

Commentary on “Dysfunction of the Magnocellular Stream in Alzheimer Disease Evaluated by Pattern Electroretinograms and Visual Evoked Potentials”

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Abstract

Alzheimer's disease (AD) represents the most common cause of dementia. Even if AD is commonly viewed as a disorder primarily of memory, there are several other additional domains, including visual function. Accumulating evidence suggests that the magnocellular or M-pathway subsystem of visual pathways is preferentially affected in AD compared to other neurodegenerative disease. A study of Sartucci et al. few years ago tested the three main visual pathways subsystem electrophysiologically in AD patients. They used Pattern Electroretinograms (PERG) and Visual Evoked Potentials (VEP) to luminance-contrast and chromatic-contrast stimuli to elicit responses differentially driven by generators of M-pathway, P-pathway (Parvocellular) and K-pathway (Koniocellular), and found that responses driven by the M-pathway were relatively more altered. The results of Sartucci et al., together with the body of available literature, are consistent with the hypothesis that a primary dysfunction of M-pathway impairment does occur in a sufficient number of AD patients to warrant support for a specific Magnocellular deficit associated with this disease.

Keywords: Magnocellular stream, Alzheimer's disease, Visual pathways subsystem, Chromatic and luminance visual evoked responses

Introduction

Alzheimer's Disease (AD) is a progressive chronic neurodegenerative disorder and the most common cause of dementia in the older adults worldwide [1]. AD is commonly viewed as a disorder primarily of memory, which represents usually the initial sign; moreover, this disease is characterized by impairment in several additional domains, including visual function. However, the NINCDS-ADRDA clinical diagnostic criteria [2] make no mention of sensory changes. Several main fields of researches on vision in AD currently have undertaken,

from structure to function and behavior at this time, and current directions in AD vision studies are extensively reported in many papers, including some exhaustive books [1].

This commentary will briefly review current knowledge on dysfunction of the visual pathway in AD, focusing on differential involvement of M, P, and K visual subsystems at either retinal or cortical levels. Visual dysfunction in AD will be compared visual dysfunction occurring in physiological aging and other age-related degenerative disorders.

Clinical Aspects

Alzheimer's disease (AD) impairs visual function at an early-intermediate state of degeneration and functional losses correlate with severity of cognitive progressive impairment. Different visual deficits have been reported in AD patients, such as alteration of contrast sensitivity [3], motion perception [4,5], performance on masking tests [3], color discrimination of blue, short-wavelength hues [3], visual attention and visual behavior, face discrimination, imagery [6]. However further sensory and motor dysfunction in AD patients may be detected [7]. In the absence of an accurate biomarker, the diagnosis relies on cognitive profile supported by neuroimaging [8]. Following the abovementioned reports, the eye as has been proposed as a convenient biomarker for diagnosis and progression of AD [9,10]. Visual involvement features in AD, together with functional and morphological changes of the retina and visual structures, have received a great deal of attention [11].

Neuropathological Changes in Alzheimer's Disease: The Visual Variant

In addition to the typical form of AD, a growing number of cases of focal cortical presentations has recently been described: in particular, the condition known as posterior cortical atrophy (PCA) is commonly accompanied by visuospatial impairment, which recalls the clinical characteristics of both Balint's and Gerstmann's Syndromes, visual agnosia, dressing apraxia, environmental disorientation. PCA presents as bi-parietal syndrome and tends to remain confined to posterior areas for a very long time before spreading away [12,13]. Patients with PCA are older than those with typical AD and have less memory loss or reduced verbal fluency. Unfortunately, differential diagnosis remains anamnestic, even if modern functional imaging, such as amyloid binding ligand PIB or positron emission tomography with carbon 11 [14], could be helpful to discriminate these pathologies *in vivo*. Moreover, the distribution of senile plaques (SP) and neurofibrillary tangles (NFT) is quite different between typical AD and visuospatial variant. Areas 17, 18 and 19 contain a much higher density of NFT in PCA; in patients with visual agnosia also the regions of inferior temporal cortex and occipito-temporal junction (areas 37, 20 and 21; [15]) show increased deposition of NFT and SP compared to typical AD. These data are consistent with the view that PCA affects the feed-forward projections to high-level regions and to associative visual areas, but the etiopathological bases remain elusive so far.

