A Developmental Study on Effective Filtering: The Role of Flanker Distance and Perceptual Load

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Abstract

The effect of perceptual load and target-flanker proximity on developmental patterns of filtering efficiency was examined among children 5-12 years and a group of adults. The participants were asked to respond to a centrally presented arrow surrounded by congruent or incongruent flanker arrows. Filtering was operationalized in terms of the flanker congruency effect (FCE) and measured as the response latency difference between trials with incongruent flankers versus trials with congruent flankers. Conditions varied with regard to target-flanker distances and levels of perceptual load. Developmental changes in susceptibility to the FCE did not appear to be related to target-flanker proximity, but were related to a perceptual load manipulation that involved varying the response associated with the target. The FCE was larger in magnitude for 7-10 year old children than for 11-12 year old children and adults under low perceptual load conditions. However, these developmental differences in susceptibility to the effects of interference were no longer apparent under high perceptual load conditions. This finding suggests differential developmental trajectories for filtering efficiency based on the processing demands involved in the task, and can be understood within the framework of the perceptual load model of selective attention.

Résumé

L'effet du niveau de perception et la proximité entre la cible et les objets de distraction sur le développement d'attention ont été examinés parmi des enfants de 5-12 ans et sur un groupe d'adultes. Les participants devaient identifier la flèche cible située au centre de l'écran entourée par des flèches de distraction identiques ou différentes de la flèche cible. La distraction a été mesurée selon la différence du temps de réponse entre les essais avec les flèches de distraction identiques et les essais avec les flèches de distraction différentes. Les conditions ont variées selon les distances entre la flèche cible et les flèches de distraction ainsi que les niveaux de la perception. La distraction n'était pas reliée à la distance entre la flèche cible et les flèches de distraction mais plutôt reliée au niveau de la perception impliqué dans la tâche. L'ampleur de la distraction était plus grande chez les enfants de 7-10 ans que chez les enfants de 11-12 ans et les adultes, dans des conditions de niveau de perception bas. Cependant, les différences de développement de distraction n'étaient plus apparentes dans les conditions de niveau de perception élevé. Ces résultats suggèrent des trajectoires de développement d'attention différentielle basée sur le niveau de perception impliqué dans la tâche et peuvent être comprises dans un modèle de niveau d'attention sélective.

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A Developmental Study on Effective Filtering: The Role of Flanker Distance and Perceptual Load

Humans are constantly exposed to more stimuli than can be consciously processed. Accordingly, the ability to attend selectively to the relevant part of the vast amount of information that impinges upon the sensory systems is a critical feature of cognition (Enns & Trick, 2006; Kinchla, 1992; Lane & Pearson, 1982). One aspect of selective attending to visual stimuli is referred to as filtering or the ability to ignore irrelevant stimuli or attributes in the visual field while task-relevant information or attributes are processed (Burack, 1994; Enns & Akhtar, 1989; Plude, Enns, & Brodeur, 1994). Efficient filtering facilitates the processing of relevant information and maximizes performance on any given task (Enns & Cameron, 1987; Enns & Girgus, 1985; Pastò & Burack, 1997). For example, school age children need to utilize visual filtering skills when they copy a homework assignment from a chalkboard filled with other information, such as the lessons of the day. Within this framework, filtering is typically studied with regard to the effect on performance of distracting information from the environment (Miller, 1991; Yantis & Johnston, 1990).

The flanker task (Eriksen & Eriksen, 1974; Eriksen & Schultz, 1979) is a frequently used paradigm in the study of visual filtering. In typical versions of this task, two sets of letters are assigned to one of two possible manual responses. For example, the letters C and D may be mapped onto one response and letters H and I mapped onto another. These letters are then presented in three letter horizontal arrays. The central letter is the target and the two letters located on either side of the target, referred to as flankers, are assigned to an identical response as the target (e.g., D C D), or to a response opposite to that of the target (e.g., H C H). The participants in these studies typically respond faster in the *congruent condition*, in which the flankers belong to the same response set as the target, than in the *incongruent condition*, in which the flankers belong to the other response set. The response latency difference between the congruent and incongruent conditions is known as the flanker congruency effect (FCE; MacLeod, 1991) and provides evidence that irrelevant and supposedly ignored dimensions of a stimulus array are processed, at least, to some extent.

Developmental improvements with regard to the effect on performance of variations in the congruence of multi-element stimulus arrays are cited (e.g., Ridderinkhof & van der Molen, 1995; Ridderinkhof, van der Molen, Band, & Bashore, 1997). For example, Ridderinkhof and van der Molen (1995) found developmental reductions in the detrimental effect of incongruent flankers in a study of children aged 5-6, 7-9, 10-12 years and a group of adults. Participants responded to a centrally presented arrow surrounded by congruent or incongruent flanking arrows. The FCE was greater for the 5-6 year old children than for the older children and the adults. The FCE among 7-9 year old children was greater than the FCE among 10-12 year olds and adults, but the magnitude of the FCE did not discriminate between the 10-12 year olds and the adults.

In a subsequent study, designed to examine the mechanisms underlying reductions in susceptibility to interference, Ridderinkhof, van der Molen, Band, & Bashore, (1997) also reported a developmental decrease in the magnitude of the FCE. The detrimental effect of incongruent flanker arrows on the processing of the target arrow decreased among children aged 5-7, 8-9 and 10-11 years and a group of adults. The findings reported by Ridderinkhof and van der Molen (1995) and by Ridderinkhof et al. (1997) are evidence that younger children appear to be more susceptible to the effects of interference than older children and adults.

Evidence of increased distraction with development was also found. For example, Enns and Cameron (1987) reported that the detrimental effects of incongruent flankers was greater among the 7-year-olds than the 4-year-olds on a task that required the participants to respond to a centrally presented target arrow that was flanked by a congruent or incongruent distractor arrow. In a subsequent study, Enns and Akhtar (1989) asked children aged 4, 5 and 7 years and adults to respond to 1 of 4 targets letters that were mapped to 2 responses and included trials with both congruent and incongruent flankers. The FCE was significant for adult participants but not for children. Thus, the developmental findings related to the FCE are inconsistent.

The extent to which developmental differences in filtering efficiency are apparent may be due to methodological issues such as the proximity of the flankers to the target. In a developmental study on selective attention by Enns and Girgus (1985), target-flanker distances ranged from 0.5° to 16° of visual angle. A FCE was displayed by the 8-year-olds only when flankers were located 0.5° and 2° of visual angle from the target. Ten-year-olds displayed a FCE only with distractors located 0.5° of visual angle from the target and adults never displayed a FCE regardless of the target-flanker distances. Similarly, Pastò and Burack (1997) demonstrated that developmental differences in filtering efficiency were apparent among children aged 5-9 years as compared to adults when flankers were located approximately 1° of visual angle from the target but not with flankers located 5.7° of visual angle. However, 4-year olds showed increased flanker effects at both visual angles. Both Enns and Girgus and Pastò and Burack concluded that the interference effects of closer, rather than farther flankers was more profound for children than adults because the ability to constrict attentional focus for most efficient processing develops from immature to optimal states in childhood.

The developmental improvement in filtering efficiency related to target-flanker proximity reported by Enns and Girgus (1985) and Pastò and Burack (1997) may be understood within the context of a zoom-lens model of selective attention. Within a zoom-lens framework, the selection of stimuli for processing is largely based on their spatial location within the visual field (e.g., Burack, 1994; Eriksen & St. James, 1986). The appearance of irrelevant information located in close proximity to relevant information interferes with performance by adding demands to available attentional resources. However, irrelevant stimuli are only distracting if they fall within the spatial region covered by the attentional lens that is directed at the relevant stimuli. Accordingly, filtering efficiency is dependent upon the extent that visual focus can be narrowed to include only relevant information (Eriksen & Yei, 1985). The findings by Enns and Girgus and Pastò and Burack are evidence that younger children, as compared to older children and adults, are more susceptible to interference at target-flanker distances of about 1° of visual angle. Within a zoom-lens framework, the inability of young children to filter irrelevant information located in close proximity to the target would indicate that the flankers appeared within their visual focus and were, therefore, processed. However, close flankers did not affect older children and adults performance because they were able to narrow their visual focus and exclude the flankers from processing. Thus, within a zoom-lens framework, older children and adults are less susceptible than younger children to distracting information located in close proximity to relevant information, because they are more efficient in constricting their attention lens.

