Feature-based interference from unattended visual field during attentional tracking in younger and older adults

Viola S. Störmer Max Planck Institute for Human Development, Berlin, Germany

Shu-Chen Li Max Planck Institute for Human Development, Berlin, Germany

Hauke R. Heekeren Max Planck Institute for Human Development, Berlin, Germany, & Department of Psychology and Education, Freie Universität Berlin, Berlin, Germany

Ulman Lindenberger Max Planck Institute for Human Development, Berlin, Germany

The ability to attend to multiple objects that move in the visual field is important for many aspects of daily functioning. The attentional capacity for such dynamic tracking, however, is highly limited and undergoes age-related decline. Several aspects of the tracking process can influence performance. Here, we investigated effects of feature-based interference from distractor objects that appear in unattended regions of the visual field with a hemifield-tracking task. Younger and older participants performed an attentional tracking task in one hemifield while distractor objects were concurrently presented in the unattended hemifield. Feature similarity between objects in the attended and unattended hemifields as well as motion speed and the number of to-be-tracked objects were parametrically manipulated. The results show that increasing feature overlap leads to greater interference from the unattended visual field. This effect of feature-based interference was only present in the slow speed condition, indicating that the interference is mainly modulated by perceptual demands. High-performing older adults showed a similar interference effect as younger adults, whereas low-performing adults showed poor tracking performance overall.

Keywords: attention, spatial vision, perceptual organization, motion-2D, aging

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Introduction

Natural visual scenes often contain far more objects than our visual system can process efficiently. Most objects in our visual environment are dynamic, namely, they move on predictable or unpredictable trajectories. In everyday situations, such as driving a car in heavy traffic or watching children playing on the playground, we are often required to monitor multiple moving objects at the same time. Attention allows us to select relevant objects in crowded scenes and to sustain this selection over time and space to track the moving objects.

The ability to attend to multiple moving objects simultaneously has been studied using the multiple-object tracking (MOT) paradigm. In the basic MOT paradigm, the observer is confronted with a number of objects with identical features and is instructed to covertly track a subset of target objects while all items move randomly across the visual field for several seconds (Pylyshyn & Storm, 1988). On average, younger adults are able to track up to 4 or 5 objects at a time (Cavanagh & Alvarez, 2005; Pylyshyn & Storm, 1988). Tracking performance is known to be influenced by several aspects of the task, including tracking duration, number of target and non-target objects, as well as the density and speed of the moving objects (Cavanagh & Alvarez, 2005). Of specific interest, recent studies also showed that the tracking capacities of the left and right visual hemifields may be separable, suggesting that the two hemispheres can, in principle, track moving objects independently of each other (Alvarez & Cavanagh, 2005; Carlson, Alvarez, & Cavanagh, 2007; see also Drew & Vogel, 2008). This finding implies that some processes of attentional tracking are hemifield-specific, calling for a close inspection of tracking performance for each hemifield separately.

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Interfering effect of nontargets

Previous studies of attentional tracking focused on effects of nontarget objects *within* the attended region. This line of research has consistently shown that tracking performance declines as the number of nontargets increases (Horowitz, Place, Van Wert, & Fencsik, 2007; Pylyshyn, Haladjian, King, & Reilly, 2008). The effect of nontargets on tracking performance has been interpreted in terms of requiring attention for distractor suppression (Flombaum, Scholl, & Pylyshyn, 2008; Pylyshyn & Annan, 2006; Pylyshyn et al., 2008), crowding effects (Franconeri, Alvarez, & Enns, 2007), or both (Bettencourt & Somers, 2009). However, less is known about the effects of nontarget stimuli *outside* of the attended region. Such irrelevant distraction seems to be common in everyday visual perception. For example, during driving, moving stimuli at the roadside, such as a rolling red ball, may cause interference even when they appear at a location that is not covertly attended (Forster & Lavie, 2008).

In the common attentional tracking paradigm, the nontarget objects are not entirely task-irrelevant as they appear within the attended region and are in one sense or the other associated with the main task (Alvarez & Franconeri, 2007). The question whether moving objects that neither directly interact with target processing nor appear at the attended locations would interfere with tracking performance has not been systematically addressed so far.

Interfering effect of shared stimulus features between targets and nontargets

Distractors resembling target objects may cause larger interference effects than distractors that do not (Driver & Baylis, 1998; Duncan & Humphreys, 1989; Jiang & Chun, 2001). For example, distant distractors that move in the same manner as a target letter produce more interference than nearby distractors that are static (Driver & Baylis, 1989). In the same manner, when distractors and targets share the same color, distractors interfere more than when they do not (Baylis & Driver, 1992). These findings of similarity-based perceptual interference were interpreted as an effect of early feature registration (Treisman, 2006; Treisman & Gelade, 1980). Feature integration theory proposes that objects that share basic features such as color, form, or motion are perceptually grouped automatically at an early stage of visual processing (Treisman & Gormican, 1988; Treisman & Sato, 1990).

In research on attentional tracking, commonly used paradigms generally involve the presentation of *identical* target and distractor objects. Consequently, attention may initially be distributed across the entire perceptual group based on feature similarity, even to the objects that are not designated as targets. Hence, even objects that need not be attended to or appeared in irrelevant regions of the visual field may initially still be processed in the same manner as target objects, thereby causing interference.

