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Improving the efficiency of multisensory integration in older adults: Audio-visual temporal discrimination training reduces susceptibility to the sound-induced flash illusion

Annalisa Setti[a,b,c], John Stapleton[a,b], Daniel Leahy[d], Cathal Walsh[e], Rose Anne Kenny[f,g], Fiona N. Newell[a,b,*]

[a] School of Psychology, Trinity College Dublin, Ireland
[b] Institute of Neuroscience, Lloyd Building, Trinity College Dublin, Ireland
[c] School of Applied Psychology, University College Cork, Ireland
[d] School of Computer Science and Informatics, University College Dublin, Ireland
[e] School of Computer Science and Statistics, Trinity College Dublin, Ireland
[f] School of Medicine, Trinity College Dublin, Ireland
[g] St. James's Hospital, Dublin, Ireland

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ABSTRACT

From language to motor control, efficient integration of information from different sensory modalities is necessary for maintaining a coherent interaction with the environment. While a number of training studies have focused on training perceptual and cognitive function, only very few are specifically targeted at improving multisensory processing. Discrimination of temporal order or coincidence is a criterion used by the brain to determine whether cross-modal stimuli should be integrated or not. In this study we trained older adults to judge the temporal order of visual and auditory stimuli. We then tested whether the training had an effect in reducing susceptibility to a multisensory illusion, the sound induced flash illusion. Improvement in the temporal order judgement task was associated with a reduction in susceptibility to the illusion, particularly at longer Stimulus Onset Asynchronies, in line with a more efficient multisensory processing profile. The present findings set the ground for more broad training programs aimed at improving older adults' cognitive performance in domains in which efficient temporal integration across the senses is required.

1. Introduction

The possibility to capitalise on brain plasticity to train the brain through behavioural training programs represents an exciting perspective to support independent living in older age (Greenwood & Parasuraman, 2010). A relatively recent and yet large body of work has been dedicated to identifying effective training programs and to testing their validity in different populations, with mixed results (Green & Bavelier, 2008; Kraft, 2012; Kramer & Willis, 2002; Noack, Lövdén, Schmiedek, & Lindenberger, 2009). Brain training programs have shown that it is possible to obtain improvement in cognition (e.g. attention, memory, reasoning, language, etc.) in older age although the benefits do not always extend to non-trained tasks (Ball et al., 2002; Ball, Edwards, & Ross, 2007; Ball, Edwards, Ross, & McGwin, 2010; Edwards et al., 2005; Edwards, Ruva, O'Brien, Haley, & Lister, 2013; Mahncke et al., 2006; Mozolic, Hayaska, & Laurienti, 2010; Mozolic, Long, Morgan, Rawley-Payne, & Laurienti, 2011; Smith et al., 2009; Szelag & Skolimowskaa, 2012; Willis et al., 2006).

To maximise the effectiveness of training programs, such as their impact on non-trained skills and, ultimately, their positive contribution to daily living, it is necessary to identify which specific cognitive processes can be trained. Moreover, it is pertinent to establish how (i.e. under which conditions) they can be trained (Bavelier & Davidson, 2013). One of these processes is multisensory integration, where integration of stimuli from different senses allows the brain to capitalise on the richness of our sensory environment for the purpose of more efficient cognitive functioning. Temporal coincidence is one of the criteria (together with spatial coincidence) used by the brain to establish whether integration should occur, producing multisensory perception, or

* Corresponding author at: Institute of Neuroscience, Lloyd Building, Trinity College Dublin, Ireland. Tel.: +353 1 896 3914; fax: +353 1 896 3183.
E-mail addresses: asetti@tcd.ie (A. Setti), stapletj@tcd.ie (J. Stapleton), daniel.leahy@trilcentre.org (D. Leahy), cathal.walsh@tcd.ie (C. Walsh), rkenny@tcd.ie (R.A. Kenny), Fiona.Newell@tcd.ie (F.N. Newell).

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not, as is evident for example in perceiving body ownership, or audio-visual speech (Calvert, Spence, & Stein, 2004).

The present study aims to train temporal discrimination processing in older adults. Specifically, it aims to improve their ability to discriminate the temporal order of inputs across two different modalities, vision and audition, and to show that this improvement generalises to a related, but not trained, multisensory integration task.

Temporal processing across different senses represents a challenge for the brain as different sensory inputs have different transmission velocities (e.g., from the source, light reaches the sensory receptors faster than sound) and different neural transduction rates (e.g. from the sensory receptors, sound reaches the brain faster than light) (Vroomen & Keetels, 2010). The minimum time interval necessary for the human brain to establish whether a visual input or a sound occurred first or whether they were coincident is thought to be under 100 ms in young adults (Zampini, Guest, Shore, & Spence, 2005; Zampini, Shore, & Spence, 2003a). When one input reaches the sensory receptors it 'opens' a window of opportunity whereby stimuli from other senses can be merged with this input to generate a multisensory experience. This window remains open only for a few milliseconds, after which any other sensory input will be perceived as independent and not merged into a multisensory percept (Colonius & Diederich, 2004, 2011; Pöppel, 1997). The temporal window of integration is the maximum temporal delay between the onset of two stimuli (e.g. a sound and a visual object or event) that the brain tolerates for the purpose of multisensory integration (Burr & Alais, 2006). This window is adaptive in that it varies across different sensory combinations, stimulus complexity and familiarity (e.g. Maier, Di Luca & Noppeney, 2011). As we age, however, the temporal discrimination thresholds become higher (Humes, Busey, Craig, & Kewley-Port, 2009) and the temporal window of integration becomes larger (Diederich, Colonius, & Schomburg, 2008) possibly in order to partially compensate for age-related decline in sensory acuity in peripheral sensory organs (Owsley, 2011) or for the general cognitive slowing characterising late adulthood (Salthouse, 1996, 2009). This implies that perception in older adults becomes more susceptible to multisensory integration. As a consequence perception becomes more efficient when multisensory stimuli are available and provide congruent information (Laurienti, Burdette, Maldjian, & Wallace, 2006; Peiffer, Mozolic, Hugenschmidt, & Laurienti, 2007). However, perception in older adults can also become more exposed to interference effects from sensory stimuli that are not task relevant (Poliakoff, Ashworth, Lowe, & Spence, 2006).