Maylor and Lavie (1998) proposed that the perceptual load, or the total amount of task relevant information available in the external environment, may be another critical factor that is relevant to the finding of age differences of filtering efficiency. This proposal was based on Lavie's (1995; Lavie & Tsal, 1994) perceptual load model of selective attention in which irrelevant information unintentionally captures spare attention when the perceptual load created by the task-relevant information is not large enough to require all of an individual's attentional capacity. However, if all available attentional capacity is exhausted by task-relevant information, distracting task irrelevant information will not be processed. Maylor and Lavie applied the perceptual load hypothesis to the study of age differences in filtering efficiency in a group of younger participants (aged 19-30 years) and older participants (aged 65-69 years). The participants were asked to respond to either an X or an N target that was presented in 1 of 12 positions arranged in a circle at the centre of a screen. The perceptual load was manipulated by varying the number of non-targets in the circle, as the target appeared with 0, 1, 3, or 5 non-target letters. Based on previous evidence of reduced cognitive capacity in old age (e.g., Madden & Plude, 1993; Salthouse, 1991, 1992), Maylor and Lavie predicted that compared to younger adults, the older adults would show greater interference effects under conditions of low perceptual load. However, the older participants were also expected to show greater improvements in filtering efficiency at lower loads. The results showed that under low perceptual load conditions (set size one), the magnitude of the FCE was larger for the older adults and, as predicted, the magnitude of the FCE was no longer significant for older participants at a lower level of perceptual load (set size of four), than for the younger adults (set size of six). Maylor and Lavie concluded that age differences in filtering efficiency are dependent upon the level of perceptual load involved in the task.

Within a perceptual load context, low perceptual loads then allow for irrelevant information to unintentionally capture spare attention and enable irrelevant information to be included at later stages of information processing. Conversely, the semantic and/or motor interference control over the flankers is not necessary in high load circumstances, because the identification of the distractor is prevented. Thus, from a load dependent framework, developmental differences in filtering efficiency should be reduced in circumstances of high load, as the identification of flankers should be completely inhibited for all age groups. However, in circumstances of low perceptual load children should demonstrate greater interference effects than adults, as they should have less ability to control the semantic and motor interference created by the identified distractors.

In this study, developmental patterns of filtering efficiency were examined within the framework of the zoom lens and the perceptual load models of selective attention. As in previous studies (e.g., Enns & Girgus, 1985; Ridderinkhof & van der Molen, 1995; Ridderinkhof et al., 1997), filtering was operationalized in terms of the FCE and measured as the response latency difference between trials with incongruent flankers versus trials with congruent flankers. The focus here was to investigate conditions that may lead to an increase or to an attenuation of developmental differences in susceptibility to the FCE. Based on the zoom lens and the perceptual load models of selective attention, developmental changes in susceptibility to the FCE were expected to vary as a function of flanker distance and/or perceptual load.

A Zoom Lens Model: Empirical and Developmental Issues

The zoom-lens model is frequently discussed within the context of early selection theories of attention, in which selective attention is presumed to occur at a perceptual level (Miller 1991; Pastò & Burack, 1997). Within the zoom-lens metaphor, a reciprocal relationship is presumed between the size of the visual field and the distribution of attentional resources. As the field of vision increases, attentional resources become distributed over a larger viewing area and the ability to discriminate stimuli decreases. Conversely, when attentional resources are concentrated on smaller spatial ranges, the ability to discriminate visual stimuli is greater (Eriksen & St. James 1986; Eriksen & Yei, 1985). Experimental data appear to be consistent with the zoom-lens conceptualization of visual attention. For example, LaBerge's (1983) finding that attention can be prefocused to an area encompassing one letter or expanded to include a 5-letter word supports the claim that the size or area of attentional concentration can vary. Concordantly, Egeth's (1977) finding that response time (RT) for a common central location was more rapid with a smaller than with a larger viewing area is consistent with the claim that smaller visual fields allow for greater allocation of attentional resources to relevant stimuli. Furthermore, Yantis and Johnston's (1990) finding that incongruent flankers produced interference only when they were either directly adjacent to the target or separated by one item demonstrates that attention can facilitate the processing of any stimulus appearing within the attended region, relative to stimuli that appear outside that region.

Developmental changes in filtering efficiency: A zoom lens explanation. In a selective attention task, Enns and Girgus (1985) provided initial support to the claim that the ability to constrict attentional focus improves with age, and demonstrated that developmental changes in susceptibility to distracting information are related to target-flanker proximity. Across ages from 8 years to 24 years, participants classified the direction (left or right) of a curved line in the presence of a single curved line flanker slower with closer (0.5° and 2° of visual angle) than with farther (4°, 8° and 16° of visual angle) target-flanker spacing. The slower responding associated with closer proximity was greater for younger children than for older children and adults. The magnitude of the FCE was significant for the 8-year-old participants at target-flanker distances of 0.5° and 2° of visual angle. The FCE was significant for 10-year-old participants only when the distances were 0.5° of visual angle from the target, and adults did not show a significant FCE at any spacing. Enns and Girgus concluded that older children are more efficient than younger children at ignoring close flankers as they are better able to constrict attentional focus.

Pastò and Burack (1997) also found developmental improvements in the ability to constrict attentional focus. Four-year-old children, in comparison to older children and adults, displayed slower RTs with conditions of close (0.95° of visual angle) and of far (5.7 ° of visual angle) flankers. The presence of flankers close to the target slowed RTs for 5, 7, and 9 year olds, but did not seem to interfere with adults' performance. Furthermore, the presence of a visual window cue, used to narrow the visual area to which attentional resources were directed, facilitated the performance of 4-year-olds, but did not affect the performance of older children or adults. These findings demonstrate that developmental differences in the ability to resist flanker interference were apparent only at the closer target-flanker distances (Pastò & Burack, 1997). Both Pastò & Burack and Enns and Girgus interpreted their findings based on a zoom-lens framework of selective attention and concluded that age-related changes in filtering efficiency are consistent with a developing ability to constrict the size of attentionl focus.

The Load Dependent Model of Selective Attention

Lavie (1995, 2000, 2001) proposed a load dependent model of selective attention, in which the historical "early" and "late" selection approaches are integrated. Given that not all the information we are confronted with can be processed, it is imperative to select which portion of the information will be preferred. Whether this selection takes place relatively early or late in the temporal sequence of information processing operations has been a point of contention among attention researchers in the last few decades (Lavie & Tsal, 1994). According to proponents of the early selection approach (e.g., Broadbent, 1958, 1982; Treisman, 1969;Treisman & Geffen, 1967), selection operates at a perceptual level based on brief analysis of physical features. Consequently, only attended stimuli are selected for semantic processing, but unattended stimuli are excluded from such an analysis. Proponents of late selection (e.g., Duncan, 1980; Deutsch & Deutsch, 1963; Norman, 1968) argue that perception is an unlimited process that can be automatically performed without the need for selection. According to this approach, both attended and unattended stimuli are processed semantically, and selection occurs late in the process at the level of decision making and response selection. The empirical evidence for and against each of these theories is ample. Under some circumstances, unattended visual stimuli are identified (e.g., Duncan, 1984; Eriksen &

Eriksen, 1974; Eriksen & Shultz, 1979), providing evidence for late selection accounts, but under other circumstances, unattended stimuli are not processed, providing support to early selection accounts (e.g., Driver & Tipper, 1989; Miller 1991; Posner, 1980).

Lavie (1995, 2000, 2001; Lavie & Tsal, 1994) combined these two opposing approaches and suggested that the locus of selective attention, early or late, is a function of perceptual load. Within this hybrid model, selection should be early and no flanker effects should be evidenced under conditions of high perceptual load in which relevant processing exhausts capacity. Conversely, selection should be late and the effect of flankers on relevant processing should be apparent under condition of low perceptual load in which relevant processing leaves spare capacity for the processing of irrelevant information. From a load dependent model of selective attention then, late selection should persist until attentional processing capacity is exhausted.

The perceptual load model was supported in a series of experiments with adults in which perceptual load was manipulated by increasing the relevant display set size, presented horizontally on a computer screen, from 1 to 5 letters (Lavie, 1995). In these experiments, a flanker letter that was congruent, incongruent, or neutral, was always presented above or below the relevant display set at 1.3°, 2.1° or 2.9° of visual angle from the target. Response times were slower when the target-flanker proximity was closer compared to when the flankers were presented further from the target. However, flanker interference was significant only under low-load conditions, demonstrating that the ability to ignore irrelevant information was directly related to the perceptual load involved in the task. Lavie (1995) concluded that a clear physical separation between the target and the flankers is not a sufficient condition for early selection, but that increased processing demands was also required.

In a subsequent set of experiments, Lavie and Cox (1997) provided further support for the perceptual load model using a visual search paradigm. In the first experiment, adults searched for one of two target letters (*X* or *N*) that appeared within a circular display along with five additional non-target items. In the low perceptual load condition, the non-target items were all *O*s. In the high perceptual load condition, the non-target items were heterogeneous letters that, like the target were all angular (e.g., *K*, *H*, *V*). A single peripheral distractor that was congruent or incongruent with the target response always appeared 1.4° away from the nearest central letter. In these conditions, the FCE was evident only in the low perceptual load condition. The second experiment was similar to the first, except that the target letter appeared with 0, 1, 3, or 5 non-target letters. Consistent with the findings of the first experiment, the FCE in second experiment was evident only in the low perceptual load condition. However, the decrease in the interference effect was evident only when the perceptual load manipulation exceeded four items, demonstrating that capacity limits are reached only when more than four items require focused attention. Lavie and Cox concluded that the results support the view that capacity limits determine the efficiency of selective attention, as early selection, or no distractor processing was achieved only at the highest levels of perceptual load.

