Theses of Doctoral (PhD) Dissertation

Effects of extreme environments on cognitive processes using the method of event-related potentials

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I. The aim of the thesis, general background

The main objective of the dissertation is to shed light on how cognitive functions are changed in space and in Antarctica. Several studies investigated the effects of these extreme environments on cognitive functions (Strangman, Sipes, & Beven, 2014). The results of these studies are controversial and in contrast to anecdotal reports, they predominantly show that these cognitive functions are not impaired significantly in these situations. Clarification of this is particularly important for astronauts, but it is also not negligible for the Antarctic overwintering crew, as cognitive impairments may have disastrous outcome in both environments. Among other duties, astronauts are also responsible for the maintenance of the space station. Similarly, in Antarctica, it is the crewmembers' job to maintain the station, to ensure the proper functioning of the lighting, heating etc. If the crew is unable to maintain these devices properly, it could jeopardize their life. On the other hand, the space station and Antarctica may also serve as a model for other extreme conditions where several stress factors with negative impact on cognitive performance are present simultaneously (for example sports, work or military activity in high altitude, isolation on submarines and in other similar environments).

We investigated the effect of Antarctic environment and space travel on cognitive functions by using behavioral measurements and the event-related potential (ERP) technique, with the focus on P3a component. According to the widespread theory, P3a reflects attention switch (Näätänen, 1990). We investigated the brain electrical correlate of this unexpected, rare event (P3a) in both extreme environments. Since it is important to explore the characteristics of such unexpected events in the mobilization of attentional processes, another aim of the dissertation is to investigate the effects of the complexity of unexpected events compared with the complexity of regular environmental events in the mobilization of attentional processes. Additionally, we also investigated the role of irrelevant stimulus variability in attentional processing.

Several stress factors could impair cognitive functions both in Antarctica and in the space station. The light-dark cycle is altered in both environments, which -taken together with other stress factors- may result in sleep problems. Additional stress factors related to these environments includes isolation and confinement. Microgravity in space causes cephalad-fluid shift, which together with other factors is thought to be responsible for increased intracranial pressure and visual problems, forming the so-called visual impairment and intracranial pressure (VIIP) syndrome (Alexander et al., 2012). Microgravity also has a direct effect on the neurovestibular system. One of the most severe consequences of the modification of neurovestibular system is space motion sickness during the first days of spaceflight, but it may also directly affect higher cognitive functions, such as spatial orientation, spatial attention, pattern and object recognition (Glasauer & Mittelstaedt, 1998; Kanas & Manzey, 2008). Microgravity also impacts the functioning of sensory-motor system, which is particularly important in tasks that require controlled hand movements, such as tracking and pointing arm movement tasks (Bock, 1998). In addition to direct effects of microgravity, nonspecific and other stressors may also impair cognitive functions in space. Astronauts are exposed to high workload, CO_2 level is much higher in spacecraft than on Earth and ionizing radiation may also adversely affect cognitive functions. While the above listed stress factors are not present in Antarctica, the high altitude of the research station (3233 m) may cause moderate hypoxia, which may also impact cognitive performance.