Effects of aging and performance level on object tracking

Although adult age differences in visual attention are well established (e.g., Hommel, Li, & Li, 2004; Kramer & Weber, 1999), thus far most studies investigated visual attention with respect to static rather than moving objects. Two recent studies reported impairments in older adults' performance when tracking moving objects (Sekuler, McLaughlin, & Yotsumoto, 2008; Trick, Perl, & Sethi, 2005). In addition, research on younger adults showed that tracking performance varies considerably across individuals (Oksama & Hyönä, 2004). It seems straightforward to attribute these individual and age-related differences in tracking performance to between-person variability in task-relevant cognitive capacities. However, performance at different functional ranges may also reflect differences in the mechanisms used by different individuals to perform the task (Kliegl, Mayr, & Krampe, 1994; Li & Lindenberger, 2002; Rogers, Hertzog, & Fisk, 2000), suggesting that individual differences in performance level need to be considered explicitly when attempting to delineate age-related differences in neurocognitive processes. Given that between-person differences in cognitive abilities increase with advancing age (de Frias, Lövden, Lindenberger, & Nilsson, 2007), it seems particularly important to account for performance level when investigating age-related changes in attentional tracking (cf. Nagel et al., 2009, 2010; Schneider-Garces et al., 2010).

Aims and hypotheses of the study

The main aim of the present study was to investigate whether irrelevant objects that share the same features as the targets but appear at unattended regions in the visual field interfere with tracking performance. In our task, observers were asked to track a certain number of target objects in one hemifield at a time (left, right) while irrelevant moving objects appeared concurrently on the unattended side. The crucial manipulation was the degree of feature similarity between the irrelevant distractors in the unattended hemifield to the objects in the attended hemifield. In addition, the number of objects to be tracked (2, 3, 4 targets) and moving speed (slow, fast) was varied to manipulate tracking task load and perceptual demands, respectively. The second aim of the study was to investigate how tracking capacity changes with normal cognitive aging. Performance level was taken into consideration to explore the heterogeneity of tracking performance, particularly in old age.

Central to our research question about feature-based interference from the unattended visual field, we hypothesized that irrelevant objects that resemble features of the objects presented in the task-relevant hemifield would cause more interference, whereas objects that do not share similar features would cause less interference. Based on previous research, we also expected lower tracking performance in conditions with higher tracking task load or higher perceptual demands. Another question of interest here was whether interference from the unattended hemifield would interact with motion speed or set size. Perceptual load affects distractor processing (e.g., Forster & Lavie, 2007; Lavie, 1995), thus we hypothesized that the degree of the *perceptual* demands of the task as manipulated by motion speed would interact with the perceptual-similarity interference effect. It was less clear whether feature-based interference would also be affected by task load. If feature-based interference operates primarily during early stages of perceptual processing (Baylis & Driver, 1992; Treisman & Gormican, 1988), then it may not interact with effects of tracking task load, which have been related to working memory capacity (e.g., Allen, McGeorge, Pearson, & Milne, 2006; Drew & Vogel, 2008). If, in addition to a relation to perceptual demands, feature-based interference would also interact with tracking task load, this would suggest that feature-based interference also acts on processes related to working memory capacity. Further, we hypothesized that these modulations differ between age groups, with older adults showing stronger effects of set size and speed (Sekuler et al., 2008). Furthermore, we expected that high-performing older adults would show performance patterns similar to younger adults.

Methods

Participants

A total of 104 volunteers participated in the study after giving informed consent. The Ethics Committee of the Max Planck Institute for Human Development approved the study. Fifty younger adults and 54 older adults took part in two testing sessions. All older adults lived independently in the community. Data from 8 (14.8%) older adults and 2 (4%) younger adults were excluded from the analysis because of vision abnormalities or technical difficulties during the experimental session. Of the remaining 48 younger adults (27 females, 22–35 years, mean = 26 years) and 46 older adults (25 females, 63–79 years, mean = 70 years), all were right-handed and had normal or corrected-to-normal vision, normal color vision, and normal hearing. Participants were assessed on a marker test of crystallized intelligence (Lehrl, 1977) and two tests of perceptual speed (Thurstone & Thurstone, 1941; Wechsler, 1958). In line with two-component theories of life-span intelligence contrasting the mechanics and pragmatics of cognition (Baltes, 1987; Horn, 1989), older adults attained lower scores in perceptual speed than younger adults but higher scores in verbal knowledge (see Table 1).

	Younger adults	Older adults
	M (*SD*)	*M* (*SD*)
Age	25.6 (3.1)	70.1 (3.7)
Male:Female	21:27 (56% female)	21:24 (54% female)
Digit symbol (processing speed)	71.1 (14.9)	46.8 (9.2)
Identical pictures (mechanics)	31.88 (4.8)	19.5 (3.45)
Spot-a-word (pragmatics)	18.08 (5.46)	22.48 (5.47)

Table 1. Demographic and basic cognitive characteristics of sample.

Procedure

Each participant was tested in two sessions. The first session was used to assess covariates (verbal knowledge, perceptual speed, handedness) and took place in age-homogenous groups of four to six individuals. In addition, a baseline test of the tracking experiment was conducted to ensure that younger and older participants were able to do the tracking task in the fast speed condition (see next paragraph for details). In the second session, which took place for each participant individually, the hemifield attentional tracking task was performed. Prior to the experimental task, close and distant visual acuity was measured using standard tables with Landolt rings and digits (Geigy, 1977); color vision was assessed using standard color panels.

