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Developmental Course of Auditory Processing Interactions: Garner Interference and Simon Interference

Susan Jerger

University of Texas at Dallas

Deborah A. Pearson

University of Texas Medical School at Houston

and

Melanie J. Spence

University of Texas at Dallas

Previous research suggests that with increasing age children become more efficient in inhibiting conflicting responses and in resisting interference from irrelevant information. We assessed the abilities of 100 children (ages 3–16 years) and 20 adults to resist interference during the processing of 2 auditory dimensions of speech, namely the speaker's gender and spatial location. The degree of interference from irrelevent variability in either dimension did not vary with age. Apparently, young children do not have more difficulty in resisting interference when the nontarget and the target are both perceptual attributes. We also assessed the participants' abilities to inhibit conflicting task-irrelevant information from spatial location and to resist interference from spatial variability in the context of conflict. In the presence of conflicting task-irrelevant information, both interference effects declined significantly with age. Developmental change in auditory processing seems to vary as a function of (1) the nature of the target–nontarget combination and (2) the presence/absence of conflicting task-irrelevant information. © 1999 Academic Press

Key Words: cognitive development; resistance to interference; inhibition; auditory processing; speeded-classification, selective attention task; Garner interference; Simon interference.

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Address correspondence and reprint requests to Susan W. Jerger, Ph.D., School of Human Development, University of Texas at Dallas, P.O. Box 830688, GR4.1, Richardson, TX 75083-0688.

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In contrast to age-linked improvements in a wide range of cognitive abilities, a few processes seem to show relatively little age-related change, at least after early childhood. Data from memory, matching, and semantic-categorization tasks suggest that the degree of age-related change may be minimized when a task emphasizes more perceptual types of knowledge representations. For example, the degree of developmental change may be minimized when individuals recall the spatial locations, rather than the names, of objects (Kail & Siegel, 1977). In fact, the ability to recall an item's spatial location may be fairly equivalent in children and adults (Finkel, 1973; Kail & Siegel, 1977). Children may also perform as well as adults on perceptual priming tasks and on incidental learning tasks requiring listeners to recall whether a male or a female talker produced a particular word (Drummey & Newcombe, 1995; Graf, 1990; Greenbaum & Graf, 1989; Hayes & Hennessey, 1996; Lindberg, 1980). In addition to the minimized developmental change on these memory tasks, the degree of developmental change may be less when individuals match two stimuli on the basis of a physical attribute, as opposed to a name (Keating & Bobbitt, 1978). Finally, the degree of developmental change may be reduced when individuals judge picture–picture stimuli relative to word–word stimuli on a category judgment task (decide whether two stimuli, e.g., cat–dog versus cat–bed, are from the same or different semantic categories) (Rosinski, Pellegrino, & Siegel, 1977). These data suggest that the degree of age-related change may be influenced by the type of knowledge representation underlying accurate performance.

Our previous research on multidimensional speech processing using the Garner task shows a similar pattern of results (Garner, 1974; Jerger et al., 1993). We asked participants to attend selectively to an auditory dimension of speech (speaker's gender) while ignoring a linguistic dimension (spoken word), and the reverse. In the *control* condition of the task, the nontarget dimension was held constant while the target dimension varied. In the *orthogonal* condition of the task, both the nontarget and the target dimensions varied unpredictably across trials. The logic of the Garner task for speech dimensions, which are not processed independently, is that participants cannot ignore irrelevant variation of the nontarget dimension (Pomerantz, Pristach, & Carson, 1989). Thus, performance for the target dimension is affected by what is happening on the nontarget dimension; that is, despite the listener's intentions, response times are slower for the orthogonal condition (with both dimensions varying unpredictably) than for the control condition (with only the target dimension varying). This difference in performance defines Garner interference.

Our study (Jerger et al., 1993) reported a difference in the degree of age-related change for the auditory versus the linguistic dimensions of speech, as illustrated in Fig. 1. When the gender of the talker was the target dimension, the degree of Garner interference from to-be-ignored word variability was fairly similar in children and adults. When the word was the target dimension, on the other hand, the degree of Garner interference from to-be-ignored talker-gender variability was significantly greater in children than in adults. Thus, the degree of devel-

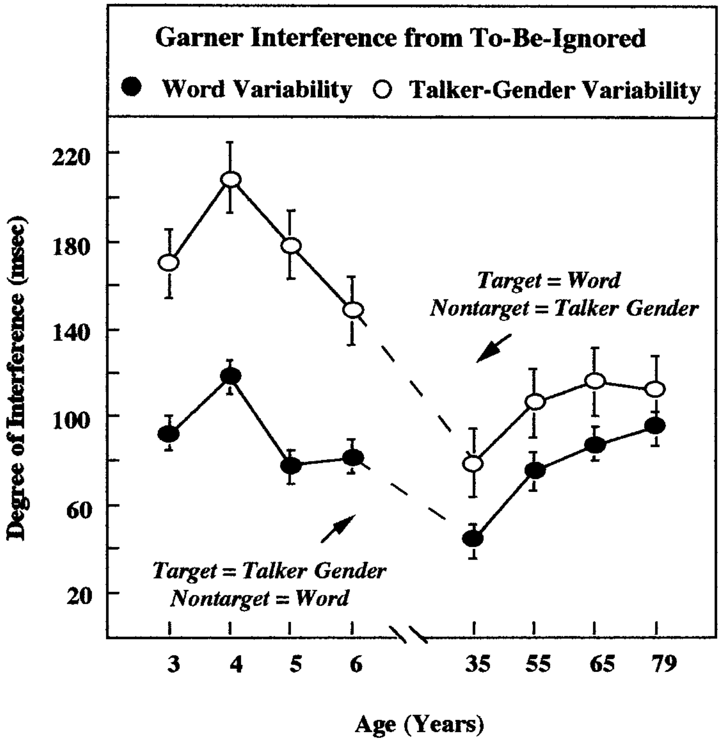

FIG. 1. Degree of Garner interference from to-be-ignored word variability (attend to talker gender) and talker-gender variability (attend to word). Redrawn from Jerger et al. (1993).

opmental change on this speeded-classification, selective-attention task also seemed influenced by different types of knowledge representations. An auditory-perceptual dimension, when opposing a linguistic dimension, seemed to minimize developmental change when it was the target and to maximize developmental change when it was the nontarget.

An interesting phenomenon that diverges from the above pattern of Garner interference is Stroop interference (Stroop, 1935). A generic Stroop task requires individuals to process a perceptual dimension while ignoring a linguistic dimension. For example, individuals are asked to name the ink color or the talker gender of word stimuli while ignoring the word. The to-be-ignored words are varied to represent congruent or conflicting relations between dimensions (e.g., the word "blue" printed in blue or red ink, respectively; the word "daddy" spoken by a male or female talker, respectively). The to-be-ignored semantic content affects performance, despite a participant's intentions, and response times are slower for the conflicting type of stimulus than for the congruent type of stimulus. The difference in performance between the two types of stimuli defines Stroop interference.

The degree of Stroop interference in both the visual and the auditory domains shows significant age-related change (Comalli, Wapner, & Werner, 1962; Jerger, Martin, & Pirozzolo, 1988). Even though participants are attending to a perceptual dimension while ignoring a linguistic dimension, the conflicting task-irrelevant information of the Stroop task disrupts performance more in younger than in older individuals. A possible explanation for this effect is that a conflicting type of Stroop stimulus sets up competing responses (Lew, Chmiel, Jerger, Pomerantz, & Jerger, 1997; MacLeod, 1991). With increasing age, children become more adept at inhibiting the inappropriate response and resisting interference (Bjorklund & Harnishfeger, 1990, 1995; Dempster, 1992, 1993; Harnishfeger, 1995). We propose that developmental change in the degree of Stroop interference is associated with the presence of conflicting task-irrelevant information, an overriding condition that enhances age-related change.

The purpose of this study was to explicate the developmental course of multidimensional processing interactions between two auditory dimensions (the gender of the talker and the spatial location), with and without the presence of conflicting task-irrelevant information. The ability to appreciate these perceptual dimensions of speech is evidenced from an early age (Morrongiello, Fenwick, Hillier, & Chance, 1994; Spence & DeCasper, 1987). In fact, an infant's orientation to the voices and the spatial locations of talking people has been suggested as an important precursor behavior to spoken language (Locke, 1997). One of us has also observed that the ability to allocate attention is achieved earlier in a spatial context than in other contexts (Lane & Pearson, 1983). We defined developmental functions for Garner interference and another interference phenomenon known as the Simon effect (Hedge & Marsh, 1975). To some investigators, Simon interference resembles a spatial variation of Stroop interference (Faber, Molen, Keuss, & Stoffels, 1986; Hasbroucq & Guiard, 1991; Umilta & Nicoletti, 1992).