Dissociating the effects of perceptual load from general task difficulty. The concept of increased perceptual load implies that additional operations must be carried out to process the relevant task information (Lavie & Fockert, 2003). These additional operations consume attentional capacity in relevant processing, and consequently inhibit processing of irrelevant stimuli. However, according to Lavie and Fockert, increased task difficulty, unlike increased perceptual load, does not always add further demands on attentional capacity. For example, if a target stimulus were degraded so severely that it became almost invisible, any further allocation of attention would not improve its perception. Lavie and Fockert predicted that degradation of a target stimulus should increase task difficulty but not decrease distractor processing, whereas a manipulation that imposed high load on attentional resources would reduce distractor effects. Lavie and Fockert tested these predictions in a study with a group of adults, using a task similar to the one used by Lavie and Cox (1997) in which participants were asked to identify target letters among several non-targets (high perceptual load) or alone (low perceptual load). The new manipulation was that in the low perceptual load condition, the targets were either intact, had reduced size, reduced duration, or reduced visual acuity. The increased perceptual load and target degradation condition were both related to increased task difficulty, as evidenced by increase response times and errors. However, only the high perceptual load condition was associated with reduced distractor interference, as target degradation actually resulted in increased processing of the distractors. Lavie and Fockert concluded that the processing of irrelevant distractors does not depend upon general task difficulty, but rather on the extent that relevant processing imposes high load on attention.

Expanding the measure of perceptual load. According to Lavie and Tsal (1994), more task relevant items in a display and/or greater effort in processing the display are associated with higher perceptual load. Most manipulations of perceptual load involve adding to the number of items presented in the display (e.g., Huang-Pollock et al., 2002;

Maylor & Lavie, 1998) However, such manipulations typically change the appearance of the display and can sometimes result in factors that confound the results. For example, when a target is presented in close proximity to non-target items, the stimuli may be grouped together perceptually, resulting in a stronger perceptual segregation between the target and the flankers (e.g., Driver & Baylis, 1989; Kahneman & Henik, 1977). In order to avoid this type of confound, Lavie (1995) examined the load dependent model of selective attention with a manipulation that varied the processing demands for displays that were identical in their appearance. In one of a series of studies, perceptual load was manipulated in accordance with feature integration theory (Treisman & Gelade, 1980; Treisman & Sato, 1990). The response associated with the target in the low load condition was dependent on a colour feature of a nearby shape and the response for the high load condition was dependent on the conjunction of its shape and colour. The results of the study were similar to the results reported in Lavie's other experiments, as distractor interference was found only under the low-load condition. Lavie concluded that manipulating selective attention by instruction alone could increase the relevant information processing sufficiently for the elimination of irrelevant flankers.

Response compatibility as a novel measure of perceptual load. Manipulating the response associated with a target stimulus also appears to increase the processing demands of a task, as performance is enhanced with certain mappings of stimuli to responses than with others (Hommel & Prinz, 1997; Kornblum, Hasbroucq & Osman, 1990). For example, *compatible responding,* such as a left response made to a left pointing arrow, is faster than an *incompatible* response, such as a left response made to a right pointing arrow (e.g., Proctor & Dutta, 1993). Congruent as compared to incongruent flankers typically facilitates responding in the compatible condition and incongruent as compared to congruent flankers facilitates responding in the incompatible condition (e.g., Ridderinkhof et al., 1997). However, despite these facilitation effects, compatible responding is typically faster than incompatible responding (e.g., Hommel & Prinz, 1997; Kornblum et al. 1990; Proctor & Dutta, 1993).

Developmental changes related to perceptual load. Huang-Pollock, Carr, and Nigg (2002) examined the developmental patterns of selective attention within the context of the perceptual load model between children aged 9-10 years and a group of adults on a task that involved the search for circular displays of varying set size flanked by incongruent or neutral distractors. The children displayed larger interference effects than adults when the relevant set size of the task was one and two letters, but the magnitude of interference did not differ between the two groups at set sizes of four or six letters. The children demonstrated a significant drop in interference between set size two and four, whereas the adults demonstrated reduced interference between set size four and six. Huang et al. interpreted these findings as indicating that early selection was initiated at smaller loads for children, likely as a result of their smaller processing capacities. These findings suggest that developmental differences in filtering efficiency can, at least in some cases, be eliminated with an increase in perceptual load.

Goals and Experimental Paradigm

The goal of this study was to map developmental patterns of filtering efficiency using the zoom lens and the perceptual load models of selective attention. Therefore, filtering efficiency was examined under conditions of varying target-flanker distances and low and high perceptual load among children aged 5 to 12 years, and adults.

The task used in this study was based on the traditional flanker paradigm devised by Eriksen and colleagues in which a target stimulus is flanked on each side by irrelevant stimuli (e.g., Eriksen & Eriksen, 1974; Ericksen & Schultz, 1979). The main stimulus display consisted of an arrow target presented at the center of the screen and a flanker arrow presented on either side of the target.

The conditions varied with regard to (a) the type of flanker presented with the target (b) the proximity of the flankers to the target, (c) the number of items presented in the display, and (d) the response associated with the target. The flanker arrows were congruent or incongruent with the target with regard to orientation. The congruent flankers were identical to the target, whereas incongruent flankers pointed in the opposite direction as the target arrow. The measure of filtering efficiency, FCE, was the response latency difference between congruent and incongruent conditions. The three distances between the target and the flankers were 1.2° of visual angle, 3.4° of visual angle, and 5.7 ° of visual angle. Flankers less than 1° of visual angle from the target were not used as that is considered to be insufficient spatial resolution to completely exclude interference from flankers (e.g., Broadbent, 1982; Eriksen & Eriksen, 1974). The farthest flanker location, 5.7 ° was chosen because this distance exceeds that for which flanker effects are typically not found even among children as young as 5 years (e.g., Pastò & Burack, 1997), and to allow for comparisons with Pastò and Burack's findings. As interference effects were not expected at the farthest target-flanker proximity, an intermediate location of 3.4° of visual angle was included in order to allow for a wider spatial extent over which age differences in interference could occur. A set size manipulation of perceptual load and a manipulation that involved increasing the processing demands associated with the task were included in this study. Adding two shapes above and two shapes below the target stimulus increased the number of items presented in the display. In low set size conditions, only the main stimulus display was presented. In the high set size conditions, the main stimulus display was presented with the addition of four shapes. The processing demands involved in the task were manipulated by assigning the target to a compatible or an incompatible response. In the compatible response conditions, the participants were instructed to press the response key that corresponded to the direction indicated by the arrow, whereas in the incompatible response conditions, the participants were instructed to press a response key that corresponded to the opposite direction indicated by the target. The stimulus display in both compatibility conditions remained unchanged. The response compatibility manipulation was used in this study as an attempt to generalise the findings reported when display set size is increased to a perceptual load manipulation that did not involve altering the stimulus display.

Predictions

As the FCE is the measure of interference in this study, the first prediction was that RTs for congruent flanker conditions would be faster than RTs for incongruent flanker conditions. Based on previous research findings related to the zoom-lens model of selective attention (e.g., Enns & Girgus, 1985; Pastò & Burack, 1997; Yantis and Johnston, 1990), a second prediction was that RTs would decrease as target-flanker distance increased. One indication that a perceptual load manipulation is successful is that RTs in the high load condition are typically higher than RTs in the low load condition (Lavie & Fockert, 2003). Thus, if the perceptual load manipulations are successful, RTs should be slower under conditions with five relevant items versus conditions with only one relevant task item and also in conditions that require an incompatible response versus conditions that require a compatible response.

Developmental predictions based on a zoom-lens model. Consistent with a developmental framework of the zoom-lens model, children aged 10 years and older and adults are more efficient than are children younger than 10 years at constricting their visual focus (Enns & Girgus, 1985; Pastò & Burack, 1997). The ability to narrow attentional focus is important from this perspective as most attentional resources are allocated to visual stimuli located within the range of visual focus, thereby blocking the processing of irrelevant stimuli located outside this range. If target-flanker proximity is the main moderating factor for developmental differences in filtering efficiency, then, under close target-flanker conditions (1.2°), the magnitude of the FCE will be greater for children under 10 years of age compared to children over 10 years of age and adults. However, developmental differences in filtering efficiency should not be apparent at further (3.4° and 5.7 °) target-flanker distances.

Developmental predictions based on the perceptual load model. Within a perceptual load framework, the total amount of task relevant information available in the external environment is a critical factor determining the occurrence of age differences in the FCE. Under high perceptual load conditions, development differences in the magnitude of the FCE should not be apparent as the identification of flankers is prevented altogether so that the semantic and motor interference control of flankers is not necessary. However, under low load conditions, any additional resources that are not exhausted by relevant stimuli, spill over to irrelevant stimuli and allow for flanker processing. Under low load conditions, both the target and flankers are processed semantically and participants are required to inhibit the activated identity of, and the motor response associated with the flankers. Based on a perceptual load model, developmental changes related to the FCE are expected to be apparent only under low load conditions. Thus, under low load circumstances the magnitude of the FCE should be largest for the youngest children, and then gradually decrease with age as the ability to inhibit the motor and semantic response associated with the flankers should improve with age. Under high load conditions, even children as young as 5 years of age should be as efficient as adults at ignoring distracting, irrelevant information.

