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Review paper

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BEYOND BEHAVIOUR: USING TECHNOLOGY TO INFORM APPLIED PSYCHOLOGY

Abstract

Here we presented a few relatively novel methodologies which shed light on applied psychology and offer insights that we would not have without these technological advancements. Namely, we will present how brain stimulation during certain sleep stages can enhance subsequent memory performance, how EEG/ERP can be used in attention research, in detecting guilty knowledge or in diagnosing schizophrenia. Further on, a computational simulation of human cognitive processes will be demonstrated followed by demonstration of using eye tracking methodology to study individual differences in reading. Finally, we will present a work where four different methodologies (EEG, eye-tracking, EDA and HRV) were combined in order to shed light on developmental differences in reading. Looking back to the beginnings of psychology, 140 years ago, when Wilhelm Wundt founded the first psychology laboratory, we can conclude that psychology has made tremendous progress from dealing with observable and measurable behaviors to the ability to peek into and uncover secrets of the so-called black box.

Key words: applied psychology, EEG/ERP, eye-tracking, cognitive modelling.

Introduction

Psychology was officially born in Wilhelm Wunt's laboratory 140 years ago, in 1879 to be precise. Experimental and laboratory approaches, and precise measurements, contributed to the recognition of psychology as a science, which in that period, within Wunt's laboratory in Leipzig, was primarily focused on measuring perceptual phenomena as well as phenomena of consciousness through measurement of reaction times. The results they reached then, and the methodology they developed, still have their place today, not only in the history of psychology, but also in laying the foundations for acquiring objective knowledge about human functioning.

Today, after almost a century and a half, psychology, as a science, has at its disposal methodologies by which it is able to come to conclusions, not only about "surface" measurements, purely behavioral ones, but also internal, neurocognitive,

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which during the period behaviorism, were excluded from the focus of researchers, due to the impossibility of objective measurement. Nowadays, I believe, those behavioral psychologists would be more than pleased to be in position to look deeper into the so-called black box, and with the same methodological rigor, put neurocognitive phenomena in the focus of their interests.

Here we presented a few relatively novel methodologies which shed light on applied psychology and offer insights that we would not have without these technological advancements. Firstly, it was shown how brain stimulation during certain sleep stages can enhance subsequent memory performance, how EEG/ERP can be used in attention research, in detecting guilty knowledge or in diagnosing schizophrenia. Further on, a computational simulation of human cognitive processes was demonstrated followed by demonstration of using eye tracking methodology to study individual differences in reading. Finally, a recent work was presented where four different methodologies (EEG, eye-tracking, EDA and HRV) were combined in order to shed light on developmental differences in reading.

EEG and brain stimulation during sleep

Brain electrical activity (EEG) is the basic procedure by which sleep is examined in laboratory conditions. The registered electrical activity of the brain is manifested as a series of waves of different frequencies and amplitudes. The basic EEG waves are: Alpha rhythm, whose frequency is 8 - 12 Hz, amplitude 20-100 μV and is usually recorded in a relaxed state with closed eyes; Beta rhythm, whose frequency is above 13 Hz (usually 18-25), amplitude 5 -20 μV and is a sign of increased alertness and attention, Theta rhythm whose frequency is 4 -7 Hz and which appears to a greater extent in the EEG at children, adolescents and young adults and Delta rhythm whose frequency is below 4 Hz, amplitude at least 75 μV and is characteristic of deep sleep. Delta rhythm cannot be seen during short sleep, and when it does not appear during sleep, it is an important indicator for differential diagnosis. Sleep begins with the nonREM (nREM) phase, also called quiet or synchronized, S-sleep. This phase is divided into four phases: phases 3 and 4 are called low frequency sleep during which neural activity is highly synchronized. After approximately 90 minutes from the beginning of sleep, phases 2 and 3 enter the REM phase when the EEG becomes desynchronized, with many irregular, high-frequency waves, when rapid eye movement occurs, which is why the phase got its name - REM (rapid eye movement). This sleep is also called paradoxical, desynchronized or D-sleep, active sleep. When a person falls asleep, he enters phase 1, and then phases 2, 3, and 4. External stimuli can stop this progression, e.g. noise during phase 3 can prolong that phase, or cause a return to phase 2 or 1 or even waking up. After approximately 90 min, transition from phase 4 of nREM sleep to phases 3 and 2 to REM phase. After a period of REM sleep, the entire sequence is repeated, lasting 90-100 minutes. At the beginning of sleep, phases 3 and 4 are dominant, and towards morning, phase 4 is lost, phase 3 is shortened, and REM phase is prolonged. If a sleeper wakes up during REM sleep, he will report that he dreamed in 80-90% of cases. However, if he wakes up during the nonREM phase, he will find it harder to report what he dreamed. This percentage varies from 10-70% in different studies. Large variations occur primarily due to different definitions of sleep - some authors believe that a dream is just a complex, well-defined experience, while others believe that a vague experience like an isolated image is also a dream. This is also the main difference in the quality of dreams that occur in the REM or NREM phase: sleep during REM regularly refers to the whole sequence of events, is visually complex and has an action, while sleep during nonREM refers to some isolated image (Gazzaniga et al., 2009).