The Simon effect reflects the observation that adult response times are faster when the locations of a stimulus and of a response are congruent (on the same side) and are slower when the locations are conflicting (on opposing sides), even though the spatial location is irrelevant to the task (Lu & Proctor, 1995; Simon, Craft, & Webster, 1973; Simon, Small, Ziglar, & Craft, 1970). The difference in performance between the conflicting and congruent types of trials defines Simon interference. Whereas Garner interference derives from irrelevant stimulus variability over a series of trials, Simon interference derives from an initial tendency to respond toward a source in space. Simon and colleagues (Simon & Berbaum, 1990) proposed a primitive innate tendency to react toward a source of stimulation, perhaps analogous to the directed orienting response of animals. This initial tendency to react to the irrelevant source, rather than to the content, of a stimulus facilitates or delays responding to the relevant attribute, producing Simon interference.

Defining the developmental courses of Garner interference and Simon interference simultaneously allows us to address several questions about the development of the capacity for inhibition and resistance to interference. Bjorkund (1995) clarified the distinction between these two concepts, noting that inhibition refers to the ability to inhibit an external or internal response(s) whereas resistance to interference refers to the ability to ignore irrelevant information. One of our questions concerned what pattern of results would characterize the developmental course of Garner interference for two opposing auditory dimensions. The developmental course is difficult to predict from previous findings if the results are determined by the dimension's level of abstraction. Clearly, an auditory dimension seems to predominate when opposing a linguistic dimension, minimizing change when it is the target and maximizing change when it is the nontarget (Fig. 1). It is unclear, however, how an auditory dimension will interact with another auditory dimension across age. The developmental course of Garner interference is more predictable, however, if the results are driven by the dimension's relevance, that is, target versus nontarget. Dempster's (1992, 1993) model of age-related change in resistance to interference proposes that children have more difficulty than adults in resisting perceptual sources of interference. To the extent that Dempster's model transfers to the Garner task, there should be an age-linked decrease in the degree of Garner interference from both irrelevant talker gender and spatial location. To the extent that our previous results transfer to the present Garner task, our findings also predict that the to-be-ignored auditory dimension will produce greater interference in children than in adults. In contrast to these predictions, the developmental course of Garner interference again becomes difficult to predict if age-related change in resistance to interference is a factor of not only the source of interference but also the nature of the target. If a target perceptual dimension interacts with the interfering effect of a nontarget perceptual dimension, for example, then there may be less age-related change in the degree of interference for either dimension.

The previous findings for Stroop interference suggest that the presence of conflicting task-irrelevant information enhances the degree of age-related change for a target perceptual dimension. Thus, another question is whether the developmental courses of Garner interference due to irrelevant spatial variability and of Simon interference due to irrelevant spatial conflict will differ significantly. If conflicting information represents an overriding condition, results are predicted to show a greater degree of age-related change for Simon interference than for Garner interference. To the best of our knowledge, results from our lab are the first data describing the developmental course of Simon interference and comparing Simon interference and Garner interference. A few previous investigators, however, have studied stimulus–response compatibility effects in children (Alluisi, 1965; Ladavas, 1990).

METHOD

Participants and Demographics

Participants. Individuals were 100 children (50 boys and 50 girls) and 20 adults (6 men and 14 women). Ages ranged from 3 years 6 months to 16 years 10 months for the children and from 18 to 48 years for the adults. Child participants were recruited from cooperating educational programs; adult participants were recruited from local universities. The criteria for participation were (a) no diagnosed disabilities and (b) English as the native language. The racial/ethnic distribution was 106 Whites, 5 Hispanics, 5 Asians, 3 Blacks, and 1 Arab.

Measures. Hearing sensitivity was assessed with a standard pure tone audiometer. Word recognition ability was assessed with the Word Intelligibility by Picture Identification (WIPI) test (Ross & Lerman, 1971). The test items were tape-recorded and played back via a multichannel recorder fed through amplifying and attenuating circuits to a loudspeaker. Soundfield speech detection thresholds were obtained via the standard procedure (Stach, 1998) with the WIPI word materials. Verbal abilities were estimated with the Peabody Picture Vocabulary Test–Revised (PPVT-R, Form L) (Dunn & Dunn, 1981) . Nonverbal abilities were estimated with the Southern California Figure–Ground Visual Perception Test (Ayres, 1978) in children 8 years of age or younger, with the Block Design subtest of the Wechsler Intelligence Scale for Children–Revised (Wechsler, 1974) in children 9 to 16 years of age, and with the Block Design subtest of the Wechsler Adult Intelligence Scale–Revised (Wechsler, 1981) in individuals 17 years or older. Handedness was determined by coloring and toy activities in younger children (Bryden, 1982), by writing and drawing activities in older children, and by a standardized questionnaire in adults (Annette, 1970). Socioeconomic status was estimated with the Hollingshead four-factor index (Hollingshead, 1975). Each measure was administered and scored according to the standardized technique.

Characteristics. All participants had hearing sensitivity within normal limits, that is, less than or equal to 20 dB hearing level at all test frequencies between 500 and 4000 Hz (American National Standards Institute, 1989). The ability to detect speech and to recognize spoken words was consistently within normal limits. The preferred hand was the right hand for 97 individuals and the left hand for 23 individuals. The average Hollingshead Social Strata Score (1.25) was consistent with a major business and professional socioeconomic status. Participants were arranged into six groups of 20 each according to age. In subsequent figures, each group is denoted by the average age in years. Table 1 summarizes demographic data for the groups. Nonverbal skill was equivalent among the groups, but verbal ability tended to be higher in the older groups: $F(5, 114) = 2.08$, $p = .07$. To the extent that verbal intelligence aids the capacity for inhibition and resistance to interference (Dempster, 1991), the “anchors” of the developmental functions may represent inappropriately superior performance. Thus, a lack of any age-related change would be a persuasive finding.

Materials and Instrumentation

Garner interference and Simon interference. Each speech target was digitized and stored in a computer by means of the SoundScope/16 program (GW Instruments) and MacADIOS II software and hardware (GW Instruments) sampling at 22 kHz with 12-bit amplitude resolution. The targets were played back through an anti-aliasing filter to one of two loudspeakers. A loudspeaker was placed to the right and to the left of the participant at an azimuth of 45° relative to the center

TABLE 1
Average Nonverbal and Verbal Abilities (Standard Deviations in Parentheses) for Each of Six Age Groups

	Age groups (age range in years)					
Descriptors	3	4	5	6	7–16	18–48
Age in months	44.55 (1.54)	52.50 (3.62)	65.24 (3.19)	76.50 (4.08)	124.70 (33.5)	323.85 (124.07)
Nonverbal skill in percentile	75.65 (23.23)	82.70 (23.13)	87.03 (13.22)	82.28 (18.63)	89.18 (11.97)	89.95 (7.88)
Verbal skill in percentile	70.40 (23.78)	76.85 (17.27)	80.48 (17.83)	71.15 (24.57)	85.70 (13.81)	85.95 (15.41)

Note. Each group consisted of 20 participants ($N = 120$). In subsequent figures, each group is denoted by the average age in years.

of the individual's head. The loudspeakers were at eye level at a distance of approximately 100 cm from the participant. To obtain reaction times, the computer triggered a counter/timer with 1-ms resolution at the initiation of a target. Pressure on either one of two response (telegraph) keys stopped the counter/timer. After the computer finished outputting the signal, the reaction time was read and stored and the response was tallied as correct or incorrect. The response keys were mounted on a board, separated by a distance of approximately 12 cm. A blue circle equidistant between the two keys designated the "start" position assumed before each trial. When spatial location was the target dimension, each response key had a colorful ribbon mounted above it from the loudspeaker on the corresponding side; for example, the ribbon connected the loudspeaker on the right side to the key on the right side. When the talker-gender input was the target dimension, each key had a picture of a man or of a woman mounted above it. The position (right versus left side) of the pictures on the response card was counterbalanced among participants. The fundamental frequencies of the voices were 108 Hz (male) and 204 Hz (female).