Method

Participants

The participants in the study were 20 kindergarten children 5-6 years of age, 20 second-grade children 7-8 years of age, 20 forth-grade children 9-10 years of age, 20 sixth-grade children 11-12 years of age, and 20 adults (see Table 1 for mean ages and sexes for each age group). The children were recruited from public elementary schools in the Montreal area and the adults were recruited from McGill University. Prior to their children's participation, parents provided written informed consent. The adult participants also provided written informed consent and the children provided verbal assent. All the participants had normal or corrected-to-normal vision.

Table 1

Mean age (Years-Months), Standard Deviation (Months), and Sex as a Function of Age Group.

Age Group	M Age	SD Age	Sex (Male)
5-6	5.9	2.0	9
7-8	7.6	3.3	11
9-10	9.7	3.7	10
11-12	11.8	4.3	9
Adults (21-29)	26.1	37.7	10

Apparatus

The task was presented on a Mac OS X laptop attached to a NEC monitor running SuperLab Pro software (version 1.74). The screen measured approximately 39.6 ° of visual angle horizontally (43.2 cm) and 28.5°degrees of visual angle vertically (30.5 cm) at an approximate viewing distance of 60 cm. A head rest was used for all the participants to ensure that viewing distance would remain consistent throughout the experiment. The participants responded to the target stimulus by pressing the left or right response key of the SuperLab RB-530 series response pads.

Stimuli

All the stimuli were drawn in black on a gray background and created with Adobe Illustrator 7.0 software. The presentation of the main stimulus display formed a horizontal array. Each array was composed of 3 arrows that pointed in the same direction (e.g., ⇨ ⇨ ⇨) a center arrow that pointed in one direction and flanking arrows that pointed in the opposite direction (e.g.,⇨ ⇦ ⇨), or a center arrow presented in isolation. Each arrow measured 4.7 ° of visual angle horizontally and vertically (5 cm). Some stimulus displays included a circle and diamond above the target arrow and a triangle and square below the target arrow. All shapes measured approximately 4.7 ° of visual angle horizontally and vertically (5 cm).

Experimental Design and Conditions

The baseline design included the between subjects factor of age group (5-6, 7-8, 9-10, 11-12 and adults) and the within-subjects factors of display size (0, 4) and compatibility (compatible, incompatible). The experimental design included the between subjects factor of age group (5-6, 7-8, 9-10, 11-12 and adults) and the within-subjects factors of display size (0, 4), compatibility (compatible, incompatible), flanker type (congruent, incongruent, no flankers), and flanker distance (1.2 °, 3.4 °, 5.7 °). The task comprised 28 conditions (See Appendix A for a list of conditions).

Flanker type. On congruent flanker conditions, the flankers pointed in the same direction as the target arrow. On incongruent conditions, the flankers pointed in the opposite direction as the center arrow (see Figure 1). On conditions with no flankers, the target arrow was presented in isolation.

Flanker distance. The proximity of the flankers presented to the right and left of the target was varied. The flankers were presented approximately 1.2 ° of visual angle (1.3 cm) from the target stimuli; 3.4 ° of visual angle (3.6 cm) from the target; or 5.7 ° of visual angle (6 cm) from the target stimulus (see Figure 1).

Display size. In order to increase the display set size and thereby increase the perceptual load, a circle and a diamond were added above the target arrow, and a triangle and a square were added below the target arrow. The circle and the triangle were presented 1.2° of visual angel (1.3 cm) from the target arrow and the diamond and square were presented 5.9° of visual angle (6.3 cm) from the target arrow (see Figure 1).

Compatibility. A second measure of perceptual load involved the manipulation of the response associated with the target. On compatible response conditions, the participants pressed a response key corresponding to the direction indicated by the target. For example, when the target arrow pointed right, the participant was asked to respond by pressing the right button of the response pad. On incompatible response trials, the participants responded by pressing a response key corresponding to the opposite direction

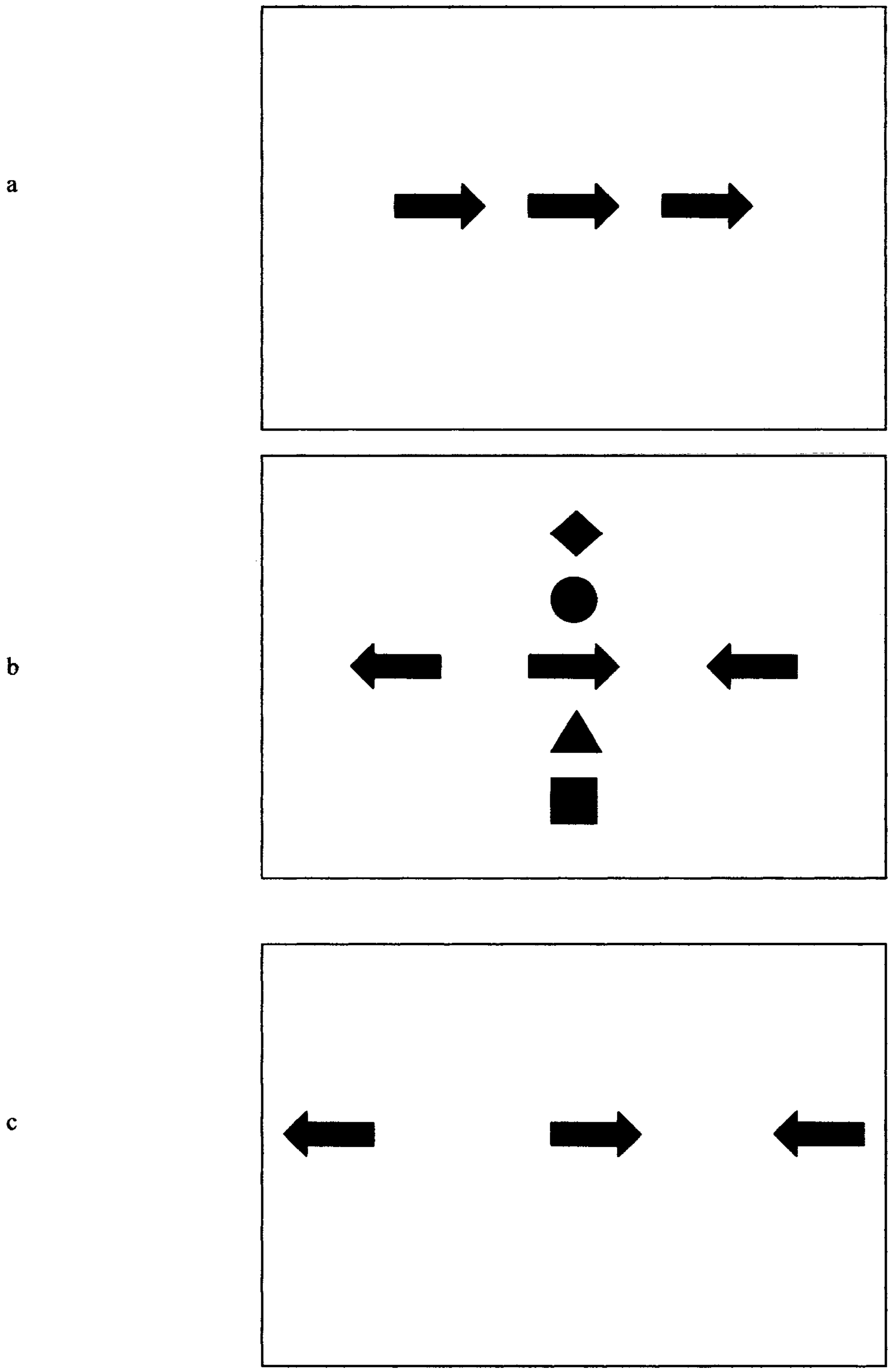

Figure 1. Examples of displays with congruent flankers presented at 1.2° for conditions of display set size 0 (a), incongruent flankers presented at 3.4° for conditions of display set size 4 (b), incongruent flankers presented at 5.7° for conditions of display set size 0 (c).

signified by the target. For example, when the target arrow pointed right, the participant was asked to respond by pressing the left button of the response pad.

Procedure

The children were taken from their classrooms one at a time to a quiet room in the school where the task was administered. The adults were tested individually at McGill University. The participants were seated 60 cm away from the computer screen and the purpose of the headrest was explained. The participant's chin was then placed in the head rest, at a comfortable height. The participants were told that they were going to play a computer game that would involve arrows and were show examples of the target stimuli. The participants were instructed to always focus on the target arrow presented at the center of the screen and to press the corresponding response key as fast as they could without making errors. The participants were also instructed to ignore the arrows presented on either side of the center arrow and any shapes that may appear above or below the center arrow. Each participant completed one block of 24 practice trials prior to the first compatible and incompatible block of trials and the instructions were repeated as necessary. Practice trials were excluded from the analyses. Once the experiment began, the experimenter refrained from engaging in conversation with the participant. Following the completion of the task, the children were asked to choose one of many small prizes (e.g., pencils, erasers, stickers) as a token of appreciation for completing the task.

