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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RECOGNITION OF 3D SFM DEFINED OBJECTS IN NORMAL AGEING: DEVELOPMENT TRAJECTORY

SCIENTIFIC ARTICLE

ÁREA CIENTÍFICA DE NEUROSCIENCES

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

MARÇO/2011

Recognition of 3D SFM defined objects in development and normal ageing

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ABSTRACT

Introduction: In structure-from-motion stimuli (SFM), 3D shape can only be extracted from dot moving patterns by integrating motion cues over time. Although some previous cross sectional studies have studied perception of 3D SFM objects in healthy and patients with neurological disease, less is still known concerning its developmental trajectory and ageing.

Objective: In the present study, we studied the developmental trajectory of 3D SFM perception by investigating the effect of duration and 3D depth levels in the ability to recognize 3D SFM objects in distinct age groups.

Methods: We developed an experimental paradigm in which participants had to discriminate between 3D SFM objects (faces and chairs) from 3D SFM meaningless objects (scrambled faces and scrambled chairs). The chairs stimuli were used as a control task, at ceiling level of performance, to make sure that subjects understood the task requirements. Stimuli duration was randomly manipulated (100ms, 160ms, 980ms) as well as depth information (flat, intermediate and full depth), resulting in a 4x3x3 design with 10 trials per condition. A total of 71 healthy volunteers were included in three different groups: Children (n=24), Young Adults (n=25) and Old Adults (n=22).

Results: Considering the Chair task**,** as expected from its difficulty level, no significant differences were found between the groups confirming it as a control task ensuring subject´s comprehension. For face stimuli, a 3x3x3 repeated measure ANOVA with within-subject variables Depth (flat, intermediate and full) and Duration (100ms, 160ms and 980ms) and between-subject variable Group (children, young adults and old adults) revealed significant main effects for depth and duration ($p<0.001$) as well as for group ($p<0,05$). Post-hoc analyses showed that significant differences occurred between the young and old adults. A similar pattern of results was found regarding scrambled face stimuli with depth and duration effects as well as a group effect. Post-hoc analysis revealed that young adults differed from the other two groups evidencing better performance in identifying 3D meaningless faces.

Conclusion: Considering our results, we are able to show that young children at the school age are able to recognize 3D SFM faces achieving adult levels of performance. On the other hand, a deterioration regarding the ability to recognize 3D SFM objects, in older adults group suggest that normal ageing mechanisms lead to a decline in extracting object information from short lived motion and depth cues processed in the visual dorsal stream.

Keywords: Developmental trajectory, Ageing, 3D depth perception, structure-from-motion, dorsal-ventral visual pathways.

RESUMO

Introdução: Nos estímulos structure-from-motion (SFM), a única forma de extrair formas tridimensionais de padrões de pontos em movimento, é a integração de estímulos de profundidade ao longo do tempo. Embora alguns estudos já tenham estudado a percepção visual de objectos tridimensionais em pessoas saudáveis e com patologia neurológica, ainda pouco se sabe acerca do seu normal desenvolvimento e envelhecimento.

Objectivo: No presente estudo, centrámo-nos na trajectória de desenvolvimento da percepção visual de objectos tridimensionais em SFM, investigando o efeito da duração e dos diferentes níveis de profundidade tridimensional na capacidade de reconhecimento dos mesmos, em grupos de diferentes faixas etárias.

Métodos: Foi desenvolvido um procedimento experimental no qual os participantes tinham que discriminar entre objectos tridimensionais SFM (caras e cadeiras) e os mesmos objectos distorcidos (caras distorcidas e cadeiras distorcidas). O teste de cadeiras foi usado para assegurar o cumprimento dos requisitos de compreensão por parte dos controlos. A duração do estímulo (100 ms, 160 ms e 980 ms) e os diferentes níveis de profundidade (máximo, médio e mínimo) foram manipulados, resultando num design 4x3x3 com 10 repetições por condição. Participaram ao todo 71 participantes, divididos por três diferentes grupos: crianças (n=24), adultos jovens (n=25) e adultos idosos (n=22).

Resultados: No teste de cadeiras, como esperado, não foram encontradas diferenças estatisticamente significativas entre os grupos confirmando a compreensão do teste pelos participantes. Para o teste de caras, usámos o teste estatístico ANOVA com análise da variância estatística para profundidade (mínimo, intermédio e máximo), para duração (100ms, 160 ms e 980 ms) e entre grupos (crianças, adultos jovens e adultos idosos), revelando efeitos significativamente estatísticos para profundidade e duração ($p<0.001$) e também para o grupo

($p<0.05$). De seguida a análise Post-hoc revelou diferenças significativas entre adultos jovens e idosos. O mesmo padrão de resultados foi encontrado para o teste de caras distorcidas com efeito de duração, profundidade e grupo. A análise Post-hoc ainda revelou que o grupo adultos jovens diferiu dos outros dois grupos com melhor desempenho na identificação de caras distorcidas tridimensionais.

