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Measurement of Attention during Movement: Acquisition of Ambulatory EEG and Cognitive Performance from Healthy Young Adults

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Abstract— **Non-invasive methods of recording human electro-cortical brain dynamics during normal daily activities would have far-reaching clinical benefits. The literature suggests a strong link between gait and cognition, where attention is seen to play a central role. This study investigated if clinically useful electrophysiological measures of attention can be collected using an auditory oddball task in ecological/non-clinic environments through analysis of the amplitude and latency of auditory P3 event related potentials (ERPs). Electrophysiological (EEG, EOG, EMG) recordings were taken for 7 healthy subjects while presented with an auditory oddball task. Data was recorded in control, static (seated) and dynamic (fixed cycling) experimental conditions. Recordings were also taken for two subjects during treadmill walking. P3 ERPs were calculated and data analysis showed that peak amplitude and component latency remained stable across all experimental conditions. For the Cz electrode position there were 0.2-2% P3 amplitude and 3-9% P3 latency differences. P3 amplitude and latency also remained stable between experimental conditions for all electrode locations. This result opens up the possibility to quantitatively investigate the interaction between gait and attention during the ageing process but also in movement disorders such as freezing of gait in Parkinson's disease.**

I. INTRODUCTION

Recording human electro-cortical brain dynamics non-invasively during normal daily activities would have far-reaching clinical benefits. While this is not yet possible due to limitations in our understanding and measurement of neural processes involved in complex physical movement, the literature does suggest a strong link between movement and cognition[1, 2]. Attention is seen to play a central role in gait and locomotion[3], in particular as we age and with increased frailty. This study investigates if clinically useful electrophysical measures of attention can be collected using an auditory task during sitting, walking and cycling and the differences in amplitude and latency between such signals, where a reduction in amplitude or increase in latency may indicate cognitive decline or cognitive load.

Current practice of simultaneously measuring attention and movement is inadequate. Kinematic studies have mainly focused on using motion sensing systems, which are precise and quantitative, but do not allow simultaneous neural activity recording to measure attention[4]. In these studies indirect behavioral measures such as neuropsychological test scores are used to measure attention. The ability to measure changes in attention through recording neural activity during normal daily activities such as fully ambulatory walking would be highly clinically beneficial.

However, current technology allows neurophysiological recordings to be taken in only extremely restrictive clinical environments as electroencephalogram (EEG) signals are thought to be too susceptible to contamination[5]. Any studies recording neural activity during motion have mainly focused on controlled motion using exercise machines (use of treadmills and exercise bicycles)[6-10]. Therefore, developments in neural activity recording and processing are needed to allow more objective methods of recording motion and attention simultaneously. This would allow insight into the extent at which attention varies during performance of a specific motor task.

EEG is the best-suited neuroimaging system for use in ambulatory applications due to the excellent temporal resolution and the portability of recording devices. Individual EEG studies are also less expensive to perform than alternative neuroimaging methods such as fMRI or PET. However, EEG is rarely used outside of clinical environments due to movement and environmental limitations. EEG can be contaminated from many conditions found in ecological environments such as illumination, electrical interference, uncontrolled environmental conditions as well as electromyographic activity (EMG), electrode movement, perspiration and increased electrooculographic activity (EOG) from subject movements.

The aim of this study was to obtain EEG recordings during ecological environments during sitting, cycling and walking test conditions and to investigate if the cognitive measurements of attention are comparable across each environment.

This study examined subject responses elicited by a standard, two-tone auditory discrimination task (the oddball task[11]) in four different environmental conditions. The experimental design follows a progression into more valid ecological environments by increasing motor tasks from sitting to cycling to treadmill walking experimental conditions.

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II. PROCEDURE

Methods

Electrophysiological (EEG, EOG, EMG) recordings were taken for 7 healthy subjects (aged 22 – 32 yrs, 4 female) while presented with an auditory oddball task. Data was recorded in control, static (seated) and dynamic (fixed cycling) experimental conditions. Recordings were also taken for two subjects during treadmill walking. Both cycling and walking occurred at a self-selected comfortable pace for the duration of the recording.