Procedure

General. Testing was carried out within a $8\frac{1}{2} \times 9$-ft double-walled sound-treated booth in two separate sessions. The sessions occurred on separate days for 100% of children between 3 and 5 years of age and for 45% of children between 7 and 16 years of age and on the same day for the remaining participants. The between-day sessions were typically about 11 days apart. Five 3-year-old children required a third session, which occurred about 9 days after the second session. The two same-day sessions were always separated by at least a 1-h (noon) break. The target dimension was spatial location in one session and talker gender in the other session. We have demonstrated that performance in children does not differ as a function of within-day versus between-day sessions with this

TABLE 2A
Garner Interference: Targets, Nontargets, Types of Trials, and Types of Conditions when Spatial Location Was the Target Dimension

Target dimension (spatial location)	Nontarget dimension (talker gender)	Type of trial	Type of condition	Primary characteristic of condition
Left	Male	Congruent	Control	The nontarget talker gender was held constant
Right	Male	Congruent		
Left	Male	Congruent	Orthogonal	The nontarget talker gender varied irrelevantly
Right	Male	Congruent		
Left	Female	Congruent		
Right	Female	Congruent		

Note. The participant was asked to ignore talker gender. When spatial location was the target dimension, all of the trials were congruent. Participants always moved their hand toward the source in space, pressing the right key for the right spatial location and the left key for the left spatial location. Thus, only Garner interference (and no Simon interference) can be computed. For this illustrative participant, the talker gender held constant for the control condition was the male speaker. Overall, the talker gender to be held constant was counterbalanced among participants.

approach (Jerger, Elizondo, Dinh, Sanchez, & Chavira, 1994). The two types of sessions were counterbalanced across participants. The child participants received candy and/or a small toy for reinforcement.

Garner interference and Simon interference. Each participant was seated at a child- or adult-size table containing a response board. For the child participants, a co-tester sat slightly behind the child, keeping him or her focused on the task and assuring (1) that the child's head was maintained in a slightly bent-down, straight-forward position and (2) that the child's hand was on the start position prior to each trial. If a participant's head or hand was not in the correct position for a trial, the tester "bombed" that trial (with replacement). The participants listened to the utterance "baba," spoken by a male voice and a female voice. The intensity level of the utterances was approximately 75 dB sound pressure level at the imagined center of the participant's head. For reaction-time measures, the participant was instructed to push the correct response key, using a whole hand movement, as quickly and as accurately as possible. Each participant spontaneously used his or her preferred hand. The interval between the participant's response and the next target varied randomly between 2 and 5 s.

Tables 2A and 2B illustrate the types of trials and types of conditions when the spatial location was the target dimension (Table 2A) and when the gender of the talker was the target dimension (Table 2B). The Garner task consisted of a set of targets administered in the control condition with the nontarget dimension held constant and in the orthogonal condition with the nontarget dimension varying irrelevantly. Administration of the two Garner conditions for each target dimension was counterbalanced across participants. The presentation of each condition comprised 12 trials. When spatial location was the target dimension (Table 2A), one half of the trials were from the loudspeaker on the left side and one half from

TABLE 2B
Garner Interference and Simon Interference: Targets, Nontargets, Types of Trials, and Types of Conditions when the Gender of the Talker Was the Target Dimension

Target dimension (talker gender)	Nontarget dimension (spatial location)	Type of trial	Type of condition	Primary characteristic of condition
Male	Left	Congruent	Control	The nontarget spatial location was held constant
Female	Left	Conflicting		
Male	Left	Congruent	Orthogonal	The nontarget spatial location varied irrelevantly
Female	Left	Conflicting		
Male	Right	Conflicting		
Female	Right	Congruent		

Note. The participant was asked to ignore spatial location. For this illustrative participant, the male picture was mapped to the left response key and the constant spatial location was the left side. When talker gender was the target dimension, individuals moved their hands toward the source in space (congruent trials) on one half of trials and away from the source in space (conflicting trials) on one half of trials within each condition. Thus, both Garner interference and Simon interference can be computed. Overall, the spatial location to be held constant and the position (right versus left side) of the pictures on the response card were counterbalanced among participants.

the loudspeaker on the right side. The participants were instructed to ignore the talker and attend selectively to the spatial location, pressing the left key if the utterance came from the left spatial location and the right key if the utterance came from the right spatial location. For the control condition, the gender of the talker was held constant. One half of participants heard the male voice and the other one half of participants heard the female voice. For the orthogonal condition, the gender of the talker varied irrelevantly and randomly. Approximately one half of the utterances from each loudspeaker were the male voice and one half were the female voice. When the participants were attending selectively to spatial location, all of the trials were congruent. Individuals always moved their hand toward the source in space, pressing the key corresponding to the spatial location. Thus, only Garner interference (and no Simon interference) could be computed.

When talker gender was the target dimension (Table 2B), one half of trials involved responding to the female voice and one half involved responding to the male voice. The participants were instructed to ignore the spatial location and attend selectively to the gender of the talker, pressing the key labeled with the woman picture for the female voice and the key labeled with the man picture for the male voice. For the control condition, the spatial location of the talkers was held constant. The constant location was the left loudspeaker for one half of participants and the right loudspeaker for the other one half of participants. For the orthogonal condition, the spatial locations of the talkers varied irrelevantly and randomly. In approximately one half of trials the talker's voice came from the left loudspeaker and in approximately one half of the trials it came from the right loudspeaker. When the participants were attending selectively to the gender of the talker, individuals moved their hands toward the source in space (congruent trials) on one half of the trials and away from the source in space (conflicting trials) on one half of the trials within each condition. Thus, both Garner interference and Simon interference could be computed. The procedure in Table 2B is a variation of the Pomerantz task for assessing Stroop interference and Garner interference simultaneously (Jerger et al., 1994; Pomerantz, Pristach, & Carson, 1989; see also Clark & Brownell, 1976).

Scoring. Performance was quantified by the reaction times of correct responses, that is, the time between the onset of a target and the execution of a motor response. When spatial location was the target dimension (see Table 2A), the degree of Garner interference was quantified by the difference between performance in the orthogonal and control conditions for the congruent type of trials. When talker gender was the target dimension (Table 2B), the degree of Garner interference was quantified by the difference between performance in the orthogonal and control conditions, either (1) for the congruent type of trial only or (2) collapsed across the types of trials. The degree of Simon interference was quantified by the difference between performance for the conflicting versus congruent types of trials, collapsed across the types of conditions. Figure 2 illustrates how we calculated the interference effects, collapsing across type of trial or type of condition, for four example trials from Table 2B. When the boxes in Fig. 2 are numbered sequentially, Garner interference is calculated as the difference between reaction times in the orthogonal condition (boxes 5, 6, 7, and 8) and in the control condition (boxes 1, 2, 3, and 4). Simon interference is calculated as the difference between the reaction times for the conflicting type of trial (boxes 2, 3, 6, and 8) and the congruent type of trial (boxes 1, 4, 5, and 7). A value of this approach for comparing Garner interference and Simon interference is that each interference effect is calculated from the same set of reaction times, thus eliminating task-specific influences.

Simple auditory reaction time. A simple reaction-time measure always preceded the experimental conditions for each target dimension. When the gender of the talker was the target dimension, we obtained six simple reaction times to the male talker and six to the female talker. The loudspeaker was constant for a participant and counterbalanced across participants. When spatial location was the target dimension, we obtained six simple reaction times to the left loudspeaker and six to the right loudspeaker. The talker-gender input was constant for a participant and counterbalanced across participants. Only the key corresponding to the predetermined correct response was labeled on the response board. The purpose of this measure was to quantify a participant's ability to detect and respond to auditory input. To control for developmental differences in these sensory and motor abilities, we subtracted each participant's simple reaction time from all of his/her experimental choice reaction times (Donders, 1969; Montgomery, Scudder, & Moore, 1990; Sternberg, 1969). Subtracting a constant from each participant's experimental measures does not affect the differences between the types of conditions/types of trials.

