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Attention and gaze shifting in dual-task and go/no-go performance with vocal responding

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Evidence from go/no-go performance on the Eriksen flanker task with manual responding suggests that individuals gaze at stimuli just as long as needed to identify them (e.g., Sanders, 1998). In contrast, evidence from dual-task performance with vocal responding suggests that gaze shifts occur after response selection (e.g., Roelofs, 2008a). This difference in results may be due to the nature of the task situation (go/no-go vs. dual task) or the response modality (manual vs. vocal). We examined this by having participants vocally respond to congruent and incongruent flanker stimuli and shift gaze to left- or right-pointing arrows. The arrows required a manual response (dual task) or determined whether the vocal response to the flanker stimuli had to be given or not (go/no-go). Vocal response and gaze shift latencies were longer on incongruent than congruent trials in both dual-task and go/no-go performance. The flanker effect was also present in the manual response latencies in dual-task performance. Ex-Gaussian analyses revealed that the flanker effect on the gaze shifts consisted of a shift of the entire latency distribution. These results suggest that gaze shifts occur after response selection in both dual-task and go/no-go performance with vocal responding.

1. Introduction

The measurement of eye movements has a long tradition in experimental psychology (see Woodworth, 1938, for a review of the early literature). Whereas it has long been assumed that eye gaze durations do not reflect much about ongoing psychological processes, since the mid-1970s it has become increasingly clear that gaze durations and psychological processes are tightly linked (e.g., Rayner, 1998, for a review). Consequently, research into psychological processes has used gaze durations as an index of the duration of underlying psychological processes in various information processing tasks, such as reading, visual search, and scene perception. Moreover, research has shown that gaze shifting and orienting of attention are tightly linked (see Wright & Ward, 2008, for a review). While individuals can shift the focus of attention without an eye movement, they cannot move their eyes to one spatial location while paying full attention to another location (i.e., shifts of eye position require shifts of attention). Thus, a gaze shift indexes a shift of attention (Wright & Ward, 2008).

Assumptions about attention and gaze shifts in relation to underlying psychological processes play a central role in theories of human attention and performance (e.g., Meyer & Kieras, 1997a; Sanders, 1998). However, although researchers have found agreement on the link between attention and gaze shifts, controversy exists on exactly when these shifts occur in relation to stimulus identification, response selection, and motor programming during the course of planning actions. In particular, researchers disagree on whether attention and gaze shifts occur *before* or *after* response selection. The research reported in the present article addresses this issue in order to resolve the controversy.

The remainder of the article is organized as follows. We start by describing the two different accounts on gaze shifts in relation to response selection together with corresponding empirical evidence. In particular, evidence from go/no-go performance on the Eriksen flanker task (Eriksen & Eriksen, 1974) with manual responding suggests that gaze shifts occur before response selection, whereas evidence from dual-task performance with vocal responding suggests that gaze shifts occur after response selection. This difference in results may be due to the nature of the task situation (go/no-go vs. dual task) or the response modality (manual vs. vocal). Next, we report the results of a new eye tracking experiment that was designed to adjudicate between these two accounts. Finally, we discuss the theoretical consequences of our results.

According to a prominent account, gaze remains focused on a certain object just as long as is necessary to identify that object, after which the gaze moves away to other places or objects of interest (e.g., Sanders, 1998). Sanders and colleagues (Sanders, 1998; Sanders & Lamers, 2002; Sanders & Van Duren, 1998; Van Duren & Sanders, 1995) obtained empirical evidence in a number of studies that gaze

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shifts may occur before response selection. In experiments conducted by Sanders and Lamers (2002), participants were presented with Eriksen flanker stimuli displayed on the left side of a computer screen and a go-symbol displayed on the right side of the screen on some of the trials. The flanker stimuli consisted of the target letter A or B flanked by two incongruent As or Bs, congruent As or Bs, or neutral distractor letters (Xs) on each side, making up incongruent (e.g., BBABB), congruent (e.g., AAAAA), or neutral (e.g., XXAXX) stimuli. Participants responded to the target letter A by pressing a left response key and to the target letter B by pressing a right response key. Previous studies showed that response times (RTs) are longer on incongruent than congruent trials, which is taken to reflect the ease of response selection (e.g., Lamers & Roelofs, 2010; see Sanders, 1998, for a review). Whether a response was actually executed in the study of Sanders and Lamers (2002) depended on the presence of a go-symbol. The response to the flanker stimulus was withheld while the participant made a shift of gaze away from the flanker stimulus to the location of the go-symbol. In 80% of the trials, a single dot (the go-signal) was presented, indicating that the manual response to the flanker stimulus should be executed. A flanker effect was present in the manual RTs, but the latencies of the gaze shifts from the flanker stimuli to the go-symbol did not differ among congruent, incongruent, and neutral flanker trials. This finding suggests that the gaze shift was initiated before response selection.

In line with Sanders and colleagues, D. E. Meyer and Kieras (1997a, 1997b) hypothesized that gaze shifts are generally initiated before response selection. Such early gaze shifting was implemented in their strategic response-deferment model of dual-task performance (Meyer & Kieras, 1997a). In one of the experiments simulated by the model, participants vocally produced the words *red* or *green* in response to the letters H or N (the primary task) and made manual key-press responses to digits (the secondary task). The letters and digits were presented at different spatial locations, so that participants had to make a gaze shift between the locations of the two stimuli. In the simulations of performance in this experiment, the eyes were instructed to move from the letter to the digit when the perceptual processing of a letter had progressed far enough to identify it as an H or N, similar to what Sanders and colleagues assumed (Sanders, 1998; Sanders & Lamers, 2002; Sanders & Van Duren, 1998; Van Duren & Sanders, 1995). The simulations showed that the model provided an excellent fit to the empirical data. However, the assumption of early gaze shifting in the model was speculative, because evidence on the actual eye movements was not available from the simulated dual-task experiment.

