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BETA FUNCTIONAL CONNECTIVITY MODULATION DURING THE MAINTENANCE OF MOTION INFORMATION IN WORKING MEMORY: IMPORTANCE OF THE FAMILIARITY OF THE VISUAL CONTEXT

C. CALMELS,[a*] M. FOUTREN[a,b] AND C. J. STAM[c]

[a] *INSEP, Institut National du Sport, de l'Expertise et de la Performance, Paris, France*

[b] *Université Paris-Est Marne la Vallée, France*

[c] *Department of Clinical Neurophysiology, VU University Medical Centre, Amsterdam, The Netherlands*

Abstract—The purpose of this study was to examine whether mechanisms, involved during the maintenance of familiar movement information in memory, were influenced by the degree of familiarity of the display in which the movements were embedded. Twelve gymnasts who possessed high visual and motor familiarity with the movements employed in this study, were recruited. They were invited to retain for a short period of time familiar movements viewed previously and presented under different displays with the aim of recognizing them at a later stage. The first display was a realistic, familiar display which presented videos of movements. The second display was an unfamiliar impoverished display never experienced in every day life which showed point-light movements. Activity during the maintenance period was considered in five frequency bands (4–8 Hz, 8–10 Hz, 10–13 Hz, 13–20 Hz, 20–30 Hz) using a non-linear measure of functional connectivity. The results in the 13–20 Hz frequency band showed that functional connectivity was greater within the frontal and right temporal areas during the unfamiliar display (i.e., point-light maintenance condition) compared to the familiar display (i.e., video maintenance condition). Differences in functional connectivity between the two maintenance conditions in the beta frequency band are mainly discussed in the light of the process of anticipation. Subjects' perception of the expected difficulty of the upcoming recognition task is discussed. © 2012 IBRO. Published by Elsevier Ltd. All rights reserved.

Key words: working memory maintenance, biological movement, functional connectivity, display familiarity.

INTRODUCTION

In everyday life, humans have to actively hold information active in memory for short periods of time in order to subsequently perform motor or cognitive tasks successfully.

Mechanisms underlying the active maintenance of information in working memory have been extensively investigated in the scientific literature and many research groups have used the multiple-component model of working memory developed by Baddeley and Hitch (1974) and Baddeley (1986, 2000, 2010) to direct their studies and support and explain findings. To examine these mechanisms, different techniques including functional magnetic resonance imaging (fMRI; Postle et al., 2000; Pochon et al., 2001; Sakai et al., 2002; Fiehler et al., 2008) or electroencephalography/magnetoencephalography (EEG; Sarthein et al., 1998; Tallon-Baudry et al., 1998, 1999; Stam et al., 2002; Hwang et al., 2005; Sauseng et al., 2005; MEG; Altamura et al., 2010) and different paradigms such as recall or Sternberg tasks (recall tasks; Sarthein et al., 1998; Stam et al., 2002; Sternberg tasks; Tallon-Baudry et al., 1998, 1999; Hwang et al., 2005; Sauseng et al., 2005; Altamura et al., 2010) have been employed. In all the aforementioned studies, the stimuli used only included still images (e.g., letters, digits, words, smooth shapes, pictures, matrixes containing coloured targets, and spatial locations). Dynamic displays, such as biological movements, have scarcely been employed in working memory studies.

To our knowledge, two studies have presented hand/finger movements to examine the mechanisms to hold movement information active in memory after a kinaesthetic stimulus presentation (Fiehler et al., 2008) and a visual stimulus presentation (Calmels et al., 2011). Using fMRI, Fiehler et al. (2008) examined the cortical regions involved when subjects kept in memory for short periods of time hand movement information in order to accomplish a recognition task at a later stage. In their study, movement information was exclusively kinaesthetic and visual input was systematically suppressed. Subjects were blindfolded and movement recognition was completed on a kinaesthetic basis. Results revealed that anterior intraparietal sulcus and adjacent areas were involved in the maintenance of kinaesthetic information. Calmels et al. (2011) investigated, via EEG, the functional connectivity among professional pianists and musically naïve subjects who were instructed to remember

*Corresponding author. Address: Mission Recherche, Institut National du Sport de l'Expertise et de la Performance, 11 Avenue du Tremblay, 75012 Paris, France. Tel: +33-(1)-41-74-43-73; fax: +33-(1)-41-74-45-35.

E-mail address: claire.calmels@insep.fr (C. Calmels).

Abbreviations: EEG, electroencephalography; fMRI, functional magnetic resonance imaging; MEG, magnetoencephalography; PLI, phase lag index; SL, synchronization likelihood.