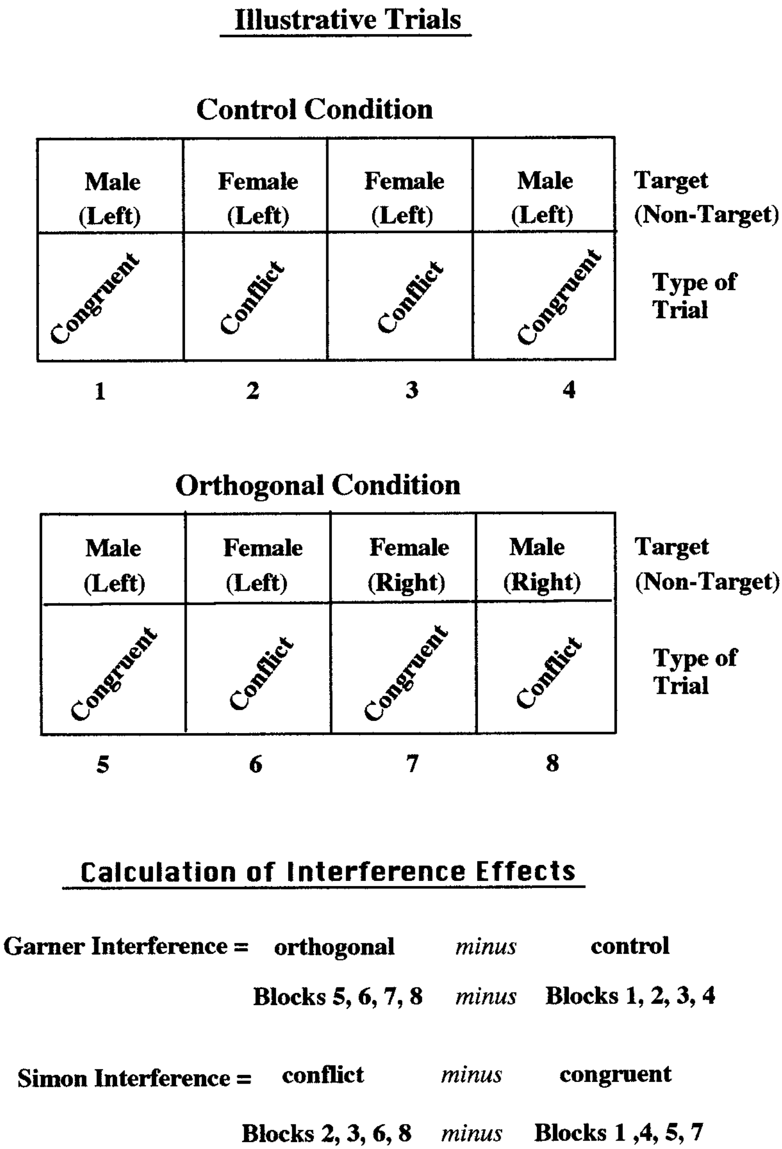

FIG. 2. Depiction of the targets, types of trials, and types of conditions for four illustrative trials when talker gender is the target dimension and spatial location is the nontarget dimension. When the boxes are numbered sequentially, Garner interference is calculated as the difference between reaction times in the orthogonal condition (boxes 5, 6, 7, and 8) and in the control condition (boxes 1, 2, 3, and 4). Simon interference is calculated as the difference between the reaction times for the conflicting type of trial (boxes 2, 3, 6, and 8) and the congruent type of trial (boxes 1, 4, 5, and 7).

Data analysis. The participants' mean reaction times for correct trials were analyzed with regression analysis or with a mixed-design analysis of variance with one between-subjects factor (age group) and several within-subjects factors (e.g., type of condition, type of trial, target dimension) (Pedhazur, 1982). Error rates are not reported. Overall, errors were few. This finding is consistent with previous studies commenting on children's apparent aversion to making errors (Jerger et al., 1993; Shepp & Swartz, 1976). When errors were observed, they were consistent with the reaction-time data, occurring for the more difficult type of condition (orthogonal) or type of trial (conflicting).

RESULTS

Age-Related Change in Simple Auditory Reaction Time

Auditory simple reaction time decreased significantly with increasing age: $r^2 = 0.4$, $p = .0001$. The extent of the decrease was approximately 445 ms, from about 830 ms for the 3-year-olds to 385 ms for the adults. An age-related decrease in simple reaction time for children and between children and adults has been noted repeatedly (Andersen, Starck, Rosen, & Svensson, 1984; Goodenough, 1935; Guttentag, 1985; Weissberg, Ruff, & Lawson, 1990). Again, experimental data are adjusted reaction times, that is, adjusted for the differences in simple reaction time.

Garner Interference: Developmental Course of Processing Interactions between Dimensions

Figure 3 shows performance for the two conditions of the Garner task as a function of age. The left-hand panel depicts results when participants were voting on the basis of the gender of the talker while ignoring spatial location; the right-hand panel depicts results when participants were voting on the basis of the spatial location while ignoring the gender of the talker. The difference between the two conditions defines, respectively, Garner interference from irrelevant spatial variability (target = talker gender) and Garner interference from irrelevant talker-gender variability (target = spatial location), as shown in Fig. 4. Analysis of these data involved one between-subjects factor (age group) and two within-subjects factors (type of condition and target dimension). Again, only the congruent types of trials were considered for comparing the degree of Garner interference between dimensions.

Performance for the control and orthogonal conditions differed significantly for both target dimensions: Condition, $F(1, 114) = 89.14$, $p = .0001$; Condition × Dimension, $F(1, 114) = 0.03$, $p = .87$. The same pattern of results was observed for all age groups: Condition × Age, $F(5, 114) = 0.62$, $p = .68$; Condition × Age × Dimension, $F(5, 114) = 0.99$, $p = .42$. Thus, the processing of the target dimension was significantly affected by irrelevant variability of the nontarget dimension in all groups. The auditory dimensions of talker gender and spatial location are not processed independently by either children or adults.

Age per se significantly affected overall adjusted reaction times, collapsed

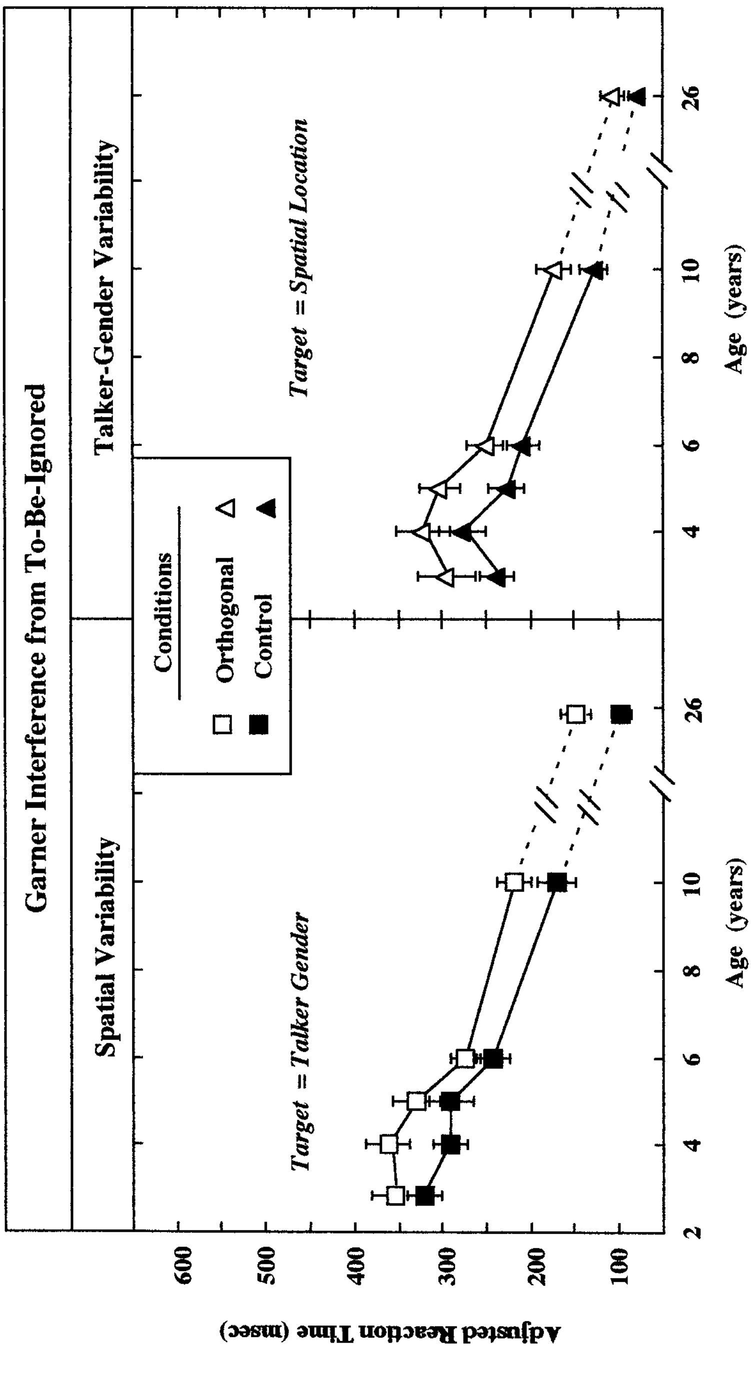

FIG. 3. Performance for the control and orthogonal conditions of the Garner task as a function of age. The left-hand panel depicts performance when participants were voting on the basis of the gender of the talker while ignoring spatial location; the right-hand panel depicts performance when participants were voting on the basis of the spatial location while ignoring the gender of the talker. Only the congruent types of trials were considered.

