1 **Influence of dual-tasking with different levels of attention diversion on**

2 **characteristics of the movement-related cortical potential**

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1   **Abstract**

2   Dual tasking is defined as performing two tasks concurrently and has been shown to have a significant effect
3   on attention directed to the performance of the main task. In this study, an attention diversion task with two
4   different levels was administered while participants had to complete a cue-based motor task consisting of foot
5   dorsiflexion. An auditory oddball task with two levels of complexity was implemented to divert the user's
6   attention. Electroencephalographic (EEG) recordings were made from nine single channels. Event-related
7   potentials (ERPs) confirmed that the oddball task of counting a sequence of two tones decreased the auditory
8   P300 amplitude more than the oddball task of counting one target tone among three different tones. Pre-
9   movement features quantified from the movement-related cortical potential (MRCP) were changed
10 significantly between single and dual-task conditions in motor and fronto-central channels. There was a
11 significant delay in movement detection for the case of single tone counting in two motor channels only (237.1
12 to 247.4 ms). For the task of sequence counting, motor cortex and frontal channels showed a significant delay
13 in MRCP detection (232.1 to 250.5 ms). This study investigated the effect of attention diversion in dual-task
14 conditions by analysing both ERPs and MRCPs in single channels. The higher attention diversion lead to a
15 significant reduction in specific MRCP features of the motor task. These results suggest that attention division
16 in dual-tasking situations plays an important role in movement execution and detection. This has important
17 implications in designing real-time brain-computer interface systems.

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19 **Keywords:** Attention, Dual-tasking, movement-related cortical potential, brain-computer interface, Auditory oddball

1. Introduction

Brain-Computer interface (BCI) systems in the neuro-rehabilitation field aim to reduce disability of patients by using brain signals to control a device or a computer. Changes in these signals due to internal factors, such as attention variations, or external factors, such as electrical stimulation, influence the performance of BCI systems. Therefore, there have been several previous attempts to quantify the impact of these parameters on BCI systems (da Silva-Sauer et al., 2015; Diez et al. 2015; O'Sullivan et al., 2015). For example, during execution of challenging mental tasks, spectral features of EEG signals were used to detect changes in fatigue, frustration and attention on a single trial basis (Myrden and Chau, 2017). The classification accuracy of these three mental states was on average 71.6-84.8%, making them feasible to use in an online BCI system. During a motor task, where participants are asked to focus their attention on the kinesthetics of their legs moving during a passive pedaling task, attention and inattention (mind wandering) could be classified using spectral features of EEG signals with an accuracy of 61 to 68% (Melinscak et al., 2016). Besides frequency features, the characteristics of the waveform of the P300 have also been used to reveal alterations in attention (Huang et al., 2015; Linden, 2005). The P300,a positive deflection in the EEG signal first described by Sutton et al.(Sutton et al., 1965), is an event-related potential that is time locked to a visual or auditory stimulus. Although it has been used with success in BCI applications, specifically for communication and environmental control (Krusienski et al., 2008), it is commonly implemented for the quantification of attention and working memory (Huang et al., 2015; Linden, 2005). It may thus be an ideal signal modality to better understand the effects that attention has on the performance of BCI systems.

In the last decade, we have worked towards the design of an online associative BCI system for the rehabilitation of gait in stroke patients. Here the movement related cortical potential (MRCP) elicited by attempted dorsiflexion movements of the affected ankle joint is detected and used to control the activation of an electrical stimulator that provides a single stimulus to the deep branch of the common peroneal nerve. The nerve activation is timed such that the generated afferent signal arrives at the motor cortex during the peak negative (PN) phase of the MRCP. With this intervention, we have shown significant plasticity induction at the motor cortex, accompanied by functional changes in chronic and sub-acute stroke patients (Mrachacz-Kersting et al., 2017; Mrachacz-Kersting et al., 2016). The advantage of using the MRCP as the control signal in an associative BCI is that it can be detected approximately 1-2 seconds prior to movement execution and that the time of the peak negative phase is stable within a patient and session, ensuring precise timing in eliciting the afferent volley. To allow this system to be used in the clinical setting we have worked towards minimizing the number of electrode sites required for reliable detection of the MRCP (Jochumsen et al., 2014). In addition, since it is known that attention can modulate plasticity induction (Stefan et al., 2004), we have investigated the effects of artificially imposed attention shifts on the detection of the MRCP as part of the associative BCI using both spectral and time features (Aliakbaryhosseinabadi et al., 2015; Aliakbaryhosseinabadi et al., 2017; Aliakbaryhosseinabadi et al., 2017).

The aim of this study was to quantify the specific electrode sites and features of the MRCP that are necessary to detect changes in attention during the use of a MRCP-based BCI. Further, we investigate whether it is possible to differentiate between different levels of attention to a target task. For this purpose, healthy participants were asked to perform either a primary task

1   consisting of a visually cued overt (real) foot movement or a dual task with two levels of complexity consisting of the primary

2   task and a secondary task comprised of counting the number of a defined target in an auditory oddball cue. The complexity

3   of the secondary task was altered by varying the sequence of tones that had to be counted from identifying a single tone

4   (simple dual task (SDT)) to a sequence of tones (complex dual task (CDT)). The experimental procedure is illustrated in Fig.1.

5   MRCP features, extracted from nine EEG channels, were analyzed to quantify changes in movement preparation and their

6   effects on the detection accuracy. The changes in the level of attention were quantified by the amplitude of the P300. We

7   hypothesized that the dual task condition would result in a decreased P300 amplitude and a decreased performance of the

8   main task as quantified by a delayed onset and decreased amplitude of the electromyography (EMG) signal of the prime

9   mover (Tibialis anterior). We further hypothesized that the amplitude of PN of the MRCP would decrease and the variability

10   of the MRCP in the preparation phase increase, thus decreasing the detection accuracy of the BCI system.