Whereas D. E. Meyer and Kieras (1997a) assume that gaze shifts occur *before* response selection in vocal responding, eye tracking studies of dual-task performance with vocal responding suggest that gaze shifts occur *after* response selection. Roelofs (2007) presented picture–word combinations on the left side of a computer screen and left- or right-pointing arrows on the right side of the screen. The pictures and words could be semantically related (e.g., a pictured cat with the word *dog* superimposed) or unrelated (e.g., the word *house* superimposed), among other relations. Participants named the pictures and shifted their gaze to the arrow to indicate its direction by pressing a left or right button. The latencies of the vocal responses, gaze shifts, and manual responses were longer in the semantic than the unrelated condition. Similarly, Roelofs (2008a) observed that a phonological manipulation of vocal response planning was reflected in the vocal response, gaze shift, and manual response latencies (cf. Meyer, Roelofs, & Levelt, 2003). These results suggest that gaze shifts occur after response selection in vocal responding, different from what D. E. Meyer and Kieras (1997a) assumed.

In summary, whereas empirical evidence suggests that gaze shifts occur before response selection in go/no-go performance with manual responding (e.g., Sanders, 1998), recent evidence suggests that gaze shifts occur after response selection in dual-task performance with vocal responding (e.g., Roelofs, 2007, 2008a). This difference in results may be due to the nature of the task situation (go/no-go vs. dual task) or the response modality (manual vs. vocal). Roelofs (2007) provided evidence that the moment of gaze shifting in dual-task performance depends on the attentional demands of the primary task. For example, word reading is faster and requires less attention than picture naming, and gaze shifts occurred earlier for word reading than picture naming relative to articulation onset. D. E. Meyer and Kieras (1997a) observed that manual responding to the letters N and H was faster than vocal responding. Similarly, Lamers and Roelofs (2010) observed shorter RTs for manual than vocal responding in the Eriksen flanker and color–word Stroop tasks. The shorter RTs for manual than vocal responding may correspond to a difference in attentional demand. That is, manual responding may require less attention than vocal responding. If so, attention and gaze may shift earlier from one stimulus to another in a manual than a vocal task. In short, it may be that Sanders and colleagues (Sanders, 1998; Sanders & Lamers, 2002; Sanders & Van Duren, 1998; Van Duren & Sanders, 1995) obtained evidence for gaze shifting before response selection because of the manual responding in their experiments, whereas Roelofs (2007, 2008a) obtained evidence for gaze shifting after response selection because of the vocal responding.

We examined whether a difference in response modality provides sufficient explanation for the difference in results between earlier studies by having participants vocally respond to congruent and incongruent flanker stimuli (presented on the left side of a computer screen) and process left- or right-pointing arrows (presented on the right side of the screen). We employed an arbitrary stimulus–response mapping, as in the experiments of Sanders and colleagues (Sanders, 1998; Sanders & Lamers, 2002; Sanders & Van Duren, 1998; Van Duren & Sanders, 1995) with manual responding. The flanker stimuli contained target letters requiring the words *red* or *green* as vocal response, like in the experiment simulated by D. E. Meyer and Kieras (1997a). The target letters in our experiment were flanked by two congruent or incongruent letters on each side. The arrows consisted of the characters < and >. The spatial distance between flanker stimuli and arrows was larger than 20°, requiring a gaze shift from flanker stimulus to arrow. To make sure that the arrows were properly fixated and to minimize the chance that participants might identify the direction of the arrows by their peripheral vision while fixating elsewhere, the arrows were flanked by two Xs on each side, yielding XX<XX and XX>XX as stimuli. The arrows required a manual response (dual task) or determined whether the vocal response to the flanker stimuli had to be given or not (go/no-go). Participants were instructed to process the left (flanker) stimulus first, and then move their gaze to the right (arrow) stimulus. Note that, theoretically, in the dual-task condition, the responses to the flanker stimuli could be executed while the eyes shift, whereas in the go/no-go condition, the response has to be withheld until the go/no-go stimulus is perceived after a gaze shift.

If the nature of the task situation (dual task vs. go/no-go) is responsible for the difference in results between Sanders and colleagues (Sanders, 1998; Sanders & Lamers, 2002; Sanders & Van Duren, 1998; Van Duren & Sanders, 1995) and Roelofs (2007, 2008a), then gaze shifting should reflect the flanker effect in dual-task performance (replicating Roelofs, 2007, 2008a) but not in go/no-go performance (replicating Sanders & Lamers, 2002). However, if the response modality (vocal vs. manual) provides sufficient explanation for the difference in results between studies, then gaze shifting should reflect the flanker effect in both dual-task performance (replicating Roelofs, 2007, 2008a) and go/no-go performance (contrary to what Sanders & Lamers, 2002, observed for manual responding).

Although it has been generally assumed that the flanker effect arises in response selection (see Sanders, 1998, for a review), recent research has suggested that flanker stimuli may yield effects at both the level of stimulus identification and response selection (e.g., Verbruggen, Notebaert, Liefooghe, & Vandierendonck, 2006). In examining effects of stimulus- and response-conflict in a flanker task, Verbruggen et al. (2006) had participants identify central target-color lines and ignore flanking color lines by pressing corresponding response keys. Six colors were mapped onto three responses. Consequently, stimuli could be stimulus-incongruent (i.e., central color and flanker colors differed but were mapped onto the same response), response-incongruent (i.e., central color and flanker colors differed and were mapped onto different responses), or stimuli could be congruent (i.e., central color and flanker colors were the same). Verbruggen and colleagues observed RT differences among all three conditions, suggesting that the stimuli yielded effects at both the level of stimulus identification and response selection. To verify that the flanker effect in the present experiment arises at the level of response selection, we included two types of conflicting stimuli in our experiment, one to assess stimulus conflict (i.e., central and flanker letters differed but were mapped onto the same vocal response) and one to assess response conflict (i.e., central and flanker letters differed and were mapped onto different vocal responses).