Each trial began with a black fixation symbol that appeared on the screen for 250ms and that was followed by the presentation of the stimulus display. The visual displays remained on the screen until the participant responded by pressing a response button or until 5 seconds elapsed. The button press was followed by visual feedback in the form of a "plus sign" for a correct response, and a "minus sign" for an incorrect response or when no response was made within 5 seconds. Trials were treated as errors if the incorrect response was chosen or if no response was elicited within the designated time. Each participant completed 8 blocks of 56 trials.

Compatibility was fixed within a block of trials, so that each block consisted of either entirely compatible or entirely incompatible responses. Thus, 4 of the 8 blocks required compatible responses, while the other 4 required incompatible responses. Display set size was also fixed within a block of trials such that for two of the compatible blocks and two of the incompatible blocks, the stimulus display was increased with the addition of shapes above and below the target arrow. The order of the sessions was counterbalanced among the participants so that half began with the compatible response blocks and the other half began with incompatible response blocks. Within the blocks of compatibility, the order of presentation of the display size conditions was also counterbalanced. Distractor type and distractor distance were varied randomly within blocks of trials, such that an equal numbers of each factor level occurred within each block. An intermission of 3 minutes separated the compatible and incompatible blocks.

Results

A total of 3398 trials across 100 participants were deleted from the RT analyses (i.e., 7.6 % of the 44800 trials presented); 2611 because of incorrect responses and 787 because the RT was less than 100 ms. The average RTs, percentages of errors, and percentages of trials with RT < 100 ms for each of the age groups are presented in Table 2. An analysis of the error data for each age group revealed a positive correlation between mean correct RT and percentage errors (r =.94, $p < .05$), indicating that longer RTs were associated with more errors (see Table 2). An analysis of the error data separated by each of the 28 experimental conditions also revealed a positive correlation between mean correct RT and percentage errors (r =. 70, p = < .01), indicating that conditions with longer RTs were associated with more errors (see Appendix B). These findings reduce the likelihood that differences in mean correct RT reflect trade-offs of speed for accuracy (Plude, Enns, & Brodeur, 1994). As a result, the errors were not analyzed further.

The correct RTs were assessed with two separate repeated measures ANOVAs. A baseline analysis included only conditions with no flankers. In a second analysis, only conditions with congruent/incongruent flankers were examined and conditions with no flankers were excluded. Each analysis was based on the average RTs of each participant for each of the relevant experimental conditions.

No Flanker/Baseline Displays

The RT data for the baseline displays were analysed with a repeated measures ANOVA, with age group (5- 6, 7-8, 9-10, 11-12, and adults) as a between-group variable and display size (0, 4) and compatibility (compatible, incompatible) as within group variables.

Main effects. The common finding of faster RTs with increasing age was evident, F (1, 95) = 68.99, MSE = 34262.55, p = .000, and compatible responding was faster than incompatible responding (607 vs. 678 ms), F (1, 95) = 56.91, MSE = 8894.33, p = .000. Neither a main effect of display size nor any interactions were found.

Table 2

Mean Correct RTs, Standard Deviations, Percentage Errors, and Number of Trials with RTs < 100 ms, as a Function of Age Group.

Age Group	M RT	SD RT	% Errors	# < 100ms
5-6	858	145	8.7	303
7-8	769	159	7.1	177
9-10	653	159	6.8	224
11-12	517	94	4.9	61
Adults (21-29)	441	62	1.6	32

Congruent/Incongruent Flanker Displays.

The RT data of the varied flanker displays were analysed with a repeated measures ANOVA, with age group (5-6, 7-8, 9-10, 11-12, and adults) as a between group variable, and congruency (congruent, incongruent), flanker distance (1.2°, 3.4°, 5.2°), display size (0,4), and compatibility (compatible, incompatible) as within-group variables.

Main effects. The analysis revealed main effects of age, F (1,94) = 69.40, MSE = 205580.18, p = .000, congruency, F (1, 94) = 34.34, MSE = 4987.74, p = .000, compatibility, F (1, 94) = 49.47, MSE = 42964.37, p = .000, and flanker distance, F (2,188) = 25.54, MSE = 7147.94, p = .000, indicating that older children were faster than younger children, RTs for congruent conditions were faster than RTs for incongruent conditions (640 vs.657 ms), compatible responding was faster than incompatible responding (598 vs. 657 ms), and conditions with flankers at 3.4° and 5.2° from the target were associated with faster RTs than conditions with flankers presented at 1.2° from the target (637 and 641 ms vs. 665 ms respectively). The difference in RTs for the conditions with flankers presented at 3.4° and the conditions with flankers presented at 5.2° from the target was not significant. No main effect of display size was found.

Flanker congruity x flanker distance. Simple effects for the flanker congruity x flanker distance interaction, F (2, 188) = 3.56, MSE = 24722.81, p = .030, revealed that the effect of flanker congruity was significant when the flankers were presented at 1.2° and at 3.4° from the target but not when the flankers were presented at 5.2° from the target (see Figure 2). No age differences for this interaction were found.

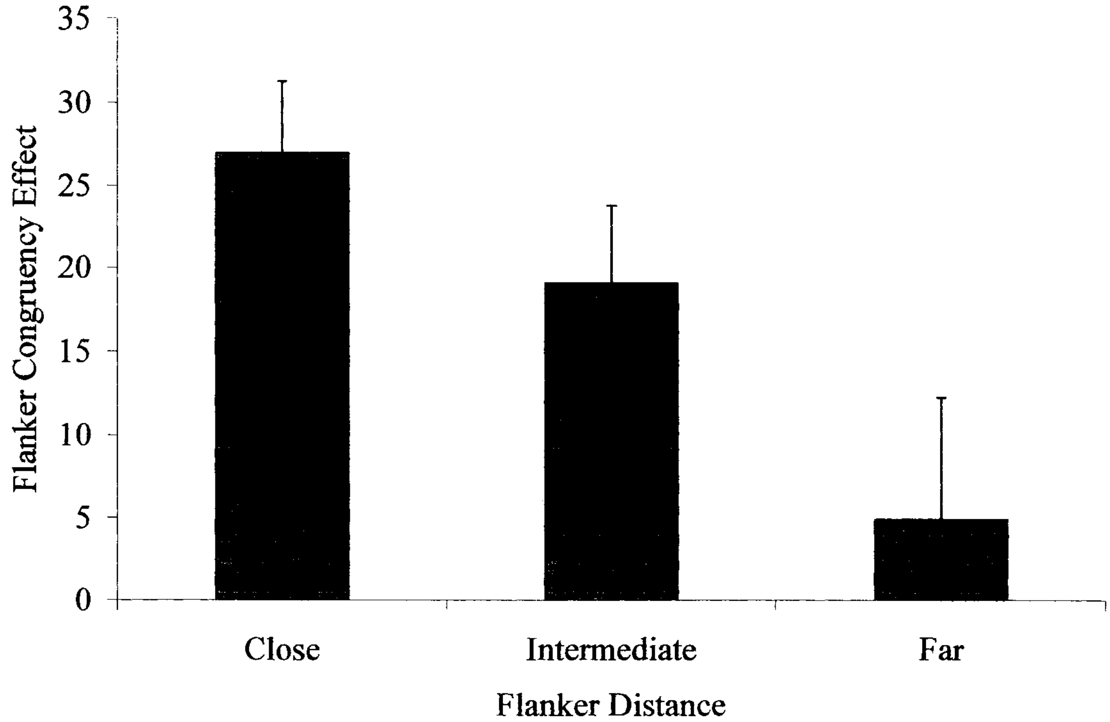

Figure 2. The FCE (incongruent RT minus congruent RT) as a function of flanker distance.

Age x *FCE x compatibility.* Simple effects for this three-way interaction revealed that the FCE was evident for the 5-6 year olds, 7-8 year olds, 9-10 year olds and the adults, but only in the compatible response condition, F (4, 94) = 2.51, MSE = 3565.17, p = .040. The FCE for each of these age groups was no longer significant in the incompatible response condition (see Figure 3 for the FCE for compatible and incompatible response conditions as a function of age group). The 11-12 year old children did not demonstrate a significant FCE in the compatible or the incompatible response condition.

Response compatibility, did not interact with age group, F (4, 94) = 1.193, MSE = 42964.37, p = .319, indicating that the RT needed to remap the response to the opposite hand was the same across all the age groups (see Figure 4 for a comparison of mean correct reaction times for each age group as a function of response compatibility). This suggests that this perceptual load manipulation increased processing demands to a similar extent for all the age groups.

