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Circadian rhythms and second language performance

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Abstract

Human behavior is not constant over the hours of the day, and there are considerable individual differences. Some people raise early and go to bed early and have their peek performance early in the day (“larks”) while others tend to go to bed late and get up late and have their best performance later in the day (“owls”). In this contribution we report on three projects on the role of chronotype (CT) in language processing and learning. The first study (de Bot, 2013) reports on the impact of CT on language learning aptitude and word learning. The second project was reported in Fang (2015) and looks at CT and executive functions, in particular inhibition as measured by variants of the Stroop test. The third project aimed at assessing lexical access in L1 and L2 at preferred and non-preferred times of the day. The data suggest that there are effects of CT on language learning and processing. There is a small effect of CT on language aptitude and a stronger effect of CT on lexical access in the first and second language. The lack of significance for other tasks is mainly caused by the large interindividual and intraindividual variation.

Keywords: circadian rhythm; chronotype; aptitude; vocabulary

1. Introduction

In the study of second language development (SLD) differences between learners have been studied intensively. There is a general agreement that individual differences (IDs) in second language learning should be taken into account in the study of SLD. IDs include foreign language aptitude, attitudes, motivation, and personality traits (Dörnyei & Skehan, 2003). In addition, anxiety, age, and language learning styles are all considered to be factors that contribute to IDs in SLA (Ellis, 1994). Dörnyei (2009) linked aspects of IDs with dynamic systems theory: He argued that IDs are dynamic factors that mutually affect each other over time.

A factor that has not yet received much attention in the study of IDs is the circadian rhythm (CR). This refers to the fact that people have individual and unique chronotypes (CTs), which could be a factor that has an impact on SLD. Schmidt, Collette, Cajochen, and Peigneux (2007) indicated that both time-of-day modulations and CTs affect performance on a series of cognitive tasks, reflecting "interindividual differences in circadian preference" (p. 755). Optimal performance is assumed to be achieved when an individual is tested at his or her optimal time.

The present study attempts to show CT effects on second language performance as measured by a verbal fluency task and one executive function, inhibition, measured through various types of the Stroop test.

2. Individual differences

In the study of SLD there is a growing awareness of the importance of IDs. Dörnyei (2009) defines them as follows: "Individual differences (IDs) are characteristics or traits in respect of which individuals may be shown to differ from each other" (p. 1).

While most L1 learners will reach a fairly high level of proficiency in the mother tongue, there is substantial variation between learners of a second language. Compared to L1 acquisition, IDs in learning an L2 are more noticeable, which can be seen not only in the learning speed, but also the completely different learning outcomes, ranging from zero achievement to native-level attainment (Dörnyei, 2009; Ellis, 2004).

IDs are now seen as "consistent predictors of L2 learning success" (Dörnyei, 2009, p. 2), rather than distractors that prevent deeper insight into the unique development process of L2. General factors such as motivation, personality, and learning aptitude are typically included in the list of IDs because of their important role in L2 acquisition (Ellis, 1994).

Ellis (2004) lists four big categories of factors that contribute to IDs in second language acquisition (SLA):[1] ability, propensities, learners' cognition about

[1] From a dynamic systems theory perspective the term *SLD* (*second language development*) should be used rather than *second language acquisition* since the same factors play a role

L2 learning, and learner actions. Different from Ellis (1994), Ellis (2004) excluded "age" because he held that age "potentially affects learners' abilities, propensities, cognitions, and actions" and probably "affects the actual psycholinguistic processes involved in learning, with younger learners able to access a 'language acquisition device' and older learners reliant on general cognitive learning strategies – the Fundamental Difference Hypothesis" (p. 529).

Dörnyei (2009) classified factors of IDs into core and optional ones. Similarly to Ellis (2004), he excluded age for the same reason. Gender was also removed from the list of core IDs because it influences all aspects of the process of SLA, "including virtually all the other ID variables" (p. 8). Different from all the categories mentioned above, Dörnyei (2009) resorted to the new concept of "group dynamics" (p. 89), an interdisciplinary field of social sciences, which focuses on institutional teaching and learning. Proposing new "dynamic conceptualizations", he believed that "ID factors enter into some interaction with situational parameters rather than cutting across tasks and environments" (p. 218).

