FACULDADE DE MEDICINA DA UNIVERSIDADE DE COIMBRA

TRABALHO FINAL DO 6º ANO MÉDICO COM VISTA À ATRIBUIÇÃO DO GRAU DE MESTRE NO ÂMBITO DO CICLO DE ESTUDOS DE MESTRADO INTEGRADO EM MEDICINA

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DORSAL-VENTRAL INTEGRATION IN THE RECOGNITION OF 3D STRUCTURE-FROM-MOTION STIMULI IN MILD COGNITIVE IMPAIRMENT

SCIENTIFIC ARTICLE

ÁREA CIENTÍFICA DE NEUROSCIENCES

TRABALHO REALIZADO SOB A ORIENTAÇÃO DE:
PROFESSOR DOUTOR MIGUEL CASTELO-BRANCO

MARÇO/2011

Dorsal-Ventral integration in the recognition of 3D Structure-From-Motion Stimuli in Mild Cognitive Impairment

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ABSTRACT

Introduction

In perception of structure-from-motion stimuli (SFM), the 3D shape can only be extracted from dot moving patterns by integrating motion cues over time. Recent studies show that integration of visual information across dorsal and ventral visual streams is needed for the perception of 3D SFM objects.

In a previous study, our group found that 3D motion integration is specifically impaired in Mild Cognitive Impairment (MCI), indicating that parietal function may become affected at a relatively early stage in the course of the disease.

Objectives

In this study, we investigated whether the ability to recognize 3D SFM objects is impaired in MCI.

Methods

We developed an experimental paradigm in which participants had to discriminate 3D SFM objects (faces and chairs) from 3D SFM meaningless objects (scrambled faces and scrambled chairs). Chair stimuli were used as a control task, at a ceiling level of performance, to make sure that subjects understood the task requirements. Stimuli duration was randomly manipulated (100 ms, 160 ms, 980 ms) as well as depth information (flat, intermediate and full depth), resulting in a 4 x 3 x 3 design with 10 trials per condition.

Groups of amnestic MCI patients (n=25) and matched Control subjects (n=22) were included. Patients were recruited from the Neurology Department of Coimbra University Hospital, where diagnosis was achieved through gold standard neurological and neuropsychological assessment, following Petersen's (2001) classification criteria for MCI.

Results

For the Face stimuli repeated measure ANOVA with within-subject variables found significant main effects for Depth and Duration ($p<0,001$) as well as for Group ($p<0,05$, comparison between MCI patients and Control subjects). Additionally, planned analyses using post hoc parametric T-tests revealed significant differences between MCI patients and Control subjects for the 160 ms stimulus Duration, on both Full and Intermediate Depth levels, and for the 980 ms Duration, on both Full and Flat Depth levels. No differences were found on the Chairs/Scrambled Chairs stimuli confirming this as a useful control condition that ensured task comprehension.

Conclusions

We conclude that pathological ageing is related to a deterioration in extracting object information from short lived motion and depth cues processed in the visual dorsal stream, leading us to believe that an impairment of dorsal-ventral integration mechanisms already exists in MCI.

Key-words: Mild Cognitive Impairment, vision, dorsal pathway, ventral pathway, Structure-from-motion perception.

RESUMO

Introdução

Para a percepção de estímulos structure-from-motion é necessário extrair a forma tridimensional a partir de padrões de pontos em movimento, integrando pistas de movimento ao longo do tempo. Estudos recentes mostram que a percepção de objectos SFM tridimensionais necessita de integração da informação visual por ambas as vias: dorsal e ventral.

Num estudo prévio realizado pela nossa equipa, demonstrou-se que a integração de imagens tridimensionais em movimento estava alterada em doentes com Défice Cognitivo Ligeiro (DCL). Estes resultados estão de acordo com a hipótese de a doença afectar precocemente a função parietal.

Objectivos

Neste estudo investigamos se a capacidade de reconhecer objectos SFM tridimensionais estava alterada em doentes com DCL.

