



## Short communication

# A simple procedure to synchronize concurrent measurements of gait and brain electrical activity and preliminary results from a pilot measurement involving motor-cognitive dual-tasking in healthy older and young volunteers



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## ABSTRACT

**Background:** The ability to record brain activity under normal walking conditions is the key to studying supraspinal influence on spinal gait control.

**New method:** We developed a procedure of synchronizing an electronic walkway (GAITRite, CIR Systems Inc.) with a multi-channel, wireless EEG-system (BrainAmp, BrainProducts).

To assess the practicability of our procedure we performed a proof of concept measurement involving concurrently recording gait pattern and brain electrical activity in two elderly and two young participants. This measurement enabled us to assess the synchronization of the two data sets under realistic conditions. **Results:** Only carrying a filled water glass reduced gait regularity in the elderly. In the young gait regularity was constant across all tasks. This concurs with previous findings reporting a task specific influence on gait. Carrying a full water glass also led to an increase in the power of the EEG gamma-band oscillations in frontal cortex of the elderly, but led to a decrease in the young participants. Carrying a full glass increased activity in frontal cortex of the elderly but decreased it in the young participants.

**Comparison with existing methods:** At present, concurrent recording of gait pattern and electrical brain activity requires participants to walk on a treadmill. Our procedure enables these measurements to be made under natural walking conditions. This allows measurements of brain activity during walking in special needs groups such as children, the elderly or the infirm under near natural conditions.

**Conclusions:** Our procedure for synchronizing EEG and gait proved simple, reliable and generated data of high-quality.

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## 1. Introduction

The ability to relate brain activity to locomotor activity is the key to studying the influence of supraspinal processes on gait. Gait cycle dependent fluctuations in the power of  $\alpha$ -,  $\beta$ - and  $\gamma$ -band of the brain electrical signal have been reported over frontal, parietal and central cortex of healthy adults walking on a treadmill (Gwin

et al., 2011); demonstrating that electroencephalography (EEG) can be used to reveal changes in brain activity during walking.

Assessing gait-related brain activity using a treadmill has a number of limitations. The first is that very young, old or infirm individuals feel uncomfortable or even anxious when walking on a treadmill. A sense of unease or even anxiety may distort measurements of gait-related brain activity. To obtain an EEG-signal untainted by emotional reactions, special needs patients have to be measured under the most natural walking conditions possible (Beurskens and Bock, 2012). A second and more important limitation is that using a treadmill precludes an assessment of the influence of cognitive tasks on gait, as walking pace cannot vary spontaneously, as it is determined by the speed of the motor

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driving the treadmill belt. An electronic walkway is a carpet 0.9 m wide and up to 7 m in length. Walking on such a walkway is like walking on a carpet, something familiar to most. Individuals can therefore vary their pace freely, thus allowing the influences of cognitive tasks on gait to be assessed. An electronic walkway is reliable and commonly used instrument to assess walking behavior under natural walking conditions. A wireless EEG system allows brain electrical activity to be recorded without the risk of a participant being impeded by wires. To relate brain activity to gait phase, the data from an electronic walkway and EEG need to be synchronized.

This paper describes the procedure we developed to synchronize data from an electronic walkway with data from a wireless EEG-system. Our electronic walkway could not provide an electric pulse at a regular interval, something that would have enabled us to determine the accuracy of the synchronization. To assess synchronization, we performed a proof of concept measurement involving two elderly and two young participants. We looked for task-specific modulation of gait regularity and brain activity to different cognitive tasks in a motor-cognitive dual-task setting. We chose this approach, because in the elderly, the former has been shown to be modulated by the nature of the cognitive task (Beauchet et al., 2005) and act as a reliable indicator of cognitive-motor interference as well as for an elevated fall risk (Bridenbaugh and Kressig, 2011). If synchronization between gait and EEG data was accurate, we expected to observe task-related changes in brain activity that mirrored gait regularity.

## 2. Material and methods

Gait measurements were performed using a 13 m walkway, composed of a 7.92 m electronic walkway (GAITrite, CIR Systems Inc., Sparta, NJ, USA) with approximately 30,000 integrated pressure sensors operating at a scanning frequency of 60 Hz and two 2.5 m dummy sections, one placed at either end of the electronic walkway. Brain electrical activity was recorded using a scalp cap with 32 active electrodes (ActiCap32, MES, Gilching, Germany). Electrode holders were distributed across the scalp following the International 10/20 system. The electrodes wires connected to a small transmitter (MOVE 32, MES, Gilching, Germany), weighing 0.12 kg and measuring 0.042 m × 0.048 m × 0.060 m and worn attached to a belt around the waist by a Velcro patch. A ground (Fz) and a reference electrode (FCz) were connected separately. The receiver has a certified range of 6 m and was positioned half-way along the walkway. It was connected to the EEG-amplifier (QuickAmp, MES, Gilching, Germany), which in turn connected to laptop PC. The sampling rate of the EEG was set to 250 Hz. Preliminary testing showed that wearing the EEG head cap, electrodes and transmitter did not influence gait.

