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THE EEG MARKER FOR INTENTIONAL GAZE DWELLS USED TO INTERACT WITH A COMPUTER IS INDEPENDENT OF HORIZONTAL GAZE DIRECTION

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Abstract. Gaze dwells can be used instead of mouse clicks in the interaction with computers. Recently, it was found that gaze dwells intentionally used to make moves in a game, but not spontaneous gaze fixations, are accompanied by a slow negative wave in the electroencephalogram (EEG) recorded from posterior locations. A new hybrid eye-brain computer interface (EBCI) based on the detection of this marker of intentional dwells was proposed to enable fluent interaction with computers (Shishkin et al., 2015, 2016). This marker was similar to the stimulus-preceding negativity (SPN), an EEG component specific for expectation of an informative stimulus, but apparently differed from the SPN by its gaze direction-dependent lateralization. In the current study, a more detailed analysis of data obtained in the same paradigm was used to clarify the nature of the intentional dwell marker. It was found that the EEG gaze direction-dependent asymmetry developed in the late part of dwells was independent of the intention factor. Thus, the slow negative wave in the intentional gaze dwells is itself not lateralized and fits well the pattern reported for the SPN. The apparent identity of the marker with SPN makes the EBCI a paradoxical system that responds to the user's expectation of its response.

Keywords: expectation, stimulus-preceding negativity, SPN, fixation-related potentials, eye-brain-computer interfaces, brain-computer interfaces, BCIs, passive BCIs, gaze interaction, gaze based control, EEG asymmetry

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Brain-computer interfaces (BCIs) and gaze-based interaction enable control of a computer without using the traditional manual tools such as a mouse or keyboard. However, noninvasive BCIs are slow and imprecise, while gaze-based interaction suffers from the "Midas touch problem" (Jacob, 1991): gaze patterns intentionally used for control, such as gaze dwell, often cannot be avoided during typical vision activity or mind wandering, so the system frequently issues unwanted commands. Recently, it was found that the gaze dwells intentionally used for control are accompanied by a slow negative wave in the electroencephalogram (EEG).

This wave can be used to differentiate such dwells from the spontaneous ones using a BCI (Shishkin et al., 2015, 2016). Importantly, the wave naturally accompanies intentional dwells, so a BCI for this task can be "passive" (passive BCIs recognize variations in the user's brain states that naturally occur, without requiring from the user to perform any additional mental task; Zander, Kothe, 2011). Relatively short (500 ms) gaze dwells were successfully classified as intentional or spontaneous. Thus, a fluent and relatively fast "eye-brain-computer interface" (EBCI) can be created using this EEG marker, with spatial accuracy depending only on its eye tracker component (Shishkin et al., 2015, 2016).

It was hypothesized that the EEG marker of gaze dwells intentionally used for control can be the stimulus-preceding negativity (SPN), because it was observed when participants expected the feedback (an informative stimulus, which is prerequisite for SPN) from the interface and because it was most pronounced in the occipito-parietal area (Shishkin et al., 2016). However, for extreme left and right gaze direction positions its focus was shifted contralaterally, an effect not known for the SPN (Van Boxtel, Böcker, 2004; Kotani et al., 2015). Understanding the nature of the marker and its dependence on various factors is important for further development of the technology and for understanding the brain mechanisms of interaction with external interactive systems (including other humans). The current study was designed to clarify why the focus of the SPN-like marker of gaze dwells intentionally used for control depends on the gaze direction.

Methods

We used data obtained in experiments aimed at the analysis of online EBCI performance (Nuzhdin et al., 2017; Nuzhdin et al., submitted), from the stages where the EEG was not used for online control. The participants in these studies were 14 healthy volunteers (4 female; age 18 to 50, median age 27). The experiment setup generally followed the study by Shishkin and colleagues (2016), although the gaze coordinates were now precisely recorded. For recording the EEG and the electrooculogram (EOG), an *actiCHamp* amplifier (*Brain Products*, Germany) was used. The EEG was recorded monopolarly from 19 positions, while the horizontal electrooculogram (hEOG) was recorded bipolarly; in both cases, high-pass filtering was not used. Gaze direction was recorded with the *EyeLink 1000 Plus* eye tracker (*SR Research*, Canada) using a head and chinrest. EEG, EOG and eye tracking data were obtained at a 500 Hz sampling rate. A gaze dwell was detected online when the gaze position range on each of the X and Y coordinates did not exceed 2° for 500 ms. The X median value during the first 500 ms of a gaze dwell was used as its X coordinate.

