Brain and Cognition 122 (2018) 45–51

Contents lists available at ScienceDirect

Brain and Cognition

journal homepage: www.elsevier.com/locate/b&c

Prefrontal cortex activation during obstacle negotiation: What's the effect size and timing?

Inbal Maidan[a,b,c,*], Shiran Shustak[a], Topaz Sharon[a,d], Hagar Bernad-Elazari[a], Nimrod Geffen[a], Nir Giladi[a,c,e,f], Jeffrey M. Hausdorff[a,d,e,g], Anat Mirelman[a,b,c,e]

[a] Center for the Study of Movement, Cognition, and Mobility, Neurological Institute, Tel Aviv Medical Center, Tel Aviv, Israel
[b] Laboratory of Early Markers of Neurodegeneration, Tel Aviv Medical Center, Tel Aviv, Israel
[c] Department of Neurology, Sackler School of Medicine, Tel Aviv University, Israel
[d] Department of Physical Therapy, Sackler Faculty of Medicine, Tel Aviv University, Israel
[e] Sagol School of Neuroscience, Tel Aviv University, Tel Aviv, Israel
[f] Sieratzki Chair in Neurology, Tel Aviv University, Israel
[g] Rush Alzheimer's Disease Center and Department of Orthopaedic Surgery, Rush University Medical Center, Chicago, IL, USA

ARTICLE INFO

Keywords:
Prefrontal cortex
fNIRS
Obstacle negotiation
Available response time
Motor planning
Gait

ABSTRACT

Background: Obstacle negotiation is a daily activity that requires the integration of sensorimotor and cognitive information. Recent studies provide evidence for the important role of prefrontal cortex during obstacle negotiation. We aimed to explore the effects of obstacle height and available response time on prefrontal activation.

Methods: Twenty healthy young adults (age: 30.1 ± 1.0 years; 50% women) walked in an obstacle course while negotiating anticipated and unanticipated obstacles at heights of 50 mm and 100 mm. Prefrontal activation was measured using a functional near-infrared spectroscopy system. Kinect cameras measured the obstacle negotiation strategy. Prefrontal activation was defined based on mean level of HbO_2 before, during and after obstacle negotiation and the HbO_2 slope from gait initiation and throughout the task. Changes between types of obstacles were assessed using linear-mix models and partial correlation analyses evaluated the relationship between prefrontal activation and the distance between the feet as the subjects traversed the obstacles.

Results: Different obstacle heights showed similar changes in prefrontal activation measures ($p > 0.210$). However, during unanticipated obstacles, the slope of the HbO_2 response was steeper ($p = 0.048$), as compared to anticipated obstacles. These changes in prefrontal activation during negotiation of unanticipated obstacles were correlated with greater distance of the leading foot after the obstacles ($r = 0.831$, $p = 0.041$).

Conclusions: These findings are the first to show that the pattern of prefrontal activation depends on the nature of the obstacle. More specifically, during unanticipated obstacles the recruitment of the prefrontal cortex is faster and greater than during negotiating anticipated obstacles. These results provide evidence of the important role of the prefrontal cortex and the ability of healthy young adults to tailor the activation pattern to different types of obstacles.

1. Introduction

Obstacle negotiation is a daily activity that is initiated by an external challenge such as going up a curb or stepping over a crack in the ground (Chen, Ashton-Miller, Alexander, & Schultz, 1991). Successful negotiation is enabled through the integration of sensorimotor and cognitive information (Chen et al., 1991; Galna, Peters, Murphy, & Morris, 2009). This integration depends on cognition, mainly on executive functions that include (1) visual spatial functions such as scanning the environment and estimating the obstacle's dimensions, (2) divided attention, (3) motor planning while approaching the obstacle and recovering from the obstacle, (4) working memory during stepping with the trailing foot, (5) response inhibition and (6) problem solving when the obstacle is unanticipated and appears while walking (Holtzer et al., 2015; Yogev-Seligmann, Hausdorff, & Giladi, 2008). All of these cognitive functions are associated with activation of the prefrontal cortex (Alvarez & Emory, 2006; Holtzer et al., 2011; Mirelman et al., 2014). Recent studies provide evidence to the important role of the prefrontal cortex during obstacle negotiation by showing increased activation during walking while negotiating obstacles (Chen et al., 2017; Maidan et al., 2016; Mirelman et al., 2017). However, it is not yet clear if or how the specific characteristics of the obstacle impact

