Active Visual Inhibition is Preserved in the Presence of a Distracter: A Cross-cultural, Ageing and Dementia Study.

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Abstract: The current study investigated a novel visual distracter task as a potential diagnostic marker for the detection of cognitive impairment and the extent to which this compares in healthy ageing across two cultures. The Inhibition of a Recent Distracter Effect (IRD) refers to the inhibition of a saccadic eye movement towards a target that is presented at the location of a previous distracter. The current study compared the IRD across a large cross-cultural sample comprising of young (N=75), old European participants (N=119), old south Asian participants (N=83), participants with Dementia due to Alzheimer's disease (N=65) and Mild cognitive impairment (N=91). Significantly longer saccadic reaction times on the target to distracter trials, in comparison to the target to target trials were evident in all groups and age cohorts. Importantly, the IRD was also preserved in participants with Alzheimer's Disease and mild cognitive impairment demonstrating that the IRD is robust across cultures, age groups and clinical populations. Eye-tracking is increasingly used as a dual diagnostic and experimental probe for the investigation of cognitive control in Alzheimer's disease. As a promising methodology for the early diagnosis of dementia, it is important to understand the cognitive operations in relation to eye-tracking that are well preserved as well as those that are abnormal. Paradigms should also be validated across ethnicity/culture, clinical groups and age cohorts.

Keywords: Distracter inhibition, Attention, Eye tracking, Inhibitory control, Alzheimer's disease, Mild Cognitive Impairment, South Asians, European, ethnicity.

1. Introduction

Multiple objects and events compete for our attention at any given moment (Crawford, Hill & Higham, 2005., Treisman & Gelade, 1980). In a football match, the object of interest is often the ball and those in possession of the ball; the other competing distracters (such as the advertising animations, the noisy opposition supporters) must be avoided to direct our eyes accurately to the target. The ability to inhibit distracting information and to focus on the task-relevant stimuli is critical for the efficient control of active visual attention. Various studies have suggested that this involves a dual process of

directing spatial attention onto the target together with the inhibition of the distracter (Wilcockson et al 2019a, Zovko & Kiefer 2013). This ability to inhibit a distracting stimulus appears to decline during the ageing process and in neurodegenerative disease (Crawford et al, 2005, Crawford, Smith & Berry, 2017).

The inhibition of a "Recent Distracter Task (IRD)" was developed to investigate the characteristics of this competitive process used in the selection of a singleton target that is coupled with a distracter (Crawford, Hill & Higham, 2005, Wilcockson et al, 2019a). The IRD comprises two consecutive visual displays (Crawford, Hill & Higham, 2005). The first display screen presents a red target and a green distracter simultaneously: participants are required to fixate on the red target and to avoid the green distracter (Figure 1). The second display presents a singleton red target after a short interval. The location of the target in the second display can appear at one of three locations relative to the first display; the same location as the previous target (i.e. target-target (T-T)), the location of the previous distracter (i.e. target-distracter (T-D)) or a new location (i.e. target-new (T-N)). The key finding was that the reaction time of a saccadic eye movement to the target in the second display (i.e. the probe display) was significantly slowed when the target was presented at the location of the previous distracter (T-D), in comparison to the T-T or the T-N trials. The inhibition of the distracter in the first display apparently carried over from the previous distracter location and was detected by its effect on a subsequent saccade to a probe-target at that spatial location. A series of follow-up experiments revealed that this slowing was derived from the location of the distracter, rather than another co-incidental feature of the distracter, such as its colour. Donovan et al. (2012) demonstrated that this IRD was also detected with naturalistic images of objects and animals and is therefore not restricted to abstract light targets in a colour display. The IRD supports the view that selective attention for eye movements incorporates a dual mechanism of target selection together with the inhibition of a distracter (Crawford, Hill & Higham, 2005).

1.1. Inhibitory control in Alzheimer's Disease

People with AD experience a decline in working memory and executive function, including inhibitory control (Baddeley et al, 2001). The brain regions and neuronal pathways involved in eye movements, fixation and gaze patterns are controlled by cortical neural networks in the frontal lobe, parietal lobe and downstream pathways that project to the cerebellum and brainstem. These areas and pathways are often impaired due to neurodegeneration in disorders such as AD resulting in deterioration of eye movements and inhibitory control processes (Abel et al, 2002). As a result, abnormal eye movements have been shown to be a useful indication of cognitive decline and neurodegeneration (Anderson and MacAskill, 2013). Multiple studies have found that AD patients suffer a reduction in inhibitory control aligning with deterioration in executive functioning and working memory (Parasuraman et al, 1992, Baddeley et al, 2001, Tales et al 2002).

Impairments of inhibitory control in AD have been reported in several studies using the anti-saccade task (Boxer et al, 2012; Crawford et al, 2005; Crawford et al, 2019 Heuer et al, 2013; Kaufman et al, 2012; Molitor et al, 2015; Wilcockson et al, 2019b). The anti-saccade task is a widely used task, that explores inhibitory control in healthy individuals and clinical populations (Hutton & Ettinger, 2006). When an object appears in view, there is a natural impulse to shift your gaze towards the object. The task requires the inhibition of this natural urge and gaze aversion to the opposite side (Crawford et al, 2005). People with AD show a high proportion of uncorrected error rates and delayed reaction times on the task (Wilcockson et al, 2019b, Crawford et al, 2019). The antisaccade task involves sensory and motor inhibition and incorporates multiple cognitive functions in addition to working memory, with research demonstrating that working memory and inhibitory control are dissociated functions (Crawford & Higham, 2016). The source of the impairment in AD participants is therefore unclear, due to the fact that, in addition to inhibitory control and working memory, the task also comprises stimulus-response incompatibility mapping and top-down volitional action.

Although a widely used paradigm, the anti-saccade task also suffers from weak ecological validity since the overriding goal of looking away from a salient target without a target to foveate is unusual and counterintuitive. More commonly the visual system is required to select a target to fixate from a set of non-targets or distracters, as for example in reading a passage of text where a target word is selected from the competing words. The traditional antisaccade task does not offer a competing target and therefore the task also requires the ability to disengage from the target which is holding the participants attention in addition to the ability to inhibit the distractor. In the inhibition of a recent distractor task (IRD) the situation is more comparable to everyday eye movements and visual search tasks, such as reading. Therefore, in the current study we employed the IRD task that was explored in our previous work (Crawford et al 2005, Donovan et al. 2012).

The IRD addresses some of the challenges presented in the antisaccade task by providing a target to foveate which is more representative of everyday gaze behaviour. The IRD examines the inhibitory trace by probing the spatial effect of the previous distracter on the reaction time of the current saccade towards a subsequent target at that location. The IRD task does not mislead the participant about the future location of the target or require an eye movement away from the target or cue. Instead the participant is presented with two visual displays; the first presents a target and distractor, followed by a second display with a single target that varies in location with respect to the target in the previous display. The IRD task measures inhibition implicitly by contrasting the reaction times to the “new” location in relation to the distracter location in the previous display. This design allows for a dual assessment of the facilitation of eye movements directed towards the target and inhibition of eye movements towards a distractor (Crawford et al., 2005).

It cannot be assumed that the IRD task and the antisaccade task target the same inhibitory control mechanisms. There are some key differences between these tasks which is likely to result in distinct inhibition mechanisms being deployed. The antisaccade task requires a motor signal to direct the eyes to the opposite location rather than a signal to suppress the target per se. In the IRD task the antisaccade, eye movement requiring the participant to direct their gaze away from the target, is absent. In the IRD task, a competing distractor target is vital for generating the distractor inhibition (Donovan et al. (2012) which is absent in the antisaccade task. Studies have shown that this is distinct from general gaze aversion which is present in the antisaccade task. Crawford et al. (2005) demonstrated that the antisaccade task is unable to generate the spatial inhibition at the location of a distractor which is found on the IRD. Donovan et al. (2012) highlighted the importance of the distractor in the display as spatial inhibition is enhanced when a competing target is present. It is possible AD participants may have a loss of inhibitory control towards a distracter that would yield a reduced IRD effect. However, if the IRD effect is preserved in AD and MCI participants this will provide an important insight into the limitations of inhibitory control frequently reported in these disorders (Crawford et al, 2019).