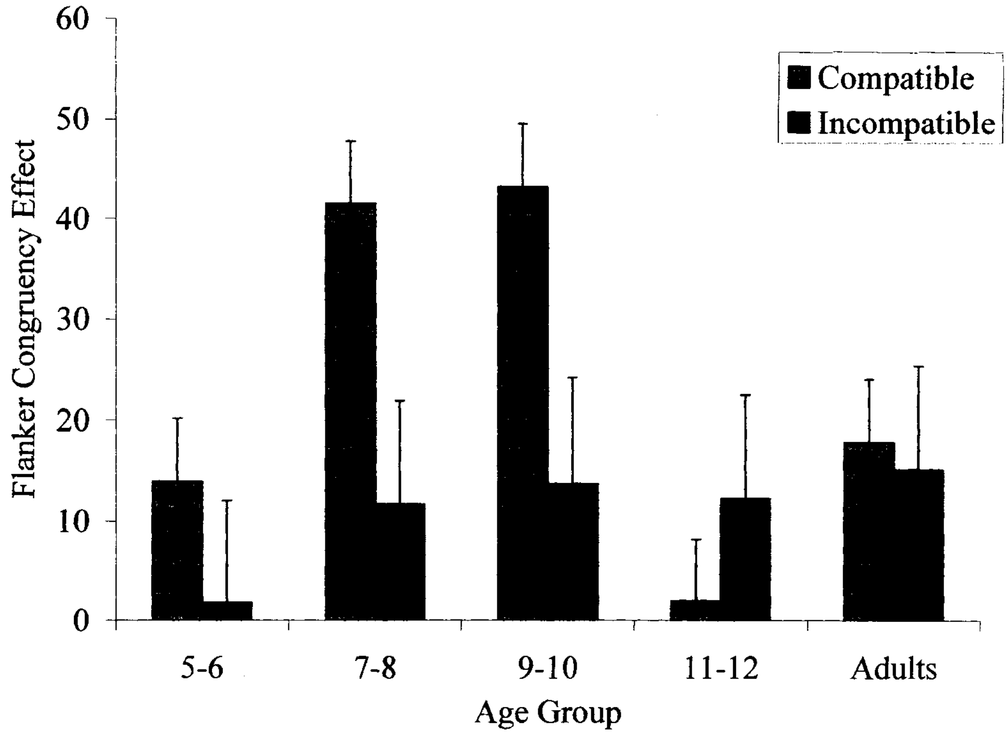

Figure 3. The FCE (incongruent RT minus congruent RT) for compatible and incompatible response conditions as a function of age.

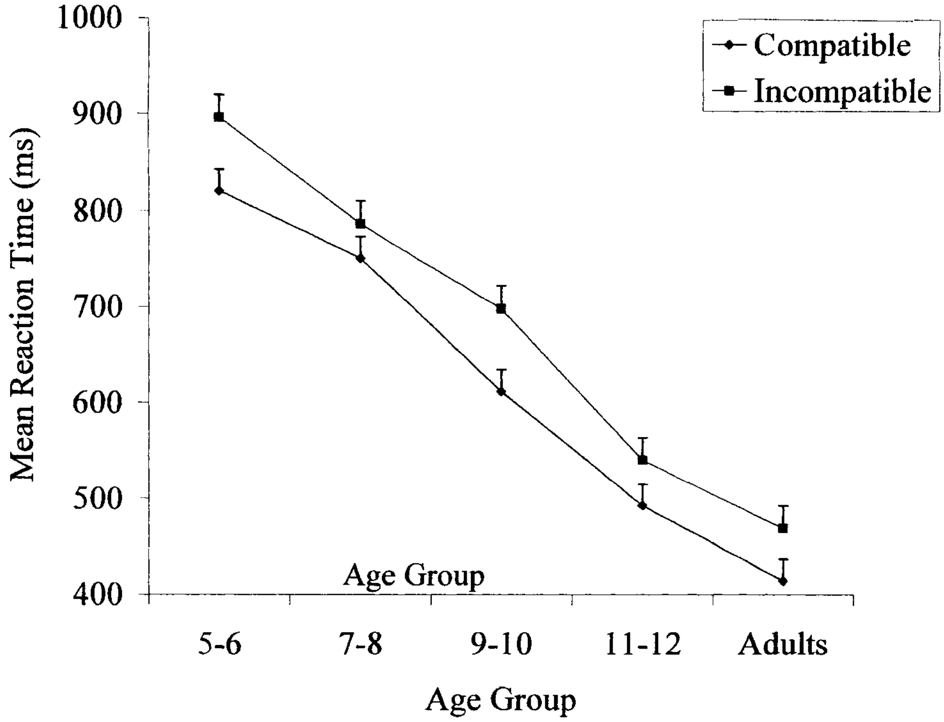

Figure 4. Mean correct reaction times for each age group as a function of response compatibility.

Age group comparisons of the FCE. In order to examine developmental changes in the magnitude of the FCE, a series of paired *t*-tests were conducted using the mean difference scores for trials with congruent versus incongruent flankers (FCE) for the compatible and the incompatible response conditions separately.

The paired *t*-tests conducted on the scores in the compatible response condition revealed that the magnitude of the FCE for the 5-6 year olds was less than the magnitude of the FCE for the 7-8 year olds and the 9-10 year olds, but no different than the magnitude of the FCE for the 11-12 year old and the adults. There was no difference in the magnitude of the FCE for the 7-8 year olds and 9-10 year olds (see Table 3 and Figure 3). However, the magnitude of the FCE was greater among the 7-8 year olds than the 11-12 year olds and the adults, and was also greater among the 9-10 year olds as compared to the 11-12 year olds and the adults. The FCE was similar for the children 11-12 year of age and the adults (see Table 3 and Figure 3). In the incompatible response condition, no differences were found between the age groups in the magnitude of the FCE, demonstrating that developmental changes in filtering efficiency vary as a function of the type of processing, compatible versus incompatible, required to complete the task.

Table 3

Age Group Comparisons of the FCE, as a Function of Response Compatibility.

	Age									
	5-6 vs. 7-8	5-6 vs. 9-10	5-6 vs. 11-12	5-6 vs. adults	7-8 vs. 9-10	7-8 vs. 11-12	7-8 vs. adults	9-10 vs. 11-12	9-10 vs. adults	11-12 vs. adults
Compatible	-3.54**	-3.16**	.18	-.60	-.02	3.86**	3.06**	3.00**	2.88**	-.756
Incompatible	-1.12	-.89	-.44	-1.88	-.099	.798	-.331	.639	-.087	-1.93

Note: *t*-statistics (df = 19) yielded by paired t-tests are reported.
** $p < .01$

Discussion

The goal of this study was to examine developmental changes in filtering efficiency based on the zoom lens and the perceptual load models of selective attention. The findings indicated that the developmental improvement that occurred after 10 years of age in the processing of flankers was related to a perceptual load manipulation that involved varying response compatibility, but not to flanker proximity. In the compatible response conditions, the FCE was larger in magnitude for the younger children aged 7-10 years than for older children aged 11-12 years and adults. These developmental differences in susceptibility to the effects of interference were no longer apparent in the incompatible response condition. This finding suggests differential developmental trajectories for filtering efficiency based on the processing demands involved in the task, and can be understood within the framework of the perceptual load model of selective attention. In high load circumstances the filtering mechanism that allowed for early selection, or no flanker processing, operated at adult efficiency among school-aged children. However, in low load circumstances, late selection persisted, which resulted in flanker processing and developmental differences in filtering efficiency.

Differential Developmental Trajectories for Filtering Efficiency: A Perceptual Load Explanation

The 3-way interaction among age, congruency and compatibility revealed that the children aged 5-6, 7-8 and 9-10 years and the adults displayed the FCE only in the compatible response condition. When incompatible responding was required, the FCE was no longer apparent for any age group. These findings indicate that flanker perception can be inhibited when the processing of task relevant stimuli involve a high perceptual load (e.g., incompatible response condition). This is consistent with theories of early selection since irrelevant stimuli were not fully processed. However, flanker interference effects remained, as in late selection, when processing of task relevant stimuli involved a low perceptual load (e.g., compatible response condition). This is consistent with notions of late selection, as the flankers could not be ignored and influenced response selection. These findings support the perceptual load conceptualization of selective attention and indicate that perceptual load appears to influence the stage of information processing, early versus late, at which selection occurs.

Developmental differences in the magnitude of the FCE were also apparent in the compatible response condition but not in the incompatible response condition, indicating that developmental trajectories in filtering efficiency varied as a function of the type of processing required to complete the task. Based on the perceptual load model, developmental differences in filtering efficiency should be most apparent under low load conditions that allow for greater processing of irrelevant information, as older children and adults are typically more efficient than young children at controlling the semantic and/or motor interference associated with flankers. Under conditions of high perceptual load, developmental changes in filtering efficiency should be less evident, as the semantic and/or motor interference control over the flankers is not necessary. In this study, developmental change in filtering efficiency was moderated by the response compatibility manipulation of perceptual load. Under conditions of low perceptual load (compatible response condition) the processing of the target information likely did not consume all available attentional resources for any of the participants, thereby leaving spare capacity to spill over to the processing of flankers. Once flankers were processed, the identity of the flankers and the motor response associated with the flankers had to be inhibited. Children 7-10 years of age appeared to be less efficient than children aged 11-12 years and adults at inhibiting flanker processing under conditions of low perceptual load. However, under conditions of high perceptual load (incompatible response condition), the processing of the target information likely consumed all available attentional resources for all participants, thereby blocking or preventing the processing of the flankers. Consistent with this notion, the children of all ages were as efficient as the adults at ignoring distracting information under high perceptual load circumstances. This is evidence that developmental changes in filtering efficiency can be moderated by the perceptual load involved in the task.

