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Kamen A. Tsvetanov[1], Carmel Mevorach[1], Harriet Allen[2] and Glyn W. Humphreys[3]

[1] School of Psychology, University of Birmingham, Birmingham B15 2TT, UK; [2] School of Psychology, University of Nottingham, Nottingham NG7 2RD; [3] Department of Experimental Psychology, University of Oxford, Oxford OX1 3UD

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Corresponding Author: Kamen Tsvetanov

School of Psychology, University of Birmingham, Birmingham B15 2TT, United Kingdom

Tel: (+44) 121 414 3679

Fax: (+44) 121 414 4932

Email: kat893@bham.ac.uk

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Abstract

We examined the ability of older adults to select local and global stimuli varying in perceptual saliency – a task requiring non-spatial visual selection. Participants were asked to identify in separate blocks a target at either the global or local level of a hierarchical stimulus, while the saliency of each level was varied (across different conditions either the local or the global form was the more salient and relatively easier to identify). Older adults were less efficient than young adults in ignoring distractors that were higher in saliency than targets, and this occurred across both the global and local levels of form. The increased effects of distractor saliency on older adults occurred even when the effects were scaled by overall differences in task performance. The data provide evidence for an age-related decline in non-spatial attentional selection of low-salient hierarchical stimuli, not determined by the (global or local) level at which selection was required. We discuss the implications of these results for understanding both the interaction between saliency and hierarchical processing and the effects of aging on non-spatial visual attention.

Keywords: Saliency, non-spatial visual attention, aging, global and local processing, inhibition deficit theory, distraction

Introduction

In order to survive in complex, dynamic environments we need efficient mechanisms of attention to select information relevant to our behavioural goals. Current theories of visual attention hold that selection is determined by the interaction between bottom-up and top-down signals. Bottom-up signals act to draw attention to salient items that differ from their local surroundings (Theeuwes, 2005; Theeuwes, 1992). Top-down forms of selection become involved when participants have particular expectations about the target they are required to select (e.g., knowing its location or one of its features)(Wolfe et al., 2003) and/or when the target is less salient than particular distractors – when the bottom-up attraction of attention to the salient distractors must be overcome. In addition, top-down selection itself can be fractionated into excitatory processes, that guide attention to targets, and inhibitory processes, which can filter out irrelevant distractors (see Braithwaite et al., 2005; Dent et al., 2012).

There is evidence that the mechanisms of selection operate less efficiently as we age (Madden et al., 1999; Plude, 1990), but the interplay of bottom-up and top-down processes in the effects of aging remain poorly understood (see Madden, 2007). For example, there is evidence that the role of top-down expectations for targets, and of excitatory guidance, may be stronger in older than younger adults (Madden et al., 1999). On the other hand, the ability to suppress irrelevant distractors may decrease – as argued by the *inhibition deficit theory of cognitive ageing* (Lustig et al., 2007). According to this account, cognitive ageing is associated with a selective decrease in the ability to inhibit irrelevant stimuli and responses, worsening attentional selection in older adults. Though the loss of inhibitory control may be compensated for by increased top-down excitatory guidance, problems will emerge under conditions in which distractors strongly compete for selection with targets (e.g., under conditions in which distractors have the higher saliency).

In the present study we set out to examine the interplay between bottom-up and top-down processing by examining the effects of aging on the ability to select stimuli based on their relative perceptual saliency. The relative saliency of a stimulus will reflect the strength of its bottom-up representation compared with other stimuli in the field. The bottom-up saliency of a stimulus can then either match or be pitched against top-down drivers of selection, according to whether the target or a distractor stimulus has the higher relative salience. The effects of responding to bottom-up saliency can be assessed by examining the selection of high saliency targets accompanied by low saliency distractors. In contrast the strength of top-down control of selection can be assessed by performance when the target has low saliency and the distractor high saliency. Here we ask whether aging differentially affects either the guidance of attention to salient targets (e.g., due to reduced sensitivity to bottom-up salience) or the rejection of salient distractors when low saliency targets are selected (due to inhibitory deficits affecting top-down modulation of selection).

Inhibitory Deficits in Visual Selection

Evidence for the inhibitory deficit theory emerges from studies using negative priming. Negative priming tasks measure the unfavourable influence of a prior exposure to a distractor stimulus on the response to the same stimulus when a target. Classic studies of negative priming have contrasted cases where an item’s identity is inhibited, slowing its subsequent identification (Tipper & Cranston, 1985). Reduced negative priming in older adults might reflect less efficient inhibition when the stimuli are first encountered as distractors (Hasher et al., 1991). In addition, there is evidence for age-related changes in location-based inhibition, for example in preview search tasks. Preview search typically uses conjunction-like displays but presents distractors with one common set of properties prior to the second set of distractors plus the target (Watson & Humphreys, 1997). Provided there is a sufficient period between the two sets of distractors (of the order of 400ms or so), the first set of distractors can be efficiently ignored (Humphreys et al., 2004). There is substantial evidence that the lack of impact of the initial distractors is dependent, at least in part, on a process of active distractor suppression of its location (Watson & Humphreys, 2000; Humphreys et al., 2004; Allen et al., 2008) and features (Olivers & Humphreys, 2003). As in studies of negative priming it has been shown that older participants can show a selective reduction in the efficiency of preview search, particularly under conditions where distractor inhibition is challenged (e.g., with moving distractors). This is consistent with reduced inhibition of distractor locations and/or features in older adults relative to young adults (Watson & Maylor, 2002).

However there are many instances in everyday life where selection is neither feature nor space-based, but rather dependent on the ability to select the appropriate level of a form. For example, when trying to make a judgement about someone's identity we may want to select the whole face to take advantage of configural relations between features, but in doing this we may not want to attend to the local features themselves. On the other hand, when we make a judgement about part of a face (is the person smiling?), we may want to focus attention on the local part without processing the whole. For such cases, we need to be able to flexibly select the local or the global level of a form, an ability that likely depends on different underlying mechanisms to those studied through feature or space-based selection. For example, while there is much evidence for spatial selection being dependent on a largely bilateral fronto-parietal network (Corbetta & Shulman, 2002), the selection of local and global forms has been associated with lateralized brain recruitment, with the left hemisphere being selectively linked to local processing and the right hemisphere to global processing (Lux et al., 2004). In addition, other regions may be recruited irrespective of whether the local or global level of form needs to be selected, as a function of whether the target level (local or global) is high or low in salience. For example, the right posterior parietal cortex (PPC) has been linked to the guidance of attention towards the more salient of the levels when the target is at that level (Hodsoll et al., 2009), while the left PCC is involved when the target is at the less salient level and the distractor at the higher level of salience (Mevorach et al., 2009b). This PPC system has been linked also to a 'down regulation' of the early visual regions which would otherwise respond differentially to the salient stimulus (in this case the distractor level). For example, under conditions where high saliency distractors have to be ignored, there is increased activity in the left PPC which in turn is associated with decreased activity in left occipital cortex (using psycho-physiological interaction analysis; Mevorach et al., 2009b). Consistent with the left PPC inhibiting high saliency distractors, the application of suppressive transcranial magnetic stimulation (TMS) to the left PPC (to suppress activity there) leads to increased activity in left occipital cortex under conditions with high-salient distractors (Mevorach et al., 2010). To date, work addressing the decreased ability to inhibit salient distractors, as a function of age, has been conducted under conditions of spatial selection and we know little about how ageing affects the ability to suppress irrelevant distractors when other forms of selection are demanded, such as selecting the level of form and/or selecting hierarchical stimuli according to their relative salience. Here we set out to address this issue by evaluating how cognitive ageing alter an individual's ability to select a low saliency target in a hierarchical form, compared to when the target is highly salient.

