequisites of creativity (Cropley, 2006; Karwowski et al., 2016; Runco, 2008). Real-life creative achievements are influenced by other factors as well, such as domain-specific knowledge or a social environment that supports innovation, not to mention the historical-cultural milieu (see Batey & Furnham, 2006).

Regarding the limitations of our study, we should acknowledge that testing was scheduled in a relatively narrow time range and did not extend to the night. It is possible that testing in later time points could have produced larger effects of asynchrony in morning-types as well. Additionally, participants could personally select among the time points provided by the researcher. Further studies might first determine participants’ peak times and then randomly assign them to optimal or nonoptimal times. Sleep quality before testing was only assessed by a retrospective questionnaire (AIS) and a two-itemed scale rating sleep quality and duration the night before testing. Although these measures might capture more persistent and transient sleep disruption, a longer sleep agenda assessed before testing might have provided a more precise estimate about sleep quality. Moreover, given the complexity of the applied tasks, we cannot determine which mechanisms (e.g. inhibition, levels of arousal or fatigue) underlie the observed pattern of creative thinking. Further studies examining the interaction between chronotype and asynchrony in relation to creative thinking should include more basic measures of cognitive processes (e.g. inhibitory functions), as well as more direct markers of sleep pressure and alertness.

In spite of these limitations, the present study is the first to show the influence of chronotype and asynchrony on convergent thinking. Nevertheless, given the paucity of research on the complex relationship between chronotype, time of testing and creativity, these preliminary results have to be followed by further investigations.

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Declaration of interest

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