Although Dörnyei (2009) proposed a dynamic perspective to re-evaluate IDs, he neglected a potentially important characteristic of human beings—the different daily rhythms of individuals—the CR and CT. De Bot (2013) has argued that CT should also be included in the list of IDs. He indicated that factors such as motivation and attitude are much more easily affected by external factors, and some seemingly stable factors are not as stable as previously assumed (e.g., language aptitude, working memory, etc.). He also pointed out some stable factors, such as personality style, anxiety and learning style. Along those lines he believed that CT, a relatively stable factor, should be added to the list of IDs, although there is only limited research on how CT affects language development and change.

3. Circadian rhythms and chronotype

All creatures on earth, including humans, are influenced by CRs. Physical behaviors, such as eating when hungry, sleeping when tired, drinking when thirsty, are all defined by the internal biological clock. Emotions and mood fluctuations are also subject to the daily rhythm. The rhythms that are generated within us are based on biological clocks. The times of activities and other diurnal and nocturnal propensity are all synchronized by our biological clock, which leads to optimal performance of activities when we have access to food, sunlight and other resources (Kreitzman & Foster, 2011). These environmental changes during the day are controlled by solar clocks.

in language acquisition and in language attrition. Development is used as an overarching term for both acquisition and attrition.

Solar clocks, together with social clock and biological clock, work together and influence our activities during the day (Roenneberg, Wirz-Justice & Merrow, 2003). If our daily life was shunned from both the solar and social clocks for a longer period of time, our biological clock would run out of control. However, in normal life, the biological clock is entrained by the solar clock of the 24-hour time (Roenneberg et al., 2003) and constrained by the social clock, which is formed by working hours, study schedules, appointments and other constraints. In general, the three clocks work together yet asynchronously. The biological clock is influenced by the interaction between homeostatic and circadian factors, which can have an effect on a large set of neurobehavioral events. The non-linear interaction between these two factors will cause temporal fluctuation, leading to the time-of-day variation and to peaks and troughs in cognitive performance in daily life. Additionally, since the circadian process is not precisely 24 hours in the light-dark cycle, it is entrained by what in chronobiology has been labelled *zeitgebers* 'providers of time'. These are sources of information about time, such as day and night (Schmidt et al., 2007). The most important zeitgeber is daylight. For most plants and animals daylight defines their CR. It is based on "the interaction of multiple external and internal oscillators" (Dijk & von Schantz, 2005, p. 279). The oscillations have been shown in "both biological (e.g. body temperature and levels of hormone secretion) and psychological variables (e.g. mood and performance)" (Díaz-Morales, 2007, p. 770).

4. Chronotypes

Chronotypes can be defined as "human preferences in the timing of sleep and wake" (Roenneberg et al., 2003, p. 81). Human behaviors are largely affected by the unique individual circadian timing system. The particular individual CT can be seen in different "favorite periods of diurnal activities, like working hours, and in specific sleep habits" (Roenneberg et al., 2003, p. 758). Generally, people can be classified on a continuum between two types, the morning type, "larks," and the evening type, "owls". Larks are those people who wake up early in the morning and prefer to finish their work in the daytime, while owls are those who prefer to do their work late at night and wake up with difficulty in the early morning (Giampietro & Cavallera, 2007). The difference between extremely early larks and extremely late owls can be such that "extreme 'larks' wake up when extreme 'owls' fall asleep" (Roenneberg et al., 2003, p. 80). Moreover, the aging process plays a significant role in the circadian and sleep rhythms (Schmidt et al., 2007). The shift of the CRs occurs during the time when children become adolescents, when their CTs change from morning-preferred types to evening-preferred ones (Hahn et al., 2012). Another shift of rhythmicity towards larks appears around 50 years of age (Giampietro & Cavallera, 2007). The majority of elderly people are larks and most young adults are owls (Schmidt et al., 2007).

Fluctuations of circadian arousal can affect individual performance in various ways. Performance on a certain task can be influenced by one's "peak circadian arousal period" (Hahn et al., 2012, p. 123) and the time of testing of the study. The optimal performance of a certain task is assumed to be achieved at the matching time of these two variables, which has been labelled the *synchrony effect* (Hogan et al., 2009; May & Hasher, 1998).