In common with the majority of published research in experimental psychology in Europe and the USA (Rad, Martingano & Ginges, 2018; Barratt, 2020), the participants in our previous work were exclusively, young British/European university students (Crawford, Hill & Higham, 2005; Donovan et al, 2012). Eye tracking research has demonstrated distinct cross-cultural differences in eye tracking (Knox, Amatya, Jiang and Gong, 2012, Alotaibi, Underwood & Smith, 2017). Chua, Boland and Nisbett (2005) found differences between native Chinese and native English-speaking in eye movement scan patterns during scene viewing. Growing evidence shows that the eye-tracking characteristics that are deployed by individuals are not a universal constant, but that cultural factors can influence these eye movements. English speaking participants tended to look initially at the foreground objects with an increase in the number of fixations in comparison to Chinese participants who focused on the background visual areas of the scene. Apparently, differences in thinking style lead to variations in the strategy and scanning patterns across cultures. Alotaibi, Underwood and Smith (2017) found more fixations and longer search times for Saudi participants compared to British participants on eye movement tasks. This was attributed to differences between the analytic thinking style (more common in individualistic cultures) and the holistic thinking style (more common in collectivist cultures). In contrast, Rayner and Castelhano (2009) investigated scan patterns in American and Chinese viewers and found no evidence of cultural differences when viewing the presented scenes. This brings into question the true impact of cultural influences on eye movements and scan patterns and it is therefore important to expand further investigations into the range of cultural influences on established and novel paradigms. Recent work in our laboratory (Mardenbegi et al. 2020) revealed that the morphology of post-saccadic oscillations differed between Chinese-born and European-born participants. However, the level of attentional disengagement in South Asian participants (reflected in a similar decrease in

mean saccadic latency and overall latency distributions) was comparable to European participants in the saccadic gap/overlap paradigm (Polden et al. 2020). Therefore, in this study, we expanded the diversity to examine the potential effects of age, ethnicity and neurodegenerative disease.

In summary, this work is an exploration of inhibitory control, specifically inhibition of a distracter target, and will assess the potential effects of: a) Cognitive impairment (contrasting AD and MCI participants with European healthy older adults); b) Healthy ageing (contracting healthy young and older European participants) and c) Ethnicity (contracting European older adults with South Asian older adults).

2. Experiment 1 - Materials and Methods

2.1. Participants

The study included 269 participants in total, consisting of: 48 young European (mean age = 21 years, *SD* = 3 years) and 101 older European participants (mean age= 69 years, *SD*= 2 years) recruited from the local community, all born and residing in the UK and native English speakers; 35 south Asian participants (mean age =65 years, *SD*=5 years) recruited from local Hindu temples in the North-west area of England, born outside of the UK but residing in the UK for an average of 47 years (*SD* = 6 years). Thirty-three participants with dementia due to Alzheimer's disease (mean age= 74 years, *SD*= 11 years) and 52 mild cognitive impaired (mean age= 71 years, *SD*= 7 years) participants were recruited by various National Health Trusts and memory clinics across the UK. Participants had received a clinical diagnosis from a dementia specialist following a full neurocognitive assessment. Participants were white British or European and fluent English speakers with at least 11 years in formal education. The AD participants met the requirements for the American Psychiatric Association's Diagnostic and Statistical Manual of Mental Disorders (DSM IV) and the National Institute of Neurological and Communicative Disorders and Stroke (NINCDS) for AD. The MCI participants had received a diagnosis of dementia due to mild cognitive impairment and met the following criteria (Lemos et al 2015): (1) subjective reports of memory decline (reported by individual or caregiver/ informant); (2) memory and/or cognitive impairment (scores on standard cognitive tests were >1.5 *SD*s below age norms); (3) Activities of daily living were moderately preserved. Participants were excluded from the study if any of the following criteria applied: previous head trauma, stroke, cardiovascular disease, cerebrovascular disease, focal cerebral lesions, physical or mental conditions severe enough to affect their ability to participate, previous and current alcohol or substance misuse. Control participants were excluded if they had previously received a diagnosis of a cognitive or memory impairment. A power analysis was conducted using G*Power software version 3.1.9.7. This was to ensure the tasks offer adequate power. For the analysis the power level was set at .80 with an error of .05 (Faul et al., 2007). The effect size was based on the Crawford et al (2005) study which assessed the IRD effect in young

adults. Results revealed a minimum sample size of N=31 (approximately 6 per condition) per experiment is necessary to achieve a power of .80 at an alpha of .05. However, given that the Crawford et al (2005) sample of participants recruited was a relatively homogeneous group of young, healthy university students this would underestimate the required sample sizes for the current study. This is first study of IRD using elderly, and neurodegenerative disease therefore we decided to aim to recruit as many participants as we could achieve. Written informed consent was gained with all participants having capacity to provide consent. Ethical approval was granted by Lancaster University Ethics committee and by the NHS Health Research Authority, Greater Manchester West Research Ethics Committee.

2.2. Neuropsychological Assessments.

Participants were required to complete a series of three cognitive assessments and a computerised eye tracking task termed the "Recent Distracter Task". The Montreal Cognitive Assessment (MoCA, Nasreddine et al, 2005) was used to assess cognitive impairment and as an indicator of probable dementia or mild cognitive impairment. Verbal working memory was estimated using the digit span task taken from Wechsler Adult Intelligence Scale III (Wechsler, 1997) and spatial memory using the Corsi block spatial memory task (Wechsler, 1997). The neuropsychological measures of memory yielded separate scores: forwards and backwards scores for digit and spatial memory, thus 4 measures of memory in total. The forwards recall score yields an index for memory span, whilst the backwards recall score yields a more direct measure of working memory since it relies not simply on pure recall, but also cognitive manipulation of the items in short term memory. These measures where included to assess baseline working memory, executive functioning and spatial memory abilities for the control participants. In this study we distinguished between verbal and spatial memory span assessments and also between forwards and reverse recall as research has demonstrated these to be distant memory processes (Baddeley, 2007). When verbal and spatial items are recalled in the forwards order (in the same order they are presented) there is no requirement to manipulate the memory items. These items are instead held in a temporary buffer and repeated. If the items are asked to be recalled in the reverse order this is a more complex working memory process involving working memory. The forwards version provides a simple measure of memory span whereas the reverse version requires working memory to store, inhibit, and re-sequence the items (Boxer et al. 2006; Garbett et al. 2008).

2.3. The Inhibition of a Recent Distracter (IRD) Task.

2.3.1. Apparatus

Participant's eye movements were recorded using the EyeLink Desktop 1000 sampling at 500Hz. The computer monitor size was 24 inches with a resolution of 1366 x 768. Participants were positioned approximately 55cm from the computer monitor (60Hz). A chin rest was used to reduce head

movements. Participant's gaze was calibrated prior to the start of the tasks using a 9-point calibration. The stimulus was created and controlled via the use of Experiment Builder Software Version 1.10.1630. The data was analysed and extracted using Data Viewer Software Version 3.2.

2.3.2. Procedure

Participants were first presented with a white central fixation point for 750-1000ms, randomised to prevent anticipatory responses (see Figure 1). Following this, the fixation point was removed and a red and green circular disk (i.e. target/distracter display 1) presented simultaneously for 1500ms. Participants were instructed to look towards the red 'light' as quickly and accurately as they could and to ignore the green distracter 'light'. Target display 1 was then removed and the central fixation point re-appeared for a randomised interval of 750-1000ms (fixation). Finally, a single red target was displayed for 1500ms (target display 2). The stimulus onset asynchrony between the target display 1 and target display 2 was 2250-2500ms. A blank interval screen was displayed for 3500ms between trials. The red target and green distracter were position at 4° from the central fixation both at horizontal and vertical locations. The distance of the targets from the central fixation point was 8cm. The fixation point and coloured targets measured 15mm in diameter (visual angle, 1.56°). The mean luminance of the display targets was measured, with the red target measuring at 35.66 lux and the green target at 39.57 lux.