Moreover, in addition to measuring the mean latencies of vocal responding, gaze shifting, and manual responding, we analyzed whole latency distributions. Following D. E. Meyer and Kieras (1997a), Roelofs (2007, 2008a) assumed that participants strategically set a criterion for when the shift between two stimuli (here, letter and arrow) should occur. This criterion concerns an event during the course of the vocal task processes, such as the completion of response selection. That is, the criterion is set in the information domain (i.e., a particular type of processing has to be done) rather than the temporal domain (i.e., a deadline). The position of the shift criterion within the processes related to the first stimulus (here, the flanker stimuli) serves to maintain acceptable levels of speed and accuracy, to minimize resource consumption and to avoid crosstalk between aspects of the tasks, and to satisfy instructions about task priorities. In the present experiment, participants were instructed to give the vocal response before the manual one in dual-task performance, or to execute or withhold the vocal response depending on the go/no-go signal. This account of gaze shifting predicts that the flanker effect should shift the whole latency distribution toward slower responding on incongruent as compared with congruent trials (cf. Roelofs, 2008a, 2008b, 2008c). This prediction was tested for the gaze shift latencies in the present experiment.

In summary, participants had to vocally respond to congruent and incongruent flanker stimuli and shift gaze to left- or right-pointing arrows. The arrows required a manual response (dual task) or determined whether the vocal response to the flanker stimuli had to be given or not (go/no-go). If the nature of the task situation (dual task vs. go/no-go) determines whether gaze shifts occur before or after response selection, then gaze shifting should reflect the flanker effect in dual-task performance but not in go/no-go performance. However, if the response modality is responsible, then gaze shifting should reflect the flanker effect in both dual-task performance and go/no-go performance. To assess whether the flanker effect arises at the level of response selection, we included two types of conflicting stimuli, one to assess stimulus conflict and the other to assess response conflict. Moreover, to assess whether participants strategically set a criterion for when the shift between the flanker and arrow stimuli should occur, we examined whether the flanker effect is present as a shift of the entire latency distribution.

2. Method

2.1. Participants

Eighteen Dutch students from Radboud University Nijmegen (13 of them female) volunteered to participate in the experiment. Their age varied from 17 to 30 years with a mean of 22.7 years. All had normal or corrected-to-normal vision. Participants were either paid 15 euro or received partial course credit for their participation.

2.2. Materials and design

The display consisted of two simultaneously presented stimuli. For the flanker stimulus presented on the left of the screen, four letters were used as central target: H, N, P, and S. These letters were also used as flankers (two on each side of the target letter, e.g., HHSHH) for each of the four targets, resulting in 16 different flanker stimuli. For the arrows presented on the right of the screen, only two stimuli were used: XX>XX and XX<XX. All letters were written in white capital letters, Arial font size 24. The letter strings were centrally placed in an invisible rectangle that was 30 mm $\times$ 9 mm (corresponding to 2.86° $\times$ .86° of visual angle at a viewing distance of approximately 60 cm). The horizontal distance between the middle of the flanker stimulus and the arrow was 25.2 cm (22.8°). The background of the computer screen was black.

In half of the trials, the flanker stimulus was congruent (i.e., target and flankers are associated with the same response), whereas in the other half they were incongruent (i.e., target and flankers evoke competing responses). In order to be able to differentiate response conflict from stimulus conflict, we used a design in which two target letters were mapped onto the same response. In particular, H and P were associated with one response, whereas N and S were associated with the alternative response. This target-to-response mapping was counterbalanced across participants. Due to this 2-to-1 design, the eight congruent stimuli were divided into two groups of equal size. For the congruent stimuli containing no conflicting information (henceforth CON-NC), the flankers were identical to the target (e.g., HHHHH). For the congruent stimuli containing stimulus conflict (henceforth CON-SC), the flankers were different from the target, but associated with the same response as this target (e.g., PPHPP). For the incongruent stimuli (henceforth INC), the flankers and the target evoked different responses (e.g., HHSHH). The arrow stimuli pointed equally often to the left as to the right.

Two different task conditions were employed, a dual-task condition and a go/no-go condition. In the dual-task condition, participants responded vocally to the target letters of the flanker stimuli by saying either “rood” (red) or “groen” (green) and manually to the arrow. If the arrow pointed to the left (i.e., XX<XX), a left key response was required, and vice versa if the arrow pointed to the right (i.e., XX>XX). In the go/no-go condition, only a vocal response was required to the flanker stimuli and the direction of the arrow indicated whether the response had to be executed or not. All participants were given both the dual-task and the go/no-go conditions. The order of task conditions was counterbalanced across participants.

The dual-task condition consisted of 32 practice trials, 12 dummy trials (i.e., 3 startup trials at the beginning of each block), and 256 test trials. The go/no-go condition consisted of 32 practice trials, 12 dummy trials, and 320 test trials (256 go-trials and 64 no-go trials). The presentation of the stimulus combinations was pseudo-randomized within a block of 64 trials (dual task) or 80 trials (go/no-go) with the following restrictions to reduce stimulus feature and response priming effects: For the flanker stimuli, each of the 16 stimuli was never immediately repeated and both the distractor condition (CON-NC, CON-SC, and INC) and the vocal response could never be the same on more than three consecutive trials.

2.3. Apparatus

The experiment was conducted on two microcomputers. The subject PC (Intel 82443 BX Pentium II processor) ran the software package Nijmegen Experimental Setup Utility (NESU) version 2006.11.22, which generated the visual displays and collected the experimental vocal and manual data. Vocal responses were measured by an electronic voice key and manual responses by a NESU button box with two buttons, with an accuracy of 1 ms (1000 Hz). Two CRT color monitors were connected to this subject computer. A 17 in. VGA monitor showed the stimuli displays to the participants. Infra-red display markers mounted on this subject monitor sensed the subject's head position, for adjusting the estimated gaze positions. The second (14 in.) monitor showed control information to the experimenter, such as the participant's response latencies, the button that had been pressed, and the correct response. A third color CRT monitor was connected to the second (operator) PC (Intel 82443 LX/EX Pentium II processor) which controlled the eye tracker device. Eye movements were measured using an SMI EyeLink-HiSpeed 2D headband-mounted eye tracking system (EyeLink I 2.11 SR Research Ltd. Mississauga, Canada) with two high-speed eye cameras and one high-speed head position compensation camera.