4.1. The establishment of chronotype

There are various instruments to assess CT. In the studies reported on here, CT types are assessed with the Munich Chrono Type Questionnaire (MCTQ). The mid-sleep time is taken as the referent point for CT. For example, a 3.00 a.m. mid-sleep time would be with the sleep onset at 11.00 p.m. and 7.00 a.m. wake-up. It should be noticed that a person who falls asleep at 12.00 p.m. and wakes up at 6.00 a.m. has the same mid-sleep time, 3.00 a.m. Mid-sleep is thus used as the indicator of CT but does not tell us much about the amount of sleep a person gets.

4.2. Chronotype and cognitive activities

Blatter and Cajochen (2007) provide a general overview of early studies in the 19th and 20th century which provided evidence for the time-of-day effects for a range of activities. Nathainel Kleitman is "the pioneer in circadian and sleep research" (p. 196) as he systematically combined information from cognitive performance, chronobiology and sleep research. He found a time-of-day fluctuation in cognitive performance: Performance was found to be optimal in the afternoon and worst in the early morning and late night. Similarly, the time-of-day fluctuations of brain activities and cognitive performance have been also mentioned by Ebbinghaus (1885/1964). He reported that the performance in learning nonsense syllables is better in the morning than in the afternoon (Schmidt et al., 2007). Farrell, Sood, Dewsnap, and Schmitt (2013) made the first attempt to examine the question if the morning-evening (ME) type has an effect on the performance of university students in the UK. They found a clear effect of CT on cognitive performance. So far, no research has been done on CT and second language development. In the present contribution a number of recent studies on this issue are presented.

5. Study 1: De Bot (2013)[2]

De Bot (2013) made the first attempt to test the CT impact on aspects of SLD, with a focus on language aptitude and word learning and retention. Based on the assumption that "different CTs will lead to time-of-day effects: larks generally doing better in the morning and owls performing better in the early evening" (p. 6), the study looked at CT, word learning and aptitude. The instruments used were the Munich Chronotype Questionnaire (MCTQ) and Meara's Llama Language Aptitude Tests. A total of 24 informants, mainly university students, were tested on language learning aptitude and word learning. The group of informants was divided into an early group (Larks) and a late group (Owls) on the basis of the median. The range of CTs was fairly limited, and therefore there was little variation in mid-sleep time. The participants were tested with the Llama Aptitude Test, they had to learn a number of pseudo words, and they were tested later at the preferred and non-preferred time of the day. A significant time-of-day effect was only found in the aptitude tests (the sound-symbol correspondence test and the grammatical inferencing subtest), in which the participants showed synchrony: They performed better at their preferred time. No effect of CT on word learning was found.

6. Study 2: Fang (2015)

In this experiment the focus was on lexical access and inhibitory control. Lexical access is a crucial factor in language production. It can be assessed in different ways. Here a verbal fluency task was used. This task has been used extensively in psycholinguistic studies on bilingualism (Portocarrero, Burright, & Donovick, 2007). For the assessment of inhibitory control a number of versions of the Stroop test were used.

The research hypothesis addressed was the following: Larks have better performance than owls in the morning, and owls perform better than larks in the evening on lexical access and inhibitory control.

The 94 participants in this study were individuals with different L1 backgrounds whose second/foreign language was English. The age range was from 19 to 34. All participants had learned English since primary school, and only nine of them had never been abroad. The English proficiency levels of the 85 participants who had been abroad were measured by IELTS scores, the range of which was from 6.5 to 7.5. For those who had never been abroad, their English proficiency levels were measured by the Test for English Majors (TEM-8).[3] Therefore, all the participants were assumed to have similar English competency.

[2] This study is summarized here. Details can be found in de Bot (2013).

[3] TEM-8 is one of the most difficult English tests in China for English major students.

40 participants were selected to join the second part of the study on the basis of their CTs. They were divided randomly into two groups, Group 1 and Group 2, as shown in Table 1. Both groups included 10 larks and 10 owls. Group 1 was tested in the evening, which is assumed to be the time owls prefer but is non-preferred by larks, while Group 2 was tested in the morning, the time that larks prefer and is non-preferred by owls.

