Don't look! Don't touch!
Inhibitory control of eye and hand movements

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Inhibitory control of eye and hand movements was compared in the stop-signal task. Subjects moved their eyes to the right or left or pressed keys on the right or left in response to visual stimuli. The stimuli were either central (angle brackets pointing left or right) or peripheral (plus signs turning into Xs left or right of fixation), and the task was either pro (respond on the same side as the stimulus) or anti (respond on the opposite side). Occasionally, a stop signal was presented, which instructed subjects to inhibit their responses to the go stimulus. Stop-signal reaction times (SSRTs) were faster overall for eye movements than for hand movements, and they were affected differently by stimulus conditions (central vs. peripheral) and task (pro vs. anti), suggesting that the eyes and hands are inhibited by different processes operating under similar principles (i.e., a race between stop and go processes).

We interact with objects in the environment by way of eye and hand movements. Anatomical evidence suggests that the eyes and hands are controlled, in part, by different pathways (Keele, 1986; Schall, 1991). On the other hand, behavioral evidence suggests that the oculomotor and manual motor systems are interrelated during the production of an aimed movement toward some target. For example, Abrams, Meyer, and Kornblum (1990) found that people almost always direct their eyes to a target to which a manual movement must be made, and manual movements are less accurate if subjects are not allowed to move their eyes. Perhaps most dramatically, Bekkering, Abrams, and Pratt (1995) found that adaptation of the oculomotor system transfers to the manual motor system; they found that pointing movements by an unseen hand were shorter when the eyes were adapted to make short movements than when the eyes were unadapted, suggesting that, at some level, the eyes and the hands rely on a common code or signal.

The purpose of the present study was to compare eye movements and hand movements on another dimension of motor behavior—namely, its withholding. Inhibition of voluntary movement is an important part of executive control over cognition and action (Logan, 1985). Our goal was to determine whether inhibition of eye and hand movements is governed by the same or different processes.

To measure inhibition, we used the stop-signal task. In the stop-signal task, subjects are presented with a go signal to which they must respond immediately, and, on occasion, a stop signal is also presented, which tells them to inhibit their response to the go task. The main datum of interest

is whether or not subjects succeed in inhibiting their go response when the stop signal occurs. The probability of inhibiting the go response depends on the delay between the go signal and the stop signal (stop-signal delay) and on the reaction time (RT) to the go signal: Subjects are more likely to inhibit, the shorter the delay and the longer the go RT (for a review, see Logan, 1994).

Performance on the stop-signal task has been modeled quite successfully as a race between the processes responding to the go signal and the processes responding to the stop signal (Logan & Cowan, 1984; Ollman, 1973; Osman, Kornblum, & Meyer, 1986, 1990). If the go processes are faster than the stop processes, the go response escapes inhibition and is executed much like a normal go response. If the stop processes are faster than the go processes, the go response is inhibited. Go RT and stop RT are both random variables, so the race is stochastic; given the same go signal, the same stop signal, and the same interval between them, subjects will sometimes inhibit and sometimes fail to inhibit.

The race model predicts the probability of inhibition as a function of stop-signal delay and go RT. It predicts RT for responses that escape inhibition (signal-respond RT), and it provides four different but formally related ways to observe the unobservable—to estimate stop-signal RT (SSRT). The race model succeeds largely because it is abstract. It deals with the distribution of finishing times for the go process and the stop process without addressing the nature of the processes that give rise to the finishing times. Logan and Cowan's (1984) version is the most general. It applies to any distribution of finishing times, regardless of the form.

The race model is useful in describing performance, but it does not give much insight into the underlying processes. It applies equally well regardless of response modality. It has been used to study keypresses (Logan, 1981; Osman et al., 1986), hand squeezes (De Jong, Coles, Logan, & Gratton, 1990), typewriting (Logan, 1982), arm move-

ments (McGarry & Franks, 1997), and eye movements (Hanes & Carpenter, 1997). The race model's success in these different domains suggests that the various responses are controlled by the same principles, but it does not indicate whether the responses are controlled by the same processes. On the one hand, there may be one stop process common to all movements (which would explain why the same principles apply across tasks). On the other hand, there may be different processes involved for different responses that operate according to the same principles.

