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# Kinesthetic motor imagery training modulates frontal midline theta during imagination of a dart throw

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ABSTRACT

Motor imagery (MI) is a frequently used and effective method for motor learning in sports as well as in other domains.

Electroencephalography (EEG) and functional magnetic resonance imaging (fMRI) studies indicated that experts within a certain sport exhibit a more pronounced brain activity during MI as compared to novices. Similar to the execution, during MI the motor sequence has to be planned. Thus, the frontal attentional system, in part represented by the frontal midline theta (4–7 Hz), is closely related to these processes and presumably plays a major role in MI as well.

In this study, a MI dart training and its impact on frontal midline theta activity (fmt) during MI are examined. 53 healthy subjects with no prior dart experience were randomly allocated to a kinesthetic training group (KinVis) or to a control group (Control). Both groups performed 15 training sessions. While in the KinVis group dart throwing was accompanied by MI, the Control group trained without MI. Dart performance and fmt activity during MI within the first and the 15th session were compared.

As expected, the performance increase was more pronounced in the KinVis group. Furthermore, frontal theta amplitude was significantly increased in the KinVis group during MI in the 15th training session as compared to the baseline.

These results confirm the effectivity of MI. The enhanced fmt activity in the KinVis group can be interpreted as a better allocation of the requested resources in the frontal attentional network after MI.

## 1. Introduction

In sports, the imagination of movements has become an increasingly popular and important training method in recent years. Motor imagery (MI), defined as “the cognitive rehearsal of a task in the absence of overt physical movement” (Driskell et al., 1994) is used not only by Olympic and world-class athletes, but also by those participating in competitive sports at lower levels. MI has been found to facilitate the learning of motor skills as well as their maintenance and retention (Cooper, 1985; Di Rienzo et al., 2015; Guillot et al., 2007; Guillot and Collet, 2008; Guillot et al., 2009; Kossert and Munroe-Chandler, 2007; Mizuguchi et al., 2014; Weinberg, 2008). It can be applied when practical limitations such as pain, fatigue or limited physical strength during injury constrain physical training, or when access to facilities is restricted (Ridderinkhof and Brass, 2015). Furthermore, imagery has proven to be a valuable tool in musicians' training, the teaching of surgical skills (Cocks et al., 2014; Rao et al., 2015; Schuster et al., 2011), during rehabilitation (Stevens and Stoykov, 2003) and many more applications.

In general, MI can be performed either from a first or third-party view (Annett, 1995). Although the third-person view seems to be easier to imagine (especially by novices), it does not include the kinesthetic feeling of performing the movement. For example, Callow et al. (2013) illustrated that internal, first-person imagery leads to a better slalom performance as compared to external or third-person imagery. The first-person view can be further subdivided into pure-visual and kinesthetic imagery. During pure first person visual imagery, the subject only imagines the motor task from an inner perspective, but kinesthetic imagery also requires the feeling of all sensations, such as pressure, acoustic and olfactory stimuli, and muscle tension.

While most imagery studies focus on the effectiveness of imagery based on behavioral data (Callow and Roberts, 2010; Driskell et al., 1994), another approach addresses the respective brain activity by using functional magnetic resonance imaging (fMRI) or electroencephalography (EEG). Several studies have demonstrated that MI and motor execution share neuronal representations (Helene and Xavier, 2006; Munzert et al., 2009; Pfurtscheller et al., 2006). Moreover, Jeannerod

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(1994, 2001) claimed imagery to be the neuronal simulation of action. Lorey et al. (2013), for example, could show extended overlap of activity in the neuronal substrates of execution and imagery. Although there are common neuronal sources of imagery and execution, Ridderinkhof and Brass (2015) have outlined several differences, both in subcortical, as well as in cortical structures.

Halder et al. (2011) contrasted motor execution, motor observation and kinesthetic MI by comparing participants that were divided according to their controlling ability of a brain computer interface (BCI) in a preceding study. In this fMRI study, subjects had to imagine, observe and perform hand and foot movements. Higher activation of the supplementary motor area (SMA) was found during MI and motor observation in high skilled BCI users as compared to low skilled ones. Furthermore, the activation of the right middle frontal gyrus which is responsible for task monitoring and working memory was correlated with BCI performance during the observation condition. But in these areas, no activation differences were detected during the motor execution task between high and low skilled BCI users. As a result, motor observation, MI and therefore BCI-control seem to share similar neuronal networks which are not directly related to movement execution.

Studies using EEG report similar activations during movement execution and MI for several movement-related frequency bands, such as alpha (8–12 Hz), mu (12–14 Hz) or beta (13–30 Hz) rhythms. In general, during MI of hand movement an event-related desynchronization (ERD) of these frequencies was observed over sensorimotor areas located contralateral to the respective hand (Formaggio et al., 2010; Osuagwu and Vuckovic, 2014; Pfurtscheller and Neuper, 1997). Comparing different types of hand movement MI, Neuper et al. (2005) reported stronger activation in the sensorimotor hand area in the kinesthetic than in the pure visual imagery mode. On a single subject level, cortical activation was similar during kinesthetic imagery and real hand movement.