Stimuli and apparatus

Covariates

In the covariate session, the subjects completed a paper-pencil biographical questionnaire, the Digit Symbol test, as well as the Edinburgh handedness inventory (Oldfield, 1971). The other tests for perceptual speed (Identical Pictures) and verbal knowledge (Spot-A-Word) were performed on the computer. In the tracking baseline condition, participants were instructed to attend to one visual hemifield at a time (left, right) and to track one or three moving objects among nontarget objects that shared the same stimulus features with the targets. All stimuli moved randomly at fast speed (~3°/s) and no stimuli were presented on the unattended hemifield. A second covariate session was part of another larger study and included a battery of working memory tasks that are not reported here.

Experimental task

The experiment was conducted in a dimly lit chamber. Stimuli were presented on a 19-inch CRT computer display (1024 × 768; 85 Hz) with the background luminance set to 14.23 cd/m^2. Observers viewed the display binocularly at a distance of 60 cm with their heads stabilized by a chin rest. To keep the task at a level of difficulty that could still be managed by older adults, based on pilot studies a smaller range of set sizes was chosen for older adults (2 or 3 targets) than for younger adults (2, 3, or 4 targets). Thus, the experiment consisted of 12 blocks of 16 trials for the older participants and 12 blocks of 24 trials for younger participants. All stimuli were presented on a uniform gray background (RGB: [90 90 90]) in regions subtending 6.5° × 8.5° visual angle. Throughout the experiment, a small black fixation cross (0.47° × 0.47°) was presented in the center of the display, and participants were instructed to maintain their gaze at the fixation cross throughout each experimental block. At the beginning of each block, the instruction to attend to either the left or right side of the display appeared ("Attend Left" vs. "Attend Right"; see Figure 1). The 12 blocks followed the same pseudo-randomized sequence for all participants (LRRLLRLRLLRR). At the beginning of each trial, eight stationary disks subtending 0.47° × 0.47° visual angle were presented in both left and right regions for 1 s. On half of the trials, the disks were colored green (RGB: [0 75 0]) in one hemifield and blue (RGB: [0 0 150]) in the other (low feature-similarity condition); on the other half of the trials, the disks were all in one color (either green or blue) in both hemifields (high feature-similarity condition). The color of the disks on each attended hemifield stayed constant throughout the experiment, with only the color of the disks in the unattended hemifield changing on a trial-by-trial basis. The colors of the disks were counterbalanced between participants. On each trial, a subset of the disks on the to-be-attended side turned red (RGB: [150 0 0]) marking them as targets. After 1 s, the targets turned back to their original color (green or blue) and all items on the display started moving in random fashion for 7 s. When movement stopped, one item on the to-be-attended side turned red marking it as a test probe. The red probe disk was one of the original targets on 50% of the trials and was a randomly selected nontarget on the to-be-attended hemifield on the remaining trials. The observer had to indicate whether the red probe was a target or a nontarget by pressing a left or right button on a keyboard with their left and right index fingers. Response buttons were counterbalanced across participants. To ensure the same experimental precondition for all participants, the sequence of randomized trials was identical within each age group.

Motion parameters

The speed with which targets and distractors moved was kept constant between hemifields but varied randomly