11   **2. Results**

12   2.1 ERP analysis and task performance

13   The results of the comparison of the control levels between the two groups indicated that the P300 amplitude was not

14   significantly different for either the visual cue ($F_{(1,22)}= 0.9$, P >0.05) or for the auditory task ($F_{(1,22)}= 1.2$, P >0.05). However,

15   in the dual-task condition the P300 amplitude was significantly different between the two groups of difficulty only in the task

16   with the auditory oddball cue ($F_{(1,22)}= 14.6$, P < 0.004) but not in the visual cue ($F_{(1,22)}= 0.01$, P >0.05). Fig. 2e and 2f illustrate

17   the average P300 amplitude across all participants and groups for both the visual and the auditory cue.

18   The P300 amplitude of the task based on the auditory oddball cue was significantly increased only for the control versus the

19   CDT ($F_{(1,11)}= 29.9$, P< 0.001) . According to the visual cue, the P300 amplitude was decreased from control to CDT or SDT

20   level but not-significantly as illustrated in Fig. 2.

21   The performance of SDT was significantly better than the CDT as quantified by a lower oddball error ($F_{(1,22)}=25.5$, P<0.001;

22   SDT: 6.4$\pm$ 6.8 %, CDT: 28.5$\pm$ 24.1%). The reaction time was significantly increased only for the control versus the CDT

23   level ($F_{(1,11)}=21.9$, P<0.004; control:212$\pm$ 12.6 ms, CDT: 254$\pm$ 16.5 ms). The reaction time of CDT was also higher than SDT

24   condition but not-significantly.

25   The mean correlation coefficients of all trials within the control block showed no statistically significant difference compared

26   to those of the SDT ($F_{(1,11)}= 1$, P> 0.05) and CDT ($F_{(1,11)}= 3.1$, P> 0.05, two-way rmANOVA). This indicates that the

27   participants performed the main task of dorsiflexion in a similar manner. However, the EMG mean correlation coefficients

28   were significantly higher for the SDT ($F_{(1,22)}= 19.5$, P < 0.004; 0.76$\pm$0.08) compared to the CDT level (0.6$\pm$0.14).

29   2.2 Peak negativity comparison

30   Fig. 3 illustrates the average MRCP from nine single channels in the single and dual-task conditions for both levels of task

31   difficulties. The motor cortex and fronto-midline channels show more significant differences between the control and dual-

task both for SDT and CDT. Two-way rmANOVA revealed no significant interaction between movement blocks and task demand for all channels. Statistical analysis for the Control-CDT experiment demonstrated a significant difference between these two levels in Cz ($F_{(1,11)}$=19, P = 0.002). In the Control-SDT experiment, none of the channels represented significant differences from control to SDT level. In spite of the task demand effect, movement blocks revealed no statistical changes in any of the channels in both experiments (P>0.05). No significant variations were found in time of peak negativity measurements (P>0.05). Fig.3 shows that the time of the negative peak in the MRCP signals was similar in different movement blocks and also in both task demands.

2.3 Pre-movement amplitudes

Between the two extracted pre-movement amplitudes, the second negativity drift was significantly different based on the task demand in the control-CDT experiment in channels of FCz ($F_{(1,11)}$=14.4, P = 0.003), C1 ($F_{(1,11)}$=14.9, P = 0.003), C2 ($F_{(1,11)}$=15.6, P = 0.002) and C4 ($F_{(1,11)}$=14.8, P = 0.003) and in the control-SDT experiment in C2 ($F_{(1,11)}$=18.3, P = 0.001) (Table 1).

2.4 Pre and post phase slopes

Slopes in the range of one second before time of peak negativity to this point were different between the two task demands in both experiments (Fig. 3). This was similar for the three movement blocks. However, the slopes in the range of 2 seconds before time of peak negativity to this point look different particularly in the Control-CDT. Interestingly, statistical analysis revealed that in this experiment both slopes significantly decreased in the CDT in channels Cz ($F_{(1,11)}$=17.5, P = 0.002) and C4 ($F_{(1,11)}$=35.7, P < 0.001). However, in the SDT condition, none of the nine selected channels represented significant differences (P>0.05). None of the pre-phase slopes are statistically different among the movement blocks (P>0.05). A summary of the significantly different channels are presented in Table 1.

No significant differences were found for the post-phase slope based on both dependent factors (P>0.05).

2.5 Pre-movement variability

Pre-movement variability was compared in three time-domains and none of these were significantly different between the Control-SDT and the Control-CDT experiment (P>0.05).

2.6 Movement detection factors

RMANOVA yielded significant differences in detection latency between the two levels of the control-CDT experiment in channels Fz ($F_{(1,11)}$=16.4, P = 0.002), C3 ($F_{(1,11)}$=29.2, P < 0.001), C1 ($F_{(1,11)}$=17.1, P = 0.002), Cz ($F_{(1,11)}$=57.9, P < 0.001), C2 ($F_{(1,11)}$=23.1, P < 0.001) and CPz ($F_{(1,11)}$=19, P = 0.001). . The TPR was changed significantly between the two levels of the control-CDT in channels C1 ($F_{(1,11)}$=57.9, p < 0.001), Cz ($F_{(1,11)}$=36.5, P < 0.001), C2 ($F_{(1,11)}$=62.1, P < 0.001) and C4 ($F_{(1,11)}$=16.9, P = 0.002). However, neither detection latency nor TPR was changed significantly between two levels of control-

SDT. None of the detection parameters were significantly different for successive movement blocks. These results are presented in Table 2.

3. Discussion

The present study compared the effect of attention diversion on MRCP parameters during dual- task performance while the difficulty of the secondary task was altered. MRCP preparation parameters in the second (late) negativity drift and pre-movement slopes were attenuated by the amount of attention to the primary and secondary task, which significantly affected detection of the MRCP. Our hypothesis that preparation for the primary (main) task is significantly affected when performed with the secondary task was thus confirmed. This has important implications for the performance of BCI systems designed for neuromodulation because the detection accuracy will decline under alterations in attention (Aliakbaryhosseinabadi et al., 2017; Aliakbaryhosseinabadi et al., 2017). Thus algorithms that can detect shifts in attention may be needed to adapt the detection. On the other hand, it is well known that attention can modulate cortical plasticity (Conte et al., 2007; Stefan et al., 2004). A decrease in the attention to the task may influence the induced plasticity and be detrimental for the rehabilitation intervention (Ziemann et al., 2008).