2.4. Procedure

The participants took part individually in a dimly illuminated, quiet room, separated from the experimenter by a large, sound-reducing curtain. The walls were painted black to prevent any distracting light-sources for the eye tracker cameras. The participant was seated in front of a computer monitor, at a viewing distance that was kept at approximately 60 cm. As the vocal responses made the use of a chin support undesirable, the experimenter verified the viewing distance by means of a measuring rod that was placed between the participant's forehead and the computer screen (this was repeated occasionally in the breaks). The button box and voice key microphone were placed on a table in front of the participant. Participants were given written instructions for the first task condition (dual task or go/no-go), which were repeated orally by the experimenter.

Next, the eye tracker headband was mounted on the participant's head and the eye tracker device was calibrated and validated. For pupil-to-gaze calibration, a grid of three by three positions had been defined. During a calibration trial, a fixation target (i.e., a small black circle) appeared once, in random order, in each of these positions for one second. Participants were asked to fixate upon each target until the next target appeared. After the calibration trial, the estimated positions of the participant's fixations and the distances from the fixation targets were displayed to the experimenter. Calibration was considered adequate if there was at least one fixation within 1.5° of each fixation target. When calibration was considered poor, the procedure was repeated, sometimes after adjusting the eye cameras. Successful calibration was followed by a pupil-to-gaze validation trial. For the participants, this trial did not differ from the calibration trial, but the data collected during the validation trial were used to estimate the participant's gaze positions, and the error (i.e., the distance between the estimated gaze position and the target position) was measured. Validation was considered completed if the average error was below 1.0° and the worst error below 1.5°. Depending on the result of the validation trial, the calibration and validation trials were repeated or testing began.

Upon completing the eye tracker setup procedures, the light was switched off and 32 practice trials were given. The experimenter verified that the gaze reflected the instructed order, that is, moved from the flanker stimulus on the left to the arrow on the right. Then, any remaining questions about the task were answered by the experimenter together with feedback about the performance in the practice trials. Next, either 256 test trials (in the dual-task condition) or 320 test trials (in the go/no-go condition) were presented, divided in four blocks of equal size, with a short break in between. Each block started with three additional dummy trials to reduce startup effects. After completing the first task, the eye tracker head band was removed from the head, the light was switched on, and a break of about 10 min was given. Then, the instruction for the second task condition was given both written and orally. The eye tracker head band was mounted for a second time, the viewing distance was checked, the calibration and validation processes were repeated and the light was switched off. After finishing the second task (trials composition the same as described above for the first task), participants received some feedback on their performance and the general purpose of this experiment.

The instructions for the dual-task condition were as follows. At the start of each trial, participants had to focus on the left (empty) side of the screen. As soon as the stimuli appeared, the participant had to vocally respond to the central letter of the flanker stimulus by saying “rood” or “groen”, move the gaze to the arrow, and indicate the direction of the arrow by pressing either the left or the right button. The instructions for the go/no-go condition were slightly different. As with the dual-task condition, each trial started with focusing on the left side of the screen. When the stimuli appeared, the participant had to process the central letter of the flanker stimulus and move the gaze to the right (go/no-go) stimulus. An arrow pointing to the left (i.e., XX<XX) indicated a go-trial in which the prepared vocal response to the flanker stimulus had to be given. If the arrow pointed to the right (XX>XX), the participant had to countermand the prepared response (a no-go trial). Participants were instructed to move the eyes in the order just described (that is, not starting with the arrow and moving the gaze to the flanker stimulus) and encouraged to react as quickly and accurately as possible.

Each trial took 5 s and went as follows: An empty screen was presented for 2 s. Then, the stimulus display was shown for 3 s. The latencies of the vocal responses, gaze shifts, and manual responses (in the dual-task condition) were measured from stimulus onset. Voice key errors and incorrect vocal responses to the flanker stimuli were registered on-line by the experimenter. The beginning of a break was indicated by the Dutch word *pauze* (*pause*) for 1500 ms. The beginning of a block was preceded by the word *attentie* (*attention)* for 1500 ms. An experimental session lasted about 2 h.

2.5. Analyses

The participants' gaze shifts were analyzed using a computer program written by the first author. The gaze shift from flanker stimulus to the arrow was defined as the saccade from left to right in which the horizontal gaze position passed the (invisible) vertical line through the center of the computer screen. In each trial, the stimulus onset was subtracted from the start time for this particular saccade to obtain the duration for fixating on the flanker stimulus. Although viewing was binocular and the positions of both eyes were tracked, only the data of the left eye was analyzed. Because the stimuli were always presented at the same spatial positions on the screen, there was no fixation point to indicate the position of the flanker stimulus before stimulus onset. Indeed, as anticipated, participants were virtually always fixating this position at the beginning of a trial.

The following data-trimming procedure was used. First, the three dummy trials that were added at the beginning of each block to reduce startup effects were omitted from data analyses. Second, a manual response was considered incorrect when the wrong button was pressed (0.3% of the dual-task trials), whereas a vocal response was incorrect when it included a speech error or when a wrong word was produced (1.2% of the dual-task trials and 0.5% of the go/no-go trials). These incorrect response trials were discarded. Third, to reduce post-error slowing effects (Rabbitt, 1966), also each trial immediately following an incorrect response was omitted from analyses (1.4% of the dual-task trials and 0.4% of the go/no-go trials). Fourth, trials in which the voice key malfunctioned, was triggered inappropriately, or the measured vocal RTs were shorter than 300 ms or longer than 3000 ms were discarded (2.3% of the dual-task trials and 2.1% of the go/no-go trials). Fifth, trials in which the measured gaze duration was shorter than 200 ms, in which the gaze started at the right side of the screen, or in which the gaze position did not cross the vertical axis through the screen center from left-to-right were classified as gaze errors and omitted from analyses (1.1% of the dual-task trials and 0.8% of the go/no-go trials). The latencies were analyzed for the remaining 93.8% correct trials in the dual-task condition and 96.2% correct trials in the go/no-go condition. Because there were virtually no differences in incorrect responses among flanker conditions, the errors were not further analyzed.