Global and Local Processing in Ageing

There are several previous studies of the effects of cognitive ageing on the ability to select local and global levels of form. However the results are very mixed. Roux and Ceccaldi (2001), for example, used stimuli that showed an overall global processing advantage and reported that older participants had stronger global interference (when responding to local targets) than younger observers. In direct contrast, Muller-Oehring et al. (2007), employing stimuli with an overall local advantage, found greater local-on-global interference in older participants. Others have reported null effects of ageing on local and global interference (Bruyer et al., 2003). These contradictory results may be understood if cognitive ageing affects the ability to select stimuli varying in saliency rather than the ability to select local and global forms per se. For example, in studies showing greater interference effects in older participants, the interfering distractors were typically more salient than the target (global distractors in Roux & Ceccaldi, 2001; local distractors in Muller-Oehring et al., 2007), while experiments showing no differential interference effects have tended to have local and global forms more balanced for saliency (e.g., judged by overall RTs; Bruyer et al., 2003). The conflicting results may be accounted for by differential selection of stimuli varying in saliency, with older participants finding it particularly difficult to suppress high-salient distractors in order to select low-salient hierarchical targets (cf. Mevorach et al., 2010). We investigated this for the first time in this paper, using stimuli modelled on investigations of selection by saliency by Mevorach and colleagues.

Saliency Processing in Global/Local Level

In contrast to prior studies in this field, Mevorach orthogonally varied whether the target was at the local or global level of the forms and whether it had high or low saliency (in relation to the distractor level of form) (Mevorach et al., 2006b; Mevorach et al., 2005; Mevorach et al., 2009b; Mevorach et al., 2006a; Mevorach et al., 2009a). The saliency of the forms was varied by either presenting high contrast local forms in alternating colours (high local saliency, low global saliency) or by blurring the hierarchical letter and presenting the local forms in uniform colour (high global saliency, low local saliency; See Figure 1).

Performance was analysed by pooling the data across conditions where the target was at the local level and when it was at the global level and contrasting the results when the target had high salience (distractor low salience) and when it had low salience (and the distractor high salience). When the target level was high in salience, the demands on inhibition of the distractor level were low as selection could have been driven by bottom-up cues; however when the target was low in salience and the distractors had high salience, then the demands on distractor inhibition would be high in order to overcome bottom-up cues biasing selection in favour of the distractor. Consistent with the argument for the inhibition of high-salient distractors, Mevorach et. al. used psycho-physiological interaction analysis to demonstrate that there was increased activation of left PPC when high saliency distractors had to be ignored, and this co-occurred with reduced activation of left occipital cortex. They argued that the selection of the low-salient target was mediated by the left PPC suppressing distractor-related activity in early occipital cortex. In support of this, suppressive TMS to the left PPC led to increased activity in occipital cortex when highly salient distractors were present, suggesting that there was then reduced down-regulation of occipital cortex. The behavioural evidence indicated that there was increased interference from salient distractors and this effect was greatest when TMS was applied prior to the onset of the stimulus (Mevorach et al., 2009a, 2010). In this case, TMS appeared to block the top-down setting up of perceptual suppression.

Figure 1 about here

The Present Study

In the present study, we report a novel analysis of selection by level of hierarchical form (global/local) and saliency in young and older adults, assessing whether older adults have particular problems selecting low-salient targets in the face of high-salient distractors, and whether this occurs independently of the global or local level of the stimulus. To do this, we had participants select local and global letters under conditions of varying saliency using a blocked design – with either the target level being highly salient and the distractor having low saliency, or the distractor level having high saliency and the target low (see Figure 1). When the target has relatively high saliency there should be bottom-up guidance of attention to targets coupled to a role of top-down excitatory guidance (to the blocked target level), On the other hand, when the target had relatively low saliency (and the distractor high salience), there would be demands on top-down inhibition of the distractor level to prevent attention being drawn in a bottom-up manner to the distractor. We hypothesized that the ability to inhibit high-salient distractors for successful processing of low-salient targets is reduced with ageing, in which case performance should be disrupted for older relative to younger adults when distractors have high saliency. On the other hand, if there is increased bottom-up attentional guidance and/or use of top-down excitatory guidance to targets, then older participants should be relatively faster at selecting high-salient targets. By varying saliency orthogonally across the global and local levels of form, we tested too whether older adults had difficulties confined to one level of form or whether there was an overall effect of saliency that cut across the local and global stimuli.

Methods

Participants

The participants were twenty-four young (eleven males; group mean age, 24 years; age range 19 to 29) and nineteen older (ten males; group mean age, 74 years; age range, 65 to 84) healthy volunteers who either received course credits or cash (£6 per hour). The participants were recruited by advertisements in local communities, word-of-mouth information and advertisements on an online experiment management system (Research Participation Scheme, University of Birmingham). All the subjects had normal or corrected-to-normal vision (assessed in laboratory environment using Snellen chart) and were healthy with no history of psychiatric or neurological disease (self-report).

Stimuli

Two sets of compound-letter stimuli were created to have either high global saliency or high local saliency. The stimuli comprised the letters "H" and "S" and their combinations created figures in the shape of large orthogonal "H" and "S" letters (see Figure 1).

In the set of stimuli where local information was to be salient, the compound letters were made of red (RGB, 255 0 0) and white local letters (Figure 1, top row). The size of the local letters was 1.34° × 1.76° of visual angle (in width and height, respectively) with a distance between the letters of 0.46°. The total width and height of the global letters was 6.7° × 10.81° of visual angle, respectively.

When the compound letters were weighted for global processing, the local stimuli consisted of red blurred letters (Figure 1, bottom row). The width and the height of the local letters was 1.34° × 1.76° of visual angle respectively, with an inter-letter distance of 0.15°, resulting in a global letter subtending 5.83° × 9.22° of visual angle (in width and height, respectively).

These images were additionally blurred in MATLAB using a Gaussian lowpass filter (FWHM of 1.56 mm). Mean display luminance for white, red and black colours were 118.44, 25.77 and > 0.01, respectively. Luminance measures were performed using a Minolta LS 110 photometer.