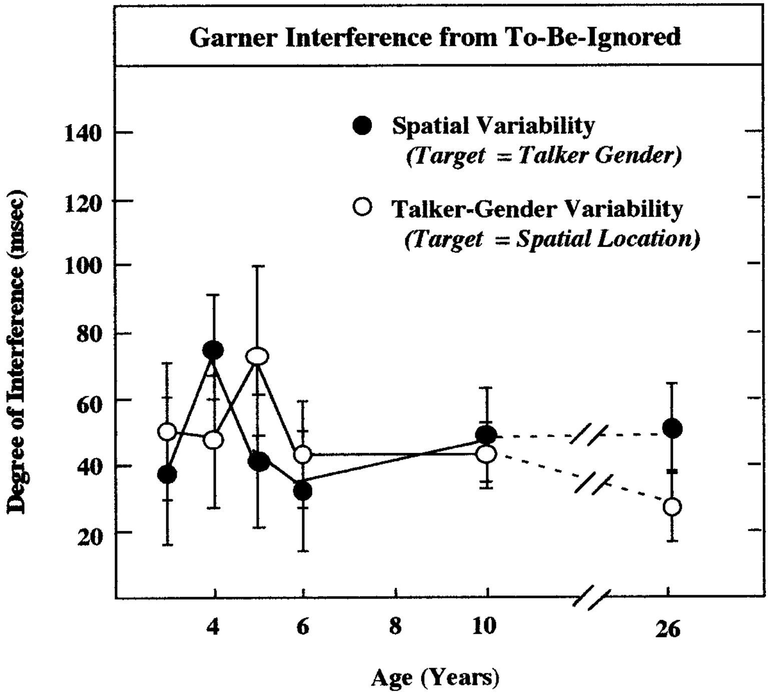

FIG. 4. Garner interference (difference in response times in the control and orthogonal conditions) from irrelevant spatial variability (target = talker gender) and irrelevant talker-gender variability (target = spatial location) as a function of age. Only the congruent-type trials were considered.

across the conditions and the dimensions: Age, $F(5, 114) = 26.48$, $p = .0001$. This finding agrees with previous observations (e.g., Kail, 1995). The average reaction times for identifying the targets decreased by about 200 ms as age increased from 3 to 26 years. However, the relation between the conditions and the dimensions remained the same regardless of age: Condition × Age, $F(5, 114) = 0.62$, $p = .68$; Dimension × Age, $F(5, 114) = 0.25$, $p = .94$; Condition × Age × Dimension, $F(5, 114) = 0.99$, $p = .42$. As highlighted in Fig. 4, the difference between the conditions, or Garner interference, does not show significant developmental change for either target dimension. The average interference from spatial location and from talker gender is roughly 50 ms, fluctuating between about 30 and 75 ms for both dimensions. The processing interactions between dimensions are symmetrical for these two auditory dimensions of speech.

Relative Discriminability of the Dimensions

Some previous studies in adults have observed that differences in the discriminability of the dimensions may influence the degree of Garner interference (e.g., Carrell, Smith, & Pisoni, 1981). The idea is that variability of a nontarget dimension that is difficult to discriminate produces less interference. Traditionally, the discriminability of the dimensions is inferred from the reaction times in the control conditions (Garner & Felfoldy, 1970). Pilot data in adults indicated equivalent discriminability of these two target dimensions (unadjusted reactions times in a control condition of 458 ms for talker gender and 453 ms for spatial location). As seen in Fig. 3, however, reaction times of the present participants differed significantly in the control conditions, with responses to the talker-gender targets about 40 ms slower than responses to the spatial-location targets: Dimension (control conditions only), $F(1, 114) = 15.31$, $p = .0002$. Slower reaction times for the talker-gender dimension were observed for all ages: Dimension (control conditions only) × Age, $F(5, 114) = 0.84$, $p = .53$.

Slower reaction times in a control condition imply that the slower dimension is less discriminable. This raises a question of whether results may have been influenced by differences in the discriminability of the dimensions. The obtained pattern of results, however, does not seem to be influenced by poorer discriminability of the talker-gender dimension. As an example, the 3- and 5-year-olds show relatively large differences between the control conditions in Fig. 3, yet these two age groups show more, not less, interference from talker-gender variability, as seen in Fig. 4. Another example is the 26-year-old group, who has relatively less difference between the control conditions yet shows one of the larger differences in the magnitudes of the interference effects. Overall, these data seem more attuned to previous investigators who concluded that the discriminability between dimensions cannot account for the degree of Garner interference (Eimas, Tartter, Miller, & Keuthen, 1978; Mullennix & Pisoni, 1990; Pomerantz, 1983; Pomerantz & Sager, 1975).

To recapitulate, all age groups show significant Garner interference from irrelevant spatial and talker-gender variability. The degree of Garner interference does not show significant developmental change for either target dimension. The degree of Garner interference is symmetrical for these two auditory dimensions of speech.

Garner Interference and Simon Interference: Effect of Conflicting Task-Irrelevant Information on Processing Interactions

The effect of conflicting task-irrelevant information on the developmental course of processing interactions may be examined by comparing, as a function of age, the degree of Garner interference and Simon interference. The target dimension is always the gender of the talker; the to-be-ignored dimension is always the spatial location. Figure 5 shows performance as a function of age for the orthogonal and control conditions of the Garner task, collapsed across the types of trials (left-hand panel), and for the conflicting and congruent trials of the Simon task, collapsed across the types of conditions (right-hand panel). Figure 6 details the degree of Garner interference from to-be-ignored spatial variability (difference between types of conditions) and of Simon interference from to-be-