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sequential finger movements viewed previously with the aim of either replicating them or recognizing them subsequently. The results showed that in the beta frequency band and in musically naïve subjects, functional connectivity was greater within the occipital, parietal, central, frontal, right and left temporal areas when the subjects were invited to remember the observed movement in order to replicate it compared to the recognition condition in which they had to recognize it. In addition, under the condition for replica, functional connectivity in professional pianists was weaker in the central area compared to musically naïve subjects.

It would be of interest to consider the mechanisms of movement information maintenance in working memory after the presentation of visual dynamic stimuli in a Sternberg task. More specifically, the maintenance mechanisms enrolled in response to different visual stimuli depicting highly familiar biological movements warrant further attention since this topic has not been addressed in the literature. In the current study, different visual stimuli depicting familiar biological movements were presented. These stimuli were different with respect to their degree of familiarity. The first kind of visual stimulus was presented via videos of ‘‘real’’ movements and emanated from a realistic, ecological display. It contained large amounts of structural and contextual information (i.e., form, shape, colour, texture). The second one was devoid of this type of information and was displayed using the technique of point-light displays pioneered by Johansson (1973). This display was an unfamiliar impoverished display never experienced in every day life. Subjects were selected from among a population of expert female gymnasts who were visually and motorically highly familiarized with the movements employed in the experimental procedure. This recruitment procedure guaranteed that the factor which has been manipulated in the present study was the display (unfamiliar vs familiar). The investigation of cortical mechanisms, in particular levels of synchronization between different brain areas, was performed using the phase lag index (PLI). PLI is a marker of functional connectivity which is invariant against the presence of common sources (volume conduction and active reference electrodes) (Stam et al., 2007).

It was hypothesized that maintenance of familiar movement information in working memory was influenced by the degree of familiarity of the display in which this movement was embedded. Mechanisms to maintain temporarily in memory motion information presented via point-light displays may require a greater treatment cost, reflected by a greater functional connectivity, in comparison to motion information presented via videos of ‘‘real’’ motions. Extra processing may be required to process point-light displays since individuals are not used to experiencing these artificial and impoverished displays in the daily life. Functional connectivity differences are expected to occur in the beta frequency band since beta oscillations are recognized as being linked to the retention of information (Tallon-Baudry et al., 1998, 1999, 2001; Hwang et al., 2005; Leiberg et al., 2006; Pesonen et al., 2007; Altamura et al., 2010; Calmels et al., 2011). More specifically, beta activity is related to the activity of subvocal rehearsal during the maintenance of information in the working memory (Hwang et al., 2005) but also to the process of (mental) imagery (Tallon-Baudry et al., 1998, 1999, 2001). It has also been demonstrated that beta rhythm is at play during imagery of motor activity. It is desynchronized over the sensorimotor cortical areas (Pfurstcheller and Neuper, 1997; Pfurtcheller et al., 1997; Neuper and Pfurtscheller, 1999; McFarland et al., 2000).

METHOD

Subjects

Fifteen French female expert gymnasts, who had normal vision and no past neurological or psychiatric history, participated voluntarily in the study. Subjects were not carrying any injury at the time of the study. Information on the aims of the investigation was not provided. To guarantee that the subjects possessed motor and visual familiarity of the movements employed in the study, they were invited to evaluate on a Likert-scale, graded from 0 to 10 (‘‘0’’ never and ‘‘10’’ very often), how often they saw the movements and how often they performed the movements. Gymnasts who scored below ‘‘8’’ were discarded from the study. After assessment using the Edinburgh Handedness Inventory (Oldfield, 1971), all subjects were classed as right handed. Participants gave their written informed consent. For subjects who were under the age of 18, parental or guardian consent was also obtained. Approval for the study was obtained by the local ethics committee (Comité de Protection des Personnes d'Ile de France VI, CPP and the Agence Française de Sécurité Sanitaire des Produits de Santé, AFSSAPS, ID RCB: 2009-A00934-53).

Three subjects were additionally discarded from the study due to high electrode impedance values and noisy EEG waveforms. Thus, data from the twelve remaining subjects (mean age = 21, SD = 4.1) were considered.

Task and production of videos

An international female gymnast performed 30 direct series of four acrobatic movements. This gymnast did not participate in the present study. The movements were performed with or without flight phase in the forward, sideward, or backward movement. The series were matched according to difficulty and were selected among a panel of 80 possible direct connections of four acrobatic movements. Connections considered as easy to remember (i.e., score assessment of 1, 2, or 3 on a 5 point-Likert scale by two national standard judges) were excluded.

The international gymnast was filmed in a gymnasium on the floor area performing the 30 direct connections. The gymnast performed all the connections at a similar angle relative to the camera. In the first case, a digital camera was used to record 30 ten second-colour videos. In the second case, 10 s point-light displays were generated for the same series using the optoelectronic Vicon 612 system. Eight infrared cameras (Charge Coupled Device) registered the spatiotemporal positions of 32 retroreflective markers at a sampling rate of 120 Hz. These were located at the conventional