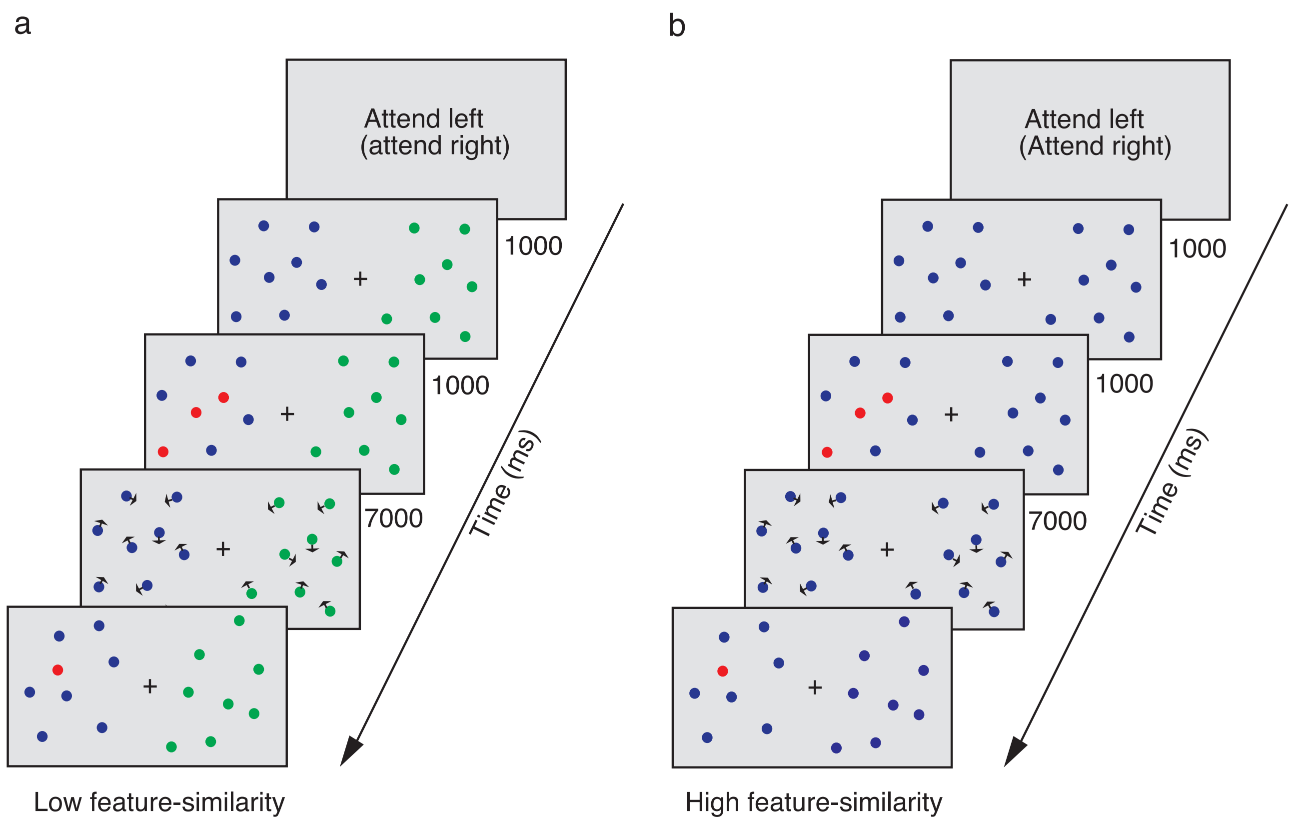

Figure 1. Examples of the trial sequence of the multiple-object tracking task (MOT) with three targets. The left panel (a) illustrates a trial with low feature-similarity in which the disks in the attended and unattended hemifields have distinct colors. The right panel (b) illustrates trial with high feature-similarity in which the disks in the attended and unattended hemifields share the same color.

from trial to trial. On half of the trials, the disks moved at a constant speed of ~2°/s (slow speed) and on the other half of the trials at a speed of ~3°/s (fast speed). These speed parameters were chosen based on previous studies (e.g., Drew & Vogel, 2008; Sekuler et al., 2008). Motion direction was linear and changed at random intervals, moving at least 1 s and at the most 3 s in one direction. The timing of each direction change was chosen randomly from a rectangular distribution. When the disk made contact with the outer barrier of the viewing area or the midline, motion direction was also changed, thereby never leaving one hemifield. The disks bounced off each other (no occlusion). Motion trajectories were generated before the experimental session and were uploaded in the same order for all participants.

Eye tracking

To ensure that participants maintained fixation throughout each experimental block, their eyes were tracked with an Eyelink 1000 at a sampling rate of 500 Hz. The eye-tracking computer and the stimulus presentation computer were synchronized such that the stimulus presentation depended on the eye position of the participant. In particular, stimulus presentation was disrupted whenever participants moved their eyes out of an (invisible) box subtending 2° × 2° visual angle surrounding the fixation cross in the center of the screen. Thus, when participants moved their eyes toward one hemifield or tried to follow the target disks with their eyes, all stimuli disappeared immediately and the entire screen turned gray.

Analysis

MOT baseline condition

The baseline condition served as a pretest control to ensure that younger and older adults did not differ in their tracking performance because of differences in speed perception of the moving objects. To test whether age groups differed in basic tracking performance, response accuracy was analyzed using repeated-measures analysis of variance (ANOVA) with age group as a between-subject factor (young, old) and set size (1, 3) as a within-subject factor.

MOT experiment

Data analysis was conducted in two steps. In the first step, performance accuracy (% correct) was analyzed using a repeated-measures ANOVA with age as a between-subject factor and set size, speed, and feature similarity as within-subject factors for the whole sample. Since set sizes 2 and 3 did not differ significantly in the group of younger adults (see Results section), set sizes 2 and 3 were collapsed for younger adults to reveal the same number of levels for the factor set size in both age groups for this analysis. Then, participants were divided into two groups based on their age. Separate repeated-measures ANOVAs, with set size (2, 3 for older adults and 2, 3, 4 for younger adults), speed (slow, fast), and feature similarity (low, high) as within-subject factors were employed. When necessary, pairwise comparisons were conducted to see at which level the effect was present.

In the second step, participants were grouped based on their overall performance in the task. Within each age group, low and high performers were selected by using a median split. Follow-up analyses were conducted separately for the slow speed condition and the fast speed condition to examine interference effects within speed conditions. Finally, orthogonal contrasts were carried out to see in which groups the condition effects were present.

Results

No age differences in baseline MOT

Both younger and older adults performed well in the attentional tracking baseline task. Younger adults were able to track one item with an accuracy of 96% and 3 items with an accuracy of 90%. Likewise, older participants tracked one item with an accuracy of 93% and 3 items with an accuracy of 86%. A repeated-measures ANOVA revealed a main effect of set size, $F(1, 92) = 43.76$, $p < 0.05$; no effect of age ($p > 0.05$) and no age by set size interaction was observed ($p > 0.05$). These results indicate that younger and older adults were, in principle, capable of tracking objects in the fast speed condition.

Tracking performance in relation to age group, set size, speed, and feature similarity

Accuracy rates for younger and older adults are depicted in Figure 2. Initial data analysis was done with a mixed between–within ANOVA. The results revealed a main effect of age group, $F(1, 92) = 18.79$, $p < 0.05$, $\eta 2 = 0.2$, indicating a drop in performance for older adults compared to younger adults. Furthermore, age interacted with feature similarity, $F(1, 92) = 31.65$, $p < 0.05$, $\eta 2 = 0.01$, and motion speed, $F(1, 92) = 10.53$, $p < 0.05$, $\eta 2 = 0.01$, but no reliable interaction between age group and set size was found ($p > 0.05$). The effects were followed up by separate analyses for each of the two age groups.