The timing and configurations for target display 1 were randomly selected from one of 18 displays (figure 1). The pairings of target display screens created three types of trials: (1) Target → Target (T1 → T2) the target on display 2 was presented at the same location of the previously displayed target in display 1. (2) Target → Distracter (T1 → D2) for this trial type the display 2 target was presented in the location of one of the previous distracter targets in display 1. (3) For the Target → New (T1 → N2) trials the display 2 target was presented in a new location, not previously occupied by the target or distracter in display 1. The task included 120 randomly mixed trials. For 50% of the trials, the target location was repeated in display 2 (T1 → T2 trials) and on 50% of the trials the target varied to the display 2 target (25% T1 → D2 +25% T1 → N2). The complete block of trials included 10 times in which the T1 → T2 was presented in each position and 5 times that the T1 → D2 and T1 → N2 were repeated in each position.

Figure 1a

Timings and sequence of the IRD in experiment 2.

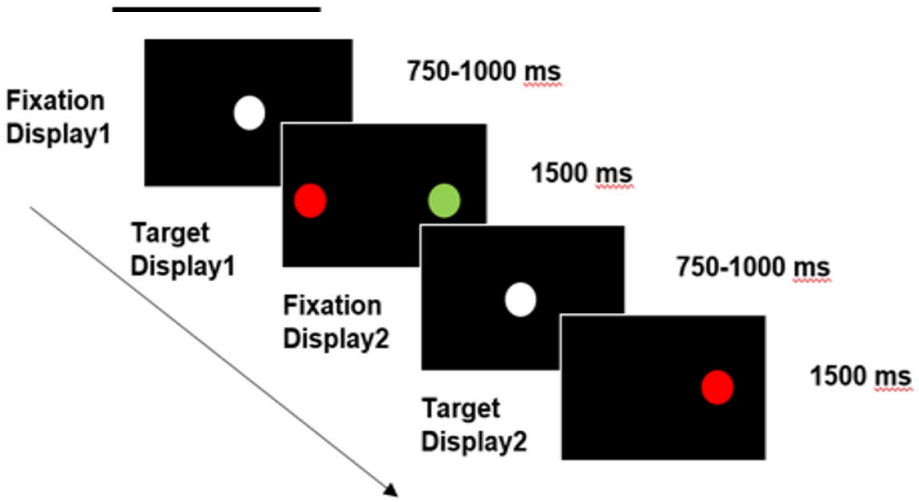


Figure 1b

Example of the three trial variations in the IRD1.

Note. The locations of the green and red targets on display screen 1 varied throughout the task.

2.3.3. Data processing.

EyeLink DataViewer software was used to export the raw eye tracking data and the data was analysed offline using a bespoke software SaccadeMachine (Mardanbegi et al, 2019). The software filtered out noise and spikes by removing all frames with a velocity signal greater than 1,500 deg/s or an acceleration signal greater than 100,000 deg^2/sec. The fixations and saccadic events were detected by the EyeLink Parser and the saccades for each trial were extracted alongside multiple spatial and temporal variables. Saccade latency was measured from the onset of the saccade to the target offset. To avoid anticipatory and delayed saccades only saccades made in the time frame of 80-700ms after the target onset where included in the analysis. Micro saccades that had an amplitude less than 0.7 deg were removed from the data. Saccade direction errors e.g. correct or incorrect were determined in relation to the target. An error was classified as an eye movement towards the distracter target in Target/distracter

display 1 and an eye movement in the opposite direction of the target in Target display 2. The inclusion/exclusion criteria for the data was determined prior to data analysis. An identical data processing procedure was conducted for experiments 1 and 2. No Part of the studies procedure or analysis was pre-registered prior to the research being conducted. The data from this study is accessible via the following link https://doi.org/10.17635/lancaster/researchdata/418.

In the study we report how we determined our sample size, all data exclusions, all inclusion/exclusion criteria, whether inclusion/exclusion criteria were established prior to data analysis, all manipulations, and all measures in the study.

3. Results

Linear mixed-effects model's analyses were carried out using RStudio version 1.2.5033. The models conducted an analysis on reaction times on the T-T, T-N and T-D trial types to assess the IRD effect. The linear mixed-effects model was also used to determine the group effects of: disease, ageing, and ethnicity.

3.1. Cognitive Assessments

An ANOVA was conducted assessing the effects of participant group on MoCA score. Table 1 shows an expected significant effect of participant group on MoCA score, F (4, 237) = 32.39, $p < .001$, $n^2_p = 0.35$. As expected, the older European participants produced significantly higher MOCA scores when compared with the AD group (F (1, 101) = 62.89, $p<.001$, $n^2_p =.38$) and the MCI group (F (1, 117) = 26.60, $p<.001$, $n^2_p =.19$). There were no significant differences in MoCA scores between the older European healthy participants and the young European group. European older participants produced significantly higher MoCA scores compared to the south Asian older adults (F (1, 106) = 35.40, $p<.001$, $n^2_p =.25$). This effect on the MOCA may derive from a combination of culturally sensitive test items, linguistic and other cultural-related factors.

Table 1 reveals that there was a significant effect of participant group on digit span score on the forwards (F (4, 197) = 6.65, $p < .001$, $n^2_p =.12$) and backwards (F (4, 197) = 12.20, $p < .001$, $n^2_p =.25$) versions of the task. Post hoc comparisons revealed that on the digit span tasks, the older European participants yielded significantly higher task scores compared to the south Asian participants for the forwards (F (1, 103) = 14.69, $p < .001$, $n^2_p =.12$) and backwards version (F (1, 103) = 26.96, $p < .001$, $n^2_p =.20$). On the backwards version of the task as expected the AD group displayed significantly lower task scores compared to the older European participants (F (1, 98) = 8.76 , $p=.004$, $n^2_p =.08$) although interestingly there was no significant difference on the forwards' version of the task (Table 1). This pattern of results was also repeated for the MCI group, who also differed from the European participants in the backwards (F (1, 113) = 5.43, $p =.021$, $n^2_p =05.$), but not on the forwards' version of the digit span

task. This implicates the vulnerability of working memory in dementia rather than memory span per se. No significant differences were found in digit span scores between the other participant groups.

There was an overall significant effect of participant group on spatial span task score for the forwards (F (4, 187) = 12.58, p < .001, n^2_p =.21) and backwards (F (4, 187) = 17.71, p < .001, n^2_p =.27) versions of the task. As expected, AD participants displayed yielded lower spatial memory scores compared to older European participants on the forwards (F (1, 90) = 11.75, p =.001, n^2_p =.12) and backwards (F (1, 90) = 8.45, p =.005, n^2_p =.09) versions of the task (Table 1). Young European participants produced significantly higher spatial span scores compared the older European participants on both the forwards (F (1, 94) = 24.52, p <.001, n^2_p =.21) and backwards versions (F (1, 94) = 42.98, p < .001, n^2_p =.31). No significant differences were found between the other participant groups.