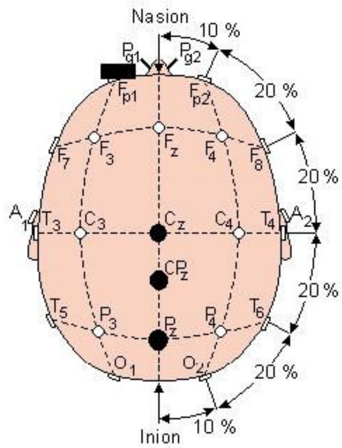

Figure 1: The 10-20 EEG electrode placement system[12] and position of Cz, CPz, Pz and Fp1 (facial EMG)

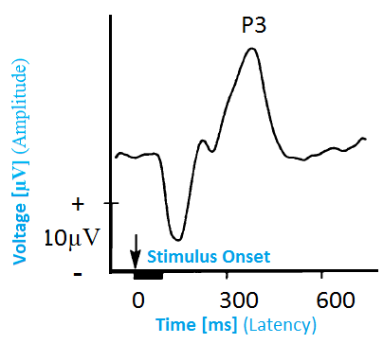

Figure 2: The auditory P3 Component – an objective measure of cognitive function. P3 occurs approximately 300 [ms] after onset of stimulus[13]

The auditory oddball task lasted seven minutes and required subjects to react to target stimuli (oddball probability of 0.2, 41 target stimuli) which occurred in a stream of more frequent non-target stimuli (probability 0.8)[11]. Target and non-target events (1000 Hz and 500 Hz tones respectively) each presented for a duration of 60ms in a pseudo-random fashion, were performed using Presentation® software, Version 0.70[14]. Subjects were asked to respond by a button press immediately after hearing the target stimulus and were instructed not to react upon hearing the non-target stimuli. Each experiment consisted of four, seven-minute long blocks of the auditory oddball task.

A Biosemi[15] data acquisition system was used to record information from eight electrodes (three EEG, a reference mastoid, one EOG and three EMG electrodes). Gait activity was recorded from two EMG electrodes which were placed on the right lateral and medical soleus muscle on the calf which has been shown to be active once per gait cycle. EEG activity was recorded from three midline electrode sites at the vertex of the head (Cz, CPz and Pz according to the 10-20 system[16]) using an elastic electrode cap[15], see Fig. 1. EOG and facial EMG (Fp1 in Fig.1) were recorded from above and below the left eye. Data were referenced to the left mastoid. Data were sampled at 512 Hz for control, static and cycling experiments and 1024Hz for the treadmill experiment due to EMG recording restrictions.

The control experiment, to provide a basis for comparison, followed standard clinical practice whereby subjects were instructed to sit in a dark room, with feet flat on the ground without moving for the duration of the experiment except to click the mouse button and to refrain from blinking as much as possible. A static experiment recorded EEG activity in an illuminated recording environment in order to ascertain effect of illumination on recordings so as to allow comparison with cycling and treadmill experiments, which needed to be performed in illuminated environments.

The third experimental condition included a motor task by way of a light intensity cycling exercise performed on a stationary exercise bicycle. The intensity of the exercise was chosen to reduce perspiration and maintain a steady body temperature and heart rate. Subjects were asked to sit upright, with minimal upper body movement and to maintain a steady cycling velocity. Subjects began cycling approximately four minutes before the oddball task started to allow settling of skin conductance.

The final experiment was a treadmill walking experiment with constant speed and direction. Subjects were asked to maintain a steady walking speed and to try to curtail their vertical motion while walking and minimize sway of arms and body.

Subjects began the motor task a few minutes before the cognitive task began, both to familiarize themselves with the procedure and to allow skin impedances to reach a steady-state level.