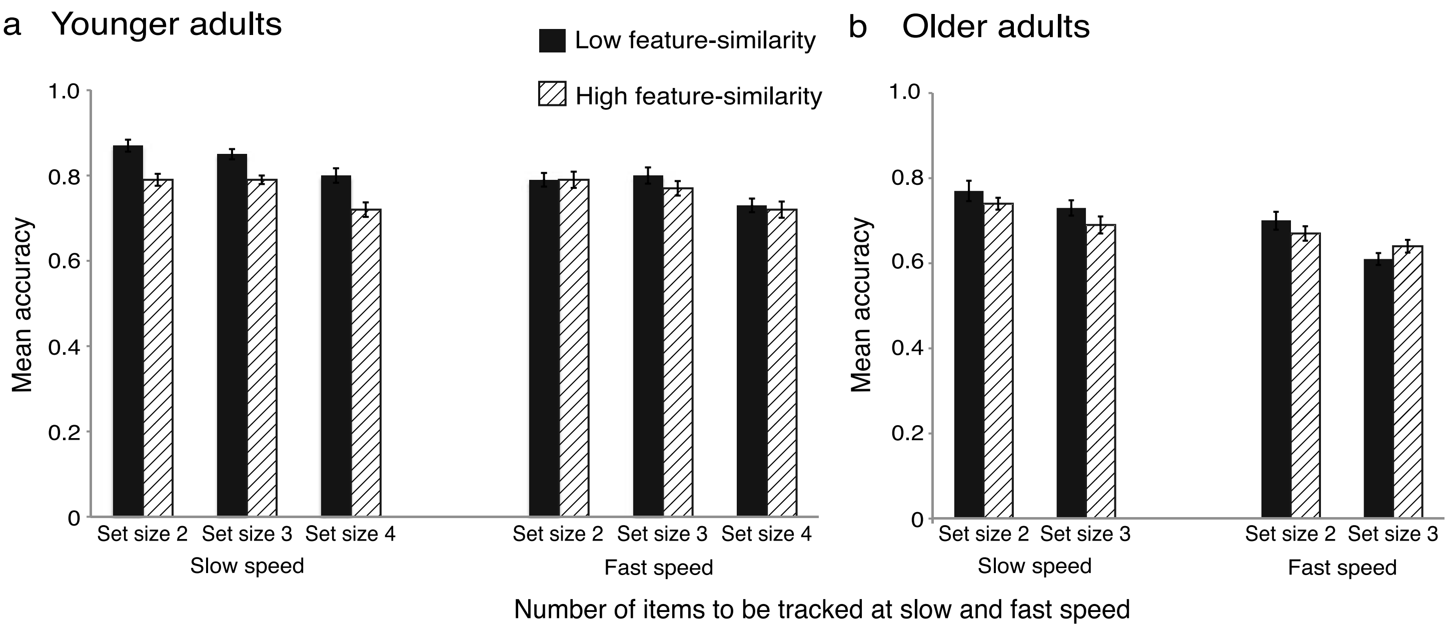

Figure 2. Performance for (a) younger adults and (b) older adults as a function of set size, speed, and the extent of feature similarity between hemifields. Bars indicate standard errors of the mean.

For younger adults, an ANOVA revealed a main effect of set size, $F(2, 94) = 24.19$, $p < 0.05$, $\eta 2 = 0.09$, motion speed $F(1, 47) = 52.58$, $p < 0.05$, $\eta 2 = 0.07$, and feature similarity, $F(1, 47) = 60.13$, $p < 0.05$, $\eta 2 = 0.09$, as well as a speed by feature similarity interaction, $F(1, 47) = 18.91$, $p < 0.05$, $\eta 2 = 0.02$. No other interactions were observed (all *ps* > 0.05). Post-hoc comparisons revealed that the set size effect was significant in both speed conditions for the comparison 2 and 4 targets (*slow speed*: $F(1, 47) = 32.79$, $p < 0.05$, $\eta 2 = 0.16$; *fast speed*: $F(1, 47) = 5.00$, $p < 0.05$, $\eta 2 = 0.03$), as well as 3 and 4 targets (*slow speed*: $F(1, 47) = 26.86$, $p < 0.05$, $\eta 2 = 0.16$; *fast speed*: $F(1, 47) = 22.55$, $p < 0.05$, $\eta 2 = 0.07$), but not for 2 and 3 targets (both *ps* > 0.05). Separate repeated-measures ANOVAs for the two speed conditions exhibited that the feature-similarity effect was reliable in the slow speed condition, $F(1, 47) = 88.12$, $p < 0.05$, $\eta 2 = 0.24$, but absent in the fast speed condition ($p > 0.05$).

For older adults, there was a main effect of set size, $F(1, 45) = 22.78$, $p < 0.05$, $\eta 2 = 0.05$, and speed, $F(1, 45) = 64.4$ $p < 0.05$, $\eta 2 = 0.18$, but no effect of feature similarity ($p > 0.05$). None of the interactions were significant (all *ps* > 0.5).

Interference effect in relation to tracking performance

The second set of analyses focused on the effect of feature similarity. Set sizes 2 and 3 were again collapsed for both groups of younger adults since there was no significant difference in performance between set sizes 2 and 3 for neither performance group (all *ps* > 0.05).