It is important to note that MI does not only include the mere motor component, but also motor planning and attentional processing (Decety, 1996). In particular, the frontal attentional network, including the medial prefrontal cortex and underlying structures such as the anterior cingulate, superior SMA, hippocampus and basal ganglia, are involved in the planning of movements. Thus, because MI needs action planning, it can be assumed that the frontal attentional system is involved in MI, as well (Decety, 1996).

The EEG frequency band which plays a basic role in this frontal attentional system is the EEG theta band from about 4 Hz to 7 Hz. Theta, more specifically the Frontal midline theta (Fm theta), is associated with working memory (Gevins et al., 1997; Klimesch et al., 2005; Kubota et al., 2001; Sauseng et al., 2005b) and sustained attention (Sauseng et al., 2007).

The importance of attentional processes during sports activity has been outlined by Baumeister et al. (2008) who reported a significantly higher Fm theta power in a golf-putting task in expert golfers as compared to novices. Similarly, Dyke et al. (2014) reported higher theta amplitudes at frontal midline sites preceding better golf puts. It was suggested that higher working memory activation and attention, which are correlated with Fm theta activation, might be necessary for optimal performance. Increased Fm theta for experts has also been described by Doppelmayr et al. (2008) for expert rifle shooters in contrast to novices. This pronounced theta activity was restricted to frontal areas and originated in the anterior cingulate gyrus.

As outlined, many studies have reported on and supported the functional equivalence of motor execution, observation and MI as well as the role of the EEG theta rhythm in focused attention. However, there are no studies addressing the effects of physical training combined with MI on the frontal theta activity in a goal-directed sports activity. In this report, we describe the effects of kinesthetic training of dart-throwing on the modulation of the Fm theta during the MI process. Darts was chosen because of a slight movement which causes minor artifacts (EEG-data during dart throwing are reported elsewhere) and the easy realization within a laboratory. It is assumed that MI training will lead to better throwing performance as well as increased Fm theta during the imagination process compared to a control condition without MI training. There are only two studies addressing dart-throwing and EEG, which, however, only report single-session data and do not focus on training or the attentional processes reflected in the Fm theta (Cheng et al., 2015; Radlo et al., 2002). Thus, this is the first EEG study focusing on the effects of repeated training combined with MI, specifically on attention-related Fm theta.

In this study, two groups of participants underwent a series of 15 training sessions with 50 times of dart throwing in each session. However, there were additional trainings including either kinesthetic-visual MI (KinVis) or an irrelevant control task (Control). We hypothesized that MI training should enhance dart-throwing performance compared to the Control group. Most important for this study, we expected that MI should lead to an increased attentional focus, as reflected in enhanced Fm theta activity during the MI. Depending on previous studies showing theta changes only over midfrontal but not over posterior regions (Baumeister et al., 2008; Doppelmayr et al., 2008), we focused on the frontal midline positions.

## 2. Methods

### *2.1. Participants and procedure*

53 healthy subjects (33 female, 20 male) with a mean age of 22.43 (*SD* = 4.06) and no previous darts experience participated in the study. Subjects were randomly assigned to two different training groups and were rewarded with 20 Euros and course credits for their participation. Furthermore, they were informed about the aims, risks and procedure of the study and gave informed consent. The study was performed in accordance with the declaration of Helsinki.

Due to contaminated data, 10 subjects had to be suspended, which left 23 subjects in the KinVis group (mean age = 24.48, *SD* = 4.92) and 20 in the Control group (mean age = 22.00; *SD* = 3.43). There was no significant age difference between groups.

The training consisted of 15 sessions for each participant. While in the first and the 15th session EEG was recorded and all subjects had to perform 30 kinesthetic dart imageries, the 2nd through to 14th sessions were performed without EEG or any additional tasks.

At the beginning of the first session, participants were instructed in detail and had to fill out an informed consent form. Then imagination ability was rated by a modified version of the Movement Imagery Questionnaire- Revised, second version (MIQ-RS) (Gregg et al., 2010). In our imagery questionnaire, subjects had to imagine five different simple movements (simple arm or foot movements as well as a dart throw) and three complex movements (swimming, cycling, somersault). While simple movements had to be executed before visualization, the complex ones only had to be imagined. Each of these movements had to be imagined both kinesthetically as well as from a 3rd person-point-of-view which resulted in 16 visualizations in sum. After each visualization, subjects had to evaluate on a seven-point Likert scale, how easy or difficult it was to imagine. For the 3rd person-point-of-view, the scale reached from "very easy to imagine"-"easy to imagine"-"rather easy to imagine"-"neither easy nor difficult"-"rather difficult to imagine"-"difficult to imagine"-"very difficult to imagine" and was valued with 1–7. For the kinesthetic visualization, the scale reached from "very easy to feel"-"easy to feel"-"rather easy to feel"-"neither easy nor difficult"-"rather difficult to feel"-"difficult to feel"-"very difficult to feel" and was again valued with 1–7.

Next, the EEG was mounted, and resting recordings of two minutes with eyes open and eyes closed were performed while the participants were standing. This was followed by two series of MI comprising 30 imaginations from a third-person's view and a kinesthetic MI (counterbalanced). Subjects were instructed to mark the imagined release of the dart with a right hand button press. The visualizations