III. DATA ANALYSIS

P3 event related potentials (ERPs), see Fig. 2, were calculated as a measure of cognitive activity, specifically reflecting attention and context updating[17]. P3s are considered a measure of cortical activity when processing complex information and are assessed by means of its two main components: amplitude and latency. Reduction in amplitude or increase in latency can indicate cognitive decline or cognitive load. In addition, P3 amplitude and latency has been correlated with neuropsychological test scores during aging[18].

Data analysis included filtering, referencing and data epoching and epoch averaging to achieve a clear ERP and P3 waveform. Filtering included high pass (1Hz), notch (47-53Hz) and low pass (95Hz) filtering to remove baseline drift, powerline noise and EMG activity from the signal respectively. Epoching included automatic epoch rejection 600 ms post stimulus and visual inspection of EOG and Fp1

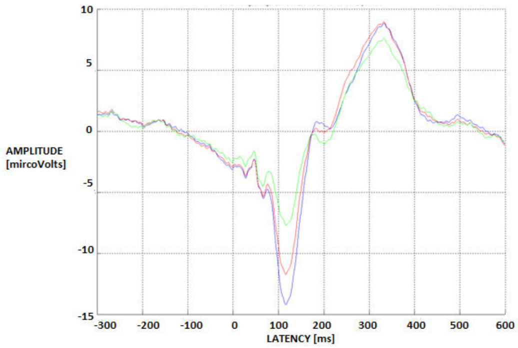

Figure 3: Subject grand averaged target stimulus response ERP data for control experiment at each electrode location (Cz (blue), CPz (red), Pz (green)): P3 occurring approximately 300 ms after onset of stimulus (based on 7 subjects).

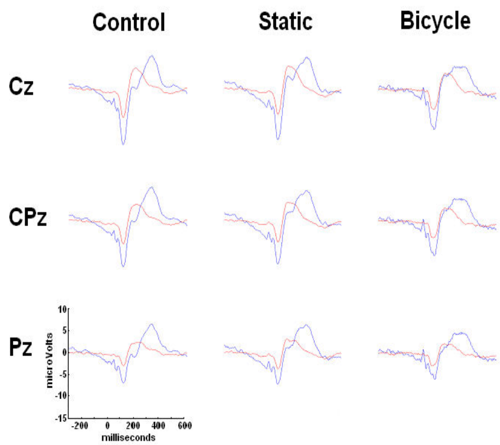

Figure 4: Subject grand averaged target and non target stimulus response ERP data (based on 7 subjects) – typically target (blue) response peaks have higher amplitude and longer latencies, compared with non-target (red) response peaks.

TABLE I. SUBJECT GRAND AVERAGED RESPONSE FOR CONTROL, STATIC AND CYCLING CONDITIONS AT EACH ELECTRODE LOCATION (CZ, CPZ AND PZ) (N= 7)

	Subject Grand Averaged P3 Amplitude and Latency		
	Electrode	***P3 Amplitude (μV)***	***P3 latency (ms)***
Control	Cz	8.85	330.86
	CPz	8.96	327.93
	Pz	7.62	327.93
Static	Cz	8.40	325.00
	CPz	8.00	318.16
	Pz	7.41	315.23
Bicycle	Cz	6.07	328.91
	CPz	5.98	325.98
	Pz	5.31	327.93

TABLE 2: SUBJECT GRAND AVERAGED RESPONSE FOR CONTROL, STATIC, CYCLING AND TREADMILL CONDITIONS AT EACH ELECTRODE LOCATION (N= 2)

	Subject Grand Averaged P3 Amplitude and Latency		
	Electrode	***P3 Amplitude (μV)***	***P3 latency (ms)***
Control	Cz	8.66	322.07
	CPz	9.37	322.07
	Pz	5.83	356.25
Static	Cz	9.32	320.12
	CPz	8.83	319.14
	Pz	7.86	322.07
Bicycle	Cz	9.76	325.00
	CPz	9.73	325.98
	Pz	8.79	333.79
Treadmill	Cz	9.57	282.52
	CPz	9.60	278.13
	Pz	8.00	291.80

channels to remove eye blinks. Peak P3 amplitudes and latencies were taken as the maximum value of average P3 peaks. Markers of muscle activity and inactivity were used on EMG data taking a threshold of greater than 200µV and 500ms after last stimulus.