We made a trigger cable by soldering the ground wire of a three-pole cable at one end to the “sleeve” of a 3.5 mm TRS connector. One of the remaining wires was then soldered to the “ring”, the other to the “tip” of the TRS connector. At the other end, we connected the ground wire to pin 18 of a male 25pin D-sub connector and connected pins 18–25 by soldering a wire across them. One of two remaining wires was connected to pin 1 the other to pin 2 of the D-sub connector. The TRS plug was connected to the “SYNC OUT” output of the control box of the electronic walkway. The D-type connector was plugged into the parallel port of the EEG amplifier. To synchronize the two systems we initiated a 5 V TTL pulse from the walkway on initial contact. This was achieved by activating “Event Capture” in the “Metronome and External Event Triggers” window of the “Metronome Setting/Reverse sync” of the “Settings” runner in the GAITrite application. In our set-up the TTL pulse appeared as a marker with the numeric value ‘3’ in the EEG data. The two data sets were thus synchronized to first foot contact with the electronic walkway.

## 3. Experimental

We measured two healthy, elderly volunteers (male 78 years, female 71 years old) and two healthy young volunteer (male and female both 26 years old). All had given their informed, written consent to participate in the measurement. Participants were asked to walk along the walkway at a normal, self-selected pace several times, until 50 steps were registered. An assistant accompanied participants during each walk, ready to grab a safety belt if necessary. Measurements were performed while walking only (single-task) and while performing the following cognitive tasks (dual-task):

- 1) Empty glass: Carrying an empty water glass (Iittala, Aino Aalto, Tumbler 0.33l) in one hand
- 2) Full glass: Carrying the water glass filled to the ridge just below its rim
- 3) Counting: Serial subtraction in steps of 3 from a three digit number provided just before each walk
- 4) Four finger tap: Repeatedly tapping each finger in succession against the thumb

In conditions (1), (2) and (4) the left and right hand were measured separately but combined in the analysis.

## 4. Calculation

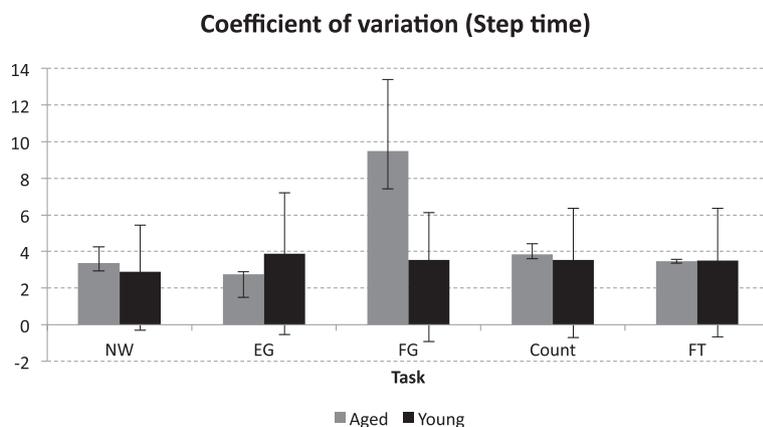
The data from the electronic walkway was processed using the manufacturer’s software “GAITrite 4.7”. To ensure that all foot prints were reported, we instructed the software not to remove partial foot prints at the beginning and end of each walk. Heel strike and toe off times for all foot falls were exported, stored and read into Microsoft Excel 2013. Excel was used to calculate all results reported here. To assess the influence of the cognitive task on gait regularity, we calculated the coefficient of variation using the formula  $CoV = ((\text{mean stride time} \times 100) / SD)$ .

The number of calculations per stride was used as a measure of cognitive performance. It was derived by dividing the total number of subtractions performed by the total number of strides taken during the serial subtraction condition.

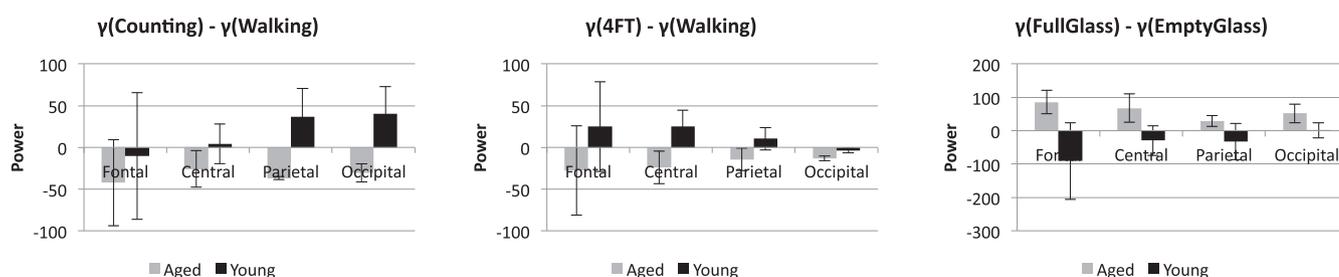
The EEG-data was processed using the manufacturer’s software, “Analyzer 2.04”. Pre-processing of the data involved band pass filtering (Min: 0.5 Hz, Max: 80 Hz, Slopes: 48 dB/Oct, 24 dB/Oct). Eye blink artifacts in the EEG data were removed using the “Ocular Correction ICA” module. Remaining artifacts were removed using the “Artifact Removal” module. Finally any remaining artifacts were identified by visual inspection and removed. After artifact removal, the signal from each electrode was re-referenced against the average signal from all electrodes. In addition the re-referenced signal from electrode FCz, was reintroduced into the dataset.