Electrode sites located over the motor-cortex area showed a greater attenuation in MRCP parameters compared to those located over the parietal and frontal lobe. Previous studies (Lin et al., 2011; Stopford et al., 2012) have shown that due to competition in dual task conditions for task resources such as motor components and attention, motor planning and motor execution can alter the effect of attention on frontal lobe activation. In the current study, the auditory oddball served as the distractor to divert attention from the main task, which was comprised of a dorsiflexion movement. Since movement activates cortical sites located within the motor and fronto-motor cortex it was expected that channels located here would present with the most significant changes in MRCP features and movement detection factors as compared to the frontal channels. The number of electrodes in clinical BCIs should be as low as possible to reduce factors such as costs and set-up time. One single channel over the motor cortex is sufficient for single-trial detection of a palmar grasp in EEG-based BCIs with an average accuracy of 78% (Jochumsen et al., 2015). In the current study, we further show that attentional changes may be reliably detected from channels located over the motor cortex. Thus, it may be feasible to use only a single (or a few) channel for both movement detection and detection of shifts in attention.

The most important outcome of this study is the effect on movement preparation with different levels of attention changes. Previously, only one study has investigated MRCP differences in the motor preparation phase between self-paced regular, alternating and random hand movements (Dirnberger et al., 2000). In that study, the regular task had the smallest MRCP amplitude particularly in the range of [1000 500] ms prior to the movement onset. The authors argue that, more attention and memory is applied in the random or alternating tasks (Dirnberger et al., 2000). Our study revealed that the preparation for the main task in the dual-task procedure was reduced compared to the single task performance, especially in electrode locations around the motor cortex. This may be related to the effect of executive function, which refers to the cognitive processes in attention allocation or performing a new task (Springer et al., 2006). When participants have to perform two tasks

concurrently, cognitive processing will be enhanced but this effect would be more enhanced for the cognitive skills related to the novel and complex task (Montani et al., 2014). The evidence for this claim is the pre-execution MRCP parameters extracted from midline and motor cortex channels, which showed a reduction in preparation for the main movement particularly in the complex oddball.

Another consideration is the amount of attention applied in the dual-task in comparison to the single task. When the attention level to a specific task is reduced, the movement preparation/execution will also decrease. According to the auditory P300 analysis (Fig.2), the attention to the auditory cue was increased as seen by the P300 amplitude increment while the visual cue required less attention in the dual-task (Nash and Fernandez, 1996). Therefore, more attention was allocated to the secondary task likely with a concomitant decrease of motor cortex inhibition during the main task preparation and execution (Bruckmann et al., 2012).

According to previous reports (Hoffman et al., 1985; Kida et al., 2004), in dual-tasks the P300 amplitude decreased since performing a dual-task is more difficult than single task execution. Thus in the current study, a reduction and attenuation of the P300 amplitude was expected (Jeon and Polich 2003; Oknina et al. 2011; Polich 1987). However, in our study the dual-task execution resulted in an increment in the auditory P300 amplitude. It is known that the P300 amplitude is influenced by task difficulty and task emphasis (Kok, 2001), which may explain the discrepancy between our results and those of previous studies. In the current study, the P300 enhancement could very well have resulted from certain salient properties of the eliciting stimulus and not by an increased internal cognitive demand. In the level of the single task, performers were only required to attend to the main task, although in the dual-task condition they attended to two tasks simultaneously. In this study, the auditory oddball is thus the new task for them and more attention will likely be allocated to this task. Thus, visual attention will be reduced and diverted to the auditory cue as also shown in Fig.2. According to the correlation of the EMG envelope, reduction of visual attention had no effect on level of movement contraction but it influenced movement preparation as pre-movement factors were significantly changed between control and diverted attention levels.

3.1 Effect of task repetition

One of the aims of this study was to quantify the effect of task repetition both in the single and dual task condition. Task/stimuli repetition that is called habituation is one way to learn a task and thus will enhance performance (Grill-Spector et al. 2006). Based on the Hebbian principle (Hebb 2002), task learning strengthens the routs among activated neurons and consequently induces neuroplasticity. Habituation changes the template of activated neurons because the area of these neurons expands with task performance (Pascual-Leone et al., 1994). Due to this reason BCI performance improved by learning the new skills (Casimo et al., 2017; Teillet et al., 2016). According to this, EEG patterns used to control BCIs such as the P300 amplitude are decreased with stimuli repetition (Katayama and Polich, 1999; Polich, 2007) and the negativity of the MRCP is increased (Falvo et al., 2010; Falvo et al., 2011) during repetitive simple tasks.

Task learning is affected when new information introduced with the additional task such as dual-task conditions (Liefooghe et al., 2005). Dual task studies reveal that the P300 amplitude, which indicates the amount of transferred information for

processing, represents the value of resources allocated to a task (Kida et al., 2004; Murray and Janelle, 2007). In the current study, repetition did not have significant effects either in the single or in the dual task. One of the possible reasons may be related to the task complexity and task experience during movement repetition. According to Pineda et al. (2003) the learning process needs more time when the task needs more control.

3.2 Study limitations

In this study, EEG signals under attention diverted conditions were recorded and analyzed offline. For clinically-viable BCI systems, in the future we will investigate the influence of attention in the online mode. For this purpose, it may be required to analyze EEG signals not only in the time domain (MRCP features) but also in the frequency domain to add more information about attention distribution in different brain regions (Melinscak et al., 2016; Myrden and Chau, 2017). A model of classification with acceptable accuracy (at least higher than chance level) should be defined to classify attention status in both healthy participants and patients with central nervous system insults, such as following a stroke. Since the latter group is often limited in their motor performance, imagery of the movement needs to be included.

4. Experimental Procedure

4.1 Participants

Twenty-four healthy participants (12 females, 12 males) subdivided into two groups of 12 participants with gender match (mean ages 23.5±3.4 and 24.25±3.5) were included in the experiment. Dividing the subjects into two groups reduce the effect of experimental habituation on the results. All participants were without hearing abnormality and neurological disease. The experiment was approved by the local ethical committee for the region Northern Jutland (N-20130039).