P3s were averaged for all target and non-target stimuli for all subjects for each electrode position and peak amplitude and latency investigated as per Table I and II.

IV. RESULTS

Auditory P3 data analysis which can be observed in Fig 3, Fig 4 and Table I for the control, static and cycling conditions for seven subjects showed that peak amplitude and component latency remained stable across all experimental conditions. For the Cz electrode location, differences in P3 amplitude were 0.2-2% while P3 latency differences were 3-9%. There were no observed differences in P3 amplitude or latency between experimental conditions for all electrode locations.

A P3 signal was also recorded for the treadmill study which can be found in Table II for the control, static, cycling and treadmill conditions for two subjects where the P3 amplitude and latency also remained stable.

V. DISCUSSION

Concurrent neuroimaging of motion and cognitive measures has traditionally been restricted by brain imaging constraints. However by investigation of the P3 ERP, using new active EEG technology, new opportunities to probe cognitive function during real life tasks is possible. The P3 is believed to underlie the neural mechanisms required to respond to changing cognitive demands, specifically attention and memory interaction. Here recording of attentional resources in non-clinical environments (while sitting, cycling and walking) has been shown to be possible for an auditory oddball task. It was found that P3 latency did not vary significantly across the four experimental conditions. This is consistent with findings that performance of a visual cognitive task during a relatively simple motor task did not present a significant change in P3 latency in healthy young adults. This positive result opens up the possibility of recording electrophysical parameters during motion for patients with gait and cognitive disorders in more ecological environments, which would allow investigation of the effect of neurodegeneration on daily activities.

Future research should focus on increasing subject numbers, increasing experimental trials per subject to gain more accurate and statistically significant results and investigating different tasks to explore more cognitive sub-domains.

Most experimentation reported in the literature in the domain of gait and cognition has been carried out with non-primates. However, there has been limited literature showing neuroimaging of human movement to be possible. A review of the literature found some studies involving motor tasks such as shooting, driving and golf-putting but the experimental protocol for these studies was generally very restrictive, with muscle activity extremely limited and movement kept to a minimum[5, 7, 9]. Success has been reported with EEG signal acquisition during performance of only very restrictive motor tasks in extremely controlled clinical environments.

Therefore, it is encouraging to observe that the P3, a measure of cognitive function, can be recorded during cycling and on a treadmill. Full ambulatory monitoring that allowed investigation of gait and cognition quantitatively and precisely in more ecological environments would be highly beneficial. However, until technology advances allow recording of accurate quantitative neural measures or processes during substantial movements links between gait and cognition will have to be investigated separately using quantitative gait measures and indirect behavioral measures, such as neuropsychological test scores.

In this study we have shown that it is possible to quantitatively and precisely measure attention during controlled movements using EEG. This platform allows investigation of attentional cues in more ecological or real world environments thereby advancing neurological measurement systems. However, technology and analysis methods need to be improved to allow simultaneous recording of cognition and less restrictive movements. This would allow ambulatory EEG to be used to investigate changes in attention on performance of gait in studies on aging and freezing of gait in Parkinson's disease [19].

VI. Conclusion

The necessity for restrictions on movement during neurophysiological recordings means our understanding of the neural processes involved in complex physical movement and measurement of such processes are limited. However, with recording of attentional resources in non-clinical environments shown to be possible here it opens up the possibility of investigating the link between gait and attention by recording attentional resources through electrophysiological parameters such as the P3 component during motion for patients with gait and movement disorders.

Acknowledgment

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