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Idiosyncratic responding during movie-watching predicted by age differences in attentional control

Karen L. Campbell[a,*], Meredith A. Shafto[a], Paul Wright[a,1], Kamen A. Tsvetanov[a], Linda Geerligs[b], Rhodri Cusack[c], Cam-CAN[d], Lorraine K. Tyler[a]

[a] Department of Psychology, University of Cambridge, Cambridge, UK
[b] MRC Cognition and Brain Sciences Unit, Cambridge, UK
[c] The Brain and Mind Institute, Western University, London, Ontario, Canada
[d] Cambridge Centre for Ageing and Neuroscience (Cam-CAN), University of Cambridge and MRC Cognition and Brain Sciences Unit, Cambridge, UK

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ABSTRACT

Much is known about how age affects the brain during tightly controlled, though largely contrived, experiments, but do these effects extrapolate to everyday life? Naturalistic stimuli, such as movies, closely mimic the real world and provide a window onto the brain's ability to respond in a timely and measured fashion to complex, everyday events. Young adults respond to these stimuli in a highly synchronized fashion, but it remains to be seen how age affects neural responsiveness during naturalistic viewing. To this end, we scanned a large (N = 218), population-based sample from the Cambridge Centre for Ageing and Neuroscience (Cam-CAN) during movie-watching. Intersubject synchronization declined with age, such that older adults' response to the movie was more idiosyncratic. This decreased synchrony related to cognitive measures sensitive to attentional control. Our findings suggest that neural responsivity changes with age, which likely has important implications for real-world event comprehension and memory.

1. Introduction

Movies have the power to transport your mind from the narrow, impersonal bore of an magnetic resonance imaging (MRI) magnet to a world more synonymous with everyday life, replete with sights, sounds, and language. Despite their complexity, these naturalistic stimuli tend to drive neural activation in the same way across individuals (Hasson et al., 2004, 2010), suggesting that our experience of real-world events is largely shared. Although responding in the same way as others is not a perquisite for perception, it does seem to reflect the optimal response to a given stimulus, in that asynchronous responding tends to relate to poor comprehension (Hasson et al., 2009) and memory (Hasson et al., 2008a). This may be because synchronized activity reflects shared attention to the most relevant stimulus in the environment, as nominated by the majority. Empirical work supports this view, as (1) participants' eye movements tend to track the same focal item within each shot (Dorr et al., 2010; Hasson et al., 2008b), (2) materials that are rated as more engaging tend to yield the highest degree of neural synchronization (Dmochowski et al., 2014), and (3) disruptions to story narrative, and ergo meaning, tend to reduce overlap across participants (Dmochowski et al., 2012; Hasson et al., 2008b). Although previous work has mainly focused on aspects of the stimulus itself that make it more or less captivating, these findings suggest that individual differences in attentional control should also predict intersubject synchronization. Individuals with greater attentional control should be better able to maintain focus on the movie and should therefore show higher synchronization with others.

Individuals of all ages differ in their ability to control the focus of attention, but on average, this ability tends to decline with age (Hasher and Zacks, 1988). For instance, relative to younger adults, older adults are less able to ignore distracting information (May, 1999), prevent reflexive eye movements toward irrelevant onsets (Campbell and Ryan, 2009), and to sustain attention to a task to produce consistent response times (RTs; Hultsch et al., 2002). They also experience more interference from internally generated distraction, such as competing responses during memory retrieval (Healey et al., 2013), and these intrusive thoughts affect their ability to stay on task, especially as task demands increase (Persson et al., 2007; Sambataro et al., 2010). This suggests that even during

* Corresponding author at: Department of Psychology, University of Cambridge, Downing Street, Cambridge CB2 3EB, UK. Tel.: +44 1223 766 458; fax: +44 1223 766 452.

E-mail address: karen@csl.psychol.cam.ac.uk (K.L. Campbell).

[1] Present address: Department of Clinical Neurosciences, Centre for Neuroimaging Sciences, King's College London, De Crespigny Park, London SE5 8AF UK.

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task-free, naturalistic viewing, older adults should be less able to sustain attention to a movie and prevent interference from both external (e.g., scanner noise; Stevens et al., 2008) and internal distraction (Mishra et al., 2013). As a result, they should show altered patterns of neural responsiveness and reduced synchronization with others during naturalistic viewing.

To test this hypothesis, we obtained functional magnetic resonance imaging (fMRI) data while participants from a large population-based cohort (aged 18–88 years) watched Alfred Hitchcock's "Bang! You're Dead", a movie previously shown to yield widespread correlations throughout the cortex (Hasson et al., 2010). Functional networks were derived using independent components analysis (ICA; Beckmann and Smith, 2005; Naci et al., 2014), a data-reduction technique that decomposes the continuous fMRI time series into a set of components (or neural networks), each with an associated spatial map, group-average timecourse, and set of individual timecourses reflecting the level of activation within a given network by a given participant at each time point. A measure of synchronization was then derived for each participant, based on the correlation between their individual timecourse and that of the group.

Given age-related declines in attentional control, we expected older adults' network timecourses to show less synchronization with the group-average timecourse. To test the reproducibility of our main finding of interest (i.e., decreased temporal synchrony with age), we also ran a supplementary region of interest (ROI) analysis looking at intersubject correlations in the raw fMRI timecourses of a large number of small ROIs (Craddock et al., 2012).