To reduce strategic focusing on a local area of the screen there were three possible positions for presentation of the stimuli – the centre or 13.16° to the left or right of the centre of the screen.

Procedure

In a selective attention task, participants undertook different trial blocks in which they were asked to concentrate only on the global or the local letters across a block of trials while ignoring the information at the other level. The task was to identify the letter (H or S) on the designated target level by pressing pre-specified buttons on a USB mouse (e.g., "Is the letter on the global level H or S?"). The experiment had four types of blocks formed from the orthogonal combination of task and saliency, each block containing one condition (see Figure 1). There were target-salient blocks: (i) identify the global letters in stimuli where global information is more salient than local information (Figure 1, bottom pair); and (ii) identify the local letters in stimuli where local information is more salient than global (Figure 1, top pair). There were two distractor-salient blocks: (i) identify the global letters in a stimulus where the local letters were more salient (Figure 1, top pair); and (ii) identify the local letters in stimuli where the global letters were more salient (Figure 1, bottom pair). The target level was blocked to allow participants to adopt a top-down set to the designated target level[1]. The first two blocks and the last two blocks of the experiment were both either globally salient displays or locally salient displays. Each block had 48 trials. On half of the trials the same

[1] Example scenario of block order: 1st Block - Target salient condition, global task using the set of stimuli with global focus (Figure 1, bottom pair); 2nd Block - Distractor salient condition, local task using the set of stimuli with global focus (Figure 1, bottom pair); 3rd Block - Distractor salient condition, global task using the set of stimuli with local focus (Figure 1, top pair); 4th Block – Target salient condition, local task using the set of stimuli with local focus (Figure 1, top pair).

letters appeared on the global and local levels (congruent trials), whereas on the other half there were different letters on the two levels (incongruent trials). Each pair of these blocks consisted of a global and a local identification task. The order of the blocks was randomized across participants. Each experimental trial started with a white fixation point presented for 2000ms followed by a 150ms presentation of a compound letter on a black background. The trial ended after the participant identified the letter (H or S) on the target level (global or local) and gave a speeded response by pressing one of the two mouse buttons (one for each letter). The inter-stimulus interval was variable (1 - 4 seconds from the response of the subject in one trial to the onset of the stimulus in the next trial) to avoid possible predictions of stimulus onset. The viewing distance was controlled with a chinrest at 65cm from the monitor. Psychophysics Toolbox for Matlab (Kleiner et al., 2007; Brainard, 1997; Pelli, 1997) was used for the presentation of the paradigm and the collection of the responses. Response times and performance accuracy were recorded. Incorrect responses were excluded from the analysis. RTs were screened for outliers after mean and standard deviation were estimated based on a convolved exGaussian function fit to each subjects data. RTs over 3.5 standard deviations away from the mean were rejected (Heathcote et al., 1991).

One difficulty for comparisons between younger and older participants is that older participants can show general deficits in processing, with generalized slowing potentially playing a major role in cognitive decline (Linden-berger & Baltes, 1994; Salthouse, 2000). These generalized effects may differentially affect performance as the task conditions become harder – a result that can masquerade a selective effect of the conditions on older relative to younger adults. In order to examine whether there is indeed a selective effect in the two age groups, we analysed the efficiency data using Z-transformations. The Z transformations aim to dissociate group differences from effects of generalized slowing/decreases in processing efficiency by examining effects of task conditions normalised by the average performance for each participant (Faust et al., 1999). Specifically, the difference of mean efficiency of all trials in one condition cell and the mean efficiency across all condition cells was normalized to the standard deviation of efficiency across all conditions cells within a subject. This procedure was repeated for each condition cells and subject separately

Results

Exploratory analysis indicated that there were lower accuracy rates for older compared to young adults, which were driven mainly by errors in distractor-salient conditions (Figure 2). In order to account for speed/accuracy tradeoffs in the analysis the data were *also* analyzed by combining RTs and accuracy into a single "efficiency" measure (RT/proportion correct, see Townsend & Ashby, 1983), as well as analysing Z-transformations (see methods section for a detailed description on the approach for transforming data) [2].

Summary Outcome

The central focus of the study was to examine whether older adults, relative to young adults, were more affected by salient incongruent distractors. Thus, it was of highest relevance to investigate the difference in performance between trials with salient incongruent distractors and salient congruent distractors i.e. congruency cost in the distractor-salient condition. Therefore, we summarize at first the outcome from efficiency and Z-transformed data pooled across visual field and task, before reporting main effects and interactions (Table 1 and Table 2) to justify pooling the data.

A significant three way interaction between saliency, congruency and age (Table 2) suggests that there may be a differential effect of congruency for older adults. Performance on trials with low-salient targets (e.g. select the local element in a stimulus with a high-salient global

[2] To the best of our knowledge this is the first time that analyses based on Z transformation have been conducted on measures of performance efficiency rather than reaction time. However, since efficiency is likely to have the same distribution as the reaction time data from which it is derived then it should be applicable here. In addition, to have analyzed the RT data alone would have been to miss the critical trade-off in accuracy in older participants.

distractor), in particular, may be difficult for older adults if they have reduced ability to suppress high-salient distractors – a result mimicking the effects of TMS on left PPC (Mevorach et al., 2010). To quantify this, the effect cost of congruency was calculated for each individual for each target saliency condition from the difference in the Z-scores between incongruent and congruent trials (incongruent - congruent), see Figure 4**Error! Reference source not found.**. A two-way ANOVA was conducted with a within-subject factor of salience (Target-salient vs. Distractor-salient) and a between-subject factor of age. This revealed significant main effects of salience and aging [F (1, 41) = 38.82, p < 0.001, F (1, 41) = 8.72, p = 0.005] and a significant interaction [F (1, 41) = 4.45, p = 0.041] (Figure 4**Error! Reference source not found.Error! Reference source not found.**). Further t-tests revealed that there was a reliable effect of age group on performance in the distractor-salient condition but not in the target-salient condition [t (1, 41) = -2.11, p = 0.041 and t (1, 41) = 0.51, p = 0.510 for distractor-salient and target-salient conditions, respectively]. Thus, the older participants had a larger congruency effect compared to the young group but only when low-salient targets had to be selected and high-salient distracters ignored (e.g. select the local element in a stimulus weighted to the global level). Importantly, the increased congruency effect was not specific to a particular level of processing (local or global) and therefore indicates a general problem in suppressing high-salient distractor irrespective of the level of form involved.

Separate from the 3-way interaction between saliency, congruency and age, there was an overall effect of task and a reliable interaction between task and age (Table 2). The main effect of task occurred because, overall, responses to global targets were more efficient than responses to local targets. However, this effect varied with age (Figure 5**Error! Reference source not found.**a). Relative to the overall average of performance for their age group, the young participants showed a larger difference between the global and local tasks (relatively fast for global and relatively slow for local, a Z difference of 0.67 in efficiency), when compared with the older participants (a Z difference of 0.27 in efficiency) [F (1, 41) = 5.35, p = 0.026]. Interestingly, the contrasting variation in performance across the age groups as a function of the task (Figure 5**Error! Reference source not found.**a) went in the opposite direction to their respective variation as a function of stimulus saliency (Figure 5**Error! Reference source not found.Error! Reference source not found.**b). We take up this point in the Discussion section below.