4.2 Experimental setup

Twenty-eight mono-polar EEG signals were recorded using an active EEG electrode system (g. GAMMAcap[2], Austria) and g.USBamp amplifier (gTec, GmbH, Austria) from AF3, AFz, AF4, F3, F1, Fz, F2, F4, FC3, FC1, FCz, FC2, FC4, C3, C1, Cz, C2, C4, CP3, CP1, CPz, CP2, CP4, P3, P1, Pz, P2, P4 based on the standard international 10-20 system. The ground electrode was placed on FP1 while the reference electrode was on the right earlobe. Bipolar surface electromyography (EMG) signals were placed on the tibialis anterior muscle of the dominant foot to determine movement onset. All signals were sampled at 256 Hz with 16 bits accuracy.

4.3 Paradigms and tasks

Each participant was seated in a comfortable chair that was approximately one meter away from a digital computer screen while their right and left legs were placed on a step with the knee joint flexed 90°. The visual experimental cue was shown on the digital screen while an auditory cue was played via a conventional headphone. Fig. 1 illustrates the experimental paradigm. Participants were randomly assigned to either the simple or the complex task. All participants were asked to complete three

blocks of a single-task (ankle dorsiflexion) and three blocks of a dual-task (ankle dorsiflexion and an auditory oddball task).
Each block contained a total of 30 trials of dorsiflexion timed to a visual cue followed by a rest period of approximately 4 min.

The dorsiflexion task: participants had to complete a dorsiflexion task during five phases of a visual cue that were defined as focus, preparation, execution, hold and rest time (Fig.4a). After a random period of 2-3 seconds of the focus time, a schematic in the form of a ramp with a moving cursor appeared on the screen. After the cursor traveled along the ramp for two seconds, it reached an upward turn. At this point participants had to perform a ballistic ankle dorsiflexion of their dominant foot and sustain it for two seconds, followed by a rest phase with a random duration of 3-5 seconds

The auditory oddball task: The auditory oddball cue differed between the two groups of participants. In the simple oddball task group, participants had to count the number of one of three tones played during the experimental block. They heard a frequent 500 Hz tone named low pitch which was randomized with the probability of 60% with a 1200 Hz tone called middle pitch and a 1900 Hz tone named high pitch, each with the probability of 20% (Fig. 4b). In the complex oddball task group, participants had to count the number of a special sequence of tones combined with the same probability. The target sequence was either the number of times the middle pitch appeared after the low pitch, the number of high pitch played after the low pitch or the number of low pitch heard after the low pitch. In each block, participants had to count one of these sequences and report it at the end of the block. The auditory oddball cue commenced at the same time as the visual cue and had a randomized inter-stimulus interval (ISI) of 2-3 s. All auditory cues were played with a duration of 200 ms and had the same sound pressure level of 75 dB and 5 ms rise/fall time. The number of auditory oddball stimuli was random among different blocks as the ISI was selected randomly. On average, 135 oddball tones were played per block.

Depending on the group, the participants had to perform one of the following two levels of task complexity in the dual-task block:

1. *Simple Dual Task (SDT):* This group of participants had to perform ankle dorsiflexion based on the visual cue and concomitantly attend to the sounds heard from the headphone. They were asked to count the number of occurrences of one of the oddball tones. The type of the target tone (the tone had to be reported at the end of each block) was altered among the three blocks to avoid habituation and could be middle, low or high pitch.

2. *Complex Dual Task (CDT):* The participants in this group were asked to do both the ankle movement and the oddball task within each block. The oddball task of this group was to determine the number of a special sequence of oddball tones. The type of the target sequence (the sequence had to be counted and reported at the end of block) was different among the three blocks and could be low pitch-middle pitch, low pitch-high pitch or low pitch-low pitch.

Each of the described task complexity was counter-balanced with the 'Control level' where participants had to perform ankle dorsiflexion timed with the visual cue described above. At the same time of movement execution, they heard auditory oddball

sounds via the headphone but they were asked to focus only on the movement performance not on the sounds. Thus, they were instructed to attend only to the execution of dorsiflexion.

4.4 Analysis of event-related potentials and oddball error

Among the outputs of the three midline channels Fz, Cz and Pz used in previous studies for ERP analysis (Neuhaus et al. 2007; Raij et al. 2003), channel Cz was selected as it was demonstrated that this channel can distinguish between target and non-target stimuli by generating larger P300 amplitudes (Xu et al., 2013). The amplitude of the P300 component of the ERP was extracted in the time window [-100 700] ms where 0 ms was the oddball stimuli onset. For the visual cue, zero was the time when the cursor commenced to move across the screen. The P300 amplitude was defined as the maximum value in this time range. The same method was used to extract the P300 amplitude for both the visual and auditory cue.

The performance was measured based on both the auditory and the visual task. For the auditory task, the number of errors in counting the target tone or sequence of tones in both types of dual tasking was considered as the performance indicator. For the visual task, the reaction time defined as the difference between real movement onset obtained from the tibialis anterior EMG signals with the expected onset based on the cue was considered as the performance criteria.

To investigate differences in how the participants performed the visual task, the correlation of EMG signals were computed in each block of movements. EMG signals were rectified and low pass filtered with a cut-off frequency of 10 Hz to obtain the EMG envelope. A correlation matrix was then calculated for all aligned single EMG trials in each block. Finally, the mean of the correlation values among all trials of each block was computed.

4.5 MRCP analysis

Continuous EEG signals were filtered in the frequency range [0.05 10] Hz using a 2nd order band-pass Butterworth filter. Five Midline channels (Fz, FCz, Cz, CPz and Pz) and four other motor cortex channels (C3, C1, C2 and C4) were selected for signal analysis and feature extraction. Movement trials were extracted in the time window of [-3 3] s where 0 s is the movement onset computed from EMG signals. Trials with electrooculography (EOG) artifacts were excluded by using a threshold of 120 µV. Data processing was done offline using MATLAB software (R2014b).