Metodologia

Desenvolveu-se um paradigma experimental em que os participantes tinham de discriminar objectos SFM tridimensionais íntegros (caras e cadeiras) de objectos SFM tridimensionais distorcidos (caras distorcidas e cadeiras distorcidas). Os estímulos das cadeiras (íntegros e distorcidos) foram utilizados numa tarefa de controlo, com um nível de desempenho máximo, para ter a certeza que os sujeitos compreendiam os requisitos da tarefa. A duração dos estímulos foi aleatoriamente manipulada (100 ms, 160 ms, 980 ms) assim como a profundidade dos mesmos (profundidade mínima, intermédia e máxima), resultando num teste com um esquema de 4 x 3 x 3, 10 repetições por cada condição.

Dois grupos de sujeitos foram incluídos: sujeitos com DLC de tipo amnésico (n=25) e sujeitos de Controlo com idade emparelhada (n=22). Os sujeitos com DLC foram recrutados pelo

Departamento de Neurologia dos Hospitais da Universidade de Coimbra, onde o diagnóstico foi conseguido através de uma avaliação neurológica e neuropsicológica, seguindo os critérios para diagnóstico de DLC de Petersen (2001).

Resultados

Relativamente aos estímulos das Caras, usando o teste estatístico ANOVA, foram encontrados efeitos significativos para a Profundidade e Duração ($p<0,001$) assim como para o Grupo (($p<0,05$), comparação entre sujeitos com DLC e sujeitos Controlo). Também se encontraram diferenças significativas entre sujeitos com DLC e sujeitos Controlo para estímulos com 160 ms de Duração, nos níveis de Profundidade Máxima e Intermédia, e para estímulos com a duração de 980 ms, nos níveis de Profundidade Máxima e Mínima, através de análises que utilizam amostras independentes do teste T de Student. Não foram encontradas diferenças nos estímulos da tarefa das cadeiras, confirmando que se trata de uma condição útil para a compreensão da tarefa.

Conclusões

Com este estudo concluímos que o envelhecimento patológico está relacionado com a deterioração em extrair informações dos objectos a partir de curtas pistas de movimento e profundidade processadas na via dorsal visual. Isto leva-nos a acreditar que já existe uma alteração na integração da via dorsal e ventral no DLC.

ACKNOLEDGEMENTS

I would like to thank the University of Coimbra, namely the Faculty of Medicine for introducing me to the World of Investigative Science.

I would like to thank my thesis advisor Professor Doutor Miguel Castelo-Branco for his guidance and wisdom throughout this study. A special thanks to Raquel Lemos for her assistance, patience and constant availability. To Inês Bernardino, my sincere thanks for her support.

I would also like to express my gratitude to all that participated in the study, without their cooperation it would not have been possible.

Love and thanks to my family, for all of their support and to André for his patience.

Finally an unconditional thank-you Ana Silva.

INTRODUCTION

Alzheimer's disease (AD) is the most common type of dementia, comprising about 50% to 80% of all dementia cases (Lobo et al., 2000). The clinical interest in establishing an early diagnosis has led to defining a transitional state between normal ageing and dementia (prodromal AD). This stage is widely known as Mild Cognitive Impairment (MCI) (Petersen et al, 1999) and aims to identify individuals with a more severe cognitive impairment than would be expected for their age and level of education but are not sufficiently debilitated to have dementia. Therefore, MCI is thought to represent a transitional stage within a cognitive continuum that spans from normal ageing to early dementia (Petersen et al, 2001), and has a high probability of converting to dementia, particularly to AD. The diagnosis of AD is generally supported by the clinical history and neurological examination, associated with neuropsychological evidence of cognitive dysfunction (Blennow et al., 2006). Deficits do occur mainly in the memory domain, but also impairment in at least one additional cognitive domain is often found, both of which result in changes of normal social function or activities of daily living. The evidence of a memory deficit in these conditions is consistent with neuropathological and imaging findings which reveal abnormal changes in the hippocampal formation and neighbouring medial temporal lobe structures (Petersen et al, 1999). In addition to an objective memory deficit, current research approaches are also focusing on impairments in several additional domains, including visual function (Cronin-Golomb et al., 1995, Mendola et al., 1995).