A growing body of research demonstrated that sleep has an important role in learning and memory, emphasizing timely sleep as one of the key factors in successful memory consolidation (Sučević, 2020). The sleep architecture reflects brain maturation and cognitive development in children, and alterations to sleep patterns are found to be present in certain developmental disorders, such as the ADHD (Scarpelli et al., 2019). Changes in sleep patterns are also related to cognitive decline in the aging population, and there is some evidence suggesting that specific sleep alterations are present in clinical conditions, such as schizophrenia (Scullin & Bliwise, 2015). Recently, several studies have revealed that sleep can also represent a possible tool for intervention and improvement of cognitive functioning. For instance, it has been shown that brain stimulation during certain sleep stages can enhance subsequent memory performance (Grimaldi et al., 2020). This is a new and promising line of research that is yet to determine to which extent intervening with sleep can drive improvements in cognitive functioning.

ERP and attention, deception detection and schizophrenia detection

Unlike the EEG method, which represents spontaneous brain activity, ERP records individual, stimulus-related potentials. However, registering the ERP potential is not an easy task, primarily because the ERP signal is mixed with a number of other electrical signals at all times. Namely, in addition to the desired, i.e., stimulus-related potential, the electrodes also record spontaneous brain activity, which in the context of research represents noise. As a result, activity related to a single stimulus cannot be easily read by visual inspection of the EEG record.

The solution to this problem lies in the display of numerous stimuli (40-100) that belong to the same experimental condition, after which the brain waves elicited by the number of stimuli for each individual condition are averaged. In this way, an isolated ERP wave represents a typical brain response to the stimuli shown, whereby randomly generated waves, so-called electrical noises, are removed. Thus, from a long, continuous EEG wave, a segments corresponding to the time of stimuli presentation are isolated. These segments are then averaged into the ERP profile, which represents a typical brain response to that type of stimulus (Luck, 2005). In the 1960s and 1970s, a number of ERP experiments were performed that addressed the neurophysiological foundations of controlled auditory attention (Hillyard et al., 1973). Using the paradigm with dichotomous listening and attention to one channel, it was found that the N1 amplitude of the ERP signal is increased at the stimuli to which attention was paid. As early as 90ms after the stimulus is displayed, the N1 component reaches its peak. The discovery of this wave on the neurophysiological level confirmed behavioral findings with dichotomous hearing, and this component of the ERP wave is called auditory N1 potential. In addition, it has been shown that attention can have an impact on auditory stimulus processing already in the early stages of cognitive processing, which supports theories of early selection.

ERP has deepened our understanding of attentional processes, opening new avenues for future research (Vilotijević, 2020). Namely, many attentional capture theories hypothesized that threatening stimuli would elicit attention capture in a bottom-up fashion, but most behavioural studies did not find any reaction time differences between threatening and neutral stimuli (Kappenman, 2014). However, recent ERP studies showed that a threat stimuli elicited a robust N2pc demonstrating an attentional bias on a threat (Gaspelin & Luck, 2018). Moreover, by using ERP it was found out that not all salient stimuli elicit N2pc but only those that are task-relevant (targets). Namely, salient but task-irrelevant stimuli (distractors) are actually being suppressed and elicited Pd.