Table 1

Means, standard deviations and post hoc contrasts for MoCA, Digit Span and Spatial span scores for all participant groups in experiment 1

	Older European participants		Older South Asian participants		Alzheimer's Disease		MCI		Young European participants		Post Hoc Contracts (P values)				
												Disease		Age	Ethnicity
	M	SD	M	SD	M	SD	M	SD	M	SD	AD vs EP	AD vs MCI	MCI vs EP	EP vs YCP	EP vs OSP
MoCA Score	27.25	2.99	22.64	4.71	19.86	5.39	22.98	5.27	28.16	1.85	<.001*	.037*	<.001*	.066	<.001*
Digit Forward	10.54	2.56	8.54	2.07	9.84	2.44	10.02	2.30	11.53	2.34	.678	.764	.262	.341	<.001*
Digit Backward	7.24	2.82	4.39	1.82	5.38	2.54	6.02	2.41	8.33	2.50	.004*	.304	.021*	.234	<.001*
Spatial Forward	7.18	1.38	6.67	1.14	5.96	1.89	6.78	1.78	8.60	1.10	.001*	.078	.194	<.001*	.570
Spatial Backward	6.65	1.50	6.21	1.18	5.46	2.31	6.05	1.75	8.70	1.20	.005*	.243	.074	<.001*	.776

Note. Dependent variable: Task score.

AD – Alzheimer's disease; MCI – mild cognitive impairment; EP – older European participants; OSP- older south Asian participants. YCP – young European participants.

*Significant at p<.05 level

3.2. Eye Tracking Data

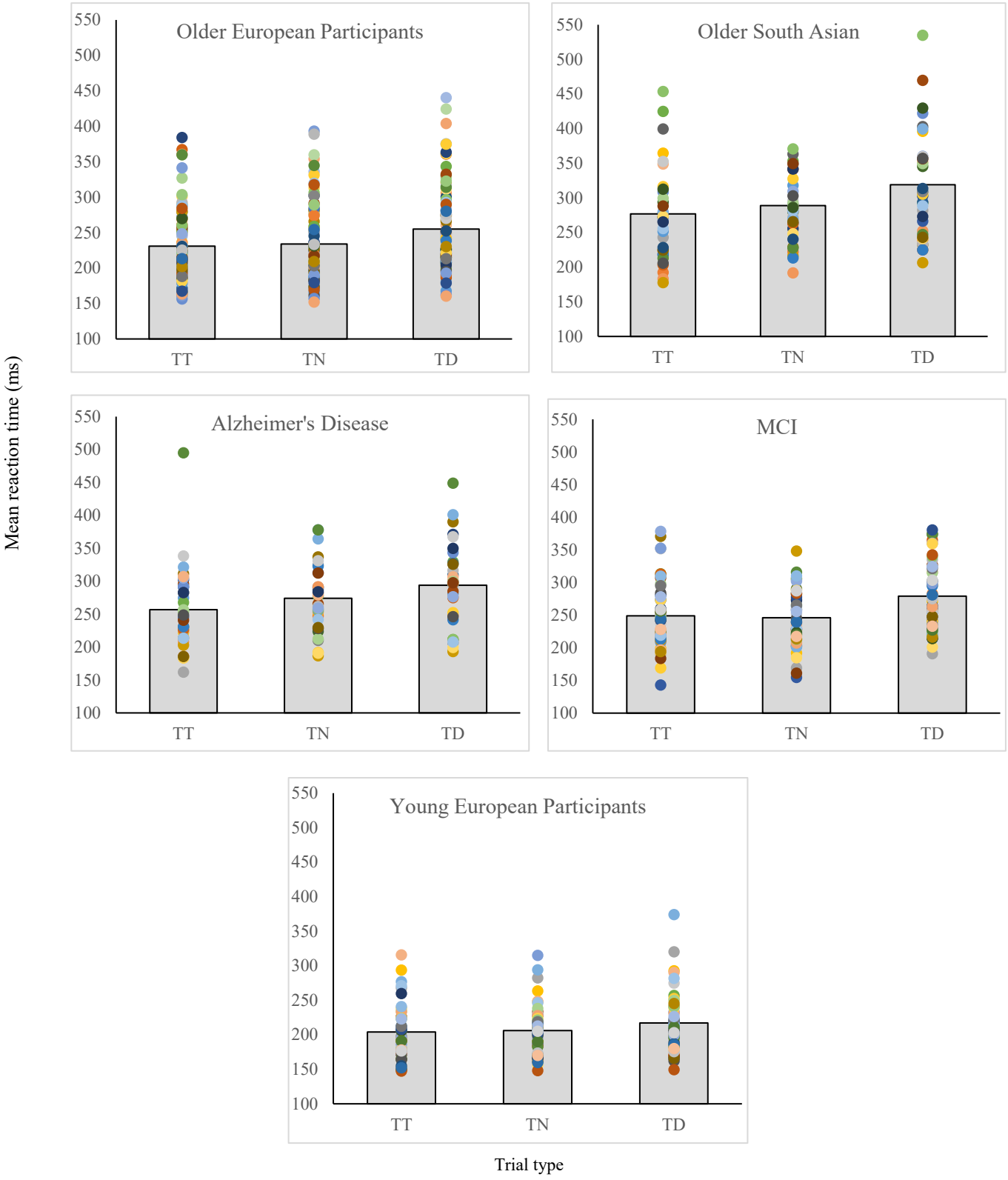
The eye-tracking data was analysed using linear mixed-effects models comparing the effects of participants group on reaction times for the three trial types: TT, TN and TD. Comparisons were conducted to explore the effects of ageing, ethnicity and disease.

3.2.1. The Inhibition of a recent distracter effect (IRD)

The groups were first examined to determine whether the IRD was evident in each of the participant groups. Figure 2 confirmed that this was indeed the case. The mean saccade reactions times significantly increased on TD compared to TT trials: AD (37ms), MCI (30ms), EP (25ms), OSP (43ms), YC (13ms) (β = -10.26, t(13497) = -5.78, p<.001). Saccadic reaction times were also significantly longer on TD trials compared to TN (β = -11.27, t(13497) = -6.56, p<.001) (figure 2). Clearly, the participants were slower in directing their gaze towards the target on display 2 when it was positioned at the location of the distracter target on display 1. There was no significant difference in the mean reaction times for the TN and TT trials (β = 1.01, t(13497) = .50, p =.615).

Figure 2

Mean reaction times and individual participant RTs on target to target, target to new and target to distracter trials for participant groups



An analysis was conducted to explore the size of the effect across the groups. The mean reaction times for the TN trials were subtracted from the TD

trials mean to provide an IRD score for each participant. To explore the facilitation effect, the TT mean reaction times were subtracted from the TN mean reaction times (Table 2). The analyses revealed that there were no significant effects of the participant group on the IRD score or facilitation (Table 2).

Table 2

Reaction time means and post hoc contrasts for the inhibition and facilitation effect on the IRD1.

	Older European participants		**Older South Asian participants**		**Alzheimer's Disease**		**MCI**		**Young European participants**		**Post Hoc Contracts (P values)**				
	M	SD	M	SD	M	SD	M	SD	M	SD	AD vs EP	Disease AD vs MCI	MCI vs EP	Age EP vs YCP	Ethnicity EP vs OSP
Inhibition Effect (TD-TN)	21.57	28.99	30.61	57.27	19.74	46.14	32.86	25.81	11.11	23.92	.999	.168	.051	.466	.726
Facilitation Effect (TN-TT)	2.99	31.37	11.94	45.46	17.37	52.71	-3.01	44.30	1.57	28.18	.344	.059	.356	1.00	.769

Note. Dependent variable: mean reaction time difference.

AD – Alzheimer's disease; MCI – mild cognitive impairment; EP – older European participants; OSP- older south Asian participants. YCP – young European participants.

*Significant at p<.05 level

3.2.2. Overall Saccade Reaction Times: Ageing Effects

Overall saccade times for the older European participants were contrasted with the young European participants to determine the effects of healthy ageing. The analyses revealed a significant ageing effect (Figure 2) with older participants yielding longer mean reaction times across the three trial types, compared to the young participants (TT=-26ms, TN= -28ms, TD= -38ms).

3.2.3. Overall Saccade Reaction Times: Disease Effects

We contrasted the AD, MCI and older European groups to examine the effect of Alzheimer's disease on the mean reaction times. The results (Table 3) revealed a significant group effect between the AD participants and older European participants: with AD participants had significantly longer reaction times across the three trial types (34ms). AD participants also had longer reaction times compared to the MCI participants across the three trial types. The MCI participants had significantly longer reaction times on the TT, TN and TD trials with an average increase in reaction times of 18ms compared to older European participants.