Furthermore, we expected intersubject synchronization to be positively related to measures which are sensitive to attentional control. Specifically, we expected higher synchronization to be associated with better performance on a test of fluid intelligence (widely thought to depend on attentional control; Duncan, 2013; Engle et al., 1999; Kane and Engle, 2002), but not on measures of crystallized intelligence (or semantic knowledge). Crystallized intelligence is less dependent on attentional control (Cole et al., 2012) and shows a different life span trajectory (Horn and Cattell, 1967). We also gave participants a speeded reaction time (RT) task, in which they had to respond as quickly as possible to visual cues. Here, we expected higher synchronization to be associated with less variable RTs, rather than faster responding per se, as previous work suggests that RT variability is a stronger predictor of attentional control than mean RT itself (MacDonald et al., 2009; Stuss et al., 2003).

2. Methods

2.1. Participants

A population-derived sample (N = 221, 18–88 years old, M = 56.23, standard deviation [SD] = 17.73) were recruited as part of the Cambridge Centre for Ageing and Neuroscience project (Shafto et al., 2014). Exclusion criteria included low performance (24 or lower) on the Mini-Mental State Exam (Folstein et al., 1975), poor hearing (failing to hear 35 dB at 1000 Hz in both ears), poor vision (below 20/50 on the Snellen test), poor English knowledge (non-native or nonbilingual English speakers), self-reported substance abuse, and current serious health conditions (e.g., self-reported major psychiatric conditions, current chemotherapy and/or radiotherapy, or a history of stroke). We also excluded people who were not appropriate for MRI or magnetoencephalograph scanning, which included people with safety- and health-contraindications (e.g., disallowed implants, pacemakers, recent surgery or any previous brain surgery, current pregnancy, facial or very recent tattoos, or a history of multiple seizures or fits) as well as comfort-related issues (e.g., claustrophobia or self-reported inability to lay supine for an hour). Demographic information (including age and sex) for this sample is provided in Supplementary Table 1. Informed consent was obtained from all participants and ethical approval for the study was obtained from the Cambridgeshire 2 (now East of England—Cambridge Central) Research Ethics Committee.

2.2. Cognitive tasks

Participants performed several cognitive tasks outside the scanner as part of a larger test battery (for a full description, see Shafto et al., 2014), but here, we focus on measures which are sensitive to attentional control (fluid intelligence and RT variability) and control measures which are less dependent on control (crystallized intelligence and mean RT). Our measure of fluid intelligence was the Cattell Culture Fair (Cattell and Cattell, 1960), a timed pen-and-paper test in which participants perform a series of nonverbal puzzles. Crystallized intelligence was measured using the Spot-the-Word Test (Baddeley et al., 1993), in which participants see word-nonword pairs (e.g., pinnace-strummage) and decide which is the real word. Finally, on the speeded choice RT task, participants used a 4-button response box and responded as quickly as possible (maximum 3s) to 1 of 4 possible cued fingers (66 trials, variable inter-trial interval with a mean of 3.7 seconds). Outlier RTs that were >3 standard deviations (SDs) away from an individual's mean were removed (6% of trials on average), and intraindividual means (choice RT_{mean}) and SDs (choice RT_{ISD}) were calculated using the remaining trials. Data from 34 participants were missing for the choice RT task because of equipment error (final N = 186).

2.3. The movie

In the scanner, participants watched an edited version of Alfred Hitchcock's "Bang! You're Dead", a black and white television drama which has previously been used to study neural synchronization (Hasson et al., 2004). Because of time constraints, the full 25-minute episode was condensed to 8 minutes with the narrative of the episode preserved. Participants were instructed to watch, listen, and pay attention to the movie (they were not aware of its title).

2.4. Image acquisition

Imaging was performed on a 3T Siemens TIM Trio System at the MRC Cognition Brain and Sciences Unit, Cambridge, UK. A 3D-structural MRI was acquired for each participant using T1-weighted sequence (Generalized Autocalibrating Partially Parallel Acquisition; repetition time = 2250 ms; echo time = 2.99 ms; inversion time = 900 ms; flip angle $\alpha = 9°$; matrix size 256 mm × 240 mm × 19 mm; field of view = 256 mm × 240 mm × 192 mm; resolution = 1 mm isotropic; accelerated factor = 2) with acquisition time of 4 minutes and 32 seconds. For the functional scan, T_2*-weighted echo planar images (EPIs) were acquired using a multiecho sequence (repetition time = 2.47 seconds; 5 echoes [echo time = 9.4 ms, 21.2 ms, 33 ms, 45 ms, 57 ms]; flip angle 78°; 32 axial slices of thickness of 3.7 mm with an interslice gap of 20%; field of view = 192 mm × 192 mm; voxel-size = 3 mm × 3 mm × 4.44 mm) with an acquisition time of 8 minutes and 13 seconds.

2.5. Imaging analyses

2.5.1. Preprocessing

Functional and structural images were preprocessed using SPM12 (Wellcome Department of Imaging Neuroscience, University College London, London, UK), as implemented in AA 4.0 pipeline (https://github.com/rhodricusack/automaticanalysis). Fieldmaps