The developmental stability of incompatible responding. The incompatible response manipulation, which required participants to respond by pressing a button that corresponded to the opposite direction indicated by the target arrow, was not more difficult for children to perform than for adults. Relative to the RTs in the compatible response condition, the increase in RT for incompatible responding was similar across all the age groups. This finding indicates that, as compared to older children and adults, younger children did not require more time to remap the response to the opposite hand, and suggests that the incompatible condition did not increase task processing to a greater extent for younger children than for older children and adults. Contrary to the findings reported by Huang-Pollock et al. (2002) that adults initiated early selection at higher loads than children, the findings here indicate that adults did not require higher perceptual loads than children to induce early selection and significantly reduce interference.

Increasing Display Set Size as a Measure of Perceptual Load

The second perceptual load manipulation, which involved increasing the number of items presented in the display, had no effect on flanker interference. The discrepancy between the findings reported here and those reported in previous studies (e.g., Huang-Pollock et al., 2002; Lavie 1995) may be better understood within the context of the theoretical definition of perceptual load. According to Lavie (1995), the idea of an increase in load implies that the attentional system must carry out further operations or must apply operations to additional units. Lavie (1995) maintained that it is the additional operations that blocks task irrelevant items from consuming scarce capacity. In the Lavie (1995) and Huang-Pollock et al. studies, the high perceptual load condition entailed the identification of a target letter among five non-target letters. This type of task manipulation both increased the number of items within the display and ensured that more processing would be required for the additional items as participants were required to search for the target among five non-target items. In the task used here, the manipulation of increasing the number of items within the display did not require the participant to perform any additional operations, and therefore did not increase the processing demands of the task. An increase in the display set size that does not increase the processing required to complete the task may not be sufficient to increase perceptual load.

Developmental Differences in Filtering Efficiency: The Role of Flanker Familiarity

Developmental differences in the magnitude of the FCE were apparent in this study when the processing demands involved in the task were low. However, contrary to findings that filtering efficiency improves with age (Ridderinkhof & van der Molen, 1995; Ridderinkhof et al., 1997), the magnitude of the FCE was greater for the children 7-10 years of age than for the children 5-6 years of age. Surprisingly, the 5-6 year old children appeared to be as efficient as the 11-12 year old children and adults at ignoring irrelevant information.

One possible explanation for the low FCE demonstrated by the youngest group of children may be related to the visual habits associated with the meaning of an arrow. The role of directional arrows in experimental research on attention is largely predicated on the findings that directional symbols, such as arrows, are so well rehearsed and familiar that their meaning cannot be ignored (e.g., Hommel, Pratt, Colzato, & Godjin, 2001). However, the finding in this study that the 5-6 year old children were just as effective as the 11-12 year old children and the adults at ignoring flanker arrows suggests that the level of familiarity with arrows develops with age and experience so that changes may be seen across development. One counter argument to this hypothesis is Ristic, Friesen, and Kingstone's (2002) finding that arrows are just as effective as eye-gaze at influencing the direction of spatial attention in children as young as 4-5 years of age, suggesting that they have already learned the visual habits associated with the spatial meaning of an arrow. However, the use and symbolic nature of the arrows in this study differ from those in the Ristic et al. study, as the direction of the arrow here was associated with a specific meaning for responding. The arrows in this study provided the participant with semantic information about the motor response associated with the target rather than with spatial information about where to orient attention. Accordingly, one notion may be that the familiarity with arrows may be more age dependent when the arrow is associated with semantic rather than spatial information.

The rationale that the meaning associated with the flankers can moderate interference effects at various ages is consistent with findings on color-naming Stroop tasks (Enns & Trick, 2006). In typical versions of this task, younger school age children are more efficient than older school age children at ignoring written words that are inconsistent with the color of the word (e.g., Schiller, 1966). Schiller proposed that the younger children did not yet read as automatically as older children so the written words did not interfere as readily with the color naming. This explanation was also supported in studies in which poor readers were less distracted by the irrelevant words than good readers (Comalli, Wapner, & Werner, 1962; Fournier, Mazzarella, Ricciardi, & Fingeret, 1975).

The Developmental Trajectory of Filtering Efficiency when Processing Demands are Low

No differences in the magnitude of the interference effect were found between children 7-8 years of age and children 9-10 year of age or between children 11-12 years of age and adults. Alternatively, the magnitude of the FCE among the 7-8 and the 9-10 year old children was greater than the FCE among the children 11-12 years of age and adults. These findings are consistent with Ridderinkof and van der Molen's (1995) report that the FCE of 7-9 year old children was greater than that of 10-12 year olds and adults, but that the magnitude of the FCE was no different for 10-12 year olds and adults. The developmental findings reported here and by Ridderinkof and van der Molen (1995) indicate that, at least when perceptual load in low, the ability to ignore distracting information appears to be adult-like at about 10-11 years of age.

Filtering Efficiency and Target-Flanker Proximity

The proximity of the flankers to the target was related to the magnitude of the FCE for all the age groups. The FCE was apparent when the target-flanker distance was 1.2° and 3.4° but not when the target-flanker distance was 5.2°. This finding is consistent with Pastò and Burack's (1997) and Enns and Girgus's (1985) report that interference was greater with flankers closer to the target, but inconsistent with their finding that closer flankers were associated with greater developmental improvements in filtering efficiency. In this study, the children aged 11-12 years and adults were not better able to filter the closest flankers (1.2° from the target) as compared to children 10 years of age and younger. As the older children and adults in this study were not more efficient than the younger children at narrowing their attentional focus, the developmental improvement in filtering efficiency that occurred by10 years of age could not be attributed to a improved ability with age in constricting attentional focus.

The relation between flanker distance and perceptual load. The FCE was no longer evident when flankers were presented 5.7° of visual angle from the target, independent of the response compatibility manipulation of perceptual load. This finding indicates that early selection, for children and adults, can also be achieved when the distance between the relevant and irrelevant information is at least 5.7°. Contrary to this finding, Lavie's (1995) findings showed that the FCE was apparent only under conditions of low perceptual load, regardless of the physical separation between the target and the flankers. However, in the Lavie (1995) study, the farthest target-flanker distance was 2.9° of visual angle. In the current study, the FCE remained when the target-flanker distance was 3.4°, but unlike the Lavie (1995) study, a target-flanker distance of 5.7° was also included. At 5.7° of visual angle between the target and the flankers, the FCE was no longer evident under both the high and the low perceptual load conditions. This finding shows that early selection, or no flanker interference was possible for all participants when the distance between the flankers and the target reached 5.7°, regardless of the perceptual load involved in the task.

Original Research Contributions

The original contributions of this study to the empirical literature are developmental, methodological, and theoretical. In this study, the examination of the perceptual load model that is typically only studied in adults was extended to children between the ages of 5 and 12 years. Two, the use of response compatibility was a novel operational formulation to study perceptual load and proved to be an effective measure. Three, two prominent, but opposing models of selective attention were examined within the same paradigm.

This is the first study in which developmental patterns of selective attention within a perceptual load framework were examined, among children between the ages of 5 to 12 years of age as well as among adults. The youngest participants in earlier studies on perceptual load were 9-year old (e.g., Huang-Pollock et al., 2002). This extension was deemed necessary in light of the findings that important developmental changes in various aspects of selective attention occur between 5-9 years of age (e.g., Enns & Girgus, 1985; Porporino, Shore, Iarocci, & Burack, 2004; Ridderinkhof & van der Molen, 1995). The results of this study demonstrated that under high perceptual load circumstances, the attentional filtering skills that allow for early selection operate at adult efficiency levels even among children as young as 5 years of age. However, under low load circumstances, children 11-12 years of age and adults were more efficient than children 7-10 years of age at ignoring irrelevant information. Thus, the inclusion of the younger children led to the finding of differential developmental trajectories that are associated with different perceptual load conditions, and might account for the apparently contradictory findings regarding developmental trends in filtering efficiency (e.g., Enns & Akhtar, 1989; Ridderinkhof & van der Molen; Enns & Cameron, 1987).

The response compatibility manipulation of perceptual load is also a unique contribution to the field of selective attention, as the FCE was eliminated when incompatible responding was required. Most other manipulations of increasing perceptual load involve adding to the number of items presented within the display (e.g., Huang-Pollock et al., 2002; Lavie, 1995; Lavie & Cox, 1997). When perceptual load is increased by adding to the number of items presented in the display, the low load and the high load conditions are no longer identical in appearance and this can result in confounding factors. For example, one confound might be a stronger perceptual segregation between the target and flankers in the high load condition, especially if the additional items are presented in close proximity to the target. In contrast, the response compatibility manipulation of perceptual load may minimize potential confounds as it allows for displays that are identical in appearance as only the instruction for responding is manipulated.