3.2.4. Overall Saccade Reaction Times: Ethnicity Effects

In comparison to the older European participants, the south Asian participants revealed significantly longer reaction times across the three trial types (52ms increase in overall reaction times, Table 3).

Table 3

Mean reaction times and standard deviations and post hoc comparisons for the IRD1 for the TT, TN and TD trials in ms.

	Older European participants		**Older South Asian participants**		**Alzheimer's Disease**		**MCI**		**Young European participants**		**Post Hoc Contracts (P values)**				
											Disease		Age		Ethnicity
	M	SD	M	SD	M	SD	M	SD	M	SD	AD vs EP	AD vs MCI	MCI vs EP	EP vs YCP	EP vs OSP
TT	231	50.10	277	66.87	257	62.99	249	51.21	204	38.52	<.001*	.028*	.034*	<.001*	<.001*
TD	255	56.63	319	77.48	294	62.15	279	51.10	217	43.33	.001*	.005*	<.001*	<.001*	<.001*
TN	234	50.94	289	45.20	274	51.61	246	43.14	206	36.09	<.001*	.002*	.034*	<.001*	<.001*

Note. Dependent variable: Reaction time.

AD – Alzheimer's disease; MCI – mild cognitive impairment; EP – older European participants; OSP- older south Asian participants. YCP – young European participants.

*Significant at p<.01 level

3.2.5. Percentage Error Rates

The mean percentage error rates were derived from saccade direction errors to the green distracter (rather than the red target) in display 1. As expected, the young European participants generated significantly fewer errors compared to the AD group (β = -10.08, $t(131) = -2.12$, $p = .036$). The young European group also generated significantly fewer errors compared error than the older South Asian group. There were no significant differences between the young and older European participants (Table 4). The results revealed a significant increase in the errors generated by the AD compared to the MCI group (β = -9.42, $t(131) = -2.18$, $p = .031$). No significant differences were found between the other participant groups (Table 4).

Table 4

Means, standard deviations and post hoc contrasts for percentage error rates on target-display screen 1

	Older European participants		Older South Asian participants		Alzheimer's Disease		MCI		Young European participants		Post Hoc Contracts (P values)				
	M	SD	M	SD	M	SD	M	SD	M	SD		Disease		Age	Ethnicity
											AD vs EP	AD vs MCI	MCI vs EP	EP vs YCP	EP vs OSP
% Error Rate	16.63	21.11	20.20	19.39	18.44	18.11	9.03	14.39	8.09	11.06	.757	.029*	.137	.102	.554

Note. Dependent variable: percentage error rate.

AD – Alzheimer's disease; MCI – mild cognitive impairment; EP – older European participants; OSP- older south Asian participants. YCP – young European participants

*Significant at $p<.05$ level

4. Discussion

The IRD requires the participant to program a saccade towards the singleton target and to inhibit the distracter. This yields a significantly longer response time to a new target that is presented at the distracter location shortly afterwards. Thus, in the healthy participants, there was an inhibitory carry-over from the previous trial, that results in the slowing of gaze towards the distracter location in the subsequent trial. Crawford, Hill & Higham (2005) report that this inhibition remains active between 2-5 seconds after the target is removed. The current study investigated whether this effect was preserved in people with dementia, across ageing and different cultural/ethnic groups. The results revealed that the IRD was clearly evident across all the participant groups. The south Asian participants revealed the largest slowing on the TD vs TT trials, whilst the young European participants showed the smallest effect of trial type. Although differences were detectable in the baseline saccade latencies, there were no significant effects of disease, ageing and ethnicity/culture on the magnitude of the IRD effect.

5. Experiment 2

Experiment 1 replicated the previous research (Crawford, Hill & Higham, 2005, Wilcockson et al, 2019a) and revealed that the IRD effect is robust across both age, culture and cognitive impairment. Nonetheless, given the previous reports of the impairment of inhibitory control on the anti-saccade task (Boxer et al, 2012, Crawford et al, 2019) it is curious that the participants with MCI and AD revealed a similar pattern of distracter inhibition as the age-matched healthy participants. The results from experiment 1 reveals that the suppression of a visual distracter is distinct from the inhibitory operations, of the anti-saccade task. Alternatively, it may be that the inhibitory load was not sufficiently demanding

in this task. Therefore, in experiment 2 the distracter load was increased by employing two distinct colour distracters that were presented simultaneously with the target (Figure 3). The experiment aimed to determine whether an increase in the inhibitory load will perturb the IRD and to what extend will this more challenging version of the IRD moderate any effects of ageing, ethnicity or disease.

6. Materials and Methods

6.1. Participants

Experiment 2 included 27 young (mean age = 24 years, *SD*= 5 years) and 18 older European participants (mean age = 69 years, *SD*= 7 years), 48 south Asian participants (mean age = 67 years, *SD* = 6 years), 32 AD participants (mean age =72, *SD* =7 years) and 39 MCI (mean age = 71 years, *SD* = 6 years) participants.

6.2. Procedure

Participants were required to complete three cognitive assessments and the eye tracking task as in experiment 1. Participants completed the MoCA, digit span task and spatial span task both forwards and backwards versions (see experiment 1 above). The key distinctive feature here was an additional distracter target which aimed to increase the inhibitory control demand and the difficulty of the task (see figure 3). Participants were presented first with a white central fixation target and instructed to fixate on the centre marker. Following this, a red, green and a blue circular disk appeared simultaneously (target display 1). A second central fixation was then displayed, followed by a single red target (target display 2). Participants were instructed to look towards the red "light" and to ignore the green and the blue "lights". The single red target was presented at one of three locations: the location of the target on the previous display 1 screen (T1 → T2), location of the green distracter target on the previous screen (T1 → D2) or at a new location not previously occupied by the target or distracter on target display 1 (T1 → N2). The blue distracter target was positioned 4° from the central fixation both at horizontal and vertical locations (see figure 3). The timing and parameters for this IRD task were identical to the experiment 1 task. The luminance of the blue display target measured at 36.81 lux.

Figure 3a

Timings and sequence of the IRD in experiment 2.

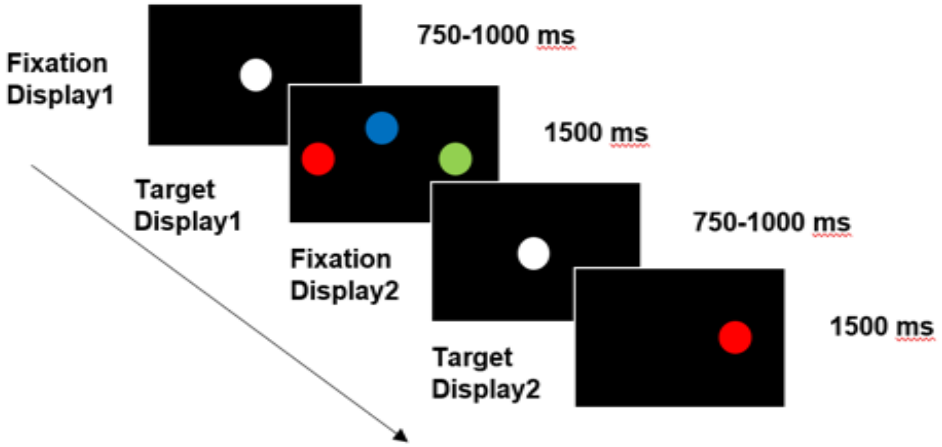
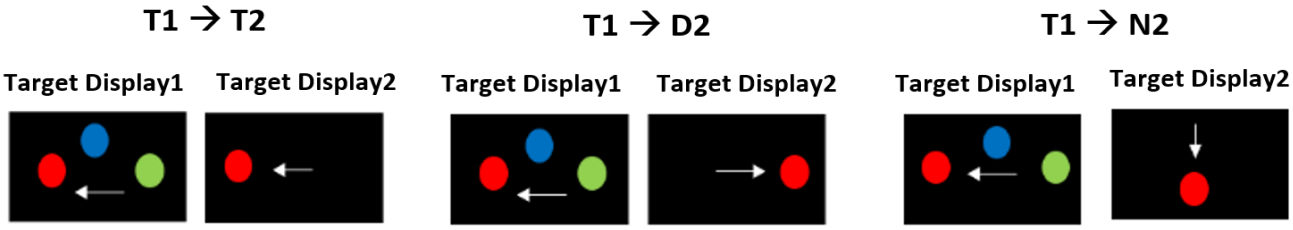


Figure 3b

Example of the three trial variations in the IRD2.The locations of the green, red and blue targets on display screen 1 varied throughout the task.