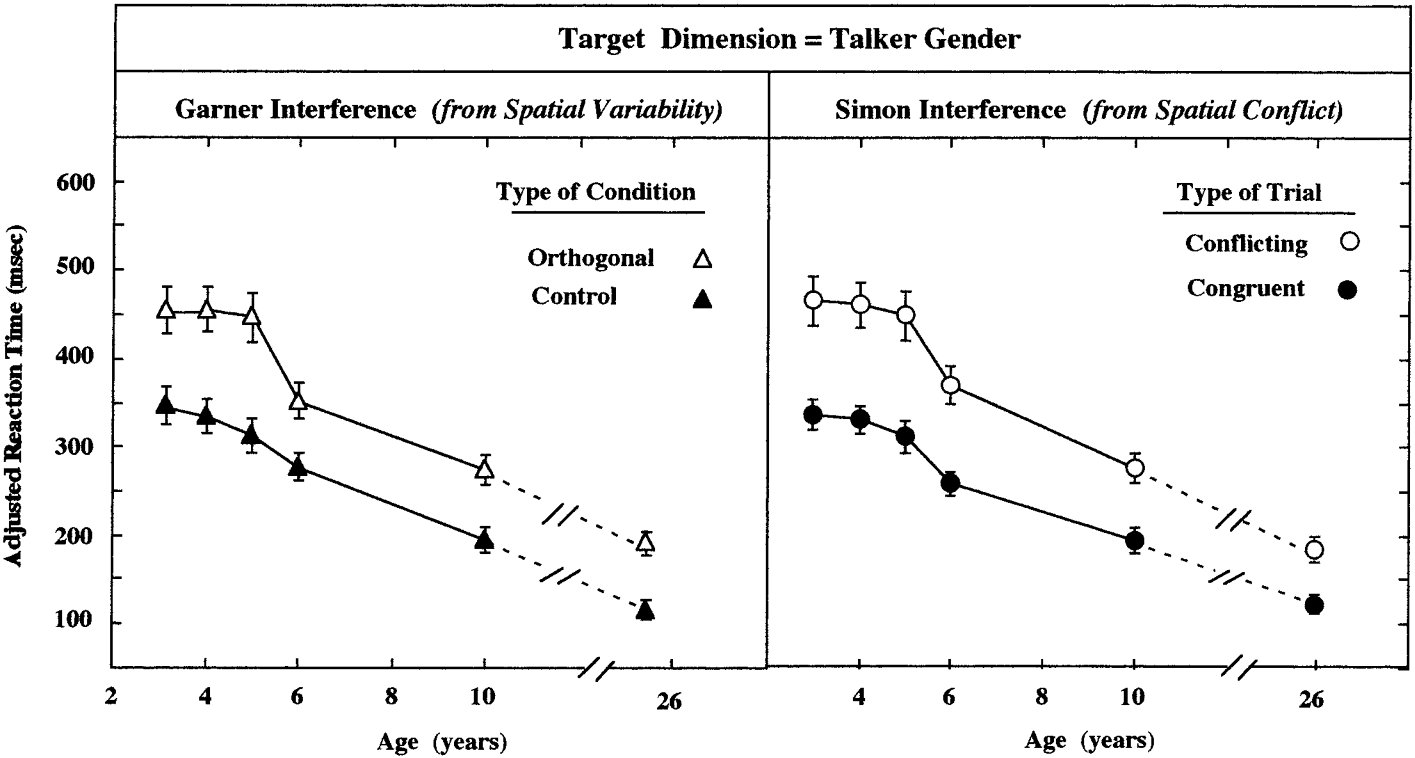

FIG. 5. Performance when participants were voting on the basis of the gender of the talker while ignoring the spatial location. The left-hand panel shows response times in the control and orthogonal conditions of the Garner task (collapsed across the conflicting and congruent trials). The right-hand panel shows response times for the conflicting and congruent trials of the Simon task (collapsed across the orthogonal and control conditions). Data are plotted as a function of age.

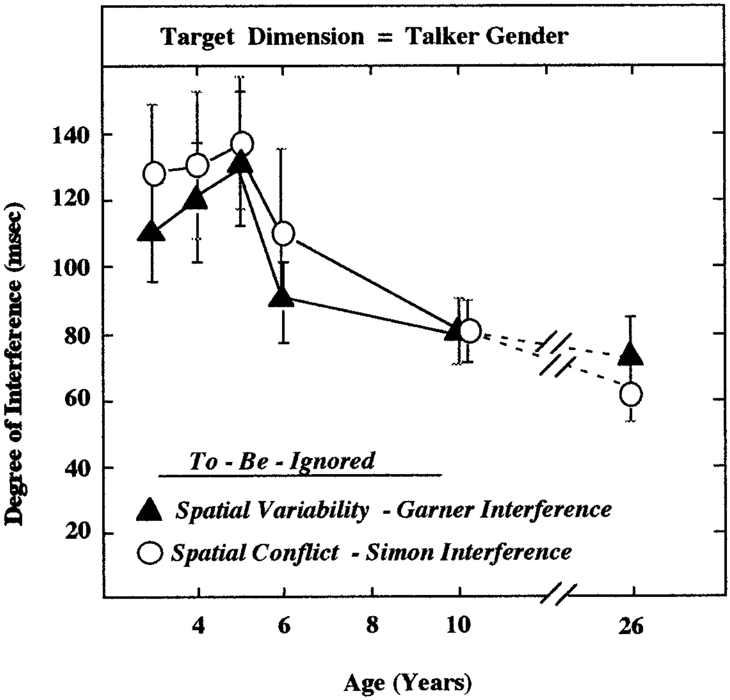

FIG. 6. Garner interference from to-be-ignored spatial variability (difference between types of conditions) and Simon interference from to-be-ignored spatial conflict (difference between types of trials). Data are plotted as a function of age.

ignored spatial conflict (difference between types of trials) as a function of age. Analysis of these data involved one between-subjects factor (age group) and two within-subjects factors (type of condition and type of trial).

Performance differed significantly between the orthogonal and control conditions and between the conflicting and congruent trials: Condition, $F(1, 114) = 217.96$, $p = .0001$; Trial, $F(1, 114) = 196.74$, $p = .0001$. We observed significant Garner interference and Simon interference in the participants. In contrast to the previous results, however, both the difference between the conditions and between the trials decreased significantly with age: Condition × Age, $F(5, 114) = 2.40$, $p = .04$; Trial × Age, $F(5, 114) = 2.59$, $p = .03$. As seen in Fig. 6, both the degree of Garner interference and the degree of Simon interference declined significantly with increasing age. The age-related change was about 45 ms for Garner interference (from about 120 ms to 75 ms) and about 65 ms for Simon interference (from about 130 ms to 65 ms). Thus, in the presence of conflicting trials, the degree of interference shows significant developmental change. The age-specific pattern of change for Simon interference is consistent with Pearson and Lane's (1990) observation that the largest gains in the orienting of visual covert attention occur between 7 and 11 years.

Dempster's (1993) model proposes that sensitivity to perceptual sources of interference initially increases before declining with increasing age. The increase reflects children's theorized shift of focus to perceptual sources of information and the decrease reflects another theorized shift of focus to linguistic sources. The data of Fig. 6 and Fig. 1 seem to reflect this claim. Post hoc pairwise comparisons, however, were not sufficiently sensitive to detect differences between the means of the younger age groups. To probe this possibility, we conducted trend analysis with age as a continuous, rather than grouping, variable. The relation between age and both Garner interference and Simon interference showed significant linear and curvilinear trends: Garner, linear $-t(1, 117) = 2.17$, $p = .03$; quadratic $-t(1, 117) = 1.92$, $p = .057$; Simon, linear $-t(1, 117) = 2.65$, $p = .009$; quadratic $-t(1, 117) = 2.07$, $p = .04$. The developmental courses in Fig. 6 have significant bends in the curves before declining linearly, offering strong empirical support for Dempster's hypothesized relation between age and susceptibility to perceptual sources of interference.

In short, the presence of conflicting information seems to alter significantly the developmental course of interference effects. The developmental course of Garner interference was flat when calculated only with the congruent trials (Fig. 4) and sloped significantly when calculated with both the congruent and conflicting trials (Fig. 6). The difference between the conditions was influenced significantly by the type of trial: Condition × Trial, $F(1, 114) = 52.88$, $p = .0001$. A trend toward this pattern of results has been observed previously in adults on the Pomerantz task (Pomerantz, Carson, & Feldman, 1994). Calculation of the interference effects was collapsed across this interaction, nonetheless, in order to respect an important advantage of the Pomerantz task, namely calculating each interference effect with exactly the same set of targets. However, it seems the case that the type of trial may influence the degree of interference more in children than in adults: Condition × Trial × Age, $F(5, 114) = 2.12$, $p = .07$. Age-related change in the degree of Garner interference declined from about 185 ms to 100 ms when calculated only with the conflicting trials, in contrast to the flat developmental function when calculated only with the congruent trials (Fig. 4). The effect of spatial conflict was also noticeably accentuated in the more difficult Garner condition. The developmental change in Simon interference declined from about 195 ms to 100 ms in the orthogonal condition and from about 70 ms to 40 ms in the control condition.