Main Analysis

The experiment also replicated the expected main effects. For better transparency of the data we now present main effects with supporting interactions for absolute RTs, efficiency and z-transformed data. At last we present evidence for justifying the polling of the data between left and right visual field into one common measure, peripheral vision.

Absolute RT

A five-way ANOVA was carried out on the absolute RTs and accuracy with the within-subject factors being target task (select Global or Local targets), saliency (Target-salient (e.g. global task with global saliency) vs. Distractor-salient (e.g. global task with local saliency)), congruency (Congruent vs. Incongruent) and visual field (VF, Central vs. Peripheral) (Figure 2). There was a between-subject factor of age group (young adults vs older adults). *F*- and *p*-values for significant main effects and interactions are displayed in Table 1.

Overall, RTs were faster and accuracy higher in the global task compared to the local task (796ms vs 858ms), in target-salient compared to distractor-salient trials (740ms vs 913ms), in congruent compared to incongruent trials (787ms vs 866ms), central vs peripheral presentations (804 vs 850ms) and in young compared to older adults (728ms vs 926ms).

The highest order interaction in the RT data was between task, congruency, VF and age group (Table 1). We estimated the cost of congruency relative to congruent trials from the difference in RTs for each task and VF conditions separately within each group. We then analysed a three-way ANOVA with the within-subject factors of task and VF and the between subject-factor of age (Figure 6). There were reliable main effects of age (F(1, 41) = 8.18, p = .007) task (F(1,41) = 3.96, p = .053) and VF, (F(1,41) = 3.44, p = .071). Significant interactions were observed between task and VF (F(1, 41) = 20.71, p < .001) and task, VF and age (F(1, 41) = 5.60, p = .023). The three way interaction was further broken down for each visual field using two separate two-way ANOVAs with the within-subject factor of task and a between-subject factor of age. The analysis for data with peripherally stimuli showed no significant effects (age, F(1, 41) = 3.08, p = .087; task, F (1, 41) = 3.39, p = .073; task x age, F (1, 41) = 1.14, p = .291), whereas the analysis for data for centrally presented stimuli generated a significant main effect of task (task, F (1, 41) = 24.82, p < .001) and an interaction between task and age (F (1, 41) = 6.06, p = .018). A post-hoc analysis revealed that the interaction was mainly driven by larger congruency effects in the global task with central presentation for older adults relative to young adults (F (1, 41) = 12.16, p = .001 and F (1, 41) = .525, p = .473, congruency cost at global and local level for central presentation, respectively).

Efficiency

Apart from the high-order interaction (task x congruency x VF x age), there was an additional three-way interaction (saliency x congruency x age) which approached significance in the RT data (F (1, 41) = 3.75, p = .060), and this was also highly significant in the accuracy data (F (1, 41) = 8.64, p = .005) (Table 1). In order to provide an overall analysis accounting for any speed/accuracy tradeoffs in the analysis the data were analyzed by combining RTs and accuracy into a single "efficiency" measure (RT/proportion correct, see Townsend & Ashby, 1983).

Performance was assessed in mixed design ANOVAs using the mean efficiency data for each participant. The within-subject factors were task (select Global or Local targets), saliency (Target-salient (e.g. global task with global saliency) vs. Distractor-salient (e.g. global task with local saliency)), congruency (Congruent vs. Incongruent) and visual field (Central vs. Peripheral). The between-subject factor was age group (Young adults vs. Older adults). *F*- and *p*-values for significant main effects and interactions are displayed in Table 2.

There was a four-way interaction between saliency, congruency, VF and age, which suggests again that there may be a differential effect of congruency for older adults. To quantify this, the effect of congruency was calculated from the difference in mean efficiency for the congruent and incongruent conditions for each variation in target saliency and VF, for each age group, see Figure 7. A three-way ANOVA was estimated with the within-subject factor of salience (Targe-salient vs Distractor-salient), VF (central vs peripheral presentation) and the between-subject factor of age group. All main effects and interactions were significant. Further breakdown of the higher order interaction (saliency x VF x age) included two separate two-way ANOVAs, one for each visual field (central and peripheral presentation), with the within-subject factor of saliency (Target-salient vs Distractor-salient) and the between-subject factor of age. Stimuli presented centrally produced main effects of saliency (F (1, 41) = 8.37, p = .006) and age (F (1, 41) = 8.43, p = .006) and a marginally significant interaction between saliency and age (F (1, 41) = 3.94, p = .054).). There was a similar set of results with peripheral presentations (main effects of age, F (1, 41) = 10.78, p = .002; and saliency, F (1, 41) = 13.20, p = .001; and an age x saliency interaction, F (1, 41) = 7.80, p = .008). For both central and peripheral stimuli, older participants showed stronger effects of congruency than younger participants particularly when the target was low-salient and the distractor high-salient.

Z-transformations

Performance was assessed in mixed design ANOVAs over the mean Z-transformation data with the within-subject factors of task (select Global or Local targets), saliency (Target-salient (e.g. global task with global saliency) vs. Distractor-salient (e.g. global task with local saliency)), congruency (Congruent vs. Incongruent) and visual field (Central vs. Peripheral). The between-subject factor was age group (Young adults vs. Older adults). *F*- and *p*-values for significant main effects and interactions are displayed in Table 2.

In these analyses all higher-order interactions including VF became non-significant, suggesting that interactions including VF in the non-transformed efficiency data were probably influenced by generalised effects of ageing.

Left vs Right Visual Field

An ANOVA on RT data from the left and right field locations (excluding centrally presented stimuli) assessed whether there were differential effects of visual field on performance. There was a reliable main effect of field, with RT values (as well as efficiency and Z-transformed data) lower to targets in the left field [left: 842ms, right: 858ms, F (1, 41) = 5.39, p = 0.025]. However, there were no other significant interactions with other factors, including age group, and the data were subsequently pooled across hemispheric field (Figure 2).

Discussion

The main finding was that, relative to young adults, older adults were more affected by salient incongruent distractors (producing higher congruency costs in the distractor-salient condition), and this held even with the analysis scaled for the effects of aging on overall efficiency (using Z transformations). The effect sizes show that this was relatively small effect, possibly because general slowing contributed to the age related changes; none-the-less it is relavent and significant. This age-related decline in the ability to select a low-salient target in the presence of a high-salient distractor held for both levels of target identification, both with local and global stimuli (respectively when the global or the local saliency of the distractor was high). Importantly, this increased congruency effect in distractor salient displays cannot be attributed to generally heightened susceptibility to salience in old age. If heightened sensitivity to salience was driving the effect, then our old participants should have also shown a difference in performance in the target salient conditions (e.g., a reduced congruency effect when salient targets were reported, since older adults would be less sensitive to target saliency). We therefore conclude that performance in the old group most likely represents reduced down-regulated inhibition of saliency, encountered particularly under conditions where distractors are salient. We note that this result mimics the effects of TMS suppression reported by Mevorach et al. (2010), where the loss of inhibitory control was most evident with salient distractors.