In the slow speed condition, there were significant main effects of performance group, $F(3, 90) = 63.11$, $p < 0.05$, $\eta 2 = 0.42$, set size, $F(1, 90) = 228.97$, $p < 0.05$, $\eta 2 = 0.03$, and feature similarity $F(1, 90) = 41.44$, $p < 0.05$, $\eta 2 = 0.04$. Furthermore, significant interactions between group and set size, $F(1, 90) = 3.62$, $p < 0.05$, $\eta 2 = 0.01$, as well as group and feature similarity, $F(1, 90) = 10.15$, $p < 0.05$, $\eta 2 = 0.03$, were found. As shown in Figure 3, for all set size conditions, accuracy was lower when feature similarity was high than when it was low in all groups except the low-performing older group. This impression was confirmed by follow-up contrasts, which revealed that the feature-similarity effect was present in high-performing younger adults, $F(1, 23) = 12.28$, $p < 0.05$, $\eta 2 = 0.22$, low-performing younger adults, $F(1, 23) = 22.61$, $p < 0.05$, $\eta 2 = 0.22$, and high-performing older adults, $F(1, 22) = 11.22$, $p < 0.05$, $\eta 2 = 0.32$. Furthermore, each of these three groups also showed expected set size effects (all *ps* < 0.05; high-performing younger adults: $\eta 2 = 0.21$; low-performing younger adults: $\eta 2 = 0.06$; high-performing older adults: $\eta 2 = 0.16$). In contrast, no reliable effects of feature similarity or set size were observed in the group of low-performing older adults (all *ps* > 0.05). In addition, we tested whether high-performing older adults reached higher levels of performance than low-performing younger adults. Post-hoc comparisons revealed that this was true for set size 2, $F(1, 44) = 9{,}77$, $p < 0.05$, $\eta 2 = 0.19$. In the fast speed condition, there were significant main effects of performance group, $F(3, 90) = 63.47$, $p < 0.05$, $\eta 2 = 0.45$, and a main effect of set size $F(1, 90) =$

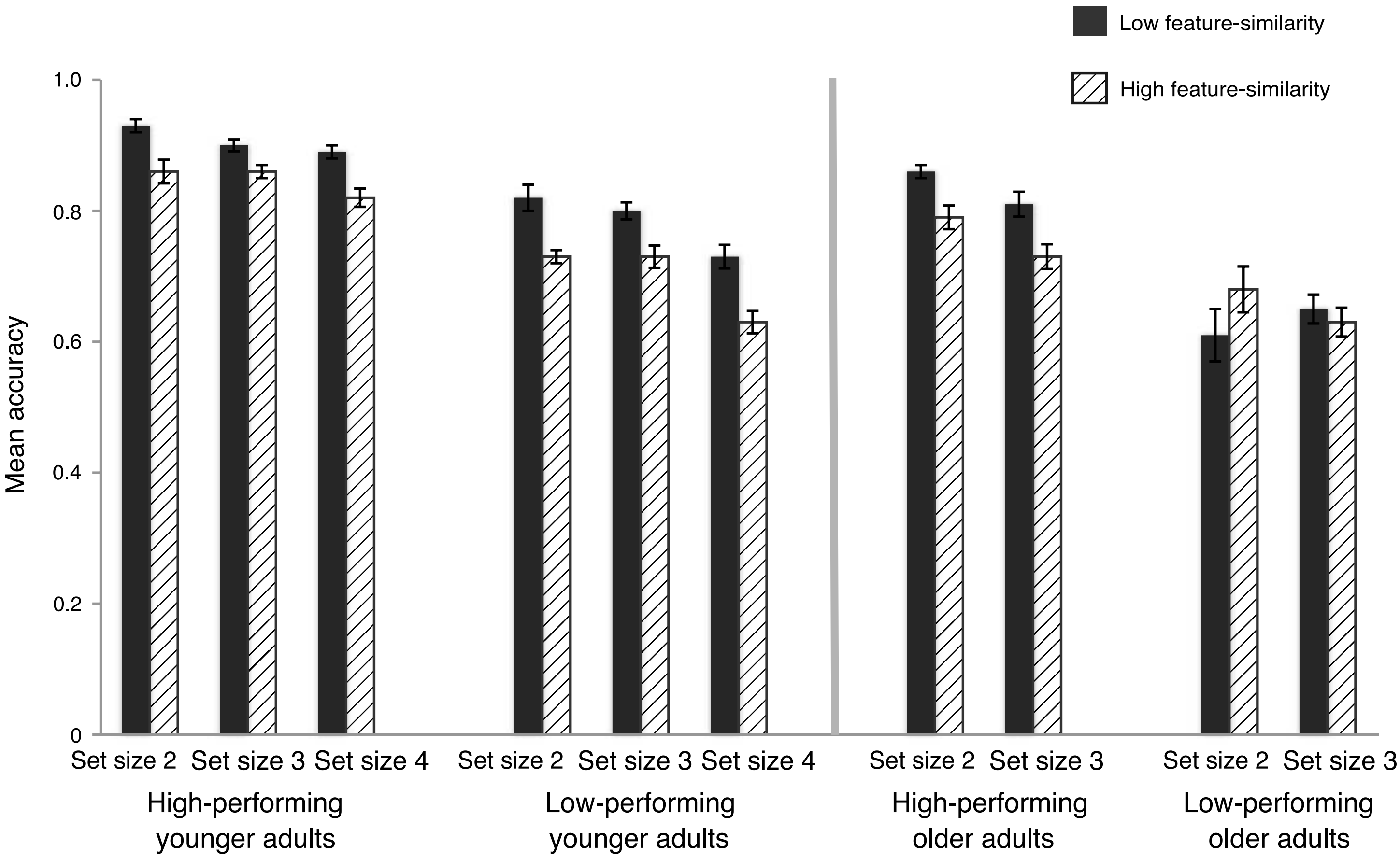

Figure 3. Performance for high- and low-performing younger and high- and low-performing older adults as a function of set size and feature similarity for the slow speed condition. Bars indicate standard errors of the mean.