On Earth, several studies have investigated the effects of these factors on cognitive performance separately. These studies are essential to clarify the contribution of stress factors to the cognitive effects observed in space and Antarctica. Among the above described stressors, sleep loss is the most studied stress factor under terrestrial condtions. Studies investigating the effects of sleep loss often demonstrate the detoriation of several cognitive functions including the attentional functions and EPR indicators which are relevant to our studies (for a review see Alhola & Polo-Kantola, 2007). The simulated cephalad-fluid shift (head down bed rest) and isolation studies mostly report intact cognitive performance, including for tasks requiring attentional functions (e.g. Basner et al., 2014; Seaton, Slack, Sipes, & Bowie, 2007). Studies investigating idiopathic intracranial hypertension (IIH), a syndrome which is highly overlapping with VIIP, show syndrome-related impairments of attention, executive functions, visuospatial memory, verbal and nonverbal learning and memory (for a review see Strangman et al., 2014). Since differences between the two syndromes also exist, conclusions derived from IIH syndrome studies should only be cautiously applied to VIIP syndrome. Similarly, even though animal studies or studies with patients undergoing radiation treatment show that ionizing radiation may negatively affect attention, memory, sensory-motor functions, executive functions and learning, it is difficult to generalize these results to space radiation, due to differences in the type and/or the dosage of radiation applied in those studies (for a review see Cucinotta, Alp, Sulzman, & Wang, 2014). Regarding an additional factor, CO_2 concentration, majority of the studies show no impairments in cognitive functions in case the ambient CO_2 level on the space station does not exceed the acceptable level. However, astronauts may be temporarily exposed to higher concentrations, which, according to research, do worsen performance in tasks requiring perception, mathematical processing, reasoning or visuomotor abilities (for a review see Strangman et al., 2014). While most studies regarding a factor related to Antarctica, hypoxia, show impaired performance in psychomotor, mathematical, logical reasoning, short-term memory and multi-tasks (e.g. Shukitt-Hale, Banderet, & Lieberman, 1998), others found no clear performance impairment (e.g. Crow & Kelman, 1973).

II. Methods

We used event-related potential (ERP) method in all three studies. Contrary to the behavioral measurements, the main advantage of the ERP method is good time resolution which allows the separation of distinct processes after the occurrence of an event by ERP components. Using this method, it can be decided which cognitive functions are impaired in extreme environments. Another advantage of this method is that it serves information in cases when no behavioral data is available. A typical example for such event is the unexpected, task-irrelevant event which does not require response.

Participants were healthy students in the first study, an Antarctic overwintering crew in the second study, and astronauts in the third study. We followed similar steps of data analysis (e.g. averaging technique, artifact rejection) in each study.

The first study aimed to identify those conditions where task-irrelevant events are able to mobilize attentional processes. We investigated the role of complexity of the rare, task-irrelevant stimuli compared those of the task-relevant events in the mobilization of attentional processes, in other words, in eliciting the P3a component. Additionally, we also investigated the role of irrelevant stimulus variability in attentional processing. All subjects were given three versions of oddball paradigm in both visual and auditory modalities. In each modality there were two traditional experimental conditions in which complex irrelevant stimuli were presented in sequences of simple, rare target and simple standard stimuli. In one of these two conditions, the irrelevant stimuli were variable and in the other condition these stimuli were identical. In contrast to the traditional oddball paradigm standards and targets were the complex ones while task-irrelevant infrequent stimuli were identical and simple in the third condition.

In the second study, we investigated the effects of long-term Antarctic residence on cognitive functions using an auditory distraction task and the attention network test (ANT).

The participating crewmembers spent one year in Antarctica. We compared measurements of six time points (one in approximately every six weeks) during 8-9 months of the campaign. In the auditory distraction paradigm (Schröger & Wolff, 1998) subjects had to decide the duration of the presented tone (long or short). Some of the presented tones deviated from the familiar standard stimuli in a task-irrelevant feature, namely, in frequency (deviant stimuli). Typical findings regarding such deviant stimuli include lower behavioral performance compared to standard stimuli. As regards to ERP, these deviant sounds typically elicit MMN (mismatch negativity), P3a and RON (reorientation negativity) components. In the ANT task (Eriksen & Eriksen, 1974; Posner, 1980) subjects were presented a group of arrows and had to make a decision about the direction of the central arrow. Other arrows could either point to the same direction (congruent condition), or the opposite direction (incongruent condition). In one third of the trials a preceding cue gave information about both the timing and location of the arrows (Spatial Cue), in the other third of the trials the preceding cue gave information only about the timing (Center Cue), while no information was given about arrows (No Cue) in the remaining trials. Three aspects of attention can be measured by this task: alerting enhancement, spatial orientation, and inhibition (or in other words, execute control function) (Fan, McCandliss, Sommer, Raz, & Posner, 2002; Posner & Petersen, 1990). Performance is typically better for congruent trials than for incongruent trials in this task. Concerning the effect of cues, performance appears to be the worst when there is no information about the timing and the location of target stimuli, performance is better after cues about the location of the targets, while the performance is the best when cues serve information about both the location and the timing of the targets. Only a few studies investigated ERPs during this task. These studies found the amplitude of occipital N1 component to be lower for target stimuli without preceding cues compared to the ones after target related cue information (Neuhaus et al., 2010). Furthermore, the incongruent events elicit similar fronto-centrally distributed N2 amplitude (Neuhaus et al., 2007), higher centrally distributed no-go P3 amplitude (Neuhaus et al., 2010) and smaller parietally distributed P3b amplitude (Neuhaus et al., 2010) compared to congruent events.