Our findings are concordant with the *inhibition deficit theory* (Hasher & Zacks, 1988), which posits that older adults are generally less able to inhibit unwanted information – though here we show for the first time that this applies to non-spatial selection of local and global forms. According to the inhibition deficit framework, early bottom-up responses to salient, exogenous stimuli require inhibitory mechanisms to limit processing when the stimuli are irrelevant (i.e. to ignore the conversation of nearby passengers while reading a newspaper in a train). Deficits in the efficiency of inhibiting irrelevant distractors may disrupt the ability to focus attention on stimuli of interest, resulting in the dilution of selection across distractors as well as targets. As noted in the Introduction, deficits in filtering out distractors have been observed across a range of conditions, with different types of stimuli (e.g., in reading (Carlson et al., 1995), language comprehension and production (Burke & Mackay, 1997; Burke, 1997; Tun et al., 2002), visual memory (Gazzaley et al., 2005) and spatial visual selection (Watson & Maylor, 2002; Schlaghecken et al., 2012)). and non-spatial visual selection in the Stroop task (Hartley, 1993; West and Bell, 1997;West and Alain, 2000; Davidson et al., 2003; Rush et al., 2006). To our knowledge this is the first study showing that age-related deficits in inhibition in non-spatial selection of hierarchical forms[3].

In addition, our findings link the *inhibitory deficit theory* with observations from neuroimaging. There is a striking parallel between our data and prior studies in which TMS was applied to the left PPC, to reduce its influence on suppressing perceptual representations of distractors (Mevorach et al., 2010; Mevorach et al., 2006b). Mevorach et al. report that, across both local and global levels, low-salient targets became difficult to select after the left PPC received TMS, and this was associated with increased activation in early occipital cortex. These data are consistent with low-salient targets being selected through modulated inhibition of high-salient distractors via the left PPC, and with this top-down selection process being compromised with age. The data also fit with the Posterior-Anterior Shift with Aging (PASA) model, which posits an age-decline in the occipito-parietal networks involved in attention (Cabeza et al., 2004; Davis et al., 2008). We may speculate that the age-related

[3] Note that the selection of a global stimulus, and ignoring of a local stimulus, cannot be explained in terms of spatial selection, since any 'fitting' of a spatial window of attention on a global stimulus would also lead to local stimuli being selected.

decline in the suppression of salient information may be due to age-related decreases in the effectiveness of connectivity between occipital and parietal cortices. Irrespective of this, our behavioural data suggest that altered control of attention to low-salient signals may be a critical factor in cognitive aging and, at least in our results, something that is more important than alterations in the selection of local and global targets.

Problems in selecting low-salient stimuli may have been critical to findings from studies using distraction as a measure of top-down attentional control in aging. The inhibition of task-irrelevant information in aging has been assessed from responses to task-irrelevant abrupt onsets (Kramer et al., 1999) and the inhibition of cued information in top-down visual search (Madden et al., 2004; Madden et al., 2007). Although there are results suggesting that there is preservation of top-down attentional control with ageing (Kramer et al., 1999; Whiting et al., 2007; Whiting et al., 2005; Madden et al., 2004), this has not been established in cases where distractors have relatively high saliency (compared with targets) (Kramer et al., 2000; Madden et al., 2004). The current results go beyond these data by suggesting that there are impairments in rejecting high-salient distractors at different levels of stimulus representation. It is perfectly possible that other forms of top-down processing, such as the guidance of attention from positive expectancies of targets, remains intact.

One somewhat different account of the present results can also be put forward. This is that older adults suffered more interference from salient distractors because they had more efficient parallel processing of both levels of the hierarchical forms. This more efficient parallel processing would mean that distractors are processed more deeply and thus create more interference. However, on this account we would expect that RTs on congruent trials would be notably fast for older adults, since they would gain more from redundancy at the distractor level. There was no evidence for this. The failure to find an increased benefit on congruent trials for older participants also goes against the idea older adults show increased congruency effects due to congruent trials being speeded.

Aside from the effects of saliency, the old and young age groups differed in how their performance varied in the global and local identification tasks. The young participants showed relatively large differences in performance in the global compared to the local task, when compared with their overall performance. The older participants showed relatively small changes between the global and local tasks, compared with their overall performance. On the other hand, the older participants showed larger variation than the young participants as stimulus saliency changed (Figure 5**Error! Reference source not found.** a and b). These data suggest that, for older but not for young participants effects of saliency produce stronger shifts in performance than effects of task (global vs. local). Our results, stressing the effects of saliency across different levels of form, also help to explain previous inconsistencies in the literature, where opposite effects of ageing have been reported under conditions where the saliency of the local and global forms was varied (cf. Muller-Oehring et al., 2007; Roux & Ceccaldi, 2001). Our data also cannot be linked to an argument that younger participants showed stronger effects of global precedence than older participants (Roux and Ceccaldi, 2001). Note that our effects occurred across the local and global recognition tasks, and we would then have expected a relatively larger congruency effect in young participants in the local task with distractor salient stimuli. We observed the opposite (**Error! Reference source not found.**).

One limitation from the present study is that, in the current procedure it is difficult to separate problems in selecting the appropriate perceptual level of the target from difficulties encountered in selecting the response to the target when the distractor had high saliency – and indeed both poor perceptual and response selection may contribute to the age-related effects we report. Note, however, that the neuro-imaging data reported by Mevorach et al. (2010) strongly points to perceptual selection being challenged when the target has low saliency and the distractor high perceptual saliency (with changes found in early occipital brain regions). Future work needs to try and tease apart the age effects on perceptual and response selection, perhaps building on the imaging work which provides a clear framework for evaluating the neuroanatomical basis of selection by saliency.

Finally, the advantage of left over right visual field was unsurprising. Prior studies have reported a left visual field advantage (Orr & Nicholls, 2005) most probably reflecting right hemisphere dominance for attentional processing (Siman-Tov et al., 2007). Critically this did not interact with age. Furthermore, there were no interactions between visual fields (centre vs peripheral) and age, which provided evidence that the results cannot be explained with loss of visual acuity in the periphery. We conclude that age has a selective effect on rejecting high-salient distraction, an ability associated with distractor suppression through the left PPC in our task.