For the dual-task condition, mean latencies were subjected to a two-way repeated measures analysis of variance (ANOVA) with *measure* (gaze, vocal, and manual) and *distractor type* (CON-NC, CON-SC, and INC) as within-subjects factors. The same held for the go/no-go condition, except that this task has no manual responses. As the absolute mean latencies for the different measures (vocal, gaze, and manual) were expected to differ substantially, standard scores (z) with zero mean and unit standard deviation (Winer, Brown, & Michels, 1991) were used for comparisons of the magnitude of effects between measures.

To compare gaze shift latencies between the two task conditions, a two-way repeated measures analysis of variance (ANOVA) was conducted on the mean gaze shift latencies for the correct trials, with *distractor type* (CON-NC, CON-SC, INC) and *task condition* (dual task, go/no-go) as within-participants factors. An alpha level of .05 was used for all statistical tests.

The gaze shifts were not only analyzed in terms of mean latencies but also at the level of distributional characteristics by performing Vincentile and ex-Gaussian analyses. Vincentile analyses do not depend on prior distributional assumptions and examine the raw distributions directly (Ratcliff, 1979). To obtain the distributions, the rank-ordered gaze shift latencies for each participant were divided into deciles (10% quantiles) and mean latencies were computed for each decile, separately for each task condition and distractor type (for a similar approach, see Lamers & Roelofs, 2007; Lamers, Roelofs, & Rabeling-Keus, 2010; Roelofs, 2008a, 2008b, 2008c; Schneider & Verbruggen, 2008). By averaging these decile means across participants, Vincentized cumulative distribution curves were obtained. Vincentizing the data across individual participants provides a way of averaging data to obtain group distributions while preserving the shapes of the individual participant distributions. Ex-Gaussian analyses characterize a latency distribution by assuming an explicit function for the shape of the distribution. The ex-Gaussian function consists of a convolution of a Gaussian (i.e., normal) and an exponential distribution, which generally provides good fits to empirical latency distributions (e.g., Luce, 1986; Ratcliff, 1979). The analyses provide three parameters characterizing a distribution: μ (mu) and σ (sigma) reflecting the mean and standard deviation of the Gaussian portion, and τ (tau) reflecting the mean and standard deviation of the exponential portion. The mean of the whole distribution equals the sum of μ and τ. Thus, ex-Gaussian analyses decompose mean latencies into two additive components, which characterize the leading edge (μ) and the tail (τ) of the underlying distribution. An effect in μ indicates a shift of the entire distribution, whereas τ reflects effects on skewing.

The ex-Gaussian parameters μ, σ, and τ were estimated from the data using the quantile maximum likelihood estimation method proposed by Brown and Heathcote (2003). The parameters were estimated per task condition and distractor type for each participant individually using the QMPE software using ten quantiles (Brown & Heathcote, 2003). All estimations converged within 25 iterations. The ex-Gaussian parameters were then submitted to ANOVAs with the crossed variables task condition and distractor type.

3. Results

Fig. 1 shows for each distractor type (CON-NC, CON-SC, and INC) the mean latencies for the vocal responses to the flanker stimuli, the gaze shifts, and the manual responses to the arrows as well as the percentages of incorrect responses for the dual-task (left panel) and go/no-go (right panel) conditions. The figure shows that for both task conditions, a flanker effect is present in the vocal response latencies. Vocal responding took longer in the incongruent condition than in both types of congruent conditions. Importantly, the gaze shift latencies also showed this flanker effect, regardless of the task condition. Moreover, the flanker effect was present in the manual response latencies in the dual-task condition. The figure shows that there is no effect of stimulus conflict in the flanker task. That is, for each measure in both task conditions, latencies appear to be similar in the CON-SC and CON-NC conditions. Thus, the flanker effect appears to be one of response conflict.

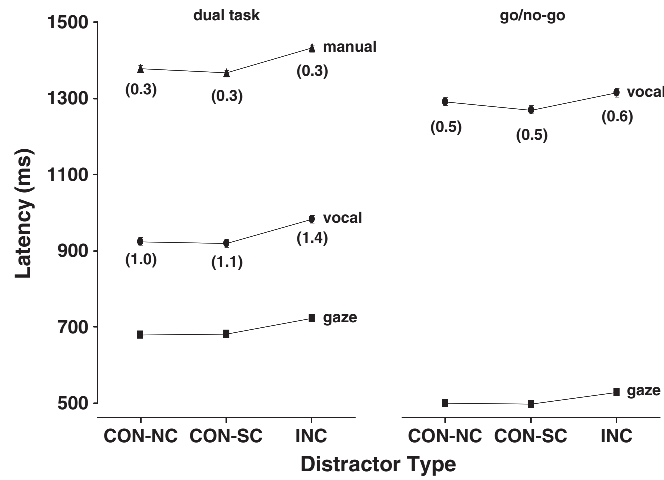

Fig. 1. Mean latencies for the vocal responses, gaze shifts, and manual responses per distractor condition for dual-task and go/no-go performance. Numbers between parentheses denote the percentages of incorrect (vocal and manual) responses for each condition. CON-NC = congruent with no conflict, CON-SC = congruent with stimulus conflict, INC = incongruent. Error bars indicating the standard error of the mean are too small to be clearly visible in the figure.

The statistical analysis of the standard (z) scores comparing the flanker effects among the vocal responses, gaze shifts, and manual responses in dual-task performance yielded a main effect of distractor type, $F(2, 34) = 33.86$, $p < .001$, which did not differ among measures, $F(4, 68) = 2.16$, $p = .105$. Pairwise comparisons revealed that latencies were longer on INC trials than CON-NC and CON-SC trials, both $ps < .001$, whereas the latter two did not differ, $p = .51$, suggesting that the flanker effect arises at the level of response selection rather than stimulus identification.

The statistical analysis of the z-scores comparing the flanker effects between the vocal responses and gaze shifts in go/no-go performance yielded a main effect of distractor type, $F(2, 34) = 15.07$, $p < .001$, which was similar for both measures as indicated by the absence of a measure × distractor type interaction, $F(2, 34) = 3.25$, $p = .053$. Pairwise comparisons revealed that latencies were longer on INC trials than CON-NC and CON-SC trials, $p = .002$ and $p < .001$, respectively, and that there was no difference between the latencies in the two congruent conditions, $p = .186$, suggesting that the flanker effect arises at the level of response selection rather than stimulus identification.