4.6 MRCP features

Ten temporal features from the initial negative drift prior to movement onset were extracted from single trials of EEG signals as pre-movement features and one feature from the re-afferent part of these trials was used as the post-movement variable. The time domains of these features are represented in Fig.4c. The amplitude of the peak negativity and the time of peak negativity were considered as the initial features since the other nine features were computed with regards to the time of peak negativity. The average amplitude of single trials in two time ranges with regards to movement onset were extracted: [-1.5 - 0.5] s (representing the preparation) and [-0.5 0] s (representing the movement) referred to as the first negativity drift and the second negativity drift respectively (Hallett, 1994). The MRCP variability, defined as the standard deviation among trials of each block and pre-phase slopes attained from linear regression on each single trial were extracted in three time intervals: [-2

1] s, [-1 0] s and [-2 0] s while 0 s is time of peak negativity. These time intervals were selected for the analysis based on previous studies where parameters associated to movement execution, such as force and speed, were decoded from the MRCP prior to movement onset (Jochumsen et al., 2013; Xu et al., 2014). The rebound rate defined as the linear regression in the range of [0 1] s in relation to the time of peak negativity was the re-afferent feature.

The Locality Preserving Projection (LPP) method followed by a linear discriminant analyses (LDA) classifier (LPP-LDA) was used to extract movement detection parameters from EEG epochs. The details of this technique are provided elsewhere (Xu et al., 2014). Detection latency (DL) defined as the difference between movement detection time and real movement onset extracted from output of bipolar EMG signals. True positive rate (TPR) that is the number of true detections divided by total true events and false positive rate (FPR) calculated as the number of false detections divided by the number of total events were used as the detection features.

4.7 Statistics

Two-way repeated measures analysis of variance (rmANOVA) was selected for statistical analysis of ERP components with 'movement blocks' and 'task demand' as within subject factors and movement blocks as the repeated independent factor. The amplitude of the P300 was considered as the response factor and task demand with two levels (Control and SDT or Control and CDT) and movement blocks with three levels (Block 1, Block 2 and Block 3) were defined as the independent variables. To investigate the differences of P300 amplitude and EMG correlation in each level between two groups, group with two levels (SDT and CDT) was used as the between subject factor in rmANOVA. The same method of two-way rmANOVA was also applied on EMG correlation when 'movement blocks' with three levels and 'task demand' with two levels considered as independent factors.

Temporal features of each single channel were compared using the same method of two-way repeated measures ANOVA with 'movement blocks' (Block 1, Block 2 and Block 3) and 'task demand' (Control and SDT or Control and CDT) considered as independent factors. A rmANOVA was used for each channel separately since the aim was to identify which channels were influenced by attention variations in dual-task conditions. Normality was confirmed according to the Shapiro-Wilk test. Bonferroni correction method was applied due to large number of comparisons and thus response factors were considered significant if $P < 0.004$.

5. Conclusion

To have reliable and robust real-time BCIs, it is required to adapt them with users' state such as attention. Attention variations should be monitored since neuroplasticity induction is dependent on this factor. The allocation of attention has differential effects on specific MRCP parameters during dual-task performance with different levels of complexity. Attention was allocated to the task with the higher demand as in the dual-task condition the P300 amplitude of the auditory cue was increased but based on the visual cue was reduced. The more complex task had a significantly greater effect on the MRCP parameters for movement preparation such as the amplitude of negative peak, pre-movement slope and the late negativity drift. The

1 results suggest that specific features of the MRCP can be implemented to detect changes in the attention of the user,

2 specifically at different levels of task complexity.

3 **Acknowledgement**

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1   **Fig. 1.** A diagram of different stages of the experiment. Two groups were conducted within the test when each group has to

2   do a simple dorsiflexion with/without executing an oddball task. The oddball task is counting the number of a single tone

3   among three different tones (SDT) or counting the number of a defined sequence of three different tones (CDT).

4   **Fig. 2.** Event-related potentials obtained from channel Cz for one participant according to the visual stimulus for (a) Control-

5   SDT and (c) Control-CDT. ERP wave obtained from the same participant in response to the auditory stimulus shown in (b)

6   Control-SDT and (d) Control-CDT. The grand average of the P300 amplitude in both conditions of Control-SDT and Control-

7   CDT is illustrated in (e) according to the visual cue and (f) based on the auditory cue. (*) indicates significant differences.

8   **Fig. 3.** Grand average of MRCP from all participants obtained from nine single channels in (a) simple dual task and (b)

9   complex dual task. Differences are more often detected for the channels over the motor cortex and fronto-midline than for the

10   parietal channels. The difference between tasks is more evident when comparing the simple and the most difficult dual tasks.

11   **Fig. 4.** (**a**) Experimental paradigm during movement recording, which consisted of five time phases. After 2-3 sec of focus

12   time a cursor traveling along a line for 2 sec appeared. When the cursor reaches to the ramp, participants had to start movement

13   execution and hold it for 2 sec. At the end, 3-5 sec rest time was provided between trials. (**b**) Illustration of different tones of

14   low, middle and high pitch used in auditory oddball cue. (**c**) Representation of different time domains of extracted features

15   form single trial EEG signals. Time of peak negativity and amplitude of peak negativity were selected at the point of most

16   negativity of single trials. D_{10}, D_{20} and D_{21} represent different time domains respect to the time of peak negativity for extracting

17   pre- slope and pre-variability. RR is the rebound rate that was measured in range of 1 sec after time of peak negativity.

18   **Table 1.** Statistical different temporal features in nine channels within both experiments. Dark gray parts indicate significant

19   channels between control and CDT level. Light gray areas show significant channels between control and SDT level.

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21   **Table 2.** Detection parameters with statistical differences within both experiments. Dark gray parts indicate significant

22   channels between control and CDT level. Light gray areas show significant channels between control and SDT level.