The finding that no flanker interference was possible under a high perceptual load condition and when target-flanker distance was at least 5.7° of visual angle, contributes to the literature on selective attention by demonstrating optimal conditions for early selection. In previous developmental studies on the effect of target-flanker distance on the FCE, the perceptual load involved in the task was not varied (e.g., Enns & Girgus, 1985; Pastò & Burack, 1997), whereas in other studies, perceptual load was examined but independent of issues related to target flanker proximity (e.g., Huang-Pollock et al., 2002). In this study, both the roles of target flanker proximity and perceptual load on developmental changes in susceptibility to interference were examined. The findings contribute to the field of selective attention as evidence that early selection (no flanker processing) is possible for all participants under conditions of high perceptual load and when the target flanker distance was at least 5.7° of visual angle.

Limitations of the Present Study

There were three main limitation of the current study. One, the manipulation of increased set size did not result in a decrease in the FCE. Two, a 4-5 year old age group was not included, thereby precluding a comparison with the findings reported by Pastò and Burack (1997) for this age group. Three, a neutral flanker condition was excluded, as this would have required increasing the already large number of conditions included in the task.

Contrary to the findings from previous reports (Huang-Pollock et al., 2002; Lavie, 1995; Maylor & Lavie, 1998); an increase in task set size had no effect on the magnitude of the FCE. The high and low set size conditions also did not differ with regard to RT, indicating that an increase in display set size did not result in the intended increase in attentional processing. The main difficulty with the manipulation of increased set size used in this study was that the participants were not required to attend to the shapes presented above and below the target arrow in order to respond. Simply adding shapes to the display did not increase the attentional processing requirements, as the shapes were not related to the processing of the target information in any way. This manipulation may have been improved if, for example, the color of the shapes varied in relation to level of load. Thus, under low load conditions the participants would be instructed to respond to the target arrow only when the shapes were red whereas in the high load conditions they would be instructed to respond only when the circles and diamonds were red and the triangles and squares were blue.

According to Pastò and Burack, the 4-5 year old children, compared to older children and the adults, were the only group to show interference effects at both the close (1°) and the far (5.7°) target-flanker distance. However, in this study, 4-5 year old children were not included, as they could not complete the task without committing a high number of errors during pilot testing. The option was either to decrease task complexity or exclude the 4-5 year old age group. The exclusion of the 4-5 year olds from the study was decided upon since developmental differences at the older ages would have been masked if the task were simplified for this younger group.

The exclusion of a neutral flanker condition precluded an examination of the baseline level of distraction caused by the mere presence of other stimuli. A comparison of the FCE with a neutral flanker condition for the 5-6 year old age group would inform as to whether the low FCE for this group was a function of diminished abilities to process the directional meaning of the arrows.

Summary and Conclusion

In sum, the findings presented here are suggestive of differential developmental trajectories for filtering efficiency based on the processing demands involved in the task and support Lavie's (1995) perceptual load conceptualization of selective attention.

Under conditions of low task processing, developmental differences in filtering efficiency were apparent. However, under conditions of high task processing, the magnitude of the interference effects was reduced and developmental differences in filtering efficiency were no longer apparent. Under conditions of low task processing, 5-6 year old children were as efficient as 11-12 year old children and adults at ignoring distracting information. This finding was likely due to less familiarity with arrows as cues or with their semantic meaning in this case among the 5-6 year old children. A developmental improvement in filtering efficiency between 10-11 years of age was apparent when task processing was low. This change was not related to an improvement with age in the ability to constrict attentional focus as the magnitude of the interference effects were larger for all participants at closer target-flanker proximity. Thus, the perceptual load model and not the zoom lens model of selective attention provided the best framework for understanding the differential developmental trajectories for filtering efficiency.

Future research directions. Future studies of response related explanations for developmental improvements may be important as the perceptually based, zoom-lens explanation, was not supported. The findings from this study suggest that the ability to inhibit the meaning associated with flanker objects may be more central to filtering than efficiency of an attentional lens. Future studies should be focused on examining the development effects of interference using flankers that the participants are more and less familiar with.

Another future research direction is to examine the role of perceptual load in selective attention tasks across different sensory modalities, such as audition. The implications of cross-modal studies would help determine whether attentional capacity is modality specific. In a future study, for example, the effects of auditory load on the processing of flanker interference may be examined. If attentional capacity is modality specific, then auditory load should have no effect on interference effects. However, if auditory capacity is shared between modalities, auditory load should determine the level of flanker processing in the visual modality. From a developmental perspective, a prediction may be that attentional capacity in young children is modality specific, but with development is used more flexibly across modalities.

Selective attention studies conducted with persons with special needs, who are often considered to have lower attentional capacity compared to typically developing persons, may be reevaluated from a perceptual load perspective. For example, Burack (1994) examined the filtering abilities of persons with autism, using a flanker paradigm. The results showed that compared to persons with organic and familial mental retardation and no handicap, the persons with autism were most adversely affected by the presence of distractors and the presence of a window around the target did not improve their performance. A future research question may be to determine whether an increase in perceptual load would improve the ability of persons with autism to ignore distracting information. Thus, attentional studies conducted with persons with special needs can be replicated using a task with variable load conditions to determine whether the perceptual load model could be applied to persons with special needs.

Conclusions. The goal of this study was to examine the influence of perceptual load and target-flanker proximity on developmental changes in filtering efficiency among children 5-12 years of age and adults. The findings show that developmental changes in filtering efficiency were apparent only under a low perceptual load condition. When perceptual load was increased, children were just as efficient as adults at ignoring distracting information. The evidence that more effortful task processes resulted in less developmental change is consistent with Lavie's (1995) perceptual load model of selective attention and suggests that the filtering component of selective attention develops in a way that is consistent with a model of differential development trajectories based on the relevant processing demands involved in the task.

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Appendix A: The 28 Experimental Conditions

Flanker Type	Flanker Distance	Display Size	Response Type
1. Congruent	Close	3	Compatible
2. Congruent	Intermediate	3	Compatible
3. Congruent	Far	3	Compatible
4. Congruent	Close	7	Compatible
5. Congruent	Intermediate	7	Compatible
6. Congruent	Far	7	Compatible
7. Congruent	Close	3	Incompatible
8. Congruent	Intermediate	3	Incompatible
9. Congruent	Far	3	Incompatible
10. Congruent	Close	7	Incompatible
11. Congruent	Intermediate	7	Incompatible
12. Congruent	Far	7	Incompatible
13. Incongruent	Close	3	Compatible
14. Incongruent	Intermediate	3	Compatible
15. Incongruent	Far	3	Compatible
16. Incongruent	Close	7	Compatible
17. Incongruent	Intermediate	7	Compatible
18. Incongruent	Far	7	Compatible
19. Incongruent	Close	3	Incompatible
20. Incongruent	Intermediate	3	Incompatible
21. Incongruent	Far	3	Incompatible

22. Incongruent	Close	7	Incompatible
23. Incongruent	Intermediate	7	Incompatible
24. Incongruent	Far	7	Incompatible
25. None	-	3	Compatible
26. None	-	7	Compatible
27. None	-	3	Incompatible
28. None	-	7	Incompatible

Appendix B: Mean RT (MS) and % Errors for each of the 28 Experimental Conditions

Flanker Type	Flanker Distance	Display Size	Response Type	Mean RT	% Errors
1. Congruent	Close	3	Compatible	615.464	2.68
2. Congruent	Intermediate	3	Compatible	594.943	2.56
3. Congruent	Far	3	Compatible	618.376	2.41
4. Congruent	Close	7	Compatible	615.631	2.6
5. Congruent	Intermediate	7	Compatible	596.984	2.33
6. Congruent	Far	7	Compatible	596.761	2.45
7. Congruent	Close	3	Incompatible	680.187	3.9
8. Congruent	Intermediate	3	Incompatible	666.143	3.25
9. Congruent	Far	3	Incompatible	684.247	2.52
10. Congruent	Close	7	Incompatible	696.988	4.09
11. Congruent	Intermediate	7	Incompatible	654.514	4.4
12. Congruent	Far	7	Incompatible	655.496	4.17
13. Incongruent	Close	3	Compatible	650.018	3.21
14. Incongruent	Intermediate	3	Compatible	612.789	3.94
15. Incongruent	Far	3	Compatible	625.216	3.52
16. Incongruent	Close	7	Compatible	660.572	3.48
17. Incongruent	Intermediate	7	Compatible	622.778	3.4
18. Incongruent	Far	7	Compatible	609.136	3.71
19. Incongruent	Close	3	Incompatible	703.931	4.67
20. Incongruent	Intermediate	3	Incompatible	671.738	3.52
21. Incongruent	Far	3	Incompatible	673.041	4.32

22. Incongruent	Close	7	Incompatible	701.656	5.09
23. Incongruent	Intermediate	7	Incompatible	681.525	5.66
24. Incongruent	Far	7	Incompatible	667.146	4.97
25. None	-	3	Compatible	612.814	1.83
26. None	-	7	Compatible	601.322	2.91
27. None	-	3	Incompatible	680.232	4.02
28. None	-	7	Incompatible	676.193	4.25

Appendix C: Ethics Certificates and Consent Forms