Vision is a complex process and requires concerted activity across several brain regions to achieve successful perceptual integration of an image. Visual functions can be subdivided in low, intermediate and high-level stages. Two anatomical and functionally separable intermediate-high level pathways have been proposed (Ungerleider and Mishkin, 1982; Milner and Goodale, 1992; Milner and Goodale, 2008). The dorsal pathway is essential in

processing spatial information (the “Where” pathway), and the ventral pathway is relevant in object recognition (the “What” pathway). In order to recognize complex objects the ventral pathway is needed, but recent findings suggest that the dorsal stream is also involved in extracting three-dimensional shapes from depth and motion cues (Konen and Kastner, 2008; Farivar et al., 2009). To perceive structure-from-motion (SFM) stimuli both pathways must interact, however their specific roles in the SFM perception is not yet clear (Konen and Kastner, 2008).

In AD, several studies have been conducted on low-level functions (Mendola et al., 1995; Cronin-Colomb et al.,1995; 2004; Butter et al., 1996; Rizzo and Nawrot, 1998; Rizzo et al., 2000). Thiyagesh et al. (2009) claim to be the first exploring the neuroanatomy of the perception of depth and motion in AD during a functional neuroimaging study. The resulting abnormal visual profile supports a pathophysiological basis for the visuospatial disorientation. In which concerns intermediate and high-level functions, visual attention is impaired in AD at different stages of processing. These deficits have been linked to dysfunction of the parietal cortex and associated networks (Buck et al., 1997), and are qualitatively and quantitatively different from the visual attention changes observed in normal ageing (Tales et al., 2002).

In MCI, most of the research on visual functions has focused on impaired attention (Levinoff et al., 2005; Tales et al., 2005) as indexed by impaired performance in visual search tasks. Mapstone et al. (2003) suggested that some MCI patients have significant visual perceptual deficits as well as memory impairment, while others only show memory impairment. There is a lack of low-level visual function studies, likely due to its recent categorization. In a previous study of our team (Lemos et al., 2011, under revision), we confirmed severe visual function deficits in AD and found that 3D motion integration is specifically impaired in MCI, indicating that parietal function may become affected early in the course of the disease.

In this study we have specifically tested the role of integration of temporal and depth 3D SFM cues in complex object recognition in pathological ageing (MCI).

MATERIALS AND METHODS

Subjects

MCI patients (N=25) were recruited from the Neurology Department of Coimbra University Hospital. The neurological examination was performed following Petersen's classification criteria for MCI (Petersen et al., 2001). As is described in the most recent guidelines (Petersen, 2004), MCI patients are classified as amnestic MCI (single or multidomain) and this type of MCI is a high-risk group for AD. A standard clinical evaluation, an extensive cognitive and staging assessment, laboratory tests and imaging studies were included as components of the diagnosis work-up. Standard laboratory tests, imaging studies (CT or MRI) and SPECT were always performed whereas PET, CSF analysis, and genetic studies were more restricted, although considered in younger patients. In summary, a comprehensive diagnostic battery of tests was administered, including: 1) Cognitive instruments as the Mini-Mental State Examination (MMSE) (Folstein et al., 1975) Portuguese version (Guerreiro et al. 2003), the Alzheimer Disease Assessment Scale-Cognitive (ADAS - Cog) (Mohs et al., 1983) Portuguese version (Guerreiro et al., 2008) and a comprehensive neuropsychological battery of tests with normative data for the Portuguese population (BLAD) (Guerreiro, 1988) exploring memory (Wechsler Memory Scale sub-tests) and other cognitive domains; 2) The Clinical Dementia Rating (CDR) (Morris, 1993; Garret et al., 2008) used for global staging.

Control subjects (N=22) were patients' spouses, age-matched hospital or university staff, and relatives, without relevant history of neurological or psychiatric conditions.

Informed consent was obtained from the subjects, and the study was conducted in accordance with the tenets of the Declaration of Helsinki, and following the guidelines of our local ethics committee. Exclusion criteria included neurological/psychiatric conditions other

than Mild Cognitive Impairment and abnormal ophthalmological conditions. All participants had normal or corrected-to-normal vision.

The two groups are matched for age, but not for educational level. (Demographic Data - Table I).