The participants played a simple gaze controlled game *EyeLines* using their gaze dwells only. A board with colored balls was presented on the computer monitor. To score, the participants had to put the balls of the same color into a line. Each move required three dwells: on a switch-on "button", on a ball, and on a free cell to which the ball was moved (see Fig. 1, top). Dwells that followed this order were considered *intentional* and evoked a visual feedback. A dwell on a ball was considered *spontaneous* (*non-intentional*) if not preceded by a dwell on the button

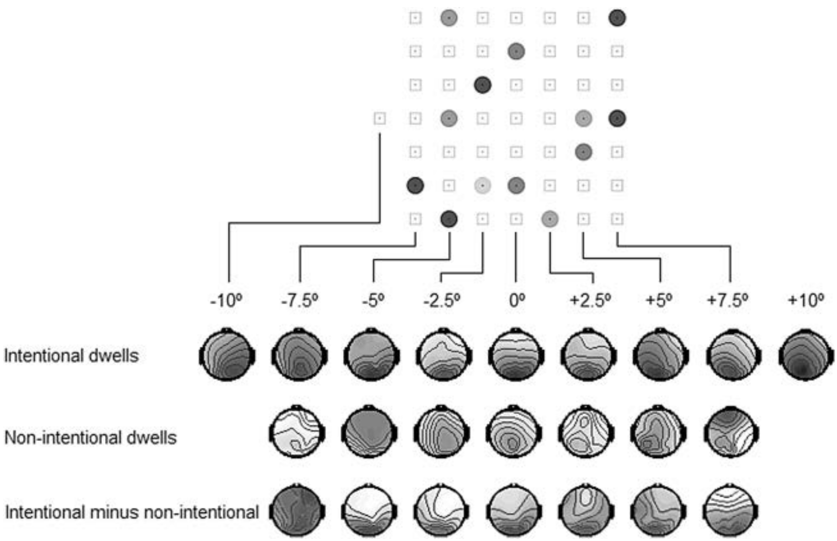

Figure 1. Game board (a screenshot) and grand average amplitude maps for dwells on the button and balls. The button was positioned to the left (as shown here) or right of the board. Amplitudes were averaged over the +400..+500 ms interval relative to the dwell start, with baseline being +200..+300 ms. A common amplitude scale was used for all maps, with the darkest color corresponding to −5 μV.

(for details, see Shishkin et al., 2016). In the current study, we did not analyze the free cell dwells because the marker amplitude was lower in these data. All components of the experiment, including EEG, EOG and eye tracking data synchronization and recording, online recognition of gaze dwells and the game presentation, were controlled by the *Resonance* software platform for multimodal interface prototyping (developed by Y. O.N.).

In the offline analysis, a baseline for the EEG and the hEOG was set at +200..+300 ms relative to dwell start (to prevent contamination of the EEG with EOG). For mapping and statistical analysis, EEG and hEOG amplitudes was averaged over a +400..+500 ms interval. ANCOVA and Spearman correlations were applied to individual data (a separate test was run for each participant).

Results and Discussion

Although the amplitude maps for the intentional dwells (see Fig. 1, upper row of scalp maps) confirmed the dependence of the amplitude distribution on the horizontal gaze position observed in the previous study (Shishkin et al., 2016), the difference maps (intentional minus non-intentional, bottom row) revealed no such dependence. We could not produce difference maps for the extreme locations, i.e. for the button, as all such dwells were intentional according to the experimental design. Moreover, the median number of the non-intentional dwells on the ball's extreme locations per participant was only 11.5 and 6 for the leftmost and rightmost columns of the game board (while it was 48 for the central column), so the averaged EEG data for the non-intentional dwells on these locations were imprecise. Nevertheless, the effects of intention (categorical factor with two levels: intentional and non-intentional) and X coordinate (continuous factor) could be differentiated using ANCOVA, applied to the EEG amplitude asymmetry assessed as the difference between mean amplitude over the right and left posterior channels in the +400..+500 ms interval. The index significantly ($p<.05$, not corrected) and consistently (always with negative regression line slope) depended on gaze X coordinate in 11 of the 14 participants (in 8 of them, with $p<.005$), but only in three of them on intention, while the interaction between the two factors was significant only in one participant. Thus, the apparent EEG asymmetry dependence on gaze in the late part of the gaze dwells is actually not specific to intention and expectation. The intention marker fits typical SPN topography and is highly likely a fixation-related SPN. In addition, no correlation was found between SPN amplitude measured at POz and gaze deviation to the left or right from the straight ahead direction.