Multisensory illusions have often been used to study susceptibility to multisensory integration (Shams, Kamitani, & Shimojo, 2000). One relatively recently discovered but already widely studied illusion is the Sound-Induced Flash Illusion (SIFI) (Shams et al., 2000). This illusion occurs when a single visual stimulus (e.g. a dot flashed on the screen) is presented with two brief sounds (e.g. two beeps), and the single visual stimulus is perceived as two stimuli (2 flashes when there is, in fact, only 1) as a consequence of the visual and the auditory stimuli being merged into a unified multisensory percept. Susceptibility to the illusion has well established neural correlates (Bolognini, Rossetti, Casati, Mancini, & Vallar, 2011; de Haas, Kanai, Jalkanen, & Rees, 2012; Mishra, Martinez, Sejnowski, & Hillyard, 2007; Shams, Kamitani, Thompson, & Shimojo, 2001) and is considered as a plausible indicator of the integrity of temporal multisensory integration processing (Foss-Feig et al., 2010; Kwakye, Foss-Feig, Cascio, Stone, & Wallace, 2011). This integrity could be compromised in older adults and especially in older adults who have a history of falls, who present a much higher susceptibility to the illusion than younger adults over a more extended temporal window (Setti, Burke, Kenny, & Newell, 2011).

The temporal discrimination threshold across vision and audition plays a large part in determining whether a person will or will not perceive the illusion (Stevenson, Zemtsov, & Wallace, 2012). Importantly, it has been shown that training can reduce this temporal window of integration (Powers, Hillock, & Wallace, 2009). Accordingly, in the present study we hypothesised that if the older brain remains plastic (Dinse, 2006; Dinse et al., 2006), particularly the sensory regions of the brain, we would obtain a refinement of older adults' ability to perform temporal discrimination by training their temporal order judgement (TOJ) skills (Hypothesis 1). We also hypothesised that older participants would be susceptible to the SIFI as previously shown (Hypothesis 2) and that the reduction of their perceptual threshold would be associated with a reduction in susceptibility to the SIFI (Hypothesis 3). Finally we hypothesised that the size of the temporal window of integration after training would be associated with individual susceptibility to the SIFI illusion (Hypothesis 4).

2. Method

2.1. Participants

Thirty-four older participants took part in the present study. All participants were recruited through the Technology Research for Independent Living (TRIL) clinic located in St. James's Hospital (Dublin). Twenty-four participants (11 male) were recruited for the 'training group' and 10 participants (4 male) were recruited for the 'control group'. All participants underwent a comprehensive health assessment in the TRIL clinic; the characteristics of the two groups of participants relevant to this study are reported in Table 1(a). Participants were then tested either in their own home or in Trinity College Dublin for the main study, according to their own preference. The experiment was approved by the St. James's Hospital Ethics Committee and by the School of Psychology Research Ethics Committee, Trinity College Dublin and conformed to the Declaration of Helsinki. All participants provided informed, written consent prior to taking part in the experiment.

2.2. Apparatus and stimuli

All tasks were presented on a DELL XPS M1530 laptop computer (screen resolution of 1280×720, refraction rate of 60 Hz). Participants were seated in front of the computer screen (approximate distance of 70 cm). An external keyboard was used when a key press was required to respond (i.e. during the training and control tasks).

The visual stimulus used in all tasks (i.e. the sound-induced flash illusion task, the TOJ training task and control tasks) comprised of a white disk with a diameter subtending a visual angle of 1.5° and a luminance of 31.54 fl, which was presented against a black background for 12 ms. The auditory stimulus comprised of a 'beep' which was a 10 ms long (1 ms ramp) sound burst of 3500 Hz presented at 79 dB. Sounds were delivered through loudspeakers positioned at the left and right sides of the monitor at the same height as the fixation cross. Additional stimuli used in the 'control' task comprised of an orange-coloured visual disc (diameter of 1.5° visual angle and a luminance of 31.54 fl), and two auditory 'beeps' of low (100 Hz) and high (250 Hz) pitch.

2.3. Procedure

The study was divided into 5 separate testing sessions over 5 consecutive days. For each participant, the 5 sessions occurred in the same environment and at approximately the same time each day. In all cases the participants were tested in a dimly lit room and the experimenter took particular care to ensure that no reflections appeared on the screen and the environment was quiet (participants were also asked to switch off their phone during the study).

In session 1 all participants were tested on the SIFI task and then performed either the TOJ task described in detail below or the control task, also described below, depending on the group to which they belonged. In sessions 2–4 only the TOJ training or the control task were performed. In session 5 the TOJ training (or the control task) was followed by the SIFI task (re-test). The first and last sessions had a duration of between 45 and 60 min for each participant, whereas the remaining sessions lasted approximately 30 min.

2.3.1. Susceptibility to the SIFI

The SIFI task (presented in sessions 1 and 5) comprised of three different types of trials randomly intermixed: those in which the illusion could occur, audio-visual (AV) congruent trials, or uni-sensory trials. For the illusory trials, a single visual