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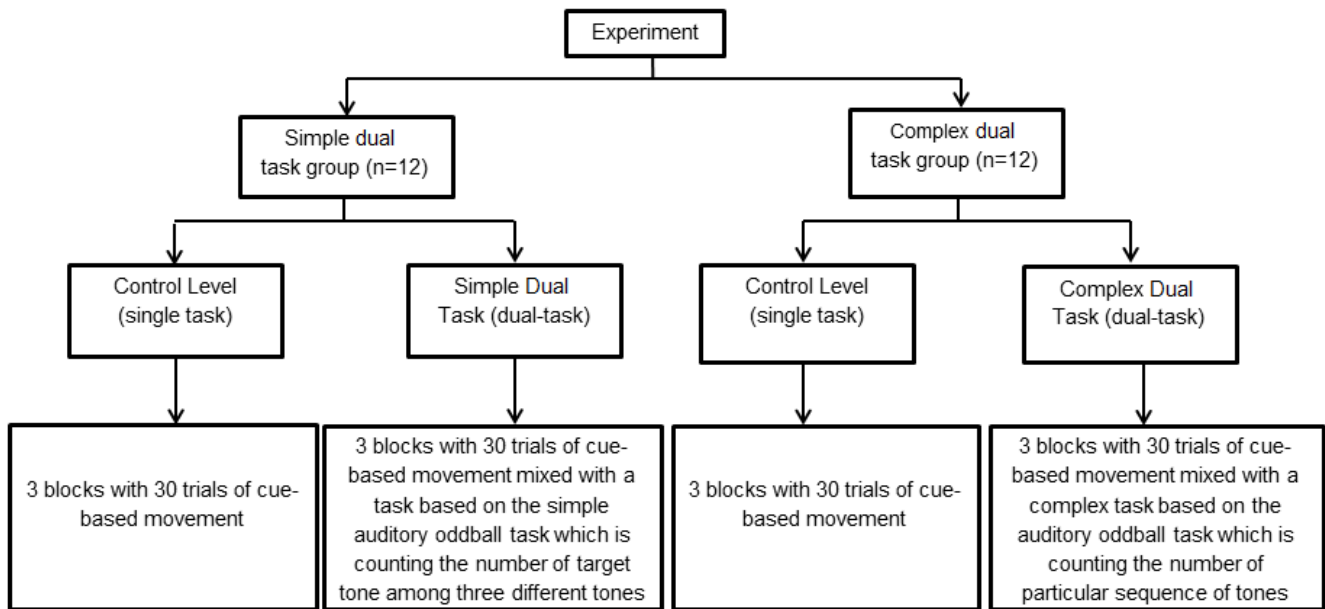
Fig. 1. A diagram of different stages of the experiment. Two groups were conducted within the test when each group has to do a simple dorsiflexion with/without executing an oddball task. The oddball task is counting the number of a single tone among three different tones (SDT) or counting the number of a defined sequence of three different tones (CDT).

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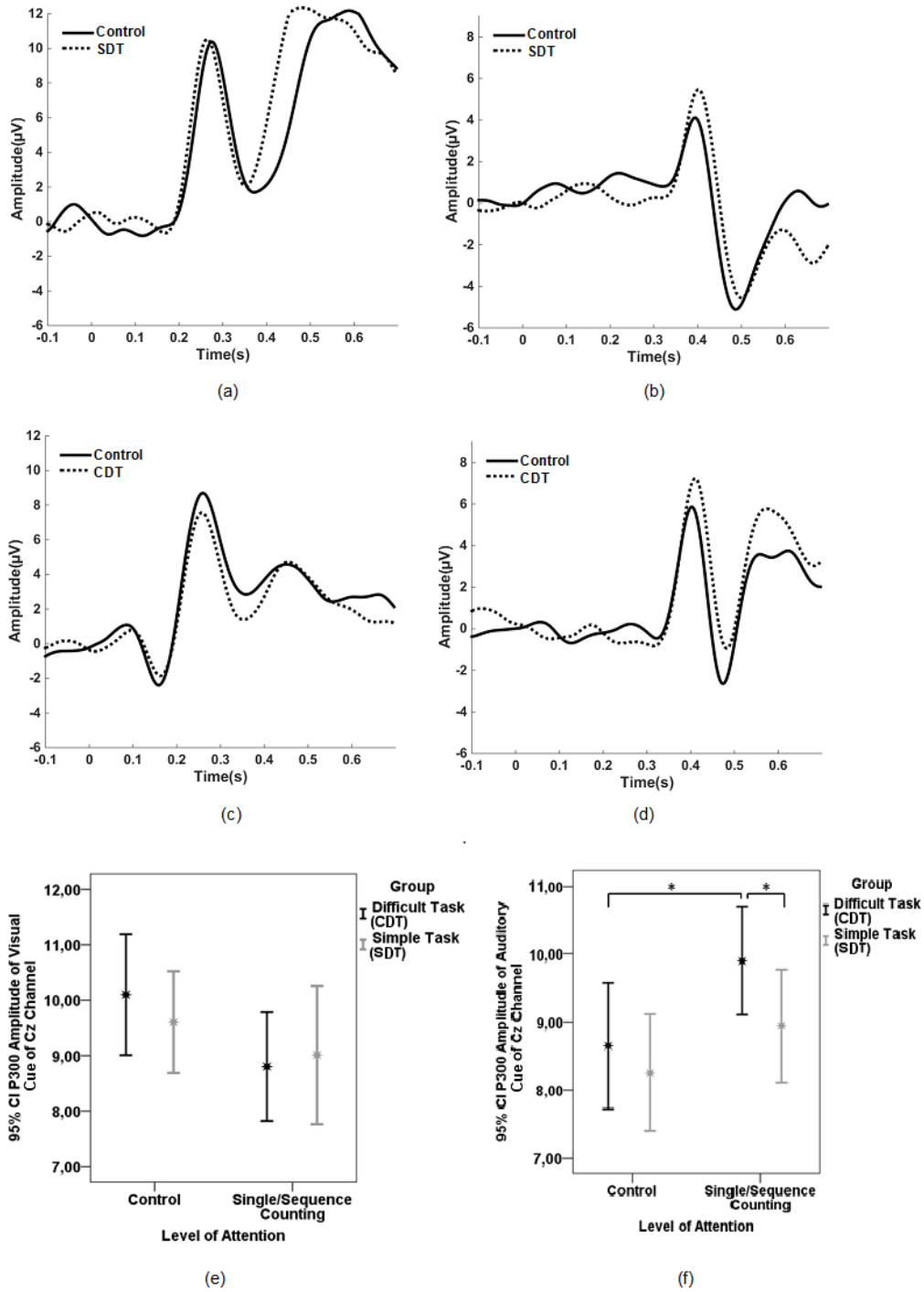
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4 **Fig. 2.** Event-related potentials obtained from channel Cz for one participant according to the visual stimulus for (a) Control-SDT and (c)