34.38, $p < 0.05$, $\eta2 = 0.03$, but no main effect of interference and no group by set size or group by interference interactions (all $ps > 0.05$).

Discussion

Effects of tracking task load, perceptual demand, and age group

Overall, we found that the tracking task load (number of objects that need to be tracked) as well as perceptual demand (motion speed) affected tracking performance in younger and older adults. In the low feature-similarity condition, mean accuracy for tracking performance dropped for younger adults when they had to track more than 3 objects in one hemifield (about 6% from 2/3 to 4 targets in slow speed condition; about 7% from 2/3 targets to 4 targets in fast speed condition). This effect of number of target objects was present for older adults from 2 to 3 targets (4% from 2 to 3 targets in slow speed condition; 9% from 2 to 3 targets in fast speed condition). However, the effect of tracking task load was similar in both the high and low feature-similarity conditions for younger (7% for 2/3 targets to 4 targets in slow speed condition; 6% for 2/3 targets to 4 targets in fast speed condition) and older adults (5% from 2 to 3 targets; 3% from 2 to 3 targets in fast speed condition). Likewise, tracking performance declined for both age groups when the objects moved at faster speed for all set sizes (see Figure 2). Furthermore, a main effect of age revealed that on average older adults had lower performance than younger adults. As indicated by the age group by speed interaction, older adults were more affected by the speed manipulation than younger adults. Overall, these results are in line with previous findings in the attentional tracking literature (Alvarez & Franconeri, 2007; Bettencourt & Somers, 2009; Cavanagh & Alvarez, 2005; Sekuler et al., 2008).

Effects of feature-based interference

In the present design, we manipulated feature similarity between attended and unattended objects. The results point to a strong effect of feature-based interference for younger adults and high-performing older adults in the slow speed condition (see Figure 3). When feature similarity was high, tracking performance dropped dramatically for all set sizes (high-performing young: 7% for 2 targets, 4% for 3 targets, 7% for 4 targets; low-performing young: 9% for 2 targets, 7% for 3 targets, 10% for 4 targets; high-performing old: 7% for 2 targets, 8% for 3 targets). The magnitude of this effect is comparable to the magnitude of the effect produced by an increase in moving speed (compare Figure 2).

These results are consistent with the idea that distractor objects that resemble target objects interfere more strongly than distractor objects that do not (Baylis & Driver, 1992; Driver & Baylis, 1989; Duncan & Humphreys, 1989). Specifically, they suggest that unattended objects that are identical with attended objects are perceptually grouped, leading to the spreading of attention throughout the entire visual field (Kasai & Kondo, 2007). Thereafter, available resources propagate compulsorily to unattended regions within the perceptual group, thereby leading to interference. In line with this interpretation, one MEG/ERP study showed that feature similarity between target and distractor items exerted stronger suppressive brain activation (Hopf, Boelmans, Schoenfeld, Heinze, & Luck, 2002). By varying the feature overlap between targets and distractors that were presented in separate hemifields, Hopf et al. showed that increasing feature overlap resulted in an increase in neural activity related to the inhibition of the distractors in the unattended hemifield. The finding implies that when distractors shared the targets' features they led to more interference, resulting in a stronger need for inhibition. The fact that feature similarity between the targets and distractors entailed a stronger inhibitory brain response is consistent with the present results.

The drop in performance between the baseline task that did not contain any distractor objects in the unattended hemifield and the low interference condition in the experimental task suggests that the appearance of *any* moving object in the unattended hemifield affects tracking performance. Albeit our study did not address this question explicitly, it appears that a substantial interference effect is already present in the low feature-similarity condition, relative to a baseline condition of no distraction at all. In the low feature-similarity condition, the objects in the unattended hemifield were not entirely different from the attended objects; rather they shared the shape and motion characteristics with the objects in the attended hemifield. Hence, the feature similarity between objects in the attended and unattended hemifields may have contributed to the observed drop in performance.

Perceptual demand and feature-based interference from unattended objects

Interestingly, the effect of feature-based interference was completely absent in the high perceptual demand condition (fast motion speed) but present for all levels of tracking task load (set sizes; see Figure 2). An increase in motion speed as well as the set size of objects to be tracked led to a drop in performance, indicating that both manipulations boosted task difficulty. Nonetheless, only an increase in motion speed affected feature-based interference. Why would motion speed of the objects interact with the interference effect but not set size? The number of the to-be-tracked objects has been attributed to the individual's capacity in working memory (Allen et al., 2006; Drew & Vogel, 2008; Oksama & Hyönä, 2004), whereas changes in speed are thought to pose higher demands on the perceptual individuation of target and distractor objects, respectively (Franconeri, Jonathan, & Scimeca, 2010; Green & Bavelier, 2007). Two recent studies showed that the decline in tracking performance with faster moving objects derives from increases in crowding rather than speed itself (Franconeri et al., 2010; Franconeri, Lin, Pylyshyn, Fisher, & Enns, 2008). In one study, for example, Franconceri et al. increased speed without increasing interobject crowding, thereby isolating changes in speed from variations in crowding. Once interobject crowding was controlled for, observers were able to track multiple moving objects at fast speed, indicating that faster speed lowers accuracy solely because it increases object spacing. In the present study, the increase in speed was also accompanied by an increase in interobject crowding: The number of encounters between targets and nontargets was larger in the fast speed condition, placing higher demands on the individuation of target and distractor objects. Thus, by increasing display density, an increase in motion speed indirectly increased the perceptual demands (Doran & Hoffman, 2010; Franconeri et al., 2010; Tripathy & Cavanagh, 2002).