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Table 1. *F*- and *p*-values for significant main effects and interactions from a five-way ANOVA over the mean RTs and accuracy. The within-subject factors included task (select Global/Local targets), saliency level (Target-salient (e.g. global task with global saliency) vs. Distractor-salient (e.g. global task with local saliency)), congruency (Congruent vs. Incongruent) and visual field (Central vs. Peripheral). The between-subject factor was age group (Young adults vs. Older adults). *Sal* - saliency; *Cong* – congruency; *VF* – visual field

		RTs			Accuracy		
	Interaction	*F*-Value	*p*-Value	Partial eta^2	*F*-Value	*p* -Value	Partial eta^2
Main Effects	Task	15.86	< .001	.279	9.83	.003	.193
	Sal	71.88	< .001	.637	61.63	< .001	.600
	Cong	99.96	< .001	.709	47.87	< .001	.539
	VF	47.66	< .001	.538	81.43	< .001	.665
	Age	20.93	< .001		7.73	.008	
General Interactions	Task x Sal	7.15	.011	.149	4.66	.037	.102
	Sal x Cong	35.58	< .001	.465	11.64	.001	.221
	Task x VF	78.51	< .001	.657	35.90	< .001	.467
	Sal x VF	4.66	.037	.102	20.87	< .001	.337
	Cong x VF	-			10.56	.002	.205
	Task x Sal x VF	-			5.01	.031	.109
	Task x Sal x Cong	-			5.86	.020	.125
	Task x Cong x VF	17.90	< .001	.304	8.76	.005	.176
Interactions with Age	Task x Age	-			-		
	Sal x Age	19.55	< .001	.323	12.08	.001	.228
	Cong x Age	13.33	.001	.245	14.11	.001	.256
	VF x Age	-			13.71	.001	251
	Task x Sal x Age	4.40	.042	.097	-		
	Sal x Con x Age	3.75	.060	.084	8.64	.005	.174
	Task x VF x Age	6.06	.018	.129	-		
	Sal x VF x Age	-			5.68	.022	.122
	Cong x VF x Age	-			7.33	.010	.152
	Task x Cong x VF x Age	6.85	.012	.143	-		

Table 2. Significance levels (*F*- and *p*-values) for the main effect and interactions involving the factors task, saliency (Sal), congruency (Cong), visual field (VF) and age.

		Efficiency (RT/Accuracy)			Z-score		
Interaction		*F*-Value	*p*-Value	Partial eta^2	*F*-Value	*p* -Value	Partial eta^2
Main Effects	Task	20.82	< .001	.337	29.81	< .001	.421
	Sal	54.76	< .001	.572	188.16	< .001	.821
	Cong	28.71	< .001	.412	166.09	< .001	.802
	VF	43.10	< .001	.512	147.17	< .001	.782
	Age	22.76	< .001		-		
General Interactions	Task x Sal	17.93	< .001	.304	-		
	Sal x Cong	13.82	< .001	.252	38.82	< .001	.486
	Task x VF	32.83	< .001	.445	140.98	< .001	.775
	Sal x VF	15.81	< .001	.278	43.58	< .001	.515
	Task x Sal x VF	9.83	.003	.193	18.69	< .001	.313
	Cong x VF	9.17	.004	.183	-		
	Task x Cong x VF	12.45	.001	.233	13.06	.001	.242
	Saliency x Cong x VF	7.83	.008	.160	-		
	Task x Sal x Cong x VF	4.36	.043	.096	-		
Interactions with Age	Task x Age	-			5.35	.026	.115
	Sal x Age	21.42	< .001	.343	8.72	.005	.175
	Cong x Age	11.53	.002	.220	-		
	VF x Age	11.12	.002	.213	-		
	Task x Sal x Age	8.27	.006	.168	-		
	Sal x Con x Age	7.68	.008	.158	4.45	.041	.098
	Task x VF x Age	9.99	.003	.196	-		
	Sal x VF x Age	7.86	.008	.161	-		
	Task x Sal x VF x Age	5.54	.023	.119	-		
	Congruency x VF x Age	6.14	.017	.130	-		
	Task x Cong x VF x Age	7.13	.011	.148			
	Sal x Cong x VF x Age	5.27	.027	.114	-		

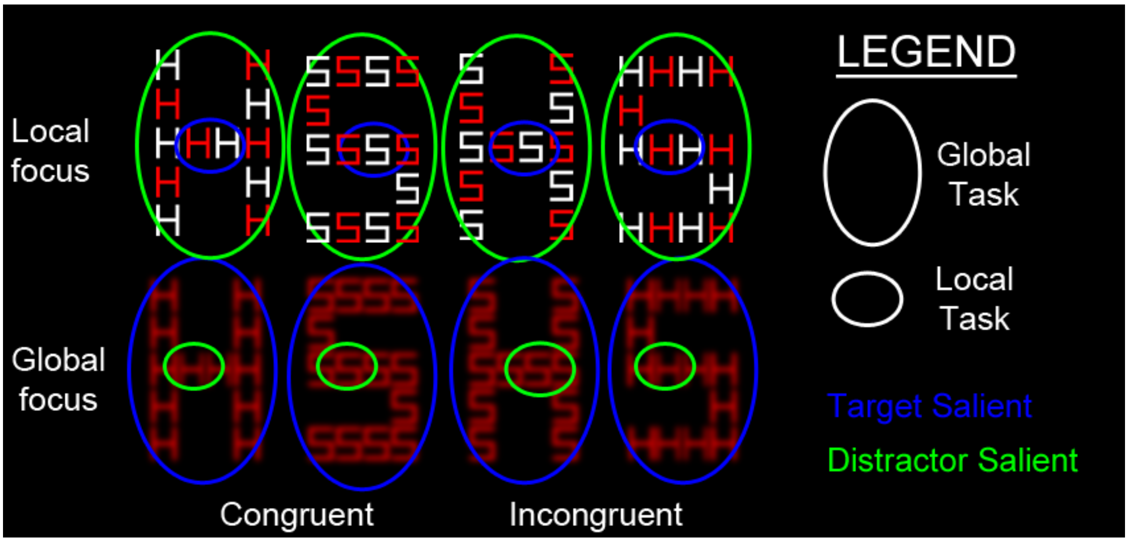

Figure 1. All compound letters with either high local saliency (top row) or high global saliency (bottom row) used in the experiment. Target saliency was varied orthogonally with the task (Local task [small circles] / Global task [Large ellipses]). The colour of the ellipse denotes the saliency level in particular condition - target salient in blue (e.g. in a block with global task using the set of stimuli with global focus, bottom row) and distractor salient in green (e.g. in a block of local task using the set of stimuli with global focus, bottom row).