5 Control-CDT. ERP wave obtained from the same participant in response to the auditory stimulus shown in (b) Control-SDT and (d) Control-

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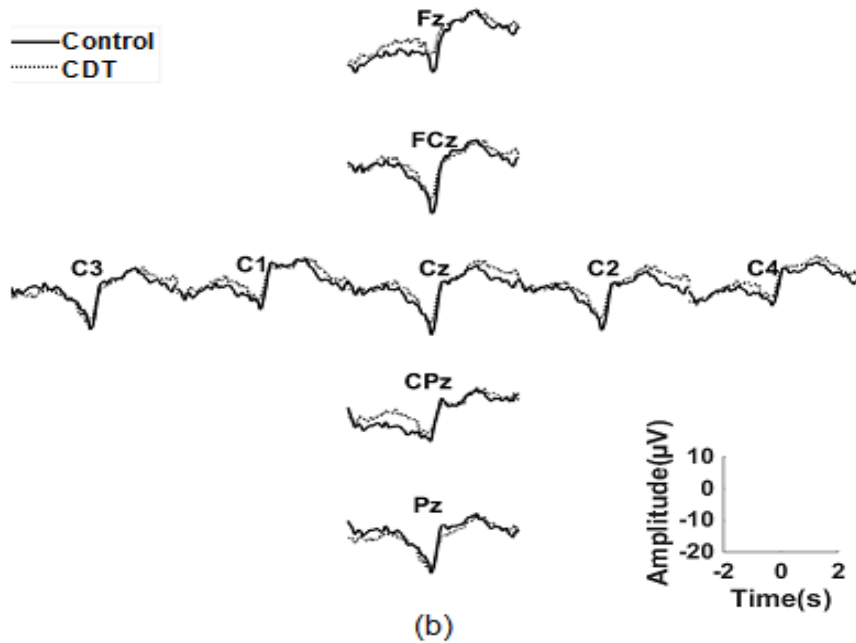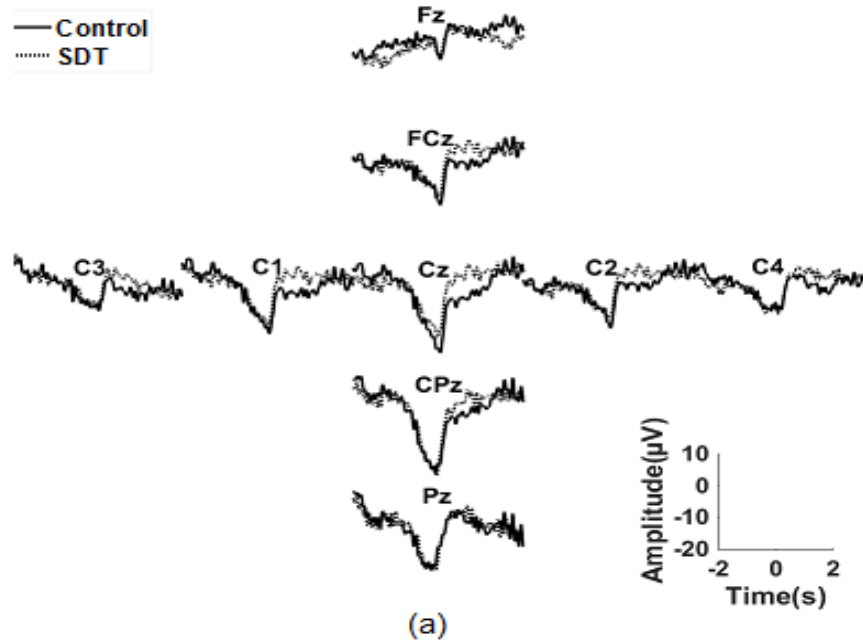
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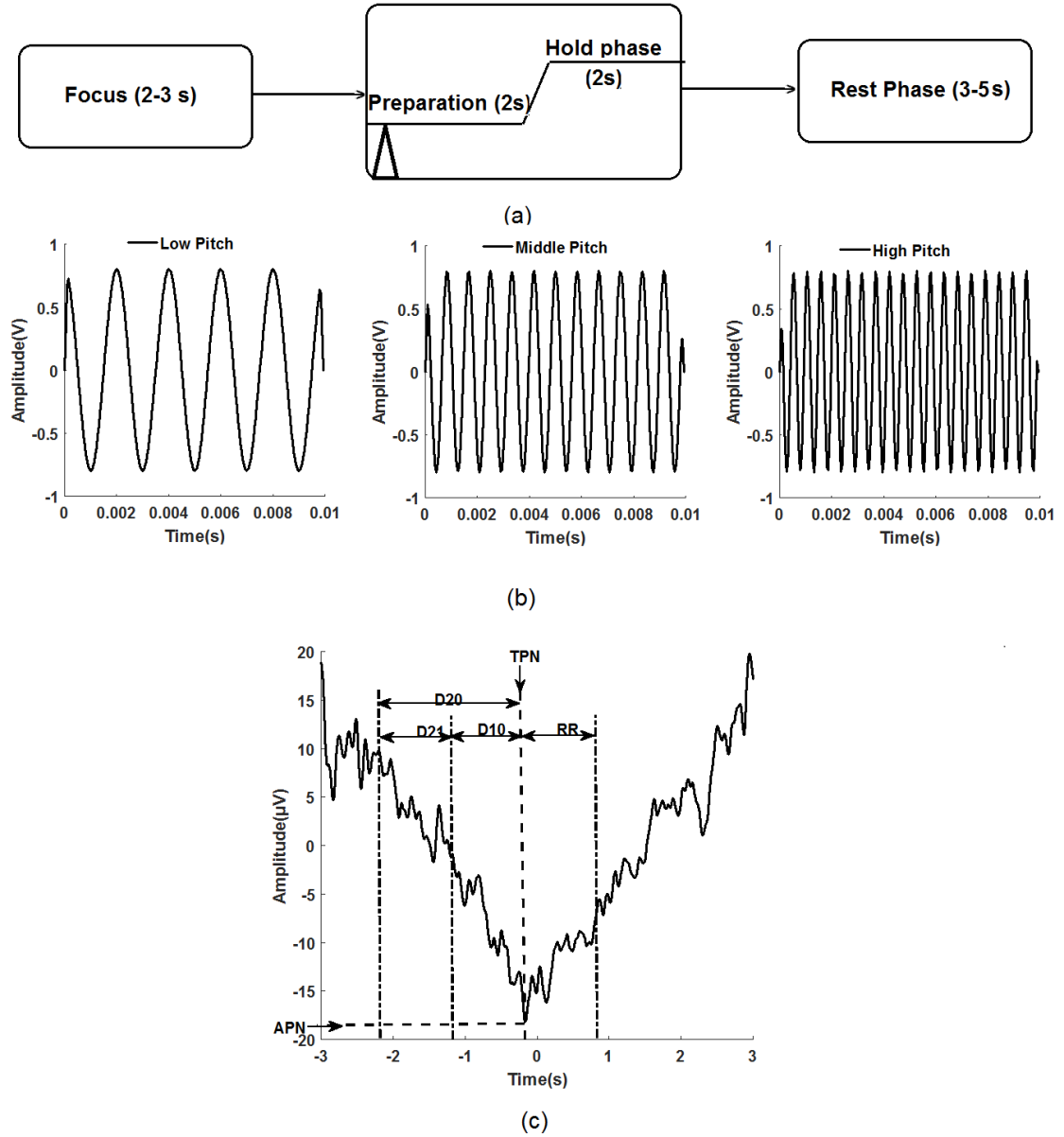
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Table 1.