In the third study, we investigated the effect of spaceflight on cognitive functions with a modified visual oddball tasks which also require visuospatial perception. We examined possible space related impairments of cognitive functions with P3a ERP component elicited by rare, task-irrelevant, complex, variable stimuli. Astronauts performed these tasks three times before launch, two times during the flight and four times after returning from space. In order to investigate the adaptation of cognitive processes during spaceflight, the two in-flight measurements were divided to an early (1-2 weeks after launch) and a late (1.5-2 months after launch) data collection. We also collected data few days (2-3 days) and few weeks (2-3 weeks) after landing to investigate the readaptation process.

III. Results of thesis

1. **The results of the first study enriched our knowledge about attention switch by a new aspect. We demonstrated that the appearance of rare unexpected irrelevant stimuli during a task execution elicit attentional orientation and generate the brain electrical correlate of this response if these irrelevant events are at least as complex as the environment determined by task-relevant stimuli.** The results also show that rare and unexpected complex events mobilize attentional processes even if these events are always the same. Furthermore, our results confirmed our hypothesis that interference with the task-set is not enough for mobilization of attention, it requires elaborative processes, like evaluation and categorization of the irrelevant stimuli. Our results help to clarify the circumstances under an unexpected event captures attention.

2. In the second study, typical effects that are present under normal conditions were confirmed for both behavioral and ERP data (e.g. reaction time for deviant events are slower than for standards). Performance of crewmembers improved and ERP components did not change significantly during the campaign. **Our results show that the overwintering crewmembers adapted to this environment successfully, as their cognitive functions showed no impairments despite the presence of hypoxia and other stressors, such as isolation, confinement, altered light-dark cycle and related sleep problems.** It is possible that some factors might have counteracted the negative influence of stressors. Since the amount of sleep per day is one of the most important factor of cognitive performance (Mollicone, Van Dongen, Rogers, & Dinges, 2008), the fact that crewmembers were allowed to take a nap may have affected their performance. The positive characteristics of the mission (e.g. the beauty of nature) could also counteract the negative impacts of stressors (pl. Suedfeld, 2005). Moreover, numerous studies show that hypoxia do not necessarily produce cognitive impairment (pl. Gustafsson, Gennser, Ornhagen, & Derefeldt, 1997) and acclimatization to hypoxia is also possible during long-term sojourn on various physiological levels (Zubieta-Calleja, Paulev, Zubieta-Calleja, & Zubieta-Castillo, 2007).

3. **The results of the third study, contrary to majority of the literature, show that cognitive functions deteriorate during spaceflight. Recognizing these cognitive**

impairments and avoiding the resulting errors can be an important step in planning further successful spaceflights. The results also show that cognitive functions do not adapt during spaceflight and the readaptation is not immediate after returning to Earth. We assume that the combined effect of several factors has caused the negative impact of spaceflight on attentional functions. According to the literature, sleep loss and mental fatigue due to high workload may also change the attentional indicator (P3a amplitude) we also studied (Gosselin, De Koninck, & Campbell, 2005; Massar, Wester, Volkerts, & Kenemans, 2010). The role of neurovestibular changes can not be completely excluded, especially during early readaptation and additionally, higher ambient CO2 level in the ISS can also lead to cognitive impairment, although this has not been proved concerning attentional functions. Even though the literature does not support the negative effect of isolation, confinement or cephalad-fluid shift on attentional functions, the role of these factors can also not be excluded, as related studies mostly investigated behavioral data. Two other factors, the ionizing radiation and VIIP syndrome that astronauts may have suffered could also affect attentional functions adversely.