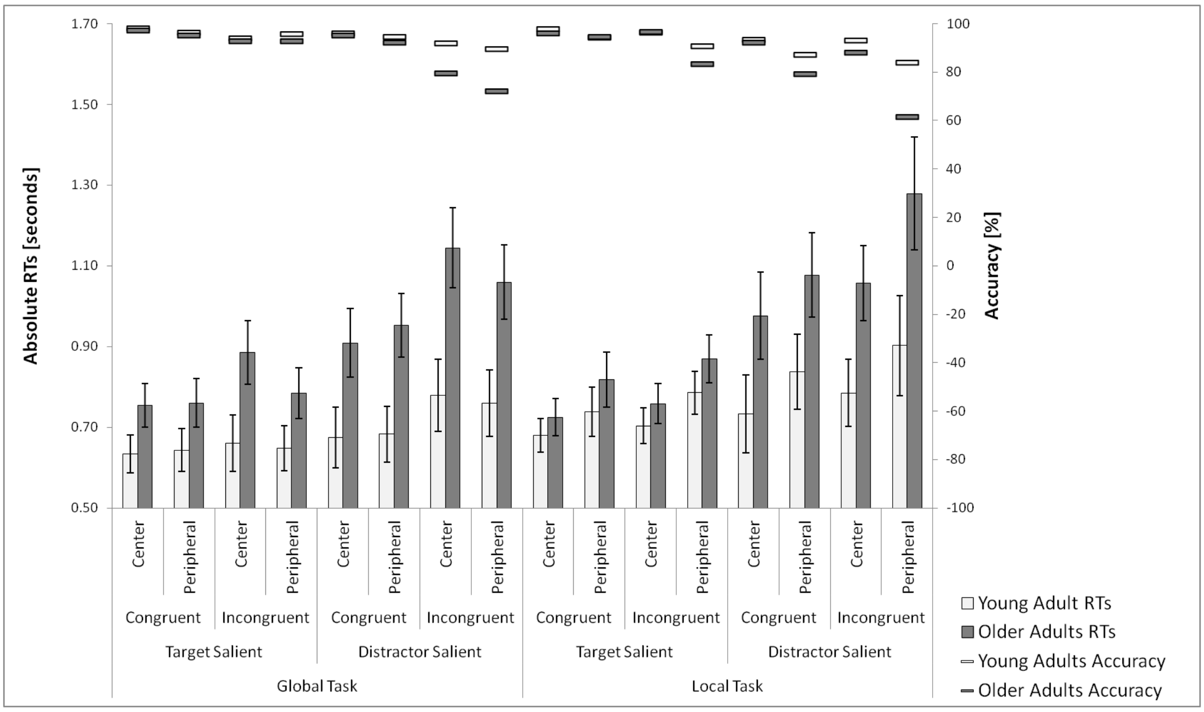

Figure 2. Mean RTs (± 95% confidence interval) and accuracy as a function of congruency, saliency and level of identification for younger and older adults.

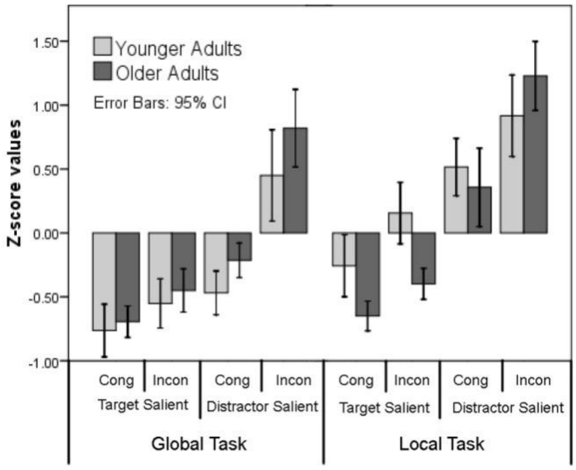

Figure 3. Mean Z-score values (± 95% confidence interval) as a function of congruency, saliency and level of identification for young and older adults. Values indicate the difficulty (-1 being easiest, +1 being most difficult) of a condition in relation to the averaged efficiency across all conditions (baseline).

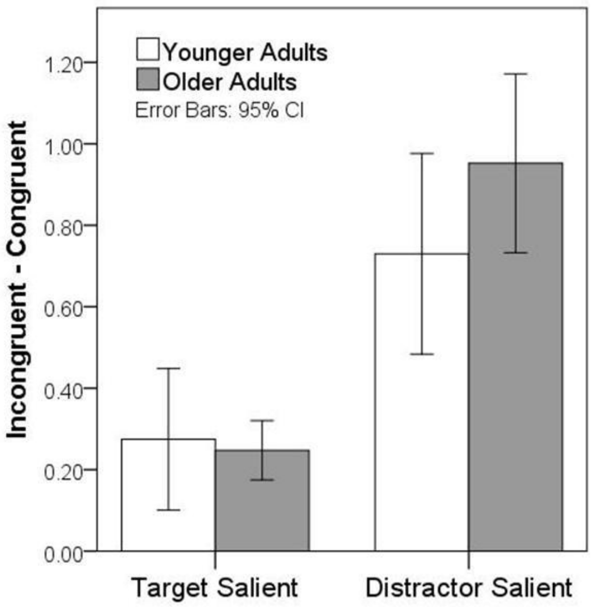

Figure 4. Congruency cost calculated from the Z-score difference between incongruent and congruent trials for target salient and distractor salient conditions separately for young and older adults.

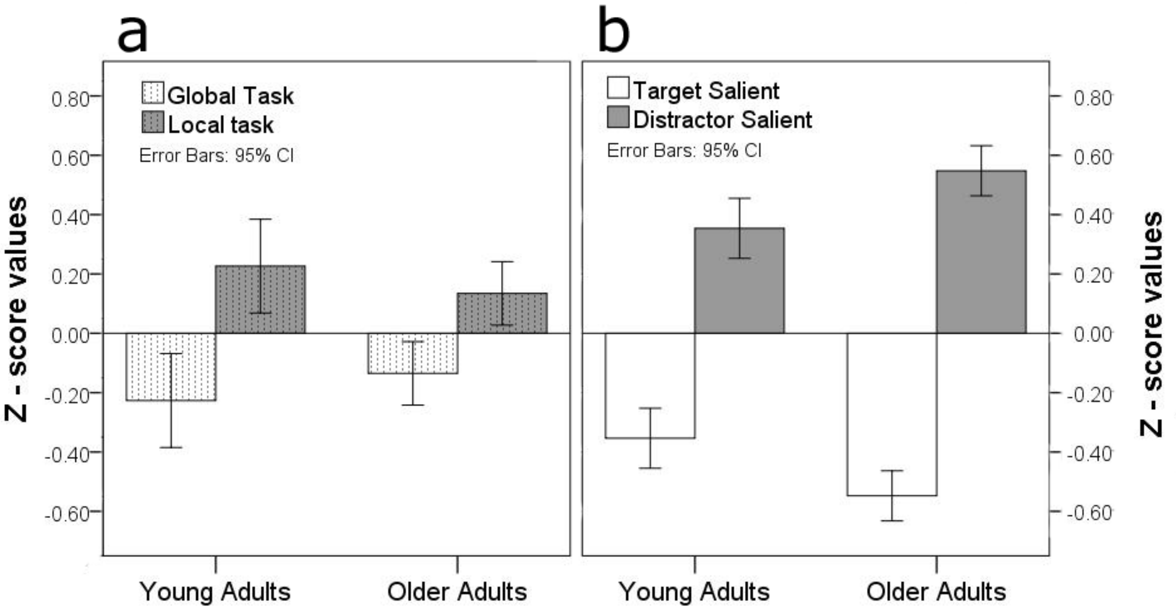

Figure 5. Mean Z-score values (± 95% confidence interval) as a function of task (Global / Local, plot a) and as a function of target saliency (Target-salient / Distractor-Salient, plot b) for young and older adults.