7. Results

The analyses conducted for experiment 2 were consistent with the procedures used in experiment 1. One participant was removed from the older European adult group due to their mean reaction times being greater than 2 standard deviations from the mean.

7.1. Cognitive Assessments

An ANOVA was conducted to examine the effect of participant group on the MoCA scores. The results revealed a significant effect of participant group $F(4, 132) = 23.105$, $p < .001$, $n^2_p = .41$) (Table 6). As expected, the AD group ($F(1, 38) = 35.59$, $p < .001$, $n^2_p = .48$) and MCI group ($F(1, 37) = 13.29$, $p = .001$, $n^2_p = .26$) scores were significantly lower on the MoCA than the older European participants. There was a significant difference between MCI and AD performance on the MoCA ($F(1, 41) = 8.85$, $p = .005$, $n^2_p = .18$). There was no difference in task scores between the European healthy older participants and the young participants. The European older participants generated significantly higher scores on the MoCA than the south Asian participants ($F(1, 66) = 29.15$, $p < .001$, $n^2_p = .31$).

On the Digit Span task, there was a significant effect of participant group on both the forwards ($F(4, 159) = 14.34$, $p < .001$, $n^2_p = .27$) and backwards ($F(4, 159) = 10.45$, $p < .001$, $n^2_p = .21$) versions of the task. For the forwards ($F(1, 48) = 7.76$, $p = .008$, $n^2_p = .14$) and backwards $F(1, 48) = 15.10$, $p < .001$, $n^2_p = .24$) version of the task there was a disease effect, as expected the AD participants had lower memory scores than the older European participants. An ethnicity effect was also revealed; the European older participants generated higher scores on the task than south Asian older adults for both the forwards ($F(1, 66) = 44.87$, $p < .001$, $n^2_p = .40$) and backwards version ($F(1, 66) = 27.96$, $p < .001$, $n^2_p = .30$). No effect of healthy ageing (young vs Older Europeans) was found on the digit span task.

The Spatial Span task revealed a significant effect of participant group on the forwards ($F(4, 148) = 14.98$, $p < .001$, $n^2_p = .29$) and backwards ($F(4, 148) = 11.53$, $p < .001$, $n^2_p = .24$) task. The AD participants, as expected, had reduced spatial span scores compared to the older European participants on both the forwards ($F(1, 43) = 11.54$, $p = .001$, $n^2_p = .21$) and backwards ($F(1, 43) = 8.13$, $p = .007$, $n^2_p = .16$) versions of the task. There was an effect of ethnicity on the backwards version of the task ($F(1, 64) = 9.01$, $p = .004$, $n^2_p = .12$), but not on the forwards' version of the task. No effect of healthy ageing (young vs Older Europeans) was found for the spatial span task (Table 5).

Table 5

Means and standard deviations and post hoc comparisons for task score on the MoCA, digit Span and Spatial Span for all participant groups in experiment 2.

	Older European participants		Older South Asian participants		Alzheimer's Disease		MCI		Young European participants		Post Hoc Contracts (P values)				
												Disease		Ageing	Ethnicity
	M	SD	M	SD	M	SD	M	SD	M	SD	AD vs EP	AD vs MCI	MCI vs EP	EP vs YCP	EP vs OSP
MoCA Score	27.72	1.78	21.26	4.94	20.64	4.77	24.43	3.46	28.50	1.18	<.001*	.005*	.001*	.398	<.001*
Digit Forward	12.39	2.38	8.58	1.95	10.31	2.61	10.62	2.44	11.89	2.14	.008*	.613	.018*	.951	<.001*
Digit Backwards	8.33	2.59	4.80	2.37	5.50	2.41	6.19	2.48	7.63	2.45	<.001*	.248	.005*	.787	<.001*.
Spatial Forward	7.39	1.38	6.52	1.24	5.93	1.44	6.45	1.30	8.44	1.42	.001*	.141	.014*	.077	.136
Spatial Backwards	7.28	2.14	5.73	1.76	5.59	1.80	5.48	1.73	8.04	1.70	.007*	.815	.003*	.637	.004*

Note. Dependent variable: Task score.

AD – Alzheimer's disease; MCI – mild cognitive impairment; EP – older European participants; OSP- older south Asian participants. YCP – young European participants.