Another avenue for future research is application of ERP in combination with a Guilty Knowledge Test (GKT, Lykken, 1959), which is a questioning technique that can be used to determine whether individuals possess guilty knowledge stored in memory or not. The test consists of a multiple-choice question concerning the crime, including one crime-relevant detail known only to the perpetrator (relevant item) and several crime-irrelevant details (irrelevant items) chosen such that innocent individuals cannot distinguish among relevant and irrelevant items (Milosavljević, 2020). The ERP P300 component is a positive potential that typically occurs between 300–800 ms after stimulus onset, which represents an unpredictable, rare, new, or meaningful change in stimulation (Luck, 2005). P300 component can be used as an electrophysiological marker for involuntary recognition of crime-related details because only for the perpetrator relevant items will be meaningful. In laboratory conditions, the accuracy of GKT-P300 usually ranges between 70% and 90%. There was an attempt to develop commercialized automated P300/ERP technology designed for the detection of deception, which can be easily used by law enforcement in order to help them to solve crime cases (Rosenfeld, 2002). However, despite all user-friendly advantages that the newly developed P300/ERP technology brings, it does not necessarily lead to the higher detection rate of guilty knowledge, as will be demonstrated in this presentation.

Another promising avenue is an application of the ERP in diagnosing schizophrenia (Jovanović, 2020). A lot has been said about schizophrenia so far: from psychoanalytical theories that emphasize early childhood development to strictly biological point that schizophrenia is a neurological disorder. Today there is no doubt that many factors contribute to the development of the disorder, with genetics as a "key player". Since its relatively late age of onset and variable symptomatic manifestations, schizophrenia can be undiagnosed or misdiagnosed, leading to lack of proper treatment that can significantly impact one's life quality. There is still no objective diagnostic test or validated biological marker that could clearly distinguish schizophrenia from other similar diseases. Development of ERP technique that is based on EEG wave analysis takes us one step closer to achieving that goal. So far, ERP studies in schizophrenia pointed mostly to the P300 component that has proven to be severely impaired both in auditory and visual domain (Ford, 1999). However, since P300 deficits are not specific to schizophrenia, there is still a lot of work to be done ranging from fine tuning of existing components and paradigms to possible construction of schizophrenia specific combinations of various component features.

Computer modeling of categorisation

Computer models are inspired by the way information is processed on the brain level (McLeod et al., 1998). Nowadays, the dominant, typical, connectionist models consist of several levels of processing units. Units play a similar role as neurons or groups of neurons on the brain plane. Namely, each unit collects information from the previous level, performs simple calculations (e.g. whether the amount of information is above or below the response threshold), and on the basis of that calculation forwards the information to the next level of units. The activation scheme presented in the first level of units represents the input stimulus. This scheme is transformed through the following levels so that at the last level the activity scheme represents the response or reaction of the model. The impact that each unit in the model has on the next level depends on the strength of the connection between them. The production of the correct answer, based on the given initial activation scheme, is achieved through a change in the strength of the connections between the units. In doing so, the goal of modeling is for models to be based on principles and calculations such as those performed by the brain system and precisely in the way the brain system functions (McLeod et al., 1998).

The effects of label difference on category learning was demonstrated with sampling training in a different number of trainings (N=1, 5, 10, 20, 100) for the simple network (Lalić, 2020). For the lower number of training sessions (N=1 or 5), results did not show any notable relation between input and output. However, once the number of training sessions is increased (N=20 or 100), results are getting more stable and functional dependence between input (label difference) and output (number of training epochs – learning) becomes almost clearly linear. Results signify the importance of the sampling training method in connectionist modelling, particularly once small and tiny effects need to be captured and identified.

Eye-tracking and reading

The method of tracking eye movements connects eye movements with the location of the gaze. The way to register the location of the view is relatively simple. Namely, the eye lens has the property of reflecting light, and if we illuminate the eye with a small source of infra-red light at a certain angle, based on the angle of reflection we can determine the eye orientation, and thus the direction, i.e., view location. As early as the 19th century, the French ophthalmologist Louis Émile Javal, without having a more elaborate methodology, and based on mere observation, noticed and described that during the reading process the eyes make sudden jumps (saccades), which are interrupted by periods of rest (fixations). One of the basic findings in the study of the reading process is that visual information is processed during the period of fixation, mainly from left to right (Rayner, 1998). Fixations usually last about 200-250 ms (although this range can vary from 50 to 500 ms). On the other hand, during eye movements that occur in the periods between fixations, there is no adoption of information. Eye movements or saccades usually last about 20-30 ms and during these periods there is a surplus of visual processing (Matin, 1974). On average, the eye jump occurs after every 7-8 letter places (although this range can also vary significantly - from one to 20 letter places) in readers of alphabetic language systems. Experimental findings support the fact that the number of letters between the jumps, rather than the visual angle, is a better measure of reading speed (Morrison & Rayner, 1981). At the same time, about 10-15% of the saccades that the reader makes fall on the so-called regressions, ie. views on parts of the text that have already been read. The harder the reading, the longer the duration of fixations, the smaller the size of the saccades, and the higher the number of regressions.