Conclusão: Considerando os nossos resultados, podemos inferir que as crianças de idade escolar são capazes de reconhecer caras tridimensionais em SFM, alcançando níveis adultos de desempenho. Por outro lado, a deterioração na capacidade de reconhecer objectos tridimensionais em SFM no grupo de adultos idosos, sugere que os mecanismos fisiológicos envolvidos no envelhecimento, levam a um declínio na capacidade de extrair informação de curtas pistas de movimento e profundidade pela via dorsal da visão.

AKNOWLEDGEMENTS

First of all, I would like to thank Faculdade de Medicina da Universidade de Coimbra for allowing me to enter the World of Investigation.

I would like to thank my thesis tutor, Miguel Castelo-Branco, PhD, for his irreplaceable guidance throughout this study.

A special thanks to Inês Bernardino for her constant presence, orientation and preoccupation. Without her guidance and support this study wouldn't be possible. Raquel Lemos, my sincere gratitude, for all acknowledgements at the right moment.

To all volunteers, a very special thank.

To my parents, for all your love, your listening skills, your support and your constant capacity to say the right thing. Ricardo, thank you for your constant patience.

To my friends, they know who they are, for still loving me.

To my dear Madeleine Stokreef, un unconditional and inestimable thank.

INTRODUCTION

Vision is a complex function that progressively matures during human development and is also modified by ageing (Rabbit & Lowe, 2000). The visual system is anatomically and functionally separated into two visual pathways: dorsal and ventral pathways (Ungerleider & Mishkin, 1982; Mishkin et al., 1982). Dorsal pathway goes from occipital lobe to parietal lobe and is responsible for visuospatial processing ("vision for action" pathway). Ventral pathway projects from occipital lobe to temporal lobe and has been related with object recognition (shape, size) (Goodale & Milner, 1992; 1995; 2008).

Even thought complex object recognition relies, preferentially, on ventral stream, is now known that dorsal stream areas (posterior parietal cortex) are also involved in extracting three-dimensional (3D) shapes from depth and motion cues (Vanduffel et al., 2002; Shikata et al., 1996, 2003; Konen & Kastner, 2008). The putative role of ventral areas in the recognition of complex dynamic faces was also established (Anderson & Siegel, 2005). These findings have been gathered from studies on structure-from-motion (SFM) perception in which the 3D shape can only be extracted from dot moving patterns by integrating motion cues over time. Studies on the neural correlates of SFM perception, explored in human (Orban et al., 1999; Kriegeskorte et al., 2003), monkeys (O'Toole et al., 2002) and lesion studies (Farivar & Blanke, 2009), have identified visual areas involved in motion perception (V5+/MT, intraparietal sulcus), and object recognition (lateral occipital complex and fusiform regions). This suggests dorsal-ventral interactions during SFM perception. However, the respective role of each visual pathway remains unclear and we still do not know its trajectory through life span (Konen & Kastner, 2008).

Psychophysical research has shown that motion perception emerges fast early in life and that the ability to process complex motion information (Kellman & Spelke, 1983) as well as the onset of steriopsis (Braddick et al., 1980) are present at 4 months. Nevertheless, other studies proposed that development of complex visual acquisitions extends until the end of childhood. SFM perception is quite mature at 7 years of age (Braddick et al., 2000; Parrish et al., 2005) and the integration of local motion into global perceptual constructions appears between 4 and 10 years and continues developing during adolescence (Braddick et al 2003). Functional brain imaging research suggested that neural activity in the dorsal pathway was not mature by the age of 6 years (Paradis et al, 2000 Lichtensteiger et al., 2008; Klaver, 2008). Considering these findings, we hypothesized that although the neural maturation is not fully achieved, subjects at the school age are close to accomplish adult levels of performance when recognizing SFM stimuli.