Neuropathological Changes on Alzheimer's Disease: Focus on the Visual System

Extensive deposition of amyloid- β ($A\beta$) leading to

the formation of plaques is considered one of the key pathological features of Alzheimer's disease (AD) [16]. However, impairment of memory and synaptic deficit occur prior to extensive extracellular deposition of $A\beta$ in the brain [17-21] during an early phase of AD progression before senile plaques (SP) [22]. Interestingly, Origlia et al. [23] demonstrated that low concentrations of oligomeric $A\beta$ are capable of disrupting synaptic plasticity in different circuits of the mouse visual cortex. An intriguing finding is that long-term synaptic plasticity (LTP) in supragranular horizontal pathways (layer II/III) is altered by lower concentration of $A\beta$ respect to other intracortical pathways (WM-layer II/III vertical pathway). Thus, sensitivity of synaptic disruption to oligomeric $A\beta$ accumulation differs between different intra-cortical pathways within the occipital cortex.

The reported results, together with previous reports [24,25] showing the presence of laminar differences within single brain areas in AD progress, raise the important question of whether the pattern of AD reflects the sensitivity of different neurons and/or synaptic connections to pathogens, including $A\beta$.

Alterations in amyloid precursor protein (APP) processing and $A\beta$ accumulation may therefore contribute to retinal damage as well as to cortical alterations as above indicated. Several reports outlined the role of oligomeric $A\beta$ in retinal pigmented epithelium (RPE) alterations and dysfunctions, ganglion cells dysfunction, inflammatory and oxidative process till cell death [26,27]; indeed, APP and its products including $A\beta$ were detected in retinal as well as in cerebral extracts from murine models of AD.

Altogether, the reported results permit to advance the hypothesis that visual system, from retina to cortical areas, might be affected during an early-intermediate stage of AD characterized by large absence of SP, NFT and cell death; following this idea an increasing amount of oligomeric beta accumulation induces synaptic toxicity and dysfunction in several cells from retina to cortex. Whether $A\beta$ -dependent visual impairment in AD is due to retinal pathology or due to post-retinal pathology remains unclear. Therefore, the eye may offer a direct window to the cerebral pathology sharing many similarities to the brain [9].

Segregation of P- and M-stream in Humans: The Ventral (P) and Dorsal (M) Cortical Stream

The post-receptoral visual pathways of primates contain two major parallel streams specific for color contrast/form discrimination and luminance contrast/movement discrimination [28-31]. The color-opponent system originates from small, tonic ganglion cells relaying to parvocellular laminae of the lateral geniculate nucleus

and then projecting to layer 4C- β of the striate cortex. More deeply, recent data showed that two color-opponent pathways, red-green (RG) and blue-yellow (B-Y), form the so-called parvo- (P) and konio-cellular (K) streams, respectively [32-35]. The second major subsystem, i.e. the achromatic stream, originates from large, phasic ganglion cells projecting to the magnocellular (M) layers of the lateral geniculate nucleus and then to laminae 4C- β of the striate visual cortex [36,37]. It is worth to note that parvocellular cells may also respond well to achromatic contrast stimuli of relatively high-spatial frequency. However, within the range of spatial frequencies to which both streams respond, M cells are relatively more sensitive to achromatic contrast and this characteristic is more prominent at higher temporal frequencies. To date, it is common knowledge that a specific decline in high-spatial contrast and low-temporal frequency sensitivity suggests a selective deficit in P-stream [38], whereas the loss of motion perception and the impairment in analyzing low-spatial frequency and contrast luminance are more likely to be related with severe dysfunction affecting M-pathway. The small receptive fields of the P channels in the center of vision yield a strong local motion signal, whereas the M ones with their fast transmission time and large receptive fields ensure the integration of global motion signals over a larger area. At higher level P inputs mainly project to the ventral pathway, whereas K and M pathways to the dorsal pathway [39].

Since parietal structures are a frequent pathophysiological target in AD, a dorsal stream visual impairment (M and K pathways) might be predominantly affected and occurs independently in AD [40].