	Control subjects (n=22)	MCI (n=25)
Gender (m:f)	12:10	9:16
Age, years (SE)	62,23 (1,99)	65,84 (1,55)
Education Level, years (SE)	10,5* (0,92)	6,76 (0,79)

SE – Standard Error

MCI – Mild Cognitive Impairment

* p>0,05

Table I. Demographic Data.

Stimuli

Videos of 3D SFM defined faces (for details see Farivar et al, 2009), chairs, scrambled faces and scrambled chairs were used as stimuli. The face stimulus consisted of one laser-scanned facial surface taken from the Max-Planck Face Database (Troje and Bulthoff, 1996). The surfaces were rendered a volumetric texture map to ensure uniform texture density - a process analogous to carving a surface out of a stone block. Shadows and shading were removed from the rendering. The faces were rendered against a similarly textured random-dot background. During the animation, the face rotated from -22.5 degrees to 22.5 degrees, centered at the frontal plan, in one cycle. This rotation was captured in a video that lasted approximately 1 second for the longer duration stimulus (26 frames corresponding to 980 ms) (Fig 1). The chair stimulus was obtained from a chair model database and was rendered in exactly the same manner as the face stimulus. Scrambled versions of the two stimuli were constructed by cutting the rendered whole object (face or chair) videos on the horizontal plane

into ten blocks and scrambling their local curvatures/positions. The resulting scrambled stimuli share many of the low-level features of the original videos and are recognized as unfamiliar objects. It is important to note that these motion-defined objects are only visible when the animation is playing, otherwise participants are not able to interpret the SFM cues in order to extract a vivid three-dimensional percept, as desired.

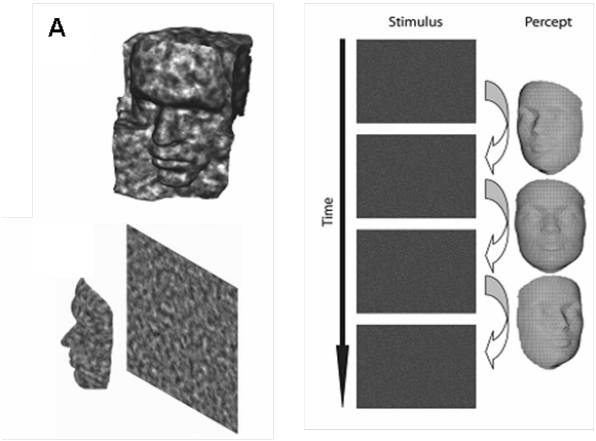

Fig. 1 Generating purely motion-defined faces (Adapted from Farivar et al., 2009).

Procedure

Participants were individually tested in a quiet and darkened room. They were seated in a comfortable chair at a distance of 50 cm from the computer screen. They viewed the screen with a maximum deviation of ~13° horizontally and ~ 10° vertically. The stimuli were always presented at the center of a 33,8 cm x 27,1 cm dark computer screen (1280 x 1024 pixels) using the software package Presentation (Neurobehavioral systems).

Participants had to discriminate 3D SFM objects (faces and chairs) from 3D SFM meaningless objects (scrambled faces and scrambled chairs). The investigator recorded subjects' oral responses using a 2-button response box to exclude confounding factors such as motor errors. The tasks were subdivided in i) *experimental task I*: a Chair discrimination task in which participants had to report if the presented stimulus was upright or scrambled - this task was used as a control task at ceiling level of performance, to make sure that subjects

understood the task requirements and were familiar with the procedures; ii) *Object Recognition task II*: a face discrimination task where participants had to discriminate between faces and scrambled faces. On both Face and Chair tasks, stimulus duration and 3D depth level were manipulated, therefore the SFM movies were randomly shown at three different durations: 100ms, 160ms and 980ms; and at three different 3D depth levels, full, intermediate and flat depth (Fig. 2). The depth levels were parameterized in terms of anterior-posterior range in which full, intermediate and flat depth conditions had 10%, 60% and 90% less object depth, respectively, using the posterior plane as a reference. Considering all the variables included in the tasks, namely four object categories (face, scrambled face, chair and scrambled chair), three stimulus duration (100 ms, 160 ms and 980 ms) and three 3D depth levels (full, intermediate and flat depth) we obtained a 4 x 3 x 3 design with 10 trials per condition. Before performing the experimental tasks, all participants underwent a demonstration and a practice phase. In the demonstration phase the stimuli included in both Face and Chair tasks were shown at the different depth levels in order to allow the participants to become familiar with the objects that they would be asked to recognize afterwards. The practice phase was applied before each experimental task and included 18 trials in which the different conditions were randomly presented. The practice phase was repeated whenever the participant did not understand the instructions.