IV. Publications

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Registry number: DEENK/159/2017.PL
Subject: PhD Publikációs Lista

Candidate: Irén Barkaszi
Neptun ID: AEYNQA
Doctoral School: Doctoral School of Human Sciences

List of publications related to the dissertation

Hungarian scientific articles in Hungarian journals (1)

1. Kondé, Z., **Barkaszi, I.**, Czigler, I.: Gátlási mechanizmusok és válaszszelekciós interferencia a feladatváltásban.
   Pszichológia. 29 (2), 119-143, 2009. ISSN: 0230-0508.
   DOI: http://dx.doi.org/10.1556/Pszicho.29.2009.2.3

Foreign language scientific articles in international journals (3)

2. **Barkaszi, I.**, Takács, E., Czigler, I., Balázs, L.: Extreme environment effects on cognitive functions: a longitudinal study in high altitude in Antarctica.
   Front. Hum. Neurosci. 10, 1-12, 2016. EISSN: 1662-5161.
   DOI: http://dx.doi.org/10.3389/fnhum.2016.00331
   IF: 3.634 (2015)
3. Takács, E., Sulykos, I., Czigler, I., **Barkaszi, I.**, Balázs, L.: Oblique effect in visual mismatch negativity.
   Front. Hum. Neurosci. 7, 1-13, 2013. EISSN: 1662-5161.
   DOI: http://dx.doi.org/10.3389/fnhum.2013.00591
   IF: 2.895
4. **Barkaszi, I.**, Czigler, I., Balázs, L.: Stimulus complexity effects on the event-related potentials to task-irrelevant stimuli.
   Biol. Psychol. 94 (1), 82-89, 2013. ISSN: 0301-0511.
   DOI: http://dx.doi.org/10.1016/j.biopsycho.2013.05.007
   IF: 3.473

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List of other publications

Hungarian scientific articles in Hungarian journals (1)

5. Balázs, L., **Barkaszi, I.**, Czigler, I., Takács, E.: Agyműködés súlytalanságban: Kísérlet a Nemzetközi Űrállomáson.
   Magy. tud. 176 (9), 1045-1051, 2011. ISSN: 0025-0325.

Foreign language abstracts (4)

6. **Barkaszi, I.**, Czigler, I., Pató, L., Balázs, L.: Target P3 decrement as a result of mental fatigue.
   Int. J. Psychophysiol. 77 (3), 330-331, 2017. ISSN: 0167-8760.
7. **Barkaszi, I.**, Takács, E., Czigler, I., Balázs, L.: The impact of Antarctic overwintering on cognitive processes.
   Psychophysiology. 50 (S1), S134, 2013. ISSN: 0048-5772.
   DOI: http://dx.doi.org/10.1111/psyp.12120
8. **Barkaszi, I.**, Czigler, I., Balázs, L.: Influence of stimulus complexity and variability to the ERP response evoked by task irrelevant stimuli.
   Psychophysiology. 48 (s1), s38, 2011. ISSN: 0048-5772.
   DOI: http://dx.doi.org/10.1111/j.1469-8986.2011.01259.x
9. **Barkaszi, I.**, Czigler, I., Balázs, L.: Stimulus complexity effects on the orienting response.
   Front. Hum. Neurosci. 00425, 206, 2011. ISSN: 1662-5161.
   DOI: http://dx.doi.org/10.3389/conf.fnhum.2011.207.00425

Total IF of journals (all publications): 10,002
Total IF of journals (publications related to the dissertation): 10,002

The Candidate's publication data submitted to the iDEa Tudóstér have been validated by DEENK on the basis of Web of Science, Scopus and Journal Citation Report (Impact Factor) databases.

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V. References

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