From Histopathology to Psychophysiology: New Insights into the Involvement of Magnocellular Stream in Alzheimer's Disease

Histopathological studies demonstrated that hippocampus and the parahippocampal regions are the earliest affected regions in AD, suggesting a hierarchical order of involvement: from limbic to associative cortical areas, from associative to primary sensory cortical areas including the visual cortex. Following this scheme, the involvement of visual system characterizes a late phase of AD, as well as the non-pathological aging [41]. However, recent studies have highlighted visual dysfunctions in AD patients. In particular, clinical studies support a link between cognitive performance and visual dysfunction even at an early stage of AD when SP and NFT are largely absent. Impairment of higher order visual processing, such as the loss of color discrimination, stereoacuity, contrast sensitivity, and backward masking, have been frequently described in AD patients [3,42,43].

Blanks and colleagues first tried to examine the

degeneration of the retinal ganglion cells, finding that cells with largest diameters, by which magnocellular stream is made up, are selectively affected in AD patients [44]. Another indirect, but highly convincing data in support of a specific visual impairment come from the study of Dentchev et al. [45] who emphasized the presence of A β proteins in the retina of AD patients compared to age and sex-matched controls.

Hof and Morrison hypothesized that, even if there is less NFT deposition in the occipital areas than in the prefrontal and temporal cortices, AD patients often exhibit a significant neuronal loss within specific cortical layers, i.e. IV-C and IV-B, where magnocellular stream terminates [46]; this observation agrees with both a motion perception impairment and an extensive M-pathway dysfunction in AD, possibly caused by oligomeric A β progressive accumulation and sensitivity in different cortical layers [23].

Author Experience

The paper of Sartucci et al. [47] tested the hypothesis that AD involves a deficit in the magnocellular pathway of the visual system using ERGs and VEPs to chromatic (Ch, P and K streams) and luminance (Lum) stimuli that differentially drive responses from different subsystems. Electrophysiological analysis of these three different streams might be relatively simple also considering that sensory inputs are conveyed to the LGN, and then to V1 cortical area and higher center, in a one-to-one ordered fashion.

To this aim, they recorded electroretinograms and visual potentials evoked by chromatic and luminance visual stimuli (ChPERGs and ChVEPs, LumERGs and LumVEPs) in a selected sample of AD patients. All cases met the diagnostic criteria of probable AD according to the Diagnostic and Statistical Manual of Mental Disorders, fourth edition (DSM-4), the ICD-10 Classification of Mental and Behavioral Disorders (ICD-10) and the criteria of the National Institute of Neurologic and Communicative Disorders and Stroke and the Alzheimer's Disease and Related Disorders Association (NINCDS-ADRDA) [48]. Severity of dementia was assessed using MMSE [49], and an extensive standardized diagnostic protocol [50]; at the time of diagnosis, all the patients presented a MMSE score below 23/30. Diagnosis of AD was supported by an exhaustive diagnostic work-up including morphological and functional neuroimaging (brain MRI scan and a FDG-PET semi quantitative study, electroencephalogram and auditory P300 Event Related Potentials (ERPs).

Visual stimuli

Visual stimuli were equiluminant horizontal sinusoidal

gratings, modulated either in luminance (yellow-black, Y-Bk) or chromaticity (red-green, R-G and blue-yellow, B-Y). Details of stimuli, modality of recordings and device used are widely illustrated and reported in several papers (for example in Porciatti & Sartucci [34,35], Sartucci & Porciatti [51], Bonfiglio et al. [52]).

Results

Individual transient waveforms and grand-average of PERGs and VEPs, obtained in both controls and AD patients, are summarized in Figures 1 and 2. Compared to controls, Lum PERGs were inconsistent in individual patients, resulting in an altered grand-average waveform with reduced amplitude and delayed latency, suggesting the existence of a specific magnocellular or M-pathway deficit. Chromatic PERGs did not show obvious differences between controls and AD patients. To assess retinal versus post-retinal defects, Retino-cortical time (RCT) analysis was performed and did not reveal a retino-calcarine pathway involvement associated with AD [47].

Locus of Visual Impairment As a Primary Marker of Alzheimer’s Disease

Evidence supporting a “magnocellular deficit hypothesis” was not previously considered. Rizzo et al. argued that visual impairment in AD is totally due to dysfunction in the associative cortices, basing their theory on normality of VEPs, full-field ERG and cortical flicker fusion threshold in AD [43,53]. On the other hand, the sensory deficits can be hidden and frequently masqueraded as higher order deficits.