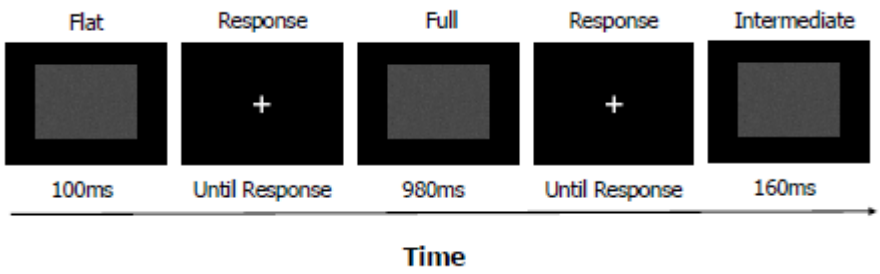

Fig. 2 Example of the experiment, involving the 3 stimuli durations and the 3 depth levels.

Analysis

The SPSS 17.0 software package was used for statistical analysis. Parametric statistics (ANOVA repeated measures analysis and post hoc parametric T-tests), were carried out for all statistical analysis, taking into account that most of the variables in the study do not violate the principles of normality and variance homogeneity.

RESULTS

Chairs and Scrambled Chairs

The Chair stimuli a 3x3x2 repeated measure ANOVA with within-subjects variables Depth (Full, Intermediate and Flat) and Duration (100 ms, 160 ms and 980 ms) and between-subjects variable Group (Control subjects and MCI), revealed significant main effects for Depth ($F(2,45)=16,964$, $p<0,001$) and Duration ($F(2,45)=17,583$, $p<0,001$). No significant effect for Group ($F(1,45)=25,099$, $p>0.05$), was recorded, as is shown on Fig. 3.

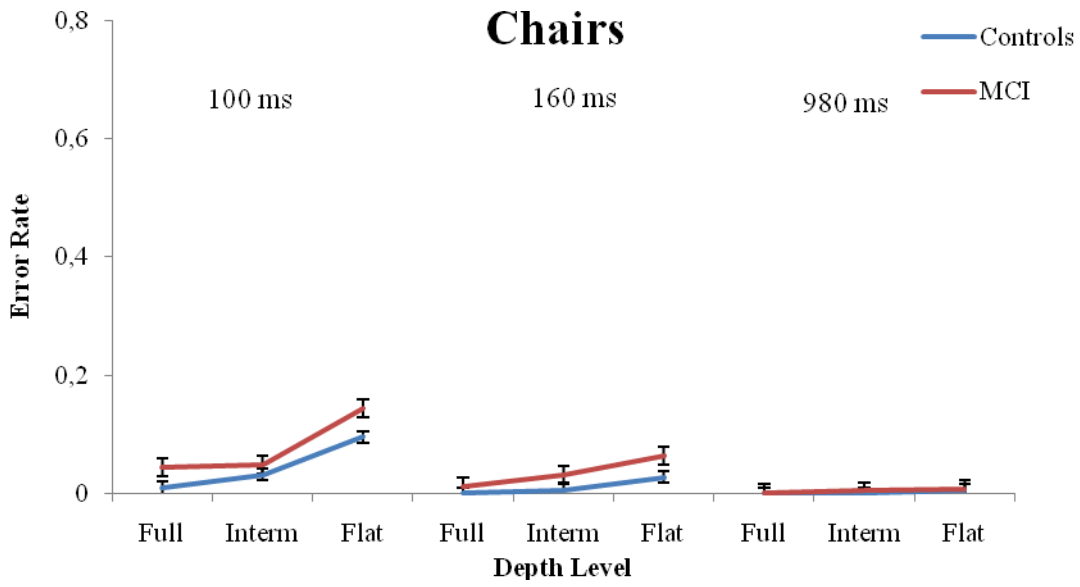

Fig. 3 Error rate of Control subjects and MCI subjects for Chairs for the three depth levels and the three stimuli durations. ± Standard error (SE). Non-parametric post-hoc analysis corroborated these results.