In an attempt to clarify possible sources of the coupling between gaze direction and EEG asymmetry in the late part of the gaze dwells, we computed Spearman correlation coefficients for the same continuous variables and also between them and the hEOG amplitude. The correlation of EEG asymmetry with gaze direction was negative in all but one participant (median −.14 for intentional and −.16 for non-intentional dwells on balls; $p<.05$ in the majority of participants). EEG asymmetry correlation with the hEOG was even higher (medians −.23 and −.21, respectively), so one could wonder about possible EOG leakage into EEG. However, no consistent correlation was found between the gaze X coordinate and hEOG amplitude (medians −.02 and −.01, respectively). Visually examined EOG and EEG time courses also revealed no signs of EEG contamination by the EOG in the analyzed intervals. Although the nature of the EEG gaze-dependent asymmetry remained unclear, the data pattern suggested that the relation between hEOG and EEG asymmetry might indeed be caused by electric potential leakage, but in the opposite direction, from EEG to EOG. In addition, the EEG asymmetry did not correlate significantly with direction of the next saccade in all but one participant, so it was not likely caused by saccade preparation.

Conclusion

Horizontal gaze direction did not influence the EEG marker of the gaze dwells used as a "click" in the interaction with a computer. The gaze-dependent EEG asymmetry observed in the late intervals of the gaze dwells was not specific to intentional dwells. Taking together this result and the earlier evidence (Shishkin et al., 2016), it is highly possible that the marker of intentional dwells is the stimulus-preceding negativity (SPN), an EEG component observed under expectation of an informative stimulus. This means that the EBCI, in accordance with the earlier proposal by Ihme and Zander (2011), *responds to the user's expectation of the EBCI's response.*

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ЭЭГ-маркер намеренных задержек взгляда при взаимодействии с компьютером не зависит от горизонтальной составляющей направления взгляда

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Аннотация. Задержки взгляда могут использоваться как аналог «кликов» мышью при взаимодействии с компьютером. Недавно было обнаружено, что задержки взгляда, намеренно используемые для совершения ходов в игре, сопровождаются — в отличие от спонтанных фиксаций — возникновением медленной негативной волны в задних отведениях электроэцефалограммы (ЭЭГ). Детекция этого маркера намеренных задержек взгляда легла в основу нового интерфейса глаз-мозг-компьютер (ИГМК), предложенного для обеспечения свободного взаимодействия с компьютером (Shishkin et al., 2015, 2016). Маркер оказался близок к предшествующей стимулу негативности (ПСН), компоненту ЭЭГ, характерному для условий ожидания стимула, однако данные указывали на наличие латерализации, зависящей от направления взгляда, которая не свойственна ПСН. В настоящем исследовании для прояснения природы маркера намеренных задержек взгляда был проведен более подробный анализ данных, полученных в той же парадигме. Было установлено, что развивающаяся в поздний период задержки взгляда асимметрия ЭЭГ, зависящая от направления взгляда, не зависела от фактора намерения. Таким образом, медленная отрицательная волна, характерная для намеренных задержек взгляда, сама по себе не латерализирована и по изученным свойствам не отличается от ПСН. То, что маркер, по-видимому, является ПСН, означает, что ИГМК является парадоксальной системой, которая срабатывает в ответ на ожидание пользователем ее срабатывания.

Ключевые слова: ожидание, предшествующая стимулу негативность, ПСН, связанные с фиксацией потенциалы, интерфейсы глаз-мозг-компьютер, интерфейсы мозг-компьютер, ИМК, пассивные ИМК, взаимодействие с помощью взгляда, управление с помощью взгляда, асимметрия ЭЭГ