Tippett et al. [54] investigated high-level visual processing involved in mild-to-moderate AD: they hypothesized two distinct pathways of visual processing altered in mild-to-moderate AD, basic shape perception and face processing. To rule out a primary, high-order visual impairment in AD it’s worth considering that (1) there is no relation between visual task performance and MMSE score and (2) truly segregated and symmetrical opponent-color systems do not exist in the cortex, where

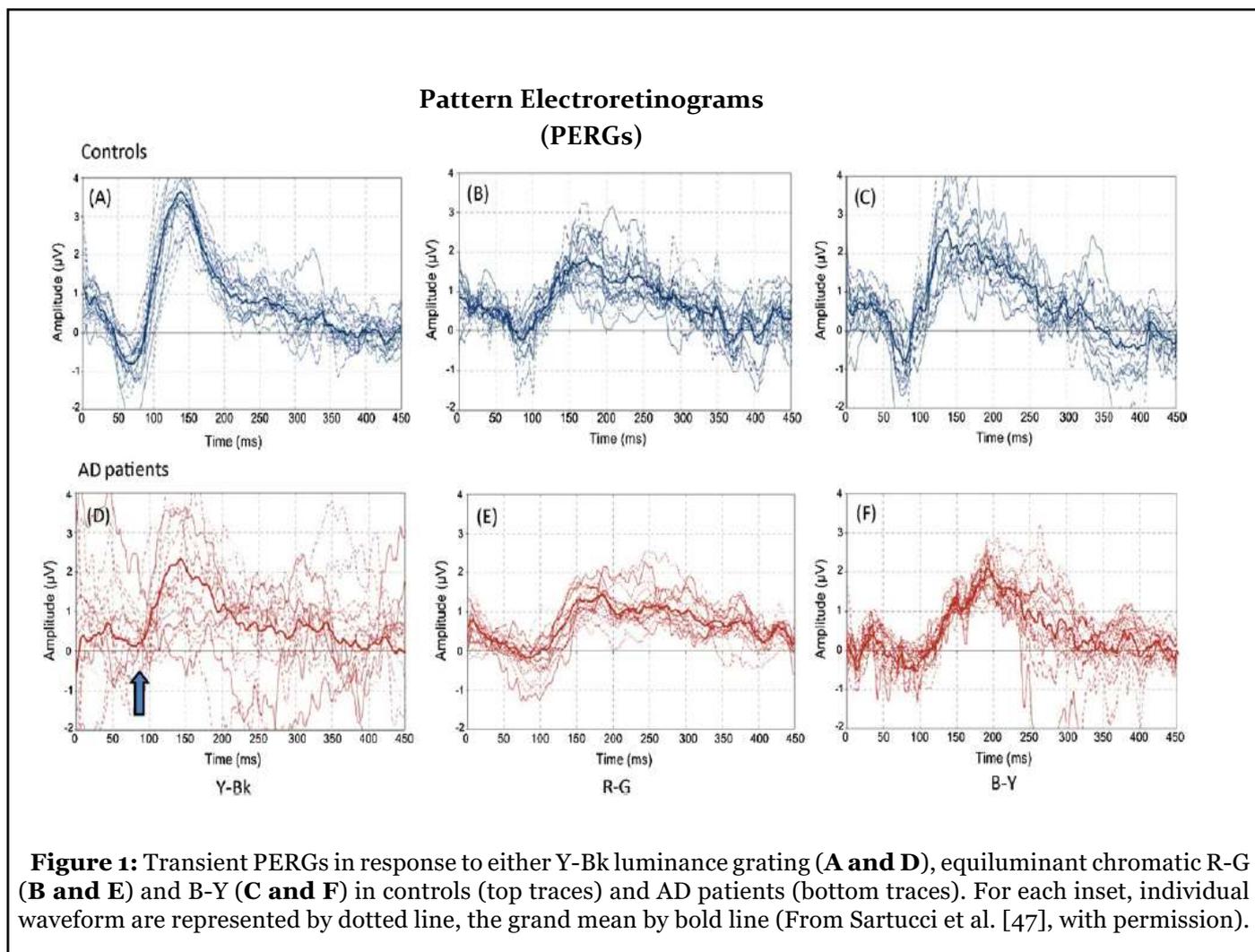
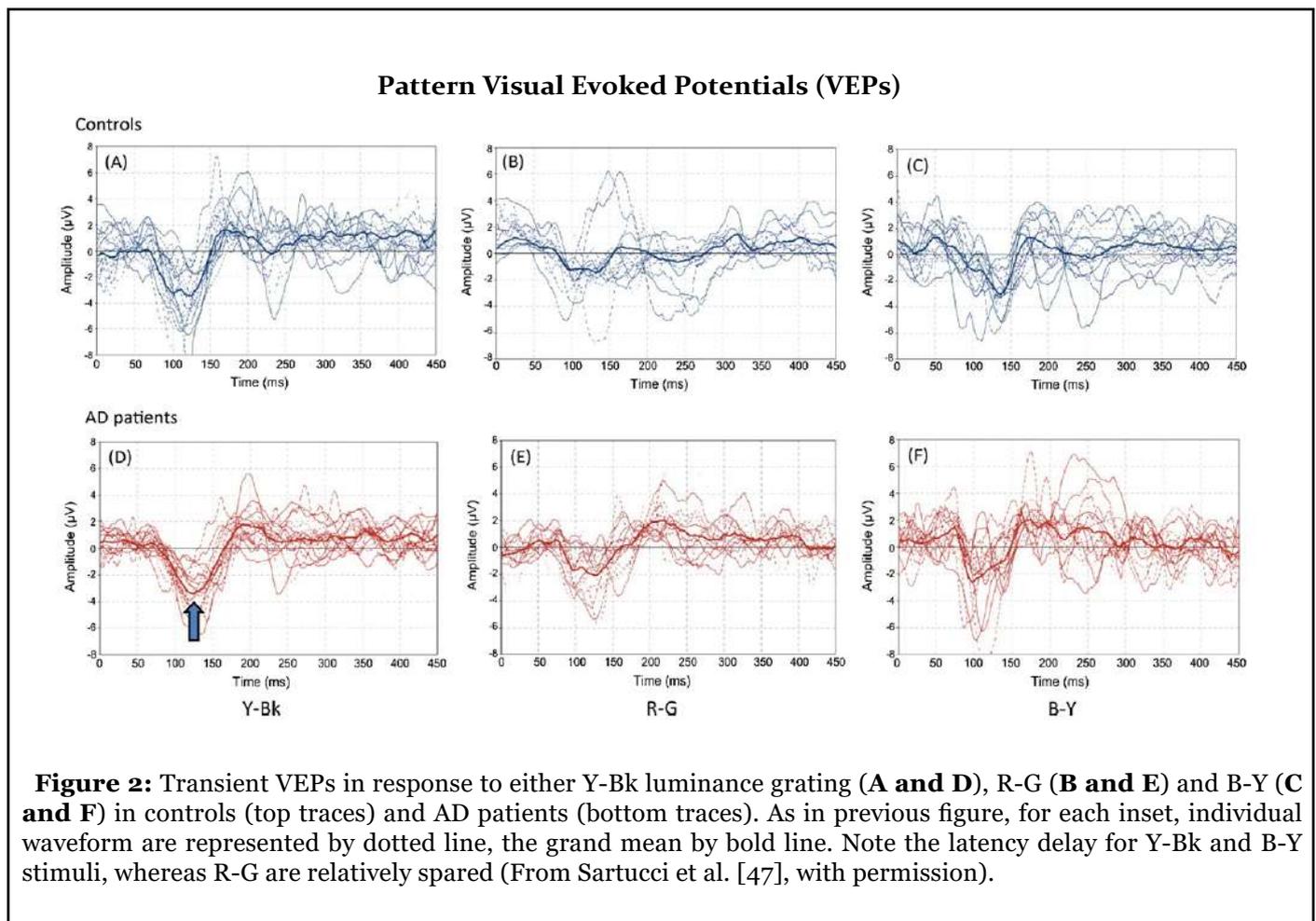


Figure 1: Transient PERGs in response to either Y-Bk luminance grating (A and D), equiluminant chromatic R-G (B and E) and B-Y (C and F) in controls (top traces) and AD patients (bottom traces). For each inset, individual waveform are represented by dotted line, the grand mean by bold line (From Sartucci et al. [47], with permission).



both luminance information and chromatic contrasts are simultaneously processed to detect spatial patterns [55]. Another interesting issue is whether the two hemispheres are asymmetrically involved in AD patients: in fact, the right hemisphere is dominant for rod-mediated scotopic behavior, whereas the left one may be dominant for cone-mediated photopic behavior [56].