Statistical different temporal features in nine channels within both experiments. Dark gray parts indicate significant channels between control and CDT level. Light gray areas show significant channels between control and SDT level.

			Fz	FCz	C3	C1	Cz	C2	C4	CPz	Pz
AMPLITUDE OF PEAK NEGATIVITY	Control-CDT	Control	-19.1 µV	-21.1 µV	-20.1 µV	-20.5 µV	-22.1 µV	-21.1 µV	-18.2 µV	-20.5 µV	-20.5 µV
		CDT	-18.5 µV	-18 µV	-16.9 µV	-18.6 µV	-19.3 µV	-17.9 µV	-14.7 µV	-17.1 µV	-19.2 µV
	Control-SDT	Control	-15.6 µV	-18.2 µV	-18.3 µV	-18.5 µV	-21.7 µV	-16.9 µV	-15.4 µV	-18.1 µV	-17.8 µV
		SDT	-16.8 µV	-15.8 µV	-18.7 µV	-17.3 µV	-18.6 µV	-13.7 µV	-18.1 µV	-17 µV	-17.3 µV
SCNV	Control-CDT	Control	-5.8 µV	-7.7 µV	-5 µV	-7.1 µV	-9.8 µV	-7.2 µV	-5.2 µV	-5.2 µV	-3.4 µV
		CDT	-6.1 µV	-5.4 µV	-3.3 µV	-5 µV	-7.7 µV	-5.3 µV	-3.2 µV	-3.8 µV	-2.3 µV
	Control-SDT	Control	-2.6 µV	-4.8 µV	-4.5 µV	-5.7 µV	-7.5 µV	-5.3 µV	-4.4 µV	-5.7 µV	-4.3 µV
		SDT	-2.2 µV	-3.6 µV	-4 µV	-4.5 µV	-5.7 µV	-3.3 µV	-4.6 µV	-4.8 µV	-4.3 µV
S20	Control-CDT	Control	-2.6 µV/s	-4.7 µV/s	-3.8 µV/s	-4.3 µV/s	-5.5 µV/s	-4.5 µV/s	-4.1 µV/s	-3.7 µV/s	-4.1 µV/s
		CDT	-2.4 µV/s	-3.6 µV/s	-3.6 µV/s	-3.2 µV/s	-4.3 µV/s	-4.2 µV/s	-3.1 µV/s	-3.6 µV/s	-3.4 µV/s
	Control-SDT	Control	-2.3 µV/s	-3.1 µV/s	-3.2 µV/s	-3.7 µV/s	-4.6 µV/s	-3.5 µV/s	-4.7 µV/s	-4.1 µV/s	-3.9 µV/s
		SDT	-3 µV/s	-3 µV/s	-3.7 µV/s	-4 µV/s	-4.5 µV/s	-3.3 µV/s	-3.9 µV/s	-4.3 µV/s	-4.2 µV/s

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Table 2.

Detection parameters with statistical differences within both experiments. Dark gray parts indicate significant channels between control and CDT level. Light gray areas show significant channels between control and SDT level.

			Fz	FCz	C3	C1	Cz	C2	C4	CPz	Pz
DL	Control-CDT	Control	224.6 ms	234.1 ms	231.7 ms	234.7 ms	233.3 ms	234 ms	235.1 ms	234.1 ms	239 ms
		CDT	244.5 ms	239.7 ms	252.2 ms	252.7 ms	250 ms	250.1 ms	242.5 ms	254 ms	246.1 ms
	Control-SDT	Control	227.9 ms	235.1 ms	238.5 ms	238.4 ms	237.4 ms	235.7 ms	236.8 ms	238.3 ms	241.3 ms
		SDT	234.6 ms	241 ms	244.7 ms	250.1 ms	244.2 ms	244.6 ms	241.3 ms	240.7 ms	242.6 ms
TPR	Control-CDT	Control	76%	83%	82%	73%	78%	83%	80%	80%	78%
		CDT	72%	78%	73%	65%	68%	74%	70%	76%	75%
	Control-SDT	Control	86%	80%	79%	80%	82%	79%	72%	80%	79%
		SDT	82%	71%	77%	76%	71%	68%	69%	76%	78%

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