Ageing processes were also thought to modify some visual functions (Sekuler et al, 1983). Initially, these changes were thought to occur due to optical problems such as ageing-related miosis or visual field loss (Keltner & Johnson, 1987). However, Johnson et. al (1989) hypothesized that the cortical aspects of vision also plays a relevant influence. Nowadays, there are unequivocal evidences concerning the decaying of visual function in elderly including visual acuity loss (Owsley et al, 1983; Higgins et al., 1988), difficulties in spatial frequency discrimination (Bennett & Cortese 1996) and visual memory impairment(Grady, 1996). However, one of the most affected capacities in elderly is motion perception (Trick & Silverman, 1991; Gilmore et al., 1992; Sekuler & Sekuler, 2000 and Norman et al (2000)), these studies suggest that older subjects can extract depth and shape from moving patterns although these abilities are often manifested at reduced levels of performance. However less is known about the decline of these visual functions.

The existing evidence is controversial, and it is crucial to study the developmental trajectory underlying 3D SFM perception and the influence of ageing processes. In this study, our main goal is to understand how 3D SFM perception is established during childhood by comparing performance of children and young adults. Furthermore, also, intended to explore if the perception of 3D SFM objects is affected by ageing by comparing young and old adults' performance in 3D SFM visual tasks involving different stimuli durations and different levels of depth levels. The knowledge of the developmental trajectory underlying SFM perception in healthy participants would contribute to better understand pathological conditions in which this circuit is impaired, such as Williams syndrome (Braddick et al., 2003; Atkinson et al., 2003; Mendes et al., 2005), and Alzheimer's Disease (Lemos et al., 2011).

MATERIAL AND METHODS

Participants

In the present study, a total of 75 healthy participants were included in order to explore the developmental and ageing patterns that underlie the perception of 3D SFM objects. Three different groups were created according to the participants' chronological age: 24 Children with age between 6 and 17 (mean ± standard error (SE)= 12.17 ± 0.74years), 25 Young Adults with age between 19 and 27(mean ± standard error (SE)= 22.64±0.34years),and 22 Older adults with age between 47 and 81 (mean ± standard error (SE)= 62.23± 1.99years). The demographic characteristics of the three groups are summarized in Table I. As expected the three groups differed concerning the chronological age ($p<0.05$) and the educational level ($p<0.05$).

All participants were healthy, with no previous history of psychiatric, neurologic and ophthalmologic illness. A short questionnaire (appendix 1) was administered to obtain the medical history and other basic information about the participants, such as, date of birth, education level, handedness, family information and medication (see Table 1). The participants were voluntary and naïve concerning to the testing procedures. Informed consent was obtained from participants themselves. The study was approved by our local ethics committee and was conducted in accordance with the declaration of Helsinki.

Table I: Demographic data (SE – Standard Error).

	Children (n=24)	Young Adults (n=25)	Old Adults (n=22)
Gender (M/F)	13:11	15:10	10:12
Age, years (SE)	12.17 (0.73)	22.64 (0.34)	62.23 (1.99)
Education Level, years (SE)	6.29 (0.74)	17.0 (0.22)	10.5 (0.92)

Materials

Stimuli used in this study consisted of videos of SFM defined faces, chairs, scrambled faces and scrambled chairs (for details see Farivar & Branke, 2009). The face stimulus consisted of 1 laser-scanned facial surfaces taken from the Max-Planck Face Database (Troje & Bulthoff, 1996). The surfaces were rendered with a volumetric texture map that ensures uniform texture density across the surface - it is 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 (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 in 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 object identities. It is important to note that these motion-defined objects are only visible when the display is moving. This ensures that, participants need these cue types to interpret SFM cues in order to extract a vivid three-dimensional percept.

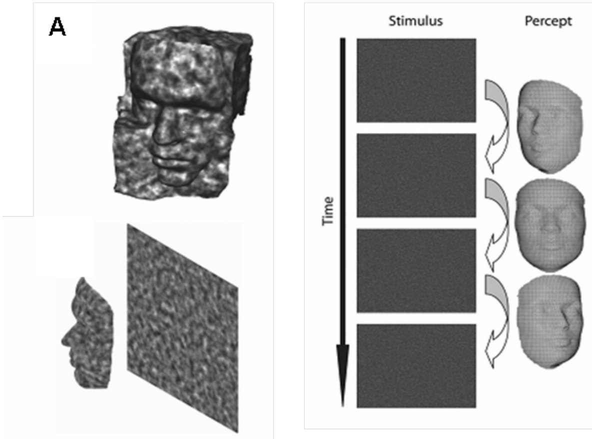

Fig.1 Construction scheme of SFM stimuli. Adapted from Farivar & Blanke, 2009.