Making the Difference between Central and Peripheral Visual Involvement in Alzheimer's Disease

In the past, the reason for a prudent interpretation of previously reported evidences is that there are many contradictory signs of a specific visual involvement: shrinkage of both P and M ganglion cells in the retina, thinning of the nerve fiber layer [57], as well as pathology in both the magno- and the parvocellular layers of lateral geniculate nucleus (LGN), without any definitive conclusion on the selective vulnerability of a visual subsystem [58]. Some authors concluded that the unspecific alterations in second-order neurons pool reflects an initial age-dependent photoreceptors dysfunction [59]. Since age-dependent modifications

were substantially the same for sensitivity to luminance and color contrast [60,61], it has been argued that they all arise at a peripheral level, with obvious reference to senile miosis, increased intraocular light scatter, decreased retinal blood flow in narrow veins or opacification of the ocular media [41], promoted by A β proteins aggregation. Some authors have also described a disease-related enlargement of the optic nerve head cupping as well as a marked thinning of neuroretinal rim [57]. For instance, it cannot be excluded that the outer retina may show some signs of impairment in AD patients: in fact, age-dependent morphological alterations in second-order retinal neurons is commonly accompanied by dendrites loss, redistribution of glutamate receptors and simplification of horizontal cells network [62,63]. These all processes are characterized by a clear spatial gradient, increasing in number from the centre to the periphery of the retina. However, it's worth remembering that compensatory remodeling, in relation to gradual increase in both ectopic synapses and collateral sprouting, follows a similar trend from the periphery, where magnocellular pathway arises, to foveal and parafoveal areas [63]. Besides, it is likely that retinal ganglion cell loss may be partially secondary to retrograde axonal degeneration

too, since there's a greater degeneration in the posterior optic nerve [64]. Taken together, these evidences play against a peripheral source of visual impairment in AD, consistent with the findings that AD particularly affects either cortico-cortical projection neurons [65,66] or geniculo-calcarine processing.

Conclusions

Results of Sartucci et al [47] in AD patients show evident abnormalities both in latency and amplitude of LumPERGs, and no significant changes in ChPERGs compared to controls, suggesting that the M-stream is the best candidate to explain impairments of visual function in this disease. In previous AD studies, it was hypothesized an aspecific deficit in primary visual processing and selective in secondary [67,68]; interestingly, Moore outlined the utility of using a black and a white monitor with large pattern and high contrast in establishing the diagnosis of AD [68], which appears to primarily drive response of the M-pathway. In agreement with Sartucci et al. [47], dysfunction of M-pathway in AD was also hypothesized and specified by Jacob et al. [69]. A specific early dorsal stream visual impairment independently has been reported using electrophysiological [70] or psychophysical [40] methods. Additional clinical and neuropathological evidence in AD supports involvement of the peripheral magnocellular stream or, in cortex, of the dorsal processing stream, supporting a formative theory that propose exceptional vulnerability of functions associated with the magnocellular pathway in AD.

It is worth noting that in another neurodegenerative pathology such as early idiopathic Parkinson's Disease, both chromatic-contrast and luminance-contrast VEPs are impaired, with no evidence of specific involvement of visual subsystems [51].

Abnormal M pathway function has been reported also in subjects with autism spectrum disorders [71,72] a condition known to include cognitive and behavioral development impairments [73], even if later disputed [74].

Altogether, even if the results obtained in AD patients using electrophysiological responses are interesting and support a preferential involvement of the M-pathway, the theme remains debated and not definitively solved. Further studies with larger sample sizes will be necessary to confirm these results and expanded to include other type of degenerative diseases and additional forms of vision testing; it is also desirable that a better understanding of vision-related magnocellular early impairment could guide interventions to improve functional abilities in AD patients with benefit for either patients, their family, caregivers and the community.

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