Table 1 The division of the 40 selected participants and their time of testing

	CT Types	Number of participants	Test time
Group 1	Larks	10	Evening
	Owls	10	
Group 2	Larks	10	Morning
	Owls	10	

6.1. Procedure

In a first step, the MCTQ was administered online, and all participants were asked to fill in the questionnaire so that they could be divided into specific groups according to their CTs. In a second step, verbal fluency tasks (phonological and semantic) were used, which required the participants to name as many words as possible from specific categories in 60 seconds:

- *Phonological verbal fluency task:* The participants were asked to list as many English words as possible in 60 seconds which begin with the letter *S*. In research on verbal fluency in English, the letter *S* is often used because it is a "large" letter compared to other letters (Monsch et al., 1992).
- *Semantic verbal fluency task*: The participants were asked to name as many English words as possible in 60 seconds that belong to the category of fruits and vegetables. Again, this is one of the most widely used categories for verbal fluency in English. The number of correct words that the participants named in both tasks was used as the dependent variable in the analysis.

Third, Stroop tests were used to assess inhibitory control. The tests were conducted through a website (https://faculty.washington.edu/chudler/words.html#seffect), which can record the time spent by the participants automatically:

- *Stroop tests*: A number of variants of the Stroop test were used in this study, the traditional COLOR-WORD Stroop Test (see Rosselli, Ardila, & Santisi, 2002 for an overview of research on the Stroop task with bilinguals) and three new variants, the Interactive Positional Stroop, Interactive NUMBER Stroop, and Interactive ANIMAL Stroop, as described below.

After determining the CTs by the MCTQ according to the group division, the 40 participants completed the verbal fluency tests and the Stroop tests. The tests were conducted one week after the MCTQ.

In the COLOR-WORD Stroop test, the participants were asked to name the colors of the words while not reading the words themselves. For example, if the word "GREEN" was printed in blue, the participants were supposed to say "*blue*." This test consists of two sub-tests, a congruent and an incongruent one. The participants were asked to name all the words as quickly as possible. If a participant was wrong for the first time, he or she was allowed to correct the error until the answer was right. The time for finishing each of the two sub-tests was recorded.

In the Interactive Positional Stroop test, the participants were asked to name the positions of the words rather than the words themselves. For example, where the word "LEFT" is positioned in the up location, the participants should say "*up*." When the word "LEFT" is located on the right, "*right*" is the correct answer. This test included two sub-tests, a congruent one and an incongruent one. The participants needed to produce the words as quickly as possible. If a participant was wrong for the first time, he or she was allowed to correct the error until the answer was right. The time of finishing each of the two sub-tests was recorded.

In the Interactive NUMBER Stroop test, the participants were asked to name the numbers of the words while not reading the words themselves. For example, if there were two words "DOG" in the box, the answer should be "*two*"; if the word "ONE" appears *three* times, then the participant is required to answer "*three.*" This test consisted again of two sub-tests, a congruent one and an incongruent one. The difference in reading time between the two versions, that is, the Stroop effect, was used as the dependent variable in the analysis. The participants were asked to read aloud all the words as fast as possible. If a participant was wrong for the first time, he or she was allowed to correct the error until the answer was right.

Finally, in the Interactive ANIMAL Stroop, the participants were asked to name the animals in the picture while not naming the pictures of words themselves. For example, the participant was supposed to say "*cow*" when the picture itself showed a cow (congruent condition), but the participant was supposed to say "*cat*" when the picture showed a cat but the printed word said "SPIDER."

6.2. Analysis

In the analysis the characteristics of the participants were first considered, which are shown in Table 2.

Table 2 The average mid-sleep time during workdays of the participants in Group 1 and Group 2

	CT types	Number of participants	Average mid-sleep time	Standard deviation	Test time
Group 1	Larks	10	3:06 a.m.	0:25	Evening
	Owls	10	4:48 a.m.	0:31	
Group 2	Larks	10	3:23 a.m.	0:24	Morning
	Owls	10	4:26 a.m.	0:22	

The data on the verbal fluency task are presented in Table 3. On both phonological and semantic verbal fluency tests, no significant differences of the performances of the larks and the owls were found in either Group 1 or Group 2.