The statistical analysis of the gaze shift latencies showed a main effect of task condition, $F(1,17) = 38.35$, $p < .001$, indicating that the gaze shift latencies were much shorter in the go/no-go condition (i.e., 509 ms, on average) than in the dual-task condition (694 ms, on average). The significant main effect of distractor type, $F(2,34) = 21.02$, $p < .001$, mirrors the above mentioned finding that the flanker effect was present in the gaze shift latencies, whereas the nonsignificant interaction between task condition and distractor type, $F(2,34) = 2.10$, $p = .141$, indicates that this effect of distractor type is similar across tasks.

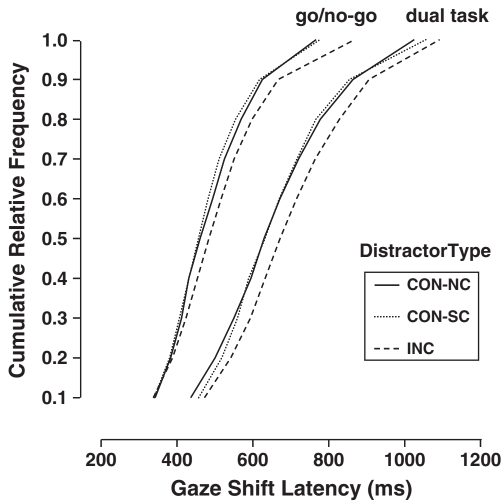

Fig. 2. Vincentized cumulative distribution curves for the gaze shift latencies per distractor condition in go/no-go and dual-task performance. CON-NC = congruent with no conflict, CON-SC = congruent with stimulus conflict, INC = incongruent.

Fig. 2 shows the distributions of the gaze shift latencies for the three distractor types in the dual-task and go/no-go conditions. The figure shows that the flanker effect was present throughout almost the entire latency range regardless of task condition, except for the shortest latencies in the go/no-go condition. The latter may reflect a floor effect. Table 1 gives the ex-Gaussian parameter estimates for the gaze shift latencies per task condition and distractor type. The table reveals that the task and distractor effects on the Gaussian parameters μ and σ are similar to the pattern observed in the mean latencies, whereas there are no effects in the exponential parameter τ.

Statistical analyses revealed that for μ, there were main effects of task condition, $F(1, 17) = 33.54$, $p < .001$, and distractor type, $F(1, 17) = 3.63$, $p = .037$. There was no interaction between task condition and distractor type, $F(2, 34) = 1.25$, $p = .30$. This suggests that the effect of task condition and distractor type was to shift the entire latency distribution. Pairwise comparisons revealed that μ was larger on INC trials than on CON-NC trials ($p = .005$) and on CON-SC trials ($p = .044$), whereas the latter two did not differ, $p = .62$, suggesting that the flanker effect arises at the level of response selection rather than stimulus identification. For σ, there were main effects of task condition, $F(1, 17) = 7.59$, $p < .01$, and distractor type, $F(1, 17) = 6.11$, $p < .005$. There was no interaction between task condition and distractor type, $F(2, 34) = 1.44$, $p = .25$. Pairwise comparisons revealed that σ was larger on INC trials than on CON-NC trials ($p = .005$) and on CON-SC trials ($p = .008$), whereas the latter two did not differ, $p = .20$, suggesting that the flanker effect arises at the level of response selection rather than stimulus identification. For τ, there was a marginally significant main effect of task condition, $F(1, 17) = 4.17$, $p = .057$, but no effect of distractor type, $F(1, 17) < 1$, $p = .747$. There was no interaction between task condition and distractor type, $F(2, 34) < 1$, $p = .52$.

To summarize, the task and distractor effects were present in Gaussian parameters μ and σ, but not in the exponential parameter τ. This suggests that task condition and distractor type shifted the entire latency distribution. These results support the assumption of D. E. Meyer and Kieras (1997a) and Roelofs (2007, 2008a, 2008c) that participants set a criterion for when the shift between flanker and arrow stimuli should occur.

Table 1
Mean ex-Gaussian parameter estimates (μ, σ, and τ) for the gaze shift latencies as a function of task condition and distractor type.

Task condition/distractor type	μ	σ	τ
Dual task			
CON-NC	539	98	128
CON-SC	535	82	140
INC	573	104	147
Go/No-go			
CON-NC	369	45	119
CON-SC	385	51	106
INC	396	71	115

Note. Mean ex-Gaussian parameter estimates are given in milliseconds. CON-NC = congruent with no conflict, CON-SC = congruent with stimulus conflict, INC = incongruent.

4. Discussion

Evidence from go/no-go performance with manual responding suggests that individuals gaze at stimuli just as long as needed to identify them (e.g., Sanders, 1998). In contrast, evidence from dual-task performance with vocal responding suggests that gaze shifts occur after response selection (e.g., Roelofs, 2007, 2008a, 2008c). This difference in results may be due to the nature of the task situation (go/no-go vs. dual task) or the response modality (manual vs. vocal). We examined this issue by having participants vocally respond to congruent and incongruent flanker stimuli and shift gaze to left- or right-pointing arrows. The arrows required a manual response (dual task) or determined whether the vocal response to the flanker stimuli had to be given or not (go/no-go). If the nature of the task situation, dual task versus go/no-go, is responsible for the difference in results between Sanders and colleagues (Sanders, 1998; Sanders & Lamers, 2002; Sanders & Van Duren, 1998; Van Duren & Sanders, 1995) and Roelofs (2007, 2008a, 2008c), then gaze shifting should reflect the flanker effect in dual-task performance (replicating Roelofs, 2007, 2008a, 2008c) but not in go/no-go performance (replicating Sanders & Lamers, 2002). However, if the response modality, vocal versus manual, is responsible for the difference in results between studies, then gaze shifting should reflect the flanker effect in both dual-task performance (replicating Roelofs, 2007, 2008a, 2008c) and go/no-go performance (contrary to what Sanders & Lamers, 2002, observed for manual responding). The results of the present experiment revealed that vocal response and gaze-shift latencies were longer on incongruent than congruent trials in both dual-task and go/no-go performance. In dual-task performance, the flanker effect was also present in the manual response latencies for the right (arrow) stimulus, reflecting a propagation of the distractor effect in the vocal responses to the flanker stimulus. Our pattern of results suggest that gaze shifts occur after response selection in both dual-task and go/no-go performance with vocal responding.