To obtain the EEG signal to each step, we edited the “marker” file associated with the EEG data and insert additional markers representing the time of each heel strike on the electronic walkway. Left and right footprints were identified using separate markers. The time of each footprint was calculated relative to first foot contact with the electronic walkway. The time of each footprint was adjusted for the sampling rate of the EEG-measurement before being recorded in the “marker” file.

Starting at each marker the EEG data was divided into epochs corresponding to mean stride time of a walk. These epochs were subjected to a fast-Fourier transformation to obtain the temporal frequency spectrum of each epoch. The temporal frequency spectrum for a specific task was calculated by averaging the temporal frequency spectra of all epochs for a specific task. To ascertain the activity of frontal cortex we averaged the values of the electrodes



**Fig. 1.** Gait regularity represented by the coefficient of variation (CoV) of stride time during the different measurement conditions. The end of the error bars marks the individual values.



**Fig. 2.** The graphs in the left and middle column show the difference in mean power of the  $\gamma$ -band when participants counted or tapped their fingers while walking and when walking only. The graph in the right column shows the difference in power of  $\gamma$ -band when the participants carried a filled and empty glass. The end of the error bars marks the individual values.

Fp1, Fp2, F7, F3, Fz, F4 & F8, to ascertain the activity of central cortex we averaged the values from electrodes C3, Cz & C4, to ascertain the activity of parietal cortex we averaged the values from electrodes P7, P3, Pz, P4 & P8 and to ascertain the activity of occipital cortex we averaged the values from electrodes PO9, O1, Oz, O2 & PO10. Power in the  $\alpha$ -,  $\beta$ - and  $\gamma$ -band of the two elderly and two young participants was then separately averaged.

## 5. Results

Average stride time of the young participants was 1224 ms (1188 ms, 1261 ms), that of the elderly 1238 ms (1263 ms, 1213 ms). The high and low values are given in brackets. The CoV of stride time in the elderly and young participants was the same for all but the task involving carrying a filled water glass. In this task the CoV of stride time of the elderly participants was considerably higher, i.e. less regular than that of the young participants (see Fig. 1). In the young participants the CoV of stride time in did not vary between the cognitive tasks. The number of calculations per stride achieved by the young participants was slightly higher than that of the elderly (0.88 vs. 0.74). The young female reached 0.72, the young male 1.03 and the two elderly attained 0.74 each.

The “first contact” trigger signal appeared reliably in the EEG data and none of the EEG artifacts could be attributed to heel strikes. Extracting the times of the individual foot falls and inserting them as markers in the EEG data took 5 min for each measurement. Compared to walking only, performing serial subtractions or finger tapping during walking increased the power in the  $\gamma$ -band over frontal cortex in the young participants but decreased it in the elderly participants (Fig. 2). Compared to carrying an empty water glass, carrying a filled water glass increased the power of the

$\gamma$ -band over frontal cortex in the elderly participants but decreased it in the young participants.

## 6. Discussion

Our proof of concept measurement demonstrated the practicality of our procedure and indicated that synchronization of the two data sets is sufficiently accurate to reveal task specific differences in brain activity that mirror differences in gait regularity. The lack of difference in both average walking speed and arithmetic performance between the two age groups indicated a high level of physical and mental fitness of the two elderly participants. Carrying a full water glass was the only task to adversely affect gait regularity in the elderly participants and confirms previous findings for task-dependent sensitivity of gait regularity (Beauchet et al., 2005). The raised  $\gamma$ -band activity over frontal cortex of the elderly when carrying a full glass, can be interpreted to indicate that either, the activity of frontal cortex was elevated in the elderly participants because they found the task more demanding or because frontal cortex had to contribute more strongly to the processing involved (Pantev et al., 1994).

While our proof of concept measurement involved a small sample, the results are consistent with established observations and so serve as an indication that our procedure is sufficiently robust to warrant a study involving a larger sample size.

## 7. Conclusion

The method described for synchronizing measurements of gait and brain electrical activity, is technically simple and yields

high-quality data, making it suitable for studying walking behavior and its neuronal correlate across all age groups.

#### Author contributions

All authors contributed to the preparation and submission of the manuscript. Authors VLM and SAB were involved in collecting and analysing the EEG and gait data.

The work reported here was carried out at the University Basel, University Center for Medicine of Aging Basel, Basel Mobility Center, Schanzenstrasse 55, CH-4031 Basel, Switzerland.

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