Here we presented three examples of how this approach can make contribution to our understanding of individual differences in reading proficiency (Šoškić, 2020). In the first study, sentence reading was compared between high and low skilled adults to examine differences in eye movement patterns while reading target words. In the second selected study (Krstić et al., 2018), participants read several paragraphs long texts and answered questions about their contents, allowing examination of more global characteristics of reading, such as problem solving strategy and allocation of attention to different parts of the text. In the third example, eye movements of dyslexic participants during a nonverbal visual task were examined, demonstrating how experimental paradigms from other fields of eye tracking research can be used to study individual differences in reading.

Finally, in the last study which goes beyond behaviour, a multimodal sensor measurement was employed to examine the influence of background colour on the reading task in children at different developmental stages (Jakovljević et. al., 2020). The reason to combine different modalities was to find a more objective approach to understanding the developmental differences in children's reading as well as to understand the contribution of different modalities and combinations of modalities in the process of reading text on a white vs colour overlay and background. Measurements of electroencephalography (EEG), eye-tracking, electrodermal activity (EDA) and heart rate variability (HRV) were employed to assess the influence of background and overlay colour on reading performance in second and third grade students of elementary school. The results showed a decreasing trend with age regarding EEG power bands (Alpha, Beta, Delta, Theta) and lower scores of reading duration and eye-tracking measures in younger children compared to older children. HRV parameters showed higher scores in second graders, with higher stress levels readable from EDA measures as well.

Conclusion

Looking back to the beginnings of psychology, 140 years ago, when Wilhelm Wundt founded the first psychology laboratory, we can conclude that psychology has made tremendous progress from dealing with observable and measurable behaviors to the ability to peek into and uncover secrets of the so-called black box. This progress, at least to some degree, is due to the technological advancement of, among others, EEG/ERP, eye-tracking and cognitive modelling. In this work, it was shown how brain stimulation during certain sleep stages can enhance subsequent memory performance, how EEG/ERP can be used in attention research, in detecting guilty knowledge and in diagnosing schizophrenia. It has been demonstrated how state of the art technology can inform applied psychology and lead the whole field to gain insights beyond behaviour. There is no doubt that these *technological advances* will continue to further accelerate discoveries in the field of psychology.

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POZITIVNI EFEKTI TEHNOLOŠKOG NAPRETKA NA PRIMENJENU PSIHOLOGIJU

Apstrakt

U radu će biti predstavljeno nekoliko relativno novih metodologija koje nude nova znanja u oblasti primenjene psihologije, ali i nove uvide koje bez ovih tehnoloških dostignuća ne bismo imali. Naime, predstavićemo kako stimulacija mozga tokom određenih faza spavanja može poboljšati naknadne performanse memorije, kako se EEG/ERP može koristiti u istraživanju pažnje, u detekciji laganja ili dijagnozi shizofrenije. Takođe će biti prikazana računarska simulacija procesa kategorizacije, praćena demonstracijom korišćenja metodologije praćenja oka za proučavanje individualnih razlika u čitanju. Na kraju ćemo predstaviti rad koji kombinuje četiri različite metodologije (EEG, praćenje očnih pokreta, srčani rad i psihogalvanski refleks) u izučavanju razvojnih razlika u čitanju. Osvrćući se na početak psihologije kao nauke, pre 140 godina, kada je Vilhelm Vunt osnovao prvu laboratoriju za eksperimentalnu psihologiju, možemo zaključiti da je psihologija napravila izuzetan pomak od bavljenja bihejvioralnim merenjima do otkrivanja načina na koji kognitivni sistem funkcioniše iznutra.

Ključne reči: primenjena psihologija, EEG/ERP, praćenje očnih pokreta, kognitivno modelovanje.