Significant at p<.05 level

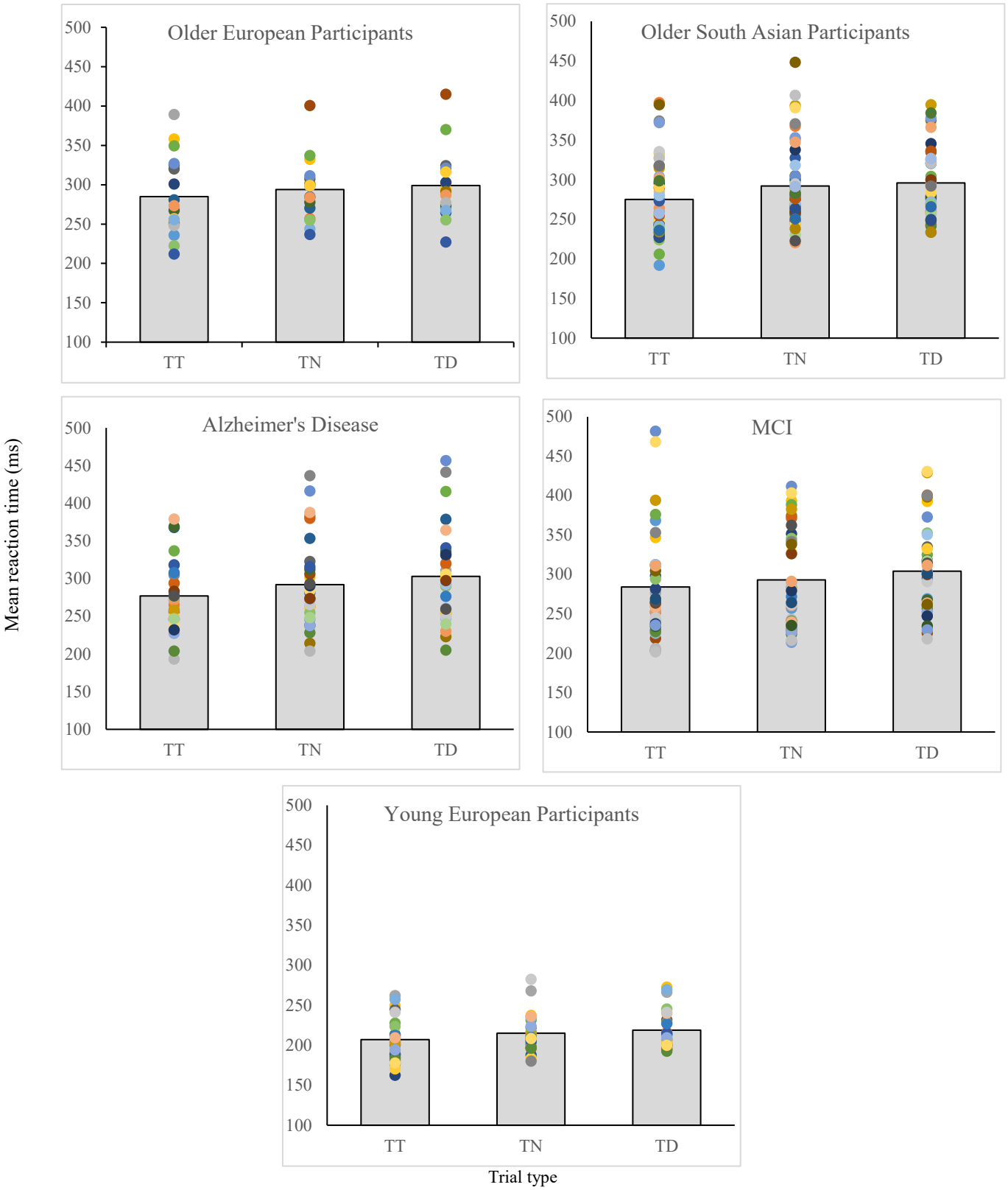
7.2. Eye Tracking Data

7.2.1 The Inhibition of Recent Distracter Effect (IRD)

The results revealed a significant effect of trial type on the mean reaction times. Participants were slower at directing their gaze towards the target in display 2 (TD) when it was located in the position of the previous distracter (figure 4) compared the location of the previous target ($\beta = -12.26$, $t(16789) = -7.55$, $p<.001$), with an increase in mean RT on TD trials for each group, AD (26ms), MCI (21ms), EP (14ms), OSP (21ms) & YC (13ms). The young participants displayed significantly faster reaction times on the three trial types compared to the older participants. There were no significant group effects between the other participant groups.

Figure 4

Mean reaction times and individual participant RTs on target to target, target to new and target to distracter trials for participant groups



The mean reaction times for the TN trials were subtracted from the TD trials mean to provide an IRD score for each participant. To explore a potential facilitation effect, the TT mean reaction times

were subtracted from the TN mean reaction times. The results revealed no significant difference between participant groups for the IRD score, $F(4, 158) = .655$, $p = .624$, $\eta^2_p = .016$ or facilitation scores, $F(4, 158) = .401$, $p = .808$, $\eta^2_p = .01$. Overall, the participant groups revealed a similar relative difference in the reaction times between the target-distracter conditions (Table 6).

Table 6

Reaction times means, standard deviations and post hoc contrasts for the inhibition and facilitation effect on the IRD2.

	Older European participants		Older South Asian participants		Alzheimer's Disease		MCI		Young European participants		Post Hoc Contracts (P values)				
												Disease		Age	Ethnicity
	M	SD	M	SD	M	SD	M	SD	M	SD	AD vs EP	AD vs MCI	MCI vs EP	EP vs YCP	EP vs OSP
Inhibition Effect (TD-TN)	4.54	21.56	3.12	34.26	10.99	26.23	11.59	35.17	4.71	16.81	.946	.937	.305	1.00	1.00
Facilitation Effect (TN-TT)	9.50	39.93	17.41	40.87	14.88	41.83	9.33	44.86	7.84	38.93	.990	.597	.972	1.00	.949

Note. Dependent variable: Mean reaction times difference.

AD – Alzheimer's disease; MCI – mild cognitive impairment; EP – older European participants; OSP- older south Asian participants. YCP – young European participants.

*Significant at $p<.05$ level

7.2.2. Overall Saccade Reaction times: Ageing Effects

The results revealed that there was a significant effect of age between the healthy European older participants and the young participants (figure 4). Young participants displayed significantly faster mean reaction times compared to the older European participants (TT= -78ms, TN = - 79ms, TD= - 79ms).

7.2.3. Overall Saccade Reaction times: Ethnicity Effects

No significant differences in mean reaction times were found between older European participants and the older south Asian participants (Table 7).

7.2.4. Overall Saccade Reaction times: Disease Effects

There was no significant difference between the mean reaction times for the older European participants and the MCI and AD group (Table 7).

Table 7

Mean reaction times, standard deviations and post hoc comparisons for the TT, TN and TD trials.

	Older European participants		Older South Asian participants		Alzheimer's Disease		MCI s		Young European participants		Post Hoc Contracts (P values)				
												Disease		Age	Ethnicity
	M	SD	M	SD	M	SD	M	SD	M	SD	AD vs EP	AD vs MCI	MCI vs EP	EP vs YCP	EP vs OSP
TT	285	48.59	275	48.59	277	44.94	284	66.83	207	26.64	.222	.089	.867	<.001*	.467
TD	299	43.13	296	45.94	303	60.77	304	59.78	219	23.12	.432	.899	.490	<.001*	.806
TN	294	38.41	292	51.21	292	57.38	293	61.61	215	23.06	.243	.919	.275	<.001*	.886

Note. Dependent variable: Reaction time.

AD – Alzheimer's disease; MCI – mild cognitive impairment; EP – older European participants; OSP- older south Asian participants. YCP – young European participants.

*Significant at p<.05 level

7.2.5. Percentage Error Rates

An analysis was conducted to explore the effect of participant group on the proportion of erroneous saccades towards the distracters. An error was classified as a primary saccade in the direction of either of the distracter target on display 1. Comparisons between the participant groups revealed no significant differences in error rates (Table 8).

Table 8

Means, standard deviations and post hoc contracts for percentage error rates on target display 1 on the IRD2.

	Older European participants		Older South Asian participants		Alzheimer's Disease		MCI		Young European participants		Post Hoc Contracts (P values)				
												Disease		Age	Ethnicity
	M	SD	M	SD	M	SD	M	SD	M	SD	AD vs EP	AD vs MCI	MCI vs EP	EP vs YCP	EP vs OSP
% Error Rate	15.23	20.17	14.07	12.22	21.88	25.43	14.53	14.11	4.36	3.78	.117	.136	.889	.092	.782

Note. Dependent variable: percentage error rate.

AD – Alzheimer's disease; MCI – mild cognitive impairment; EP – older European participants; OSP- older south Asian participants. YCP – young European participants.

*Significant at p<.05 level

7.3. Comparison of IRD effect in IRD1 and IRD2

Several previous studies (Hulleman, 2010; Kazanovich & Borisyuk, 2017; Palmer, Horowitz, Torralba & Wolfe, 2011; Proulx & Egeth, 2006; Wolfe, 2007) have shown that reaction times increase to a greater or lesser extent with increasing number distracters in the display. Therefore, we felt it was

important to explore to a limited extent whether an increase in the competing distractor would enhance or interact with inhibitory control in the IRD task. In order to explore the impact of the additional distractor on the inhibitory controls demands of the task, we ran an ANOVA analysis comparing the reaction times, inhibition effect sizes and error rates between IRD experiment 1 and IRD experiment 2. There was a main effect of distractor condition (TT, TN, TD trial type) on reaction times across both experiments ($F(2, 433) = 17.16$, $p<.001$, $n^2_p=.039$). As expected, reaction times were longer on the TD trials compared to the TT trials. There was a significant main effect of experiment $F(1, 433) = 16.30$, $p <.001$, $n^2_p=.037$) with IRD experiment 2 producing higher RTs on all trial conditions. There was no interaction between the distractor condition and experiment ($F(1, 433) = 3.50$, $p=.062$, $n^2_p=.008$). Therefore, this data reveals that the additional distractor in IRD2 increased the overall difficulty of the task.

However, we explored whether the additional distractor also increased the level of the inhibitory demand. This was clearly not the case. To the contrary, the inhibition effect was actually significantly larger on experiment 1 than experiment 2 ($F(1, 433) = 22.30$, $p<.001$, $n^2_p=.05$) (table 9). Experiment 1 with just a single distractor elicited a stronger inhibitory control demand than experiment 2 with two distractors. It appears that a single distracter generated a stronger effect due to the increased saliency of the singleton distractor. In contrast the analysis of the facilitation effect, revealed a larger effect in experiment 2 compared to experiment 1 ($F(1, 433) = 6.05$, $p=.014$, $n^2_p=.01$). Error rates were also compared between the experiments, but no significant differences were found ($F(1, 285) = .334$, $p=.564$, $n^2_p=.001$). Thus, although the additional distractor appears to generate significantly longer reaction times in experiment 2, the evidence does not show a change in the inhibitory control demands.