The lack of interference effect in the fast speed condition is consistent with the perceptual load theory of attention (Lavie, 1995). The load theory of attention assumes that all stimuli are processed in an automatic manner until a perceptual capacity limit is reached, meaning that the processing of distracting stimuli cannot be voluntarily detained when load is low. Under high perceptual demands, however, the processing of irrelevant information can be prevented because all perceptual capacities are consumed by processing the task-relevant stimuli (Lavie, 2005). According to this interpretation, feature-based interference was only present when perceptual demands were low because perceptual resources were available and involuntarily spilled over to the unattended visual field. Conversely, when perceptual demands were high, no surplus perceptual resources were available to spread to the unattended hemifield, leading to no interference from that side.

Perceptual demands modulate distractor processing in a variety of tasks (Lavie, 2005). In a recent study, perceptual load-dependent effects of interference were observed for distractors that were completely task-irrelevant, as was the case in the current experiment (Forster & Lavie, 2007). In addition, neuroimaging studies showed that distractor-related activation from unattended regions of the visual field depended on the perceptual demands. In particular, it was found that distractor-related activity in visual cortex is lower under high perceptual demands than under low perceptual demands (Pinsk, Doniger, & Kastner, 2004; Schwartz et al., 2005). A recent EEG study provided additional convergent evidence, showing that induced gamma-band activity, an electrophysiological signature of object representations, was modulated by the presentation of objects in unattended regions (Martinovic, Gruber, Ohla, & Müller, 2009). In sum, results from different lines of research converge on the proposition that the processing of distractors in unattended regions interacts with the perceptual characteristics of the target task.

The present results suggest that the perceptual demands induced by fast moving objects engage processes that are also relevant for feature-based interference, thereby attenuating the interference effect. Potentially, the increased perceptual demands due to faster motion speed act on the perceptual stage of processing as feature-based interference, whereas tracking task load does not. The fact that interference did not affect tracking task load suggests that the suppression of feature-based interference does not require the same control mechanisms that pertain to working memory capacity.

Interference effect modulated by performance group in older adults

Overall, feature-based interference effects were not reliable in the group of older adults. However, when dividing the total group of older adults into two groups based on their overall tracking performance, the group of high-performing older adults showed reliable interference effects that were similar in size to the effects observed in low- and high-performing younger adults (see Figure 3). This observation suggests that—similar to younger adults—high-performing older adults possessed residual resources to process distractors in the unattended visual field. It is worth noting that high-performing older adults reached a higher tracking performance than low-performing younger adults in the low memory load condition (set size 2, compare Figure 3). The group of low-performing older adults, however, did not exert any effects of interference nor the expected set size effect. Taken together, these results suggest that the low-performing older adults performed close to a functional floor. Put differently, the parameters we chose in the present study may not have appropriately covered the full range of performance levels in older adults. Thus, we were not able to examine the group of low-performing adults more closely. The performance group analysis used here, however, underscores the importance of considering performance level, particularly when studying aging (Nagel et al., 2009). By dividing the participants in high and low performers, we documented the presence of feature-based interference in a group of older adults. Moreover, the data show that high-performing older adults reach higher levels of tracking accuracy than low-performing young adults, highlighting the magnitude of between-person differences in attentional tracking.

Summary

The primary goal of the present study was to investigate feature-based interference effects from unattended visual regions during multiple-object tracking. The results show that unattended objects sharing the same features as attended objects can interfere with tracking performance, even when presented in the unattended regions of the visual field. The data further indicate that feature-based interference from the unattended visual field is absent when the speed of the object or the perceptual demands are high or when perceptual resources are very low. Only when resources are still available can objects from the unattended visual field be processed and cause interference. We do not know whether the feature-based interference effect observed here is restricted to situations of dynamic multifocal attention. Future studies should more systematically investigate potential differences in feature-based processing between multifocal and unifocal situations. Additionally, it would be interesting to examine the characteristics of the features underlying the interference effect. Possibly, different colors (e.g., red/green) or motion trajectories (e.g., aligned vs. random) may cause differences in the magnitude of the effect.

In line with previous findings on MOT, performance decreased with increasing set size and speed. Finally, our findings confirm that tracking performance declines in normal aging. Relative to younger adults, the performance of older participants was more negatively affected by increasing set size and movement speed. Importantly, the group of older adults showed substantial individual differences in the accuracy and pattern of tracking performance. A subgroup of high-performing older adults possessed sufficient resources to show interference effects in the slow speed conditions, just as younger adults. Future research needs to delineate the time course and the specificity of interference effects and the mechanisms that allow some individuals to track proficiently in old age.

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Corresponding author: Viola Störmer.
Email: stoermer@mpib-berlin.mpg.de.
Address: Max Planck Institute for Human Development, Center for Lifespan Psychology, Lentzeallee 94, 14195 Berlin, Germany.

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