Since the delay between the gaze shift onset and the manual response in the dual-task condition was rather constant (699, 684, and 709 ms for the CON-NC, CON-SC, and INC conditions, respectively), our results support the claim that a gaze shift indexes an attention shift. Our results indicate that conclusions about attentional processes derived from experiments with visual displays showing multiple stimuli should take into account the fact that the chosen response modality may influence the precise point at which the eyes start moving.

Although it has been generally assumed that the flanker effect arises in response selection (see Sanders, 1998, for a review), recent research (Verbruggen et al., 2006) suggested that the effect may stem not only from response conflict, but also from stimulus conflict due to greater difficulty in perceptual processing of the target in the incongruent condition than in the congruent condition. Thus, the presence of a flanker effect (incongruent vs. congruent) in the gaze shift latencies in the go/no-go condition may reflect a conflict in stimulus identification, in agreement with the view that gaze shifts happen after stimulus identification and before response selection. To exclude this latter possibility, we used a design in which response conflict and stimulus conflict could be distinguished. We used two target letters per response, so that targets and flankers could be same and require the same response (CON-NC), targets and flankers could be different but require the same response (i.e., CON-SC, indexing stimulus conflict), and targets and flankers could be different and require different responses (i.e., INC, indexing response conflict). Our findings show that for the vocal responses and the gaze shifts in both task conditions (dual task and go/no-go), there was an effect of response conflict (i.e., a latency difference between CON-SC and INC), but no effect of stimulus conflict (i.e., no latency difference between CON-SC and CON-NC). This suggests that the gaze shifts depend on the time to plan a vocal response and not on the time to perceptually separate the central target from the surrounding flankers.[1]

The present findings support the view of Roelofs (2007, 2008a) that gaze shifts occur after response selection in vocal responding, and the findings challenge the view of D. E. Meyer and Kieras (1997a) and Sanders and colleagues (Sanders, 1998; Sanders & Lamers, 2002; Sanders & Van Duren, 1998; Van Duren & Sanders, 1995) that gaze shifts generally occur before response selection. Importantly, with vocal responding, gaze shifts occur after response selection both in dual-task performance (contrary to what Meyer & Kieras, 1997a, assumed) and in go/no-go performance (contrary to what Sanders, 1998, assumed). The present results indicate that response modality (vocal, manual) provides sufficient explanation for the difference in results between the studies of Roelofs (2007, 2008a) and Sanders and colleagues (Sanders, 1998; Sanders & Lamers, 2002; Sanders & Van Duren, 1998; Van Duren & Sanders, 1995). The present results show that the difference in task situation (dual task vs. go/no-go) cannot be responsible for the difference in results, because otherwise the results of Sanders and colleagues should have been replicated for go/no-go performance with vocal responding in the present study, which was not the case. However, it remains possible that an interaction between response modality and task situation can also explain the difference between studies. If so, manual responding (as opposed to the present vocal responding) to the flanker stimuli in a dual-task situation should yield a flanker effect on the gaze shift latencies, whereas such an effect should not be present in go/no-go performance (as observed by Sanders et al.). This may be tested in future research. Importantly, the present study indicates that response modality provides sufficient explanation for the difference in results between earlier studies, which we aimed to assess. The current findings on vocal responding agree with earlier observations made on gaze shifting and vocal response planning, as we explain next.

Research on vocal response planning has shown that there is a close link between the duration of word planning and gaze shifts in object naming (e.g., Korvorst, Roelofs, & Levelt, 2006; Meyer & Van der Meulen, 2000). For example, when participants are asked to name two spatially separated objects (e.g., one to the left and the other to the right), they gaze longer at first-to-be-named objects with disyllabic names (e.g., *lion*) than with monosyllabic names (e.g., *cat*) even when the object recognition times are the same (Meyer et al., 2003). The effect of the phonological length suggests that the shift of gaze from one object to the other is initiated only after the phonological form of the name for the object has been planned sufficiently and the corresponding articulatory program is available. The phonology-dependent gaze shifts may promote naming speed and accuracy by preventing interference from the other object name. Moreover, the phonology-dependent gaze shift may diminish resource consumption. Articulating a word such as “cat” or “lion” can easily take half a second or more. If gaze shifts are initiated after identifying the first object, the planning of the name for the second object may be completed well before articulation of the name for the first object has been finished. This means that the second vocal response needs to be buffered for a relatively long time. By starting perception of the second object when planning the first object name has progressed sufficiently, the use of buffering resources can be limited (Levelt & Meyer, 2000).

However, the phonology-dependent gaze shifts are also obtained when the second naming response is replaced by a manual response to a left- or right-pointing arrow (Roelofs, 2008a). That is, gaze shifts still depend on phonological encoding when participants name an object and manually respond to an arrow. This finding suggests that the avoidance of response buffering and the prevention of interference from the second response are not the only reasons for a phonology-dependent gaze shift. Rather, some aspect of vocal response planning itself would appear to be the critical factor. If attention is required until the word has been planned far enough, this would explain why attention, indexed by eye gazes, is sustained to word planning until the phonological form is planned (Roelofs, 2007, 2008a). This should hold regardless of the need for response buffering and the prevention of interference, as empirically observed (Roelofs, 2007, 2008a, 2008c).

Evidence suggests that shifts of gaze occur closer to articulation onset in naming objects than in reading their names (Roelofs, 2007). Participants were presented with picture–word combinations, displayed on the left of a computer screen, and left- or right-pointing arrows, displayed on the right of the screen. The tasks were to name the picture or word (depending on the task assignment) and to shift gaze to the arrow to indicate its direction by pressing a left or right response key. Mean latencies for the vocal responses and gaze shifts in object naming were longer in a semantic condition (e.g., a pictured cat combined with the word *dog*) than an unrelated condition (e.g., a pictured cat combined with the word *house*), whereas latencies did not differ between distractor conditions in word reading. The finding of a distractor effect in object naming but not in word reading suggests differences in attentional demands between the two tasks (Roelofs, 2003). Gaze shifts occurred about 66 ms before articulation onset in object naming, whereas they happened already about 156 ms before articulation onset in word reading. If attention is needed until the response word has been planned sufficiently, this explains why attention, as indexed by eye gazes, is sustained longer to word planning in object naming than in word reading.