For Scrambled Chair stimuli, a similar pattern of performance results was found with significant effect for Depth ($F(2,45)=17,265$, $p<0,001$) and Duration ($F(2,45)=22,984$, $p<0,001$). No significant effect for Group ($F(1,45)=31,715$, $p>0.05$) was found (Fig. 4).

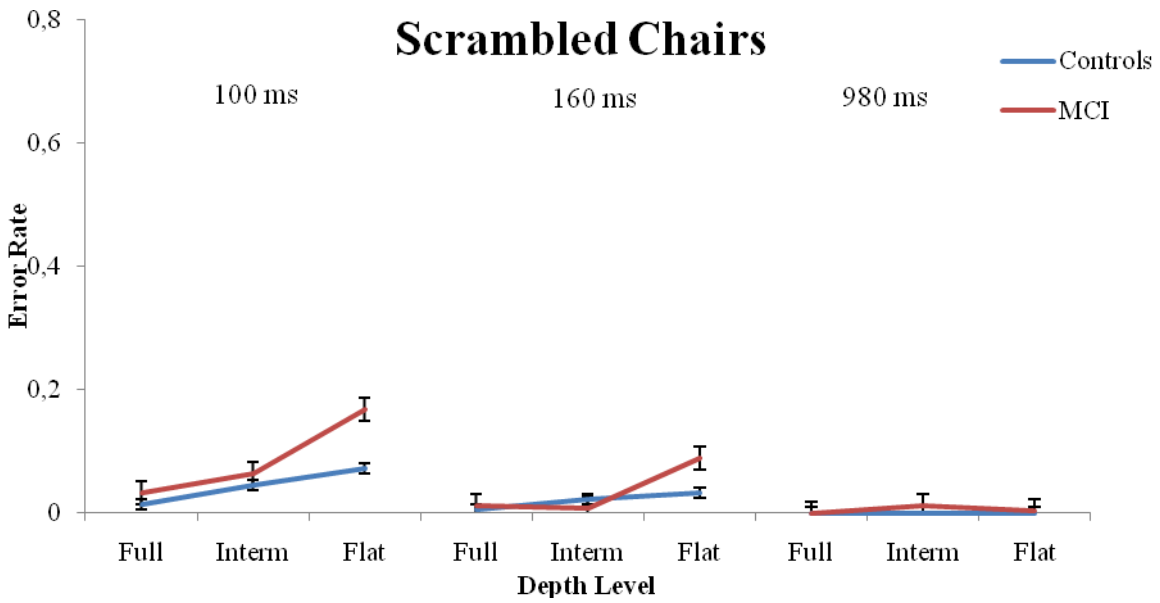

Fig. 4 Error rate of Control subjects and MCI subjects for Scrambled Chairs for the three depth levels and the three stimuli durations. ± Standard error (SE). Non-parametric post-hoc analysis corroborated these results.

No differences were found concerning Chair and Scrambled Chair stimuli, with a ceiling level of performance, confirming that this task can be taken as a control condition for the task comprehension, since the subjects were able to understand the task and complete the paradigm.

Faces and Scrambled Faces

Regarding the Face stimuli a 3x3x2 repeated measure ANOVA with within-subjects variables Depth (Full, Intermediate and Flat) and Duration (100 ms, 160 ms and 980 ms) and between-subjects variable Group (Control Subjects and MCI) revealed significant main effects for Depth ($F(2,45)=23,896$, $p<0,001$) and Duration ($F(2,45)=40,110$, $p<0,001$) suggesting that performance changes depending on the different Duration and Depth levels of the stimuli. We also found a main effect for Group ($F(1,45)=111,935$, $p<0,05$). In order to identify the conditions that differentiated the groups, independent sample T-tests were used. They revealed significant differences for the intermediate Duration (160 ms), for Full and Intermediate Depth levels ($t(45)= -3,193$, $p<0,001$; $t(45)= -2,710$, $p<0,05$ respectively) and for

the slowest Duration (980 ms), for Full and Flat Depth levels (t(45)= -1,456, p<0,05; t(45)= -1,554, p<0,05 respectively).