Procedure

Participants were individually tested in a quiet and darkened room, seated in a comfortable chair at a distance of 50cm from the computer screen viewing stimuli subtending ~13° of visual angle horizontally and ~ 10° vertically. The stimuli were always presented at the center of a dark 33,8cm X 27,1cm computer screen (1280X1024 pixels) using the software package Presentation (Neurobehavioral systems).

In the present study, 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). For that, participants were asked to perform two experimental tasks: a Chair task (Comprehension Control Training task) where participants had to discriminate between chairs and scrambled chairs and a Face task (Main Experimental task) in which participants had to report if the presented stimulus was a face or a scrambled face. The experimenter recorded subjects' oral responses to exclude confounding factors such as motor errors. The Chair task was administered always before the Face task and 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. On both Face and Chair tasks, stimulus duration and 3D depth level were manipulated. Thus, the SFM movies were randomly shown at three different durations: 100ms, 160ms and 980ms; and at three different 3D depth levels, namely, 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. Considered all the variables included on the tasks, namely four object categories (face, scrambled face, chair and scrambled chair), three stimulus duration (100ms, 160ms and 980ms) and three 3D depth levels (full, intermediate and flat depth) we obtained a 4x3x3 design with 10 trials per condition. Before the performance of experimental tasks, all participants underwent a demonstration and a practice phase. In the demonstration phase, the stimuli included on both face and chair tasks were shown at the different depth levels in order for participants to become familiar with the objects that they were asked to recognize afterwards. The practice phase was administered before each experimental task and included 18 trials in which the different conditions were randomly presented. The practice phase was repeated whenever the participants did not understand the instructions.

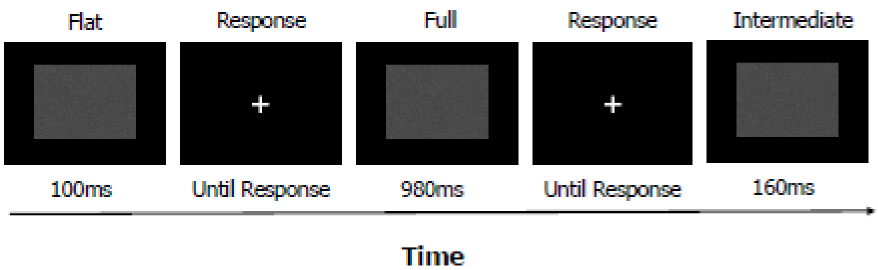

Fig.2 Example of the experiment, involving the 3 stimuli durations and the 3 depth levels.

Statistical Analysis

For the statistical analysis we used SPSS 17.0 software package. Parametric statistics (ANOVA repeated measures analysis, post-hoc corrections using Bonferroni tests and parametric Student' T-tests) were carried out for all statistical analyses. 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

Chair task (Training Task): Concerning the Chair' category of stimuli, a 3x3x3 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 (Children, Young Adults and Old Adult) revealed significant main effects for Depth ($F(2,68)=11.026$, $p<.001$) and Duration ($F(2,68)=17.098$, $p<.001$). However, no significant effect for Group ($F(2,68)=44.654$, $p>.05$) was found, as it shown at Fig.3.