Table 3 The results of the verbal fluency tasks

Verbal fluency tasks	Result type	Group 1 (evening tests)		Group 2 (morning tests)	
		Larks	Owls	Larks	Owls
Phonological verbal fluency task with the letter "S" words	*M*	16.30	15.20	17.10	17.20
	SD	6.36	5.39	5.13	2.86
	Levene's test	$F = 0.012, p > .05$		$F = 72.205, p > .05$	
	t test/significance	$t(18) = 0.417, p > .05$		$t(18) = -0.054, p > .05$	
Semantic verbal fluency task with fruit & vegetable words	*M*	13.20	15.20	17.0	13.60
	SD	4.98	6.49	6.06	4.53
	Levene's test	$F = 1.057, p > .05$		$F = 0.229, p > .05$	
	t test/significance	$t(18) = -0.773, p > .05$		$t(18) = 1.422, p > .05$	

The results of the original COLOR-WORD Stroop test and its three variations are shown in Table 4. No significant differences between the performances of the larks and the owls were found on any of the Stroop tests. The correlations between the variants of the Stroop test were fairly high (r = .60 -.70).

Table 4 The results of the Stroop tests (Unit: Second)

Stroop tests	Result type	Group 1 (evening tests)		Group 2 (morning tests)	
		Larks	Owls	Larks	Owls
COLOR-WORD-1	*M*	20.59	17.44	20.75	19.73
	SD	6.27	2.84	4.10	5.43
	t test/significance	$t(18) = 1.447, p > .05$		$t(18) = 0.475, p > .05$	
COLOR-WORD-2	*M*	29.46	27.99	28.57	29.03
	SD	7.83	6.96	6.46	5.05
	t test/significance	$t(18) = 0.445, p > .05$		$t(18) = -0.177, p > .05$	
DIRECTIONAL-1	*M*	12.30	11.53	11.92	11.78
	SD	2.82	2.49	2.56	2.77
	t test/significance	$t(18) = 0.648, p > .05$		$t(18) = 0.124, p > .05$	

DIRECTIONAL-2	*M*	16.85	16.80	16.15	16.73
	SD	4.84	3.99	3.78	5.55
	t test/significance	$t(18) = 0.026, p > .05$		$t(18) = -0.270, p > .05$	
NUMBER-1	*M*	14.81	13.17	14.93	14.59
	SD	3.00	1.76	2.67	1.79
	t test/significance	$t(18) = 1.488, p > .05$		$t(18) = 0.338, p > .05$	
NUMBER-2	*M*	16.80	14.84		
	SD	3.23	1.88		
	t test/significance	$t(18) = 1.654, p > .05$		$t(18) = -0.758, p > .05$	
ANIMAL-1	*M*	18.58	18.24	14.77	16.70
	SD	4.20	5.44	2.99	1.88
	t test/significance	$t(18) = 0.155, p > .05$		$t(18) = -1.728, p > .05$	
ANIMAL-2	*M*	23.99	23.44	20.07	21.43
	SD	8.46	8.89	3.48	3.47
	t test/significance	$t(18) = 0.142, p > .05$		$t(18) = -0.465, p > .05$	

Correlational analyses showed that there was neither a significant effect of the mid-sleep time on the individuals' performances nor a significant interaction between the mid-sleep time and test time in any tests. A significant effect of the test time on performance was only found in the animal Stroop test.

6.3. Main results study 2

For this current study, verbal fluency tests and three variants of the Stroop test were used to find out whether there is synchrony between the peak circadian time and the test time on second language performance. The results of all the tests showed that no significant difference was found between the performances of the larks and the owls in any group. No significant effect of the mid-sleep time on the performance was found in any tests. A significant effect of the test time on performance was only found in the Animal Stroop test. There was no significant interaction between the test time and the mid-sleep time in any tests either. The findings of the study did not confirm the assumption that optimal performance will be achieved at individuals' preferred time.