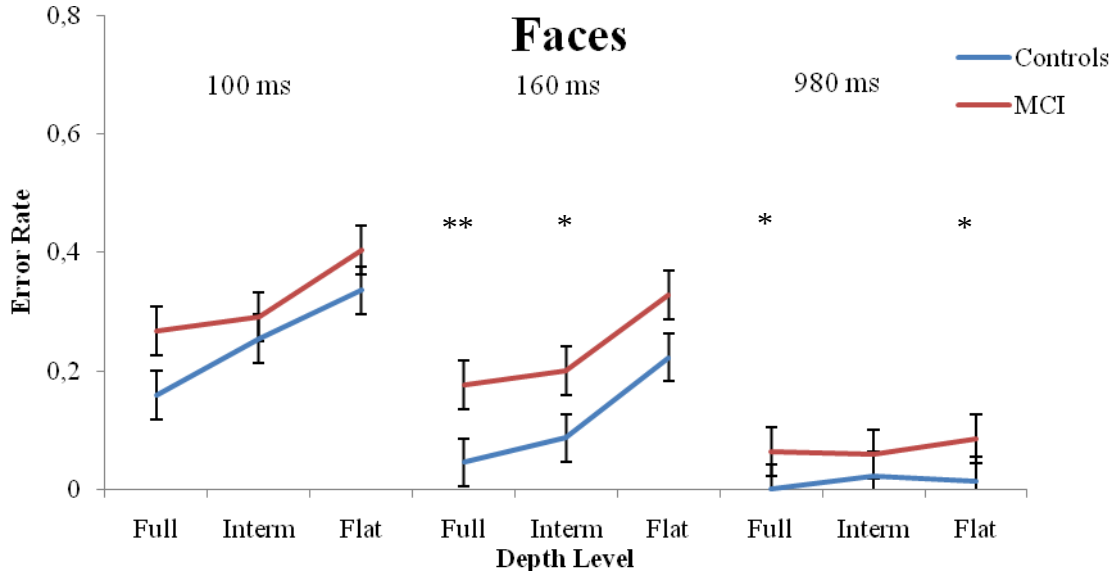

Fig. 5 Error rate of Control subjects and MCI subjects for Faces considering the three depth levels and the three stimuli durations. ± Standard error (SE). *p<0,05; **p<0,001. Non-parametric post-hoc analysis corroborated these results.

For Scrambled Faces, significant effects for Depth and Duration were also found: Depth (F(2,45)=43,471, p<0,001) and Duration (F(2,45)=31,755, p<0,001), suggesting that performance is dependent of the different stimuli Duration and Depth levels. No significant effect for Group (F(1,45)=49,736, p>0,05) was found (Fig. 6).