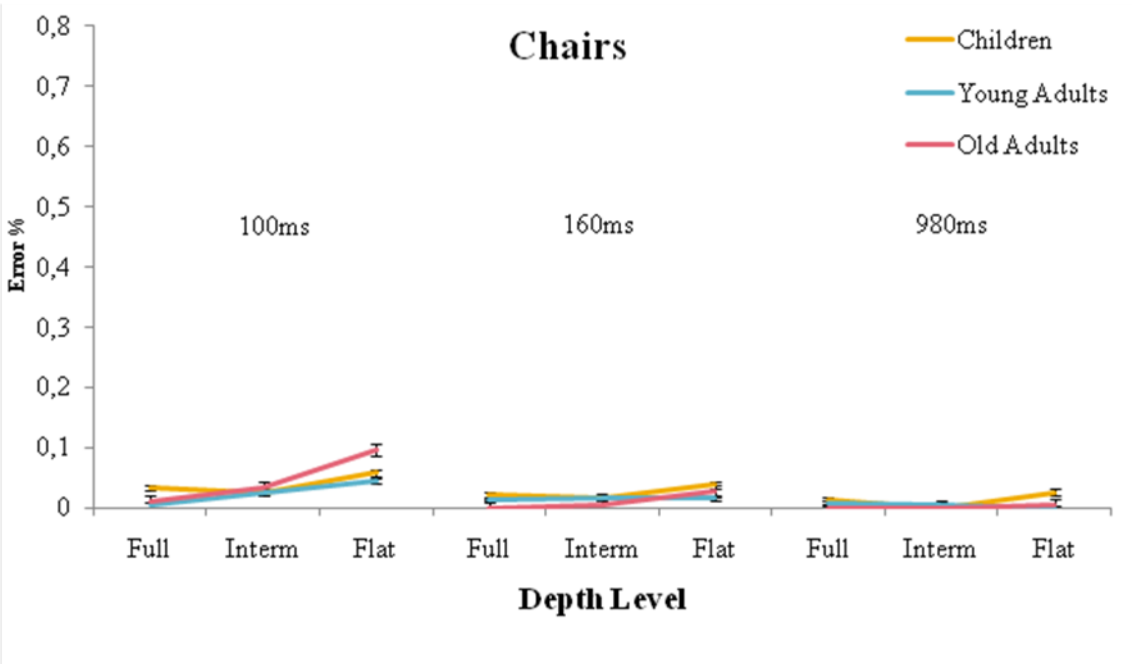

Fig. 3 Error rate of Children, Young Adults and Old Adults for Chairs stimuli considering the three depth levels and the three stimuli durations. . ± Standard error (SE). Non-parametric post-hoc analysis corroborated these results.

For Scrambled Chair stimuli, a similar pattern of performance results was found with significant effect for Depth ($F(2,68)=7.937$, $p>.05$) and Duration ($F(2,68)=23.864$, $p>.05$) . Nevertheless, in this stimuli category, we obtained a significant effect for Group

(F(2,68)=46.373, *p*<.05) as we can see at Fig.4, suggesting that participants of all groups did not perceive the SFM scrambled faces in the same way.

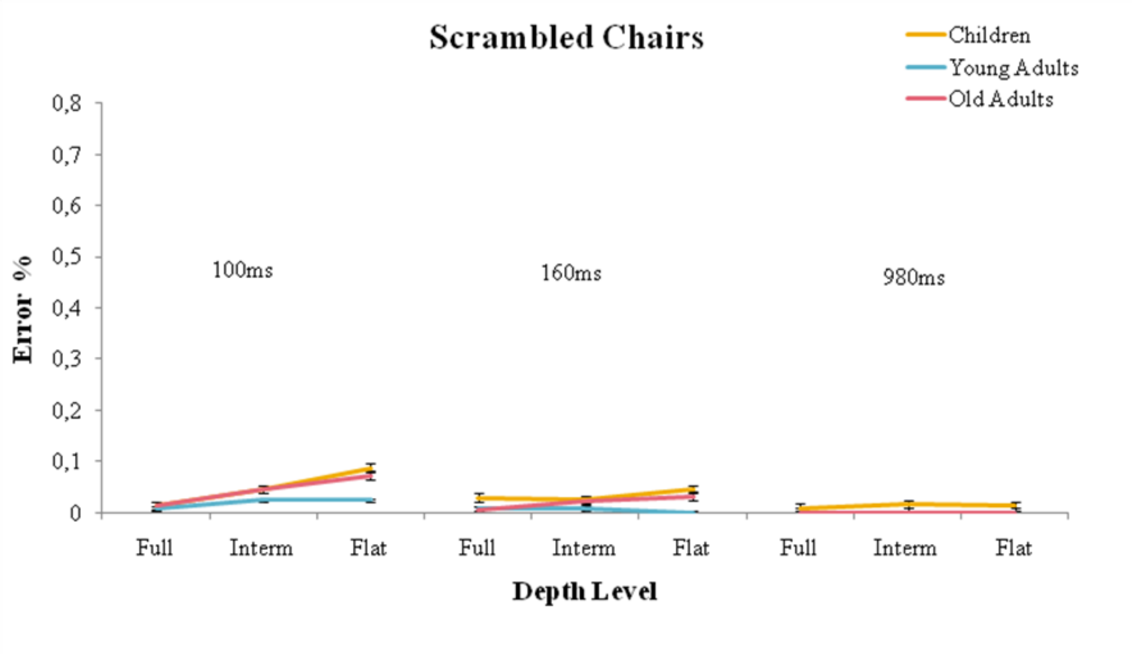

Fig. 4 Error rate of Children, Young Adults and Old Adults for Scrambled Chairs stimuli considering the three depth levels and the three stimuli durations. . ± Standard error (SE). Non-parametric post-hoc analysis corroborated these results.

In general, these results, as we expected, show that subjects performed at or near to the ceiling level and these results confirmed that they were able to understand the task requirements and complete the experimental paradigm.