Table 9

Mean values for the inhibition and facilitation effects, error rates and reaction times on the IRD1 and IRD2.

	IRD1	**IRD2**
Inhibition effect (TD-TN)	24.19	5.88
Facilitation effect (TN-TT)	2.52	12.73
Error rates	14.48	15.70
TT Reaction time (ms)	240	267
TN Reaction time (ms)	242	280
TD Reaction time (ms)	267	286

8. Discussion

Experiment 1 explored the effects of disease, ageing and ethnicity on the IRD. Experiment 2 aimed to increase the inhibitory load of the IRD task to determine whether this would reveal a change in the effect, particularly in the cognitively impaired groups however results revealed this increase in inhibitory control in the IRD2 was not evident. The results revealed that a strong IRD effect was evident in all the participants' groups, and across both of the experiments.

The IRD clearly requires a form of implicit representation or memory that tags the location of an irrelevant distracter across consecutive displays. Crawford, Hill & Higham (2005) established that this representation was based on the spatial location of the distracter, and not some other coincidental feature, such as its colour. Critically the inhibitory impact of the distracter is relatively long-lasting (2-5 seconds). IRD was originally reported in young, healthy university students, and is remarkably robust and well-preserved in atypical participants (e.g, dyslexia, Wilcockson et al, 2019a) and with both simple shapes as well as naturalistic stimuli (Donovan et al, 2012). The current work demonstrates the validity of IRD across age groups, ethnicity and cognitive impairment. Although the neural correlates of the IRD are yet to be explored, the effect is consistent with models of visual orienting which feature competitive interactions between the target and a distracter (e.g., Duncan, Humphreys & Ward, 1997; Trappenberg et al., 2001).

Given the pervasive and progressive nature of the cognitive impairments, it is remarkable that the IRD is so well preserved in AD and MCI participants. This presents a stark contrast with previous research with AD participants using the anti-saccade task (Boxer et al, 2012; Crawford et al, 2005, 2013, 2019; Noiret et al, 2018, Wilcockson et al, 2019b). In the anti-saccade task, participants' are required to look away from the prepotent target, to the opposite side of the display. It has been extensively used as a method to examine inhibitory control in both healthy adults and clinical populations (Broerse, Crawford & den Boer, 2001; Hutton & Ettinger, 2006; Crawford et al, 2015; Crawford et al, 2017). Patients generate a high proportion of erroneous saccade towards the prepotent target and fail to self-correct many of these errors, consistent with an impairment of inhibitory control and error monitoring. This impairment correlated with the severity of dementia (Faust, 1997, Crawford et al, 2005). When healthy adults make errors on the task, they are quickly corrected and are very rarely left uncorrected. Our lab has recently demonstrated that these errors are more prominent in amnesic MCI in comparison to non-amnesic MCI participants (Wilcockson et al, 2019b). The key aspect of this finding is linked to the fact that people with Amnesic MCI are at an increased risk of progressing to develop dementia in the future (Yaffe et al, 2006, Fischer et al, 2007, Ward et al, 2013). Inhibitory control is clearly not a unitary concept and has multiple forms that can be dissociated at many levels of the visuomotor control networks. The IRD and the anti-saccade tasks clearly do not target identical inhibitory control mechanisms. The anti-saccade task focuses on gaze aversion requiring an eye movement directed away from the target. The motor requirement to generate an anti-saccade eye movement is not present in the IRD. The IRD uses a distracter that competes with the target to generate

inhibition at the spatial location of the distracter, a key distinction from the anti-saccade task. This competition for attention is a significant factor for inhibition of the distracter and has been demonstrated in multiple negative priming studies. Research has shown that the distracter in the probe display in addition to the prime displays is also required for object inhibition (Donovan et al., 2012). In a series of experiments Donovan et al (2012) demonstrated that when there is no competing distracter in the probe display, there was a lack of negative priming for the visual objects and no inhibition to the location of the distracter. Crawford et al (2005) demonstrated that the anti-saccade task per se does not generate spatial inhibition of the distracter, as witnessed in the IRD. Together, these findings demonstrate that the fundamental nature of the IRD "inhibition" is quite distinct from the top-down processes of the anti-saccade task. The current study undermines the idea that uncorrected errors and deficits demonstrated on the anti-saccade task are due primarily to a failure to inhibit a distracter target and the inhibition appears to be linked to top-down inhibitory control and working memory capabilities (Crawford et al, 2005, Crawford et al, 2013).

8.1. Ageing

Another key finding was a clear effect of age on the mean saccadic reaction times for both versions of the IRD. Although the IRD effect was present in the European older adults, the young adults revealed significantly faster saccadic reaction times on the three trial types. This indicates an overall slowing in prosaccade eye movements during natural ageing. This is consistent with previous research and demonstrates that eye movements are susceptible to ageing effects, in particular to reductions in processing speed, inhibitory control and spatial memory (Salthouse, 1996, Salthouse, 2009, Peltsch et al, 2011, Crawford, Smith & Berry, 2017).

8.2. Ethnicity

As previously stated, the European and South Asian older adults both demonstrated the IRD effect, with a slowing in reaction times when the target was presented in the location of a previous distracter. Experiment 1 revealed significant differences in mean reactions time between the groups with faster reaction times for the European group across the three trial types. Interestingly, this difference was not evident using the double distracter display in experiment 2. The differences were present on the three trials types demonstrating that this may be due to baseline differences in the prosaccade eye movements. Previous research has uncovered clear differences in eye movements across ethnic and cultural groups (Rayner et al 2007, Knox et al 2012, Alotaibi, Underwood & Smith, 2017). Differences in scanning patterns between native Chinese and native English-speaking participants were reported using visual scenes (Chua, Boland & Nisbett, 2005). English participants focused on the foreground objects and showed an increased number of fixations than Chinese participants who often focused on the background areas of the scene demonstrating clear strategy differences. Evidently, specific features of eye movement control are subject to the influence of culture and ethnicity.

Knox and Wolohan (2014) explored whether the variations in saccadic eye movements were due to culture or culture-unrelated factors. This study examined saccades in Chinese, European and UK born Chinese participants with similar cultural experiences to the European group. Interestingly, the Chinese participants showed similar eye movement patterns regardless of cultural experience demonstrating that culture must not be the primary cause of variations in oculomotor processes. These variations in oculomotor characteristics may result from a combination of genetic, environmental and epigenetic factors (Kim et al 2010, Mardanbegi et al 2020). A recent study demonstrated clear differences in post-saccadic oscillations between UK-born adults and Chinese-born adults. It was concluded that "...genetic, racial, biological and/or cultural difference can affect the morphology of the eye movement data recorded" (Mardanbegi et al 2020). These factors should be considered when assessing eye movement saccades and fixations. Research involving South Asian populations is clearly lacking and future research should attempt to address this void leading to a deeper understanding of eye movement variations that are attributable to ethnicity and culture.

8.3. *Conclusions:*

Traditionally in this field, scientists have focussed primarily on the mnemonic and cognitive skills that degenerate in AD and understandably have paid less attention to those equally important cognitive functions that may be well preserved. We suggest that a similar research priority should be aimed at the functions that may be preserved in the disease as this will help to develop potential new early intervention strategies for the treatment of the disease, that will improve cognitive functions and hopefully delay the progression of the disease. This study has demonstrated that inhibition of a distracter is preserved in people with early and chronic AD. The current evidence on preservation of the IRD will aid our understanding of oculomotor impairment in AD and MCI, in particular, the specificity of inhibitory control deficits.

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