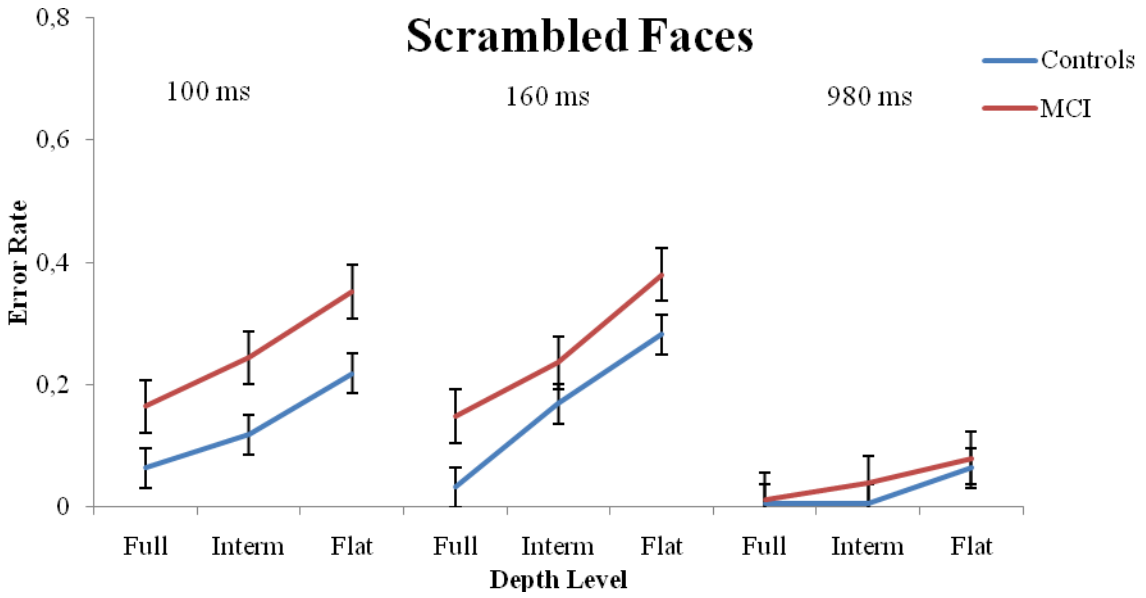

Fig. 6 Error rate of Control subjects and MCI subjects for Scrambled Faces considering the three depth levels and the three stimuli durations. ± Standard error (SE). Non-parametric post-hoc analysis corroborated these results.

DISCUSSION

The processing of visual motion is commonly believed to depend on dorsal stream mechanisms (Konen and Kastner, 2008). Dynamic aspects of a visual scene provide important cues for object segregation and identification, and 3D SFM cues can be derived from all visual objects. These cues are highly informative of an object's shape and may be capable of driving complex recognition processes in the absence of other shape cues.

The current work was developed to test the role of depth and temporal integration of three-dimensional SFM depth cues in complex object recognition, in MCI patients. Therefore, a paradigm was developed to assess the nature of dorsal-ventral integration, with stimuli that activate both dorsal and ventral pathways. These stimuli included depth-rotating laser-scanned facial surfaces with texture gradients consisting of uniformly placed dot textures. Dorsal stream mechanisms are necessary for the perception of SFM objects, whereas ventral stream areas are necessary for their identification, and an interaction between both streams is therefore likely to be required to perform this task (Farivar et al., 2009). Rizzo et al (2000) stated that visual dysfunction is evident and common in AD, and that a mild form of this disease produces both ventral and dorsal visual pathway deficits. These notions follow up Rizzo and Nawrot's (1998) study where it was concluded that "AD has significant effects on the perception of SFM". In our study we focused on a novel paradigm testing the role of depth and temporal integration of motion cues at short intervals in MCI, which is a transitional stage between normal and pathological ageing. An impairment in recognizing 3D SFM stimuli leads us to conclude that there are deficits in intermediate level visual functions, namely in ventral and dorsal streams, at such an early stage in the disease.

Our results demonstrate evidence of an impairment in the integration of dorsal and ventral pathways in the recognition of objects (in particular faces) in MCI. There were no differences in the Chairs vs Scrambled Chairs perception, proving that this task has strong merits as a

learning control task. The lack of significant differences, between MCI patients and Control Subjects, in the Scrambled Faces perception may be due to lack of statistical power and response bias in this condition. In the Face Recognition trial, only the Intermediate Duration (160 ms) enables a distinction regarding the comparison between MCI and Control Subjects. This was found for both Full and Intermediate Depth levels, suggesting that more difficult conditions (Flat depth level) are not optimal for discrimination at this duration. However for the longest Duration (980 ms) we found that MCI and Control Subjects performed differently in both Full and Flat Depth levels.

In a previous study of our group (Lemos et al., 2011), it had already been shown that an impaired cue combination of three-dimensional orientation and motion of simple objects in short time windows yield evidence for specific early dorsal stream impairment that occurs before and independently of ventral visual stream deficits in MCI. Accordingly, it appears that parietal (dorsal) function is probably affected earlier in the course of this degenerative process than occipital or infero-temporal (ventral) related functions.

In this work, we conclude that pathological ageing (MCI) is related to deterioration in extracting object information from combined short lived motion and depth cues processed in the visual dorsal stream, leading us to believe that an impairment of the dorsal-ventral integration already exists at this early stage of pathological ageing.

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