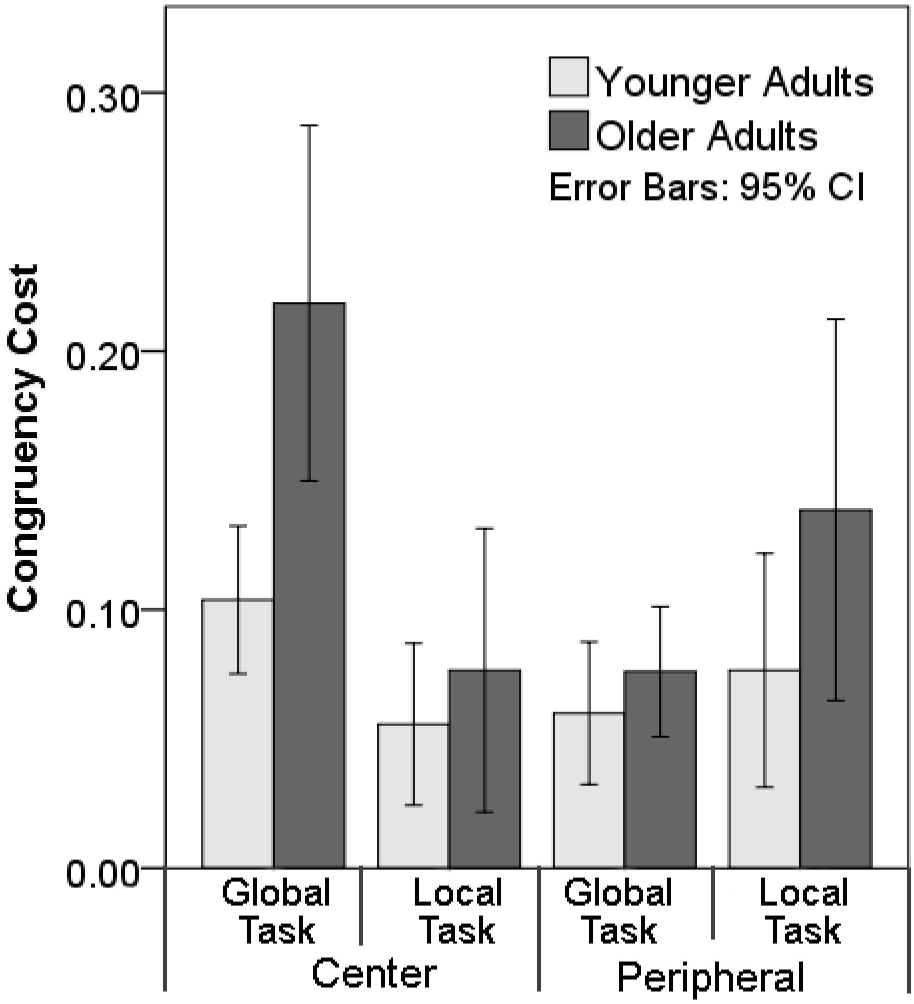

Figure 6. Mean congruency cost (± 95% confidence interval) as a function of task and visual field for young and older adults separately.

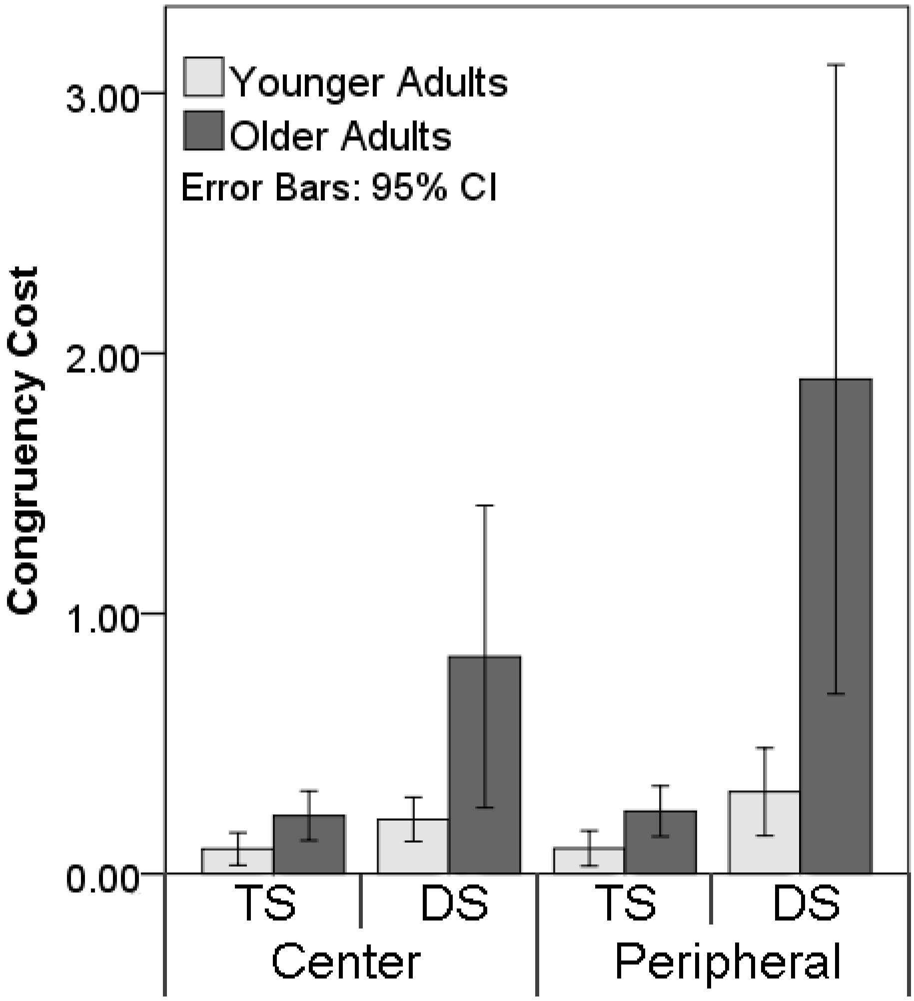

Figure 7. Mean congruency cost (± 95% confidence interval) as a function of saliency (Target Salient, TS vs Distractor Salient, DS) and visual field (Center vs Peripheral) for young and older adults separately.