7. Study 3: The Kőszeg study

In this study, which was carried out with financial support form the ISES centre in Kőszeg, we looked at the relationship between CR, executive functions and lexical access. With the help of students and student assistants, 28 informants were tested. They showed a range of ages, and they were all native speakers of Hungarian and had some knowledge of English. Again the MCTQ was used to assess CT. To measure lexical access, verbal fluency tests were used. The categories used are presented in Table 5. Because the size of categories, in particular the semantic ones, is hard to estimate, it was decided to switch the categories for half of the informants: Half of them got the "F" letter test at the preferred time and half of them at the non-preferred time. This should balance out the effect of differences in set size.

Table 5 Categories for phonological and semantic verbal fluency tests taken at the preferred and non-preferred times

Tests	Preferred time	Non-preferred time
L1 phonological	"F"	"M"
L1 semantic	Names	Fruits
L2 phonological	"R"	"T"
L2 semantic	Animals	Grocery goods

The findings of this study are summarized in Table 6 with the mean scores for L1/L2, phonological/semantic and preferred/non-preferred time of the day.

Table 6 Verbal fluency mean scores (standard deviations) for phonological/semantic, L1/L2 and preferred/non-preferred time

Language	Test	Preferred time	Non-preferred time	*p*
L1	Phonological	22.3 (6.3)	17.1 (4.2)	$t(27) = 4.9, p < .001$
	Semantic	19.9 (6.7)	17.0 (4.3)	$t(27) = 2.1, p < .050$
L2	Phonological	14.2 (3.9)	10.6 (4.7)	$t(27) = 3.7, p < .001$
	Semantic	15.6 (5.8)	10.1 (3.8)	$t(27) = 6.3, p < .001$

The data in Table 6 reveal significant effects of time of testing for all categories. L1 typically shows higher scores than L2, and phonological fluency is better than semantic fluency.

8. Discussion

On the basis of the literature on CR and cognitive functioning, it was expected that CT (chronotype) would be a factor in language learning and (multilingual) processing.

In the first study aspects of language aptitude were considered and a significant effect of CT on some components, but not all, was found. In the word learning experiment, no advantage for preferred over non-preferred time of the day was found.

In the second study different types of Stroop tests were used, and the relation between verbal fluency data and inhibitory control was assessed at different times of the day, depending on the CT of individual informants. No effect of CT was found, which may have partly been caused by the large variation within and between participants.

In the third study we looked at the effect of preferred time of the day versus non-preferred time on phonological and semantic verbal fluency in L1 and L2. Here a strong effect of time of testing was found with significant effects of CT on lexical processing both in L1 and 2 and for phonological and semantic fluency.

The verbal fluency task is a typical example of a combination of action and control. The participant has to generate words from a specific phonological or semantic category, but the generation of a word leads to activation of all the words in the network that word is part of. That can be synonyms, associations or collocations. Only a small set of the words activated are actually part of the category searched for. So the other words have to be filtered out and inhibited. It may be that different parts of the activation-control process differ in the way they are influenced by CR. The data from the second study discussed earlier show that the inhibitory control mechanism as measured by the Stroop test is not sensitive to CR effects. That means that the CR effect found in the third study mainly impacts the activation process. Why this component is affected and not the inhibitory control mechanism is still unclear.

One of the useful findings in the third study is that the choice of the testing moment, four and eight hours after getting up, seems to work to select preferred and non-preferred testing times. Apparently four hours is early enough for larks to perform effectively, while eight hours works well for owls.

9. General conclusions

The first finding of the studies reported on are time of day and CT which both appear to play a role in lexical processing. We report data from three studies on the role of CT in language processing and learning. The first study (based on de Bot 2013) reports on the impact of CT on language learning aptitude and word learning. The second project is based on Fang (2015) and looks at CT and executive functions, in particular inhibition as measured by variants of the Stroop test. The third project aimed at assessing lexical access in L1 and L2 at preferred and non-preferred times of the day.

The data suggest that there are effects of CT on language learning and processing. There is a small effect of CT on language aptitude and a stronger effect of CT on lexical access in the first and second language. The lack of significance for other tasks is mainly caused by the large interindividual and intraindividual variation.

The main conclusion from the studies reported on is that there are indications of CR effects in monolingual and bilingual processing, but also that the main positive finding is based on just one experimental task. More ecologically valid measures are needed to substantiate the CR effect. Therefore it is too early to claim that CR should be included as one of the main IDs that play a role in bilingual processing and language learning.

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