Face task (Experimental Task) Regarding the Face stimuli a 3x3x3 repeated measures ANOVA with within-subjects variables Depth (Full, Intermediate and Flat) and Duration (100 ms, 160 ms and 980 ms) and between-subjects variable Group (Children, Young Adults and Old Adult) revealed significant main effects for Depth (F(2,68)=32.492, *p*<.001) and Duration (F(2,68)=68.555, *p*<.001) suggesting that performance changes depending on the different stimuli Duration and Depth levels that we introduced on the task. We also found a main effect for Group ($F(2,68)=107.569$, $p<.05$) and post-hoc analysis, using Bonferroni correction, revealed significant differences only between Young and Old Adults. We can conclude than, that Old Adult made significantly more errors than Young Adults when asked to recognize SFM Faces. On the other hand, children performed similarly to young adults suggesting that young children (beyond 6 years old) are able to achieve adult levels of performance.

In order to individualize the conditions where young and old adults differed, we used post hoc independent sample Student' T-tests We found that significant differences only occurred for faster duration (100 ms), for the three Depth levels ((t (45)=-2.656, $p<0.05$); (t (45)=-5.861, $p<0.05$) and (t (45)=-2.387, $p<0.05$), for Full, Intermediate and Flat Depth levels, respectively) and for the intermediate duration (160 ms) at Intermediate (t (45)=-2.356, $p<0.05$) and Flat (t (45)=-2.214, $p<0.05$) depth levels (Fig. 5).

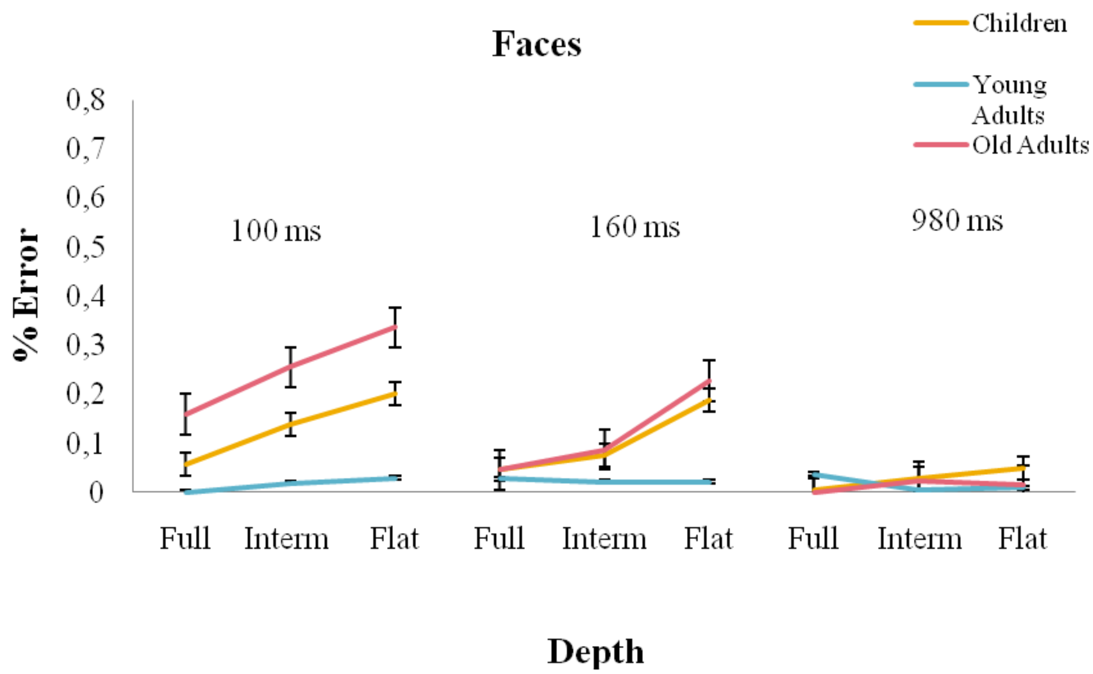

Fig.5 Error rate of Children, Young Adults and Old Adults for Faces stimuli considering the three depth levels and the three stimuli durations. . ± Standard error (SE). Non-parametric post-hoc analysis corroborated these results.