* Corresponding author at: Center for the Study of Movement, Cognition and Mobility, Neurological Institute, Tel Aviv Medical Center, 6 Weizmann Street, Tel Aviv 64239, Israel.
E-mail address: inbalm@tlvmc.gov.il (I. Maidan).

https://doi.org/10.1016/j.bandc.2018.02.006
Received 29 November 2017; Received in revised form 9 February 2018; Accepted 9 February 2018
0278-2626/

Fig. 1. The setting of the obstacle course testing. (A) the location of the fNIRS probes on the forehead (without the black fabric that cover the probes) and front view of the harness. (B) the obstacle course area: 1-anticipated obstacle module, 2-unanticipated obstacle module, 3-safety harness, 4-location sensor, 5-elliptical rail that was used to support the safety harness.

prefrontal cortex activation.

Different types of obstacles with diverse levels of difficulty may vary the motor and cognitive demands that are required to successfully negotiate the obstacle. Two important factors can be used to manipulate obstacle negotiation difficulty: (1) the dimensions of the obstacle, such as the obstacle height, and (2) the available response time (ART), i.e., the time the subject has to prepare and plan for the obstacle crossing (Brown, Doan, McKenzie, & Cooper, 2006; Weerdesteyn, Nienhuis, Geurts, & Duysens, 2007). For example, obstacles placed in the walking path well in advance allow for a long preparation time, while obstacles that appear just as the subject approaches provide a shorter preparation time and a shorter ART. As expected, higher obstacles and shorter ARTs lead to larger degradation in gait and an increased risk of falls in healthy older adults (Brown, McKenzie, & Doan, 2005; Brown et al., 2006; Lu, Chen, & Chen, 2006; Vitorio, Pieruccini-Faria, Stella, Gobbi, & Gobbi, 2010; Weerdesteyn, Nienhuis, & Duysens, 2005; Weerdesteyn et al., 2007). Comparison of the obstacle negotiation strategy of healthy older adults and young adults revealed that young adults adapt their strategy by placing the leading foot further after the obstacle and lifting the trailing foot higher when obstacles are higher and unanticipated (Maidan et al., 2017). Due to previous technological limitations associated with the ability to impose shorter ARTs and to directly measure prefrontal activation, previous studies have not simultaneously investigated the interplay between obstacle height, ART, and prefrontal activation during obstacle negotiation.

The present study aimed to better understand the effects of different types of obstacles and the complexity of task demands on the role of prefrontal cortex in healthy young adults during obstacle negotiation by using a unique obstacle course that allows for the manipulation of the obstacle height and ART. Performance was examined in conjunction with prefrontal activation, as measured using functional near infrared spectroscopy (fNIRS). We hypothesized that: (1) since higher obstacles require higher level of attention, visual spatial, and information processing, all skills associated with executive function, the cognitive demands in higher obstacles will elicit additional prefrontal activation associated with motor planning, (2) unanticipated obstacles with shorter ART will require faster recruitment of cognitive resources resulting in greater and quicker prefrontal activation as manifest as a steeper slope, and (3) the pattern of prefrontal activation will be associated with obstacle negotiation performance such as the distance of the foot from and above the obstacle. As noted above, tripping over an obstacle is associated with lower clearance over the obstacle and closer landing after obstacle (Chen et al., 1991; Galna et al., 2009; Maidan et al., 2017). As such, we speculated that insufficient motor planning associated with lower prefrontal activation will be correlated with these changes in the obstacle negotition strategy.