Evidence suggests that the allocation of attention in dual-task performance is not fixed but strategically determined (cf. Meyer & Kieras, 1997a). Attention seems to be sustained to a task just as long as needed to achieve acceptable levels of speed and accuracy (e.g., Roelofs, 2007). How long attention is sustained may depend on the nature of the secondary task. When participants name pictured objects (primary task) and manually respond to arrows or tones (secondary task), a phonological manipulation of word planning affects the manual responses to the arrows but not to the tones. This suggests that participants shift attention earlier to the tones than to the arrows, presumably because vocal response planning hampers auditory perception (Roelofs, 2008a). Consequently, the tone task needs to be protected against interference from speech planning. This might be achieved through attentional enhancement of the processing of the tones. However, there was a cost to the earlier shifts of attention to the tones, namely an increase in object naming errors. To conclude, evidence on picture naming and word reading in simple dual-task situations suggests that spoken word planning may require some attention. Moreover, it seems that attention may to some degree flexibly be allocated to vocal response planning to promote speed and accuracy.

Ex-Gaussian distributional analyses on the gaze shift latencies in the current study revealed that the distractor effect was present in the Gaussian parameters μ and σ, but not in the exponential parameter τ.

[1] Verbruggen et al. (2006) discussed the possibility that their observation of the flanker effect originating from stimulus conflict might be specific to the arbitrary stimulus–response mappings used in their experiment. However, in our present experiment, we also used arbitrary stimulus–response mappings (e.g., saying “rood” to the letter N) and still we observed the more common finding that the flanker effect stems from response conflict and not from stimulus conflict. Future research might further explore what causes this discrepancy in results. For the purpose of our present study, it is sufficient to have established that the gaze onset latencies were depending on response conflict in the flanker stimulus, and not just on perceptual conflict.

This suggests that distractor type shifted the entire latency distribution of the gaze shifts. These results support the assumption of D. E. Meyer and Kieras (1997a) and Roelofs (2007, 2008a, 2008c) that participants set a criterion for when the shift between flanker and arrow stimuli should occur.

The analysis of the latency distributions suggests that the complete distribution was shifted. However, Fig. 2 shows that the flanker effect is absent for the fastest gaze shifts in the go/no-go condition. As indicated, we believe this is due to a floor effect in speeding up gaze shifts. For the flanker task that we used, Meyer and Kieras (1997a) estimated that the gaze shift latency is 335 ms when the shift is prepared and initiated immediately after stimulus onset. This may be a lower estimate, because the presence of a flanker effect in the go/no-go condition indicates that gaze shifting was dependent on response selection in the present study. Still, the estimate of 335 ms already comes close to the fastest gaze shift latencies in the go/no-go condition. This means that there is not much room for congruent flankers to speed up gaze shifting, explaining the absence of a flanker effect in the lowest deciles.

Although the vocal task was the same in the dual-task and go/no-go conditions in the present experiment (unlike Roelofs, 2007), the gaze shift latencies were on average 185 ms shorter in the go/no-go condition than in the dual-task condition. Thus, although gazes shifted after response selection in both the go/no-go and the dual-task conditions (as suggested by the presence of the flanker effects in the gaze shift latencies), attention seemed to shift earlier in the go/no-go than the dual-task condition. D. E. Meyer and Kieras (1997a, 1997b) argued that the shift point in dual-task performance may be dynamically set by participants based on the relative difficulty of the tasks involved. More specifically, D. E. Meyer and Kieras (1997b) made a distinction between cautious and daring strategies. The shift point may be set earlier for the daring than the cautious strategy. In the present experiment, the go/no-go task condition required only one response or none at all. Therefore, there was no conflict between responses to the flanker and arrow stimuli. In contrast, the dual-task condition required two successive responses and their planning might have interfered with each other (cf. Levelt & Meyer, 2000; Meyer et al., 2003). The present results show that the eyes moved to the arrow before the vocal response to the flanker stimulus had started (cf. Meyer et al., 2003; Roelofs, 2007, 2008a). Consequently, preparing a response to the arrow might interfere with vocal response preparation (cf. Roelofs, 2007). To remain highly accurate in the dual-task condition, eye fixation on the flanker stimulus may be maintained until the vocal response planning process reaches a point where other responses can no longer interfere. This difference between dual-task and go/no-go performance may have resulted in a more cautious strategy for the gaze control in the dual-task than the go/no-go condition. A dynamical setting of shift point based on task difficulty may have caused the observed difference in gaze shift latency between the two task conditions in the present study. In line with this account, Sanders and Rath (1991) demonstrated that under extreme conditions of speed-accuracy trade-off, even perceptual variables (stimulus degradation) do not influence gaze shift latency.

To conclude, previous evidence from go/no-go performance with manual responding suggests that individuals gaze at stimuli just as long as needed to identify them. In contrast, previous evidence from dual-task performance with vocal responding suggests that gaze shifts occur after response selection. This difference in results may be due to the nature of the task situation (go/no-go vs. dual task) or the response modality (manual vs. vocal). We examined this by having participants vocally respond to congruent and incongruent flanker stimuli and shift gaze to left- or right-pointing arrows. The arrows required a manual response (dual task) or determined whether the vocal response to the flanker stimuli had to be given or not (go/no-go). Vocal response and gaze shift latencies were longer on incongruent than congruent trials in both dual-task and go/no-go performance. The flanker effect was also present in the manual response latencies in dual-task performance. Distributional analyses revealed that the flanker effect on the gaze shifts was present as a shift of the entire latency distribution. These results suggest that gaze shifts occur after response selection in both dual-task and go/no-go performance with vocal responding.

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