DISCUSSION

The purpose of the present study was to explicate the developmental course of the processing interactions between two auditory dimensions of speech, the gender of the talker and the spatial location. Prior to discussing the results, however, we should note that the reaction-time difference in the control conditions (faster responses when spatial location was the target dimension) may have been influenced by some contextual and compatibility effects characterizing the experimental design. Regarding contextual effects, reaction times for the spatial-location dimension were obtained in the context of only congruent type of trials whereas reaction times for the talker-gender dimension were obtained in the context of both congruent and conflicting types of trials. A contextual difference between dimensions may have affected obtained reaction times (Morin & Forrin, 1962; Proctor & Reeve, 1990). It is also the case that reaction times when spatial location was the target dimension may have been faster in any event due to a greater compatibility between the stimulus–response mapping (Ben-Artzi & Marks, 1995). When the children were responding on the basis of spatial location, the response itself was based directly on spatial location (right-sided stimulus and right-sided response key). When the children were responding on the basis of talker gender, on the other hand, the relation between the stimulus and the response was arbitrary. The male talker was assigned to the left button for one half of children and to the right button for the other one half of children. The reaction-time difference between dimensions may be reflecting, at least to some extent, differences in the degree of processing required to map the target attributes for spatial location and talker gender to the response keys. We did not include a Stroop-like mapping between the spatial-location dimension and the response (left-sided response to right-sided stimulus) in this initial study. Overall, both the contextual and the compatibility effects represent interesting issues that require further study. Despite these effects, the results nevertheless contribute new information about the nature of and development of auditory processing interactions in a speeded-classification selective-attention task.

First, these data add to our knowledge about the developmental course of auditory processing interactions. The degree of Garner interference from to-be-ignored spatial-location or talker-gender variability is of a similar magnitude and does not show significant variation with age. A lack of developmental change for auditory processing interactions is in distinction to the more traditional finding that younger children's performance is more disrupted by irrelevant information in selective-attention tasks, involving multiple signals or multiple dimensions (e.g., Pearson & Lane, 1991; Strutt, Anderson, & Well, 1975). The present results seem consistent, however, with the suggestion that younger children focus more on perceptual attributes (Bach & Underwood, 1970; Felzen & Anisfeld, 1970).

The developmental courses of Garner interference for the talker-gender and spatial-location dimensions also provide evidence about Dempster's (1993) proposal that children have more difficulty than adults in resisting perceptual sources of interference. The lack of developmental change for Garner interference in the present study indicates that children do not always show less ability to resist interference from a perceptual source. A target perceptual dimension minimizes the interfering effect of a nontarget perceptual dimension. Apparently, the developmental effect of a nontarget dimension depends on the target dimension. Results suggest that theoretical models of age-related change in interference should specify developmental effects not only in terms of the source of interference but also in terms of the nature of the target.

The pattern of processing interactions seems to change dramatically in the presence of conflicting task-irrelevant information. Prior to these results, we hypothesized different developmental courses for Garner interference and Simon interference. We assumed that the effect of conflicting information would be reflected only in the Simon effect, which is based directly on congruent versus conflicting types of information. This was not the case. Simon interference did indeed show significant age-related change as predicted, but so too did Garner interference when the conflicting trials entered into the calculation of the interference effect. Thus, even a context of conflicting task-irrelevant information seems sufficient to produce significant age-related change in a child's ability to resist interference from irrelevant variability.

These results are consistent with current models of cognitive development emphasizing the importance of inhibitory mechanisms (Bjorklund & Harnishfeger, 1990, 1995; Dempster, 1992, 1993; Harnishfeger, 1995). In the present study, a conflicting type of trial sets up competing responses. An individual must inhibit his/her initial tendency to respond toward the source in space and respond by moving his/her hand in the opposite direction. Bjorklund and Harnishfeger propose that individuals become more efficient with increasing age at inhibiting primary response tendencies and resisting interference from competing sources. Findings of this study support their proposal that inhibitory mechanisms underlie some important aspects of developmental change.

In short, the present findings provide further evidence in support of the important suggestion that interference is a multifaceted phenomenon (Dempster, 1992, 1993). Age-related change in interference seems to vary depending on the source of the interference, the nature of the target, and the nature of the task. The relation between age, the nature of the task, and the nature of the stimulus also seems complex. A general characteristic of age in this study seems to be that the interfering effect of irrelevant variability is accentuated by spatial conflict and the interfering effect of spatial conflict is accentuated by irrelevant variability. Age-related change seems accentuated if the context of the processing task involves conflicting information, directly or indirectly. Overall, developmental change seems critically dependent on the nature of the target–nontarget combination and the nature of the information-processing task.

REFERENCES

Alluisi, E. (1965). Interaction of S-R compatibility and the rate of gain of information. *Perceptual and Motor Skills,* **20,** 815–816.

American National Standards Institue. (1989). *American standard specifications for audiometers (ANSI S3.6-1989).* New York: ANSI.

Andersen, K., Starck, L., Rosen, I., & Svensson, E. (1984). The development of simple acoustic reaction time in normal children. *Developmental Medicine & Child Neurology,* **26,** 490–494.

Annette, M. (1970). A classification of hand preference by association analysis. *British Journal of Psychology,* **61,** 303–321.

Ayres, J. (1978). *Southern California figure–ground visual perception test* (6th ed.). Los Angeles: Western Psychological Services.

Bach, M., & Underwood, B. (1970). Developmental changes in memory attributes. *Journal of Educational Psychology,* **61,** 292–296.

Ben-Artzi, E., & Marks, L. (1995). Visual–auditory interaction in speeded classification: Role of stimulus difference. *Perception & Psychophysics,* **57,** 1151–1162.

Bjorklund, D. (1995). *Children's thinking.* Pacific Grove, CA: Brooks/Cole.

Bjorklund, D., & Harnishfeger, K. (1990). The resources construct in cognitive development: Diverse sources of evidence and a theory of inefficient inhibition. *Developmental Review,* **10,** 48–71.

Bjorklund, D., & Harnishfeger, K. (1995). The evolution of inhibition mechanisms and their role in human cognition and behavior. In F. Dempster & C. Brainerd (Eds.), *Interference and inhibition in cognition* (pp. 141–173). San Diego: Academic Press.

Bryden, M. (1982). *Laterality, functional asymmetry in the intact brain.* New York: Academic Press.

Carrell, T., Smith, L., & Pisoni, D. (1981). Some perceptual dependencies in speeded classification of vowel color and pitch. *Perception and Psychophysics,* **29,** 1–10.

Clark, H., & Brownell, H. (1976). Judging up and down. *Journal of Experimental Psychology: Human Perception and Performance,* **1,** 339–352.

Comalli, P., Wapner, S., & Werner, H. (1962). Interference effects of Stroop color word test in childhood, adulthood, and aging. *Journal of Genetic Psychology,* **100,** 47–53.

Dempster, F. (1991). Inhibitory processes: A neglected dimension of intelligence. *Intelligence,* **15,** 157–173.

Dempster, F. (1992). The rise and fall of the inhibitory mechanism: Toward a unified theory of cognitive development and aging. *Developmental Review,* **12,** 45–75.

Dempster, F. (1993). Resistance to interference: Developmental changes in a basic processing mechanism. In M. Howe & R. Pasnak (Eds.), *Emerging themes in cognitive development: Vol. 1. Foundations* (pp. 3–27). New York: Springer-Verlag.

Donders, F. (1969). On the speed of mental processes. In W. Koster (Ed.), *Attention and performance II* (pp. 412–431). Amsterdam: North-Holland.

Drummey, A. B., & Newcombe, N. (1995). Remembering versus knowing the past: Children's explicit and implicit memories for pictures. *Journal of Experimental Child Psychology,* **59,** 549–565.

Dunn, L., & Dunn, L. (1981). *Peabody picture vocabulary test–revised* (regular ed.). Circle Pines, MN: American Guidance Service.

Eimas, P., Tartter, V., Miller, J., & Keuthen, N. (1978). Asymmetric dependencies in processing phonetic features. *Perception & Psychophysics,* **23,** 12–20.

Faber, H., Molen, M. v. d., Keuss, P., & Stoffels, E. (1986). An analysis of the tendency to react toward the stimulus source. *Acta Psychologica,* **61,** 105–115.

Felzen, E., & Anisfeld, M. (1970). Semantic and phonological relations in the false recognition of words by third- and sixth-grade children. *Developmental Psychology,* **55,** 163–168.

Finkel, D. (1973). A developmental comparison of the processing of two types of visual information. *Journal of Experimental Child Psychology,* **16,** 250–266.

Garner, W. (1974). *The processing of information and structure.* Potomac, MD: Erlbaum.

Garner, W., & Felfoldy, G. (1970). Integrality of stimulus dimensions in various types of information processing. *Cognitive Psychology,* **1,** 225–241.

Goodenough, F. (1935). The development of the reactive process from early childhood to maturity. *Journal of Experimental Psychology,* **18,** 431–450.

Graf, P. (1990). Life-span changes in implicit and explicit memory. *Bulletin of the Psychonomic Society,* **28,** 353–358.