For Scrambled Faces stimuli category, significant effects for Depth ($F(2,68)=32.492$, $p<.05$) and Duration ($F(2,68)=68.555$, $p<.05$) were also found. Concerning this 3D SFM meaningless objects category, a significant effect for Group ($F(2,68)=107.569$, $p<.05$) was also identified. Post-hoc analysis showed significant differences between: Young Adults vs Old Adults ($p<0.05$) and Young Adults vs Children ($p<0.001$). No significant differences were found between Children and Old Adults. The group of Young Adults differed from Old Adults at faster stimuli duration (100ms) for Intermediate Depth (t (45)=-5.861, $p<0.05$) level condition as well as at intermediate Duration (160ms) for both Intermediate (t (45)=-2.356 $p<0.05$) and Flat (t (45)=-2.214, $p<0.05$) Depth levels. Between Young Adults and Children there were significant differences at the faster Duration (100ms) for the three levels of Depth (t (45)=-3.263, $p<0.05$); (t (45)=-2.720, $p<0.05$) and t (45)=-4.104, $p<0.05$) for Full, Intermediate and Flat levels of Depth. At intermediate Duration (160 ms), the differences occurred at Intermediate (t (45)=-3.012, $p<0.05$) and Flat (t (45)=-4.057, $p<0.05$) levels of Depth and for the slower Duration (980 ms) at Full (t (45)=-2.470, $p<0.05$) and Flat (t (45)=-2.577, $p<0.05$) levels of Depth as is shown at Fig. 6.

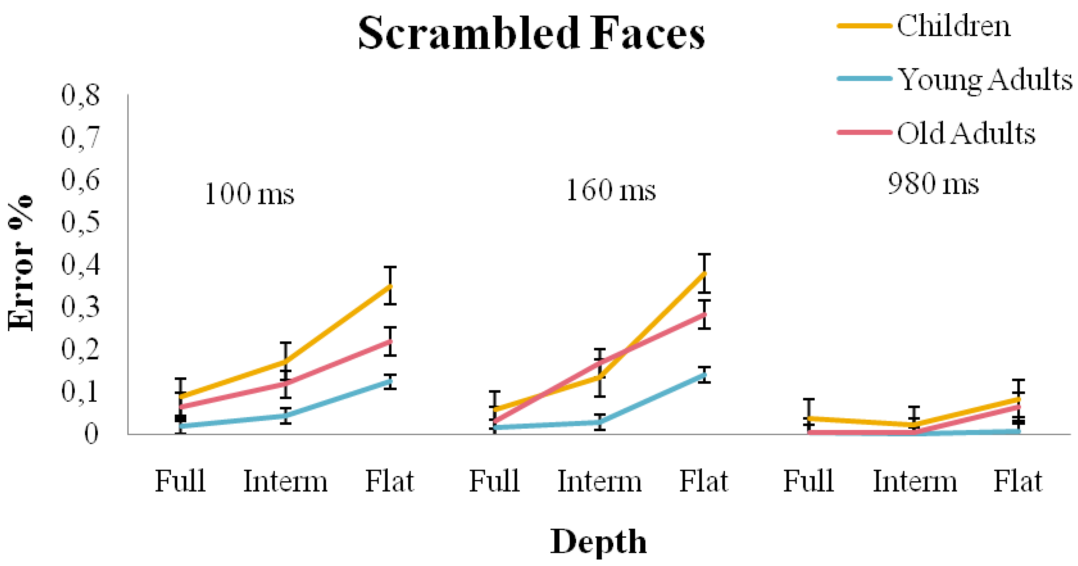

Fig. 6 Error rate of Children, Young Adults and Old Adults for Scrambled Faces stimuli considering the three depth levels and the three stimuli durations. ± Standard error (SE). [a] p<0.05. . ± Standard error (SE). Non-parametric post-hoc analysis corroborated these results.

DISCUSSION

The current study was aimed at investigating the developmental trajectory and aging patterns underlying 3D SFM perception. We conducted two experimental tasks requiring subjects to discriminate between 3D SFM objects (chairs and faces) and 3D SFM meaningless objects (scrambled chairs and scrambled faces). In the first task, involving chair stimulus discrimination, we found that all participants were able to recognize simple 3D SFM objects. It is important to note that even in this easy control paradigm, we found significant effects for Depth and Duration. The results obtained for Scrambled Chairs stimulus confirmed the role of this task as a comprehension control.