Greenbaum, J., & Graf, P. (1989). Preschool period development of implicit and explicit remembering. *Bulletin of the Psychonomic Society,* **27,** 417–420.

Guttentag, R. (1985). A developmental study of attention to auditory and visual signals. *Journal of Experimental Child Psychology,* **39,** 546–561.

Harnishfeger, K. (1995). The development of cognitive inhibition. Theories, definitions, and research evidence. In F. Dempster & C. Brainerd (Eds.), *Interference and inhibition in cognition* (pp. 175–204). San Diego: Academic Press.

Hasbroucq, T., & Guiard, Y. (1991). Stimulus–response compatibility and the Simon effect: Toward a conceptual clarification. *Journal of Experimental Psychology: Human Perception and Performance,* **17,** 246–266.

Hayes, B. K., & Hennessy, R. (1996). The nature and development of nonverbal implicit memory. *Journal of Experimental Child Psychology,* **63,** 22–43.

Hedge, A., & Marsh, N. (1975). The effect of irrelevant spatial correspondence on two-choice response-time. *Acta Psychologica,* **39,** 427–439.

Hollingshead, A. (1975). *Four factor index of social status.* New Haven, CT: Yale University, Department of Sociology.

Jerger, S., Elizondo, R., Dinh, T., Sanchez, P., & Chavira, E. (1994). Linguistic influences on the auditory processing of speech by children with normal hearing or hearing impairment. *Ear & Hearing,* **15,** 138–160.

Jerger, S., Martin, R., & Pirozzolo, F. (1988). A developmental study of the auditory Stroop effect. *Brain and Language,* **35,** 86–104.

Jerger, S., Pirozzolo, F., Jerger, J., Elizondo, R., Desai, S., Wright, E., & Reynosa, R. (1993). Developmental trends in the interactions between auditory and linguistic processing. *Perception & Psychophysics,* **54,** 310–320.

Kail, R. (1995). Processing speed, memory, and cognition. In F. Weinert & W. Schneider (Eds.), *Memory performance and competencies. Issues in growth and development* (pp. 71–88). Mahwah, NJ: Erlbaum.

Kail, R., & Siegel, A. (1977). The development of mnemonic encoding in children: From perception to abstraction. In R. Kail & J. Hagen (Eds.), *Perspectives on the development of memory and cognition* (pp. 61–87). Hillsdale, NJ: Erlbaum.

Keating, D., & Bobbitt, B. (1978). Individual and developmental differences in cognitive-processing components of mental ability. *Child Development,* **49,** 155–167.

Ladavas, E. (1990). Some aspects of spatial stimulus–response compatibility in adults and normal children. In R. Proctor & T. Reeve (Eds.), *Stimulus–response compatibility* (pp. 145–162). Amsterdam/New York: Elsevier.

Lane, D., & Pearson, D. (1983). Attending to spatial locations: A developmental study. *Child Development,* **54,** 98–104.

Lew, H., Chmiel, R., Jerger, J., Pomerantz, J., & Jerger, S. (1997). Electrophysiologic indices of Stroop and Garner interference reveal linguistic influences on auditory and visual processing. *Journal of the American Academy of Audiology,* **8,** 104–118.

Lindberg, M. (1980). Is knowledge base development a necessary and sufficient condition for memory development? *Journal of Experimental Child Psychology,* **30,** 401–410.

Locke, J. (1997). A theory of neurolinguistic development. *Brain and Language,* **58,** 265–326.

Lu, C., & Proctor, R. (1995). The influence of irrelevant location information on performance: A review of the Simon and spatial Stroop effects. *Psychonomic Bulletin & Review,* **2,** 174–207.

MacLeod, C. (1991). Half a century of research on the Stroop effect: An integrative review. *Psychological Bulletin,* **109,** 163–203.

Montgomery, J., Scudder, R., & Moore, C. (1990). Language-impaired children's real-time comprehension of spoken language. *Applied Psycholinguistics,* **11,** 273–290.

Morin, R., & Forrin, B. (1962). Mixing of two types of S-R associations in a choice reaction time task. *Journal of Experimental Psychology,* **64,** 137–141.

Morrongiello, B., Fenwick, K., Hillier, L., & Chance, G. (1994). Sound localization in newborn human infants. *Developmental Psychobiology,* **27,** 519–538.

Mullennix, J., & Pisoni, D. (1990). Stimulus variability and processing dependencies in speech perception. *Perception and Psychophysics,* **47,** 379–390.

Pearson, D., & Lane, D. (1990). Visual attention movements: A developmental study. *Child Development,* **61,** 1779–1795.

Pearson, D., & Lane, D. (1991). Auditory attention switching: A developmental study. *Journal of Experimental Child Psychology,* **51,** 320–334.

Pedhazur, E. (1982). *Multiple regression in behavioral research: Explanation and prediction* (2nd ed.). New York: Holt, Rinehart & Winston.

Pomerantz, J. (1983). Global and local precedence: Selective attention in form and motion perception. *Journal of Experimental Psychology: General,* **112,** 516–540.

Pomerantz, J., Carson, C., & Feldman, E. (1994). Interference effects in perceptual organization. In S. Ballesteros (Ed.), *Cognitive approaches to human perception* (pp. 123–152). Mahwah, NJ: Erlbaum.

Pomerantz, J., Pristach, E., & Carson, C. (1989). Attention and object perception. In B. Shepp & S. Ballesteros (Eds.), *Object perception: Structure & process* (pp. 53–89). Hillsdale, NJ: Erlbaum.

Pomerantz, J., & Sager, L. (1975). Asymmetric integrality with dimensions of visual pattern. *Perception & Psychophysics,* **18,** 460–466.

Proctor, R., & Reeve, T. (Eds.). (1990). *Stimulus–response compatibility: An integrated perspective.* Amsterdam: North-Holland.

Rosinski, R., Pellegrino, J., & Siegel, A. (1977). Developmental changes in the semantic processing of pictures and words. *Journal of Experimental Child Psychology,* **23,** 282–291.

Ross, M., & Lerman, J. (1971). *Word intelligibility by picture identification.* Pittsburgh: Stanwix House.

Shepp, B., & Swartz, K. (1976). Selective attention and the processing of integral and nonintegral dimensions: A developmental study. *Journal of Experimental Child Psychology,* **22,** 73–85.

Simon, J., & Berbaum, K. (1990). Effect of conflicting cues on information processing: The 'Stroop effect' vs. the 'Simon effect'. *Acta Psychologica,* **73,** 159–170.

Simon, J., Craft, J., & Webster, J. (1973). Reaction toward the stimulus source: Analysis of correct responses and errors over a five-day period. *Journal of Experimental Psychology,* **101,** 175–178.

Simon, J., Small, A., Ziglar, R., & Craft, J. (1970). Response interference in an information processing task: Sensory versus perceptual factors. *Journal of Experimental Psychology,* **85,** 311–314.

Spence, M., & DeCasper, A. (1987). Prenatal experience with low-frequency maternal-voice sounds influences neonatal perception of maternal voice samples. *Infant Behavior and Development,* **10,** 133–142.

Stach, B. (1998). *Clinical audiology. An introduction* (pp. 230–240). San Diego: Singular.

Sternberg, S. (1969). The discovery of processing stages: Extensions of Donders' method. In W. Koster (Ed.), *Attention and performance II* (pp. 276–315). Amsterdam: North-Holland.

Stroop, J. (1935). Studies of interference in serial verbal reactions. *Journal of General Psychology,* **18,** 643–662.

Strutt, G., Anderson, D., & Well, A. (1975). A developmental study of the effects of irrelevant information on speeded classification. *Journal of Experimental Child Psychology,* **20,** 127–135.

Umilta, C., & Nicoletti, R. (1992). An integrated model of the Simon effect. In J. Alegria, D. Holender, J. J. d. Morais, & M. Radeau (Eds.), *Analytic approaches to human cognition* (pp. 331–350). New York: Elsevier.

Wechsler, D. (1974). *Wechsler intelligence scale for children-revised.* New York: Psychological Corporation.

Wechsler, D. (1981). *Wechsler adult intelligence scale–revised.* New York: Psychological Corporation.

Weissberg, R., Ruff, H., & Lawson, K. (1990). The usefulness of reaction time tasks in studying attention and organization of behavior in young children. *Developmental and Behavioral Pediatrics,* **11,** 59–64.

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