Concerning the main task, requiring the discrimination between 3D SFM faces and 3D SFM scrambled faces, we found that children at school age (mean age = 12.17 years) were able to identify 3D SFM faces in the same way as young adults, despite their relative difficulties in correctly recognize 3D SFM scrambled faces. The selective impairment found for scrambled faces in children may indicate that the familiarity of the stimulus could play an important role for the recognition of 3D SFM objects. Altogether, these findings would suggest that, at this age, functions needed to accurately extract 3D shape information from motion and depth cues are partially mature. These results are in line with previous evidences indicating that standard SFM perception seems to be mature levels at 7 years of age even though it may continue developing during adolescence (Braddick et al., 2000; Parrish et al. 2005, Klaver et al., 2008). More specifically, Parrish et al (2005) found that the ability to perform global dot motion tasks and global arrow texture task matures by 3-4 years of age while the ability to perform motion-defined form tasks reaches mature levels at 7-8 years of age. In order to confirm this assumption, and as a target for future work, it would be interesting to study children samples with ages lower than that we have included in our study (age range: 6-17). This would allow to better explore and understand early developmental patterns of 3D SFM perceptual maturation.

Furthermore, we found the children' worse performance related to shorter stimulus durations. So, we can conclude that, although school age children already showed the capacity of recognize 3D SFM objects, they still needed more time to perceive the stimulus, especially when meaningless 3D SFM stimuli were shown. This extra time needed, suggests that the visual perception of 3D objects during childhood requires the activation of alternative neural circuits of those recruited by the mature adult brain. This interpretation is consistent with studies demonstrating alternative neural circuits in children when processing 3D motion cues (Parrish et al., 2005). Klaver et al. (2008) claimed that neural activity in the dorsal stream is not yet mature by the age of 6 years and concluded that high order processes are substituted by low order processes in the immature brain. Although our study only focused on behavioral data, could not give us sufficient information to conclude about the neural correlates of 3D SFM perception, it could provide us important clues to better conduct functional imaging studies with the main goal to dissect the underlying neural circuits of 3D SFM perception.

Additionally, our results demonstrated a significant deterioration in recognizing both faces and scrambled faces in older adults when compared to young adults, particularly for faster durations and nosiest conditions (flattest depth conditions). Although Norman et al (2000) suggested that, in general, older observers retain a significant amount of functionality with respect to the perception of depth and shape as well as a preserved stereoscopic vision, our findings, using demanding temporal and depth constraints, did not support their conclusions. Indeed, our older adults performed significantly worse than younger adults in our 3D SFM recognition task. However, the above mentioned authors also highlighted that older observers showed significant deteriorations in the ability to perceive the structure and shape of curved surfaces defined by motion (Norman et al.2000) which is directly implicated in the execution of our experimental task. These findings are in agreement with additional studies that proposed a clearly decaying of 3D visual perception along the ageing process (Sekuler et al., 1983; Grady, 1996). Furthermore, we observed that old adults performed worse for both faces and scrambled faces stimulus categories, which leads us to the outcome that the decaying in 3D SFM objects perception is a general process with no relation with the familiarity of stimulus, since we found significant impairment either for familiar (faces) as for unfamiliar (scrambled faces) objects.

In the future, it will be interesting to explore the role of performance bias , in order to better characterize performance patterns.

CONCLUSION

In sum, our study obtained results that are consistent with the hypothesis that the dorsal-ventral integration for familiar stimuli achieves adult levels during adolescence (after 12 years old). We did indeed find that the major difficulties in children are determined for the duration and the familiarity of stimulus. Additionally, we proved that a deterioration of 3D SFM object recognition occurs in parallel with ageing process, in which a decline in extracting object information from short lived motion and depth cues processed in the visual dorsal stream is observed.

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APPENDIX 1: Demographic Questionaire

3D Structure from motion: Questionário Demográfico

- **Identificação**

  Código_______________

  Nome:____

  Género____

  Data de Nascimento:______________Local de Nascimento:__________

  Nome do Pai:____

  Profissão do pai:____

  Habilitações Literárias (pai):____________________________________

  Nome da Mãe:____

  Profissão da mãe:____

  Habilitações Literárias (mãe):__________________________________

  Tem irmãos? Quantos e que idades?_____________________________

  Contactos (telef/telem)____

  Lateralidade (questionário)_____________________________________

- **Educação**

  Profissão:____

  Nível de escolaridade que frequenta:_____________________________
  Já teve alguma reprovação na escola? Quantas?___________________

- **História Médica**

  Tem alguma doença neurológica? (ex: epilepsia, traumatismo craniano, etc.)____
  Tem alguma doença psicológica? (ex: depressão, hiperactividade, défice de atenção, etc.)____
  Tem alguma doença oftalmológica? Usa óculos ou lentes de contacto?____
  Está a tomar alguma medicação? Qual?____
  Tem história familiar de demência? (apenas para adultos)____________
  ____

- **Outras Informações Importantes**________________________________

  ____