Our strategy for addressing this question was to present the same stimulus conditions and vary response requirements. Subjects responded to displays with eye movements or hand movements. Under these conditions, processing should follow a common pathway up to a point (e.g., response selection) and then branch to separate pathways specific to each response. If subjects stop their responses by disengaging processes in the common pathway, there should be no difference in SSRT between conditions. However, if subjects stop their responses by disengaging processes specific to each response, then SSRT should differ between response types and perhaps be affected differently by other manipulations in the experiment.

Our stimulus display consisted of three plus signs (+), one in the center of the screen, one to the left of center, and one to the right of center. The task was to move the eyes to the left or right stimulus or to press a button corresponding to it. There were four conditions within each response type, defined by the factorial combination of two variables: stimulus condition (peripheral vs. central) and task (pro vs. anti). In the peripheral condition, the left or the right plus sign changed to an X. In the central condition, the central plus sign changed to an angle bracket ($>$ or $<$) pointing to one of the peripheral plus signs. In the pro condition, subjects responded to the position indicated by the X or the angle bracket; if the left plus sign turned into an X or the angle bracket pointed left, they moved their eyes to the left target or they pressed the left button. In the anti condition, subjects responded to the position opposite to the one indicated by the central or peripheral cue. Thus, if the left plus sign turned into an X or if the angle bracket pointed left, they moved their eyes to the right target or pressed the right button.

We expected all three factors—response type, stimulus condition, and task—to produce main effects on go RT. Eye movement latencies are typically very fast, on the order of 250 msec even when choice is involved, so we expected them to be faster than hand responses. The task manipulation would be viewed as a manipulation of stimulus–response compatibility in the RT literature (e.g., Kornblum, Hasbroucq, & Osman, 1990), and RTs with compatible (pro) stimulus–response mappings are typically faster than RTs with incompatible (anti) stimulus-response mappings. Finally, we expected faster go RTs to peripheral stimuli than to central ones, because peripheral stimuli would likely elicit fast, reflexive responses (e.g., Posner, 1980). We had no a priori predictions about inter-

actions between these factors that were relevant to our purposes (but see Kornblum et al., 1990).

In all four conditions, with both response types, the stop signal consisted of three boxes that were centered on the positions of the three plus signs. Subjects were told to inhibit their eye movements or their buttonpresses when this stop signal appeared. We had no a priori predictions for any main effects or interactions except for the pro versus anti (compatibility) effect with hand responses. Previous research found no difference in SSRT to stop hand responses that were spatially compatible versus incompatible (Logan, 1981). We expected to replicate that null effect here.

We were concerned primarily with differences in SSRT for eye and hand movements and with interactions between response type and stimulus position and task. If eye and hand responses were both stopped by inhibiting processes in the common pathway, then there should be no difference in SSRT between response types and no interactions between response type and stimulus position or response type and task. Alternatively, if eye and hand responses were stopped by inhibiting processes in the separate pathways, then SSRT should show a main effect of response type and, possibly, interactions between response type and stimulus condition or response type and task.

The second hypothesis is stronger than the first. A main effect of response type can occur only if inhibition occurs in separate pathways. A null effect of response type could occur if inhibition occurs in the common pathway or if it occurs in separate pathways that coincidentally take the same amount of time to be stopped. Fortunately, the data are consistent with the "separate pathways" hypothesis.

METHOD

Subjects

Eight subjects participated in the experiment. The subjects were students at the University of Illinois, and they were naive about the experimental hypotheses. They were paid $5 per hour for participating.

Apparatus and Stimuli

Stimuli were presented on a Tektronix 608 oscilloscopic display equipped with P15 phosphor, which has no detectable persistence (Groner, Groner, Muller, Bischof, & Di Lollo, 1993). Stimulus presentation was controlled with a Gateway 2000 486 50-MHz computer. The x- and y-coordinates and the intensity value of each point to be plotted were stored in a plotting buffer, which is able to transfer values to the oscilloscope at a rate of 2,000 points/msec (Finley, 1985). A refresh rate of 1000 Hz was used during the experiment (i.e., each point displayed on the oscilloscope was refreshed once each millisecond).

Buttonpressing responses were made with the thumbs via handheld microswitches that were interfaced with the computer via a digital-input board. During eye-movement trials, the computer also recorded the output from an Applied Science Laboratories Model 210 scleral reflectance eyetracker by means of an analog-to-digital converter. The eyetracker was mounted on eyeglass frames that were held in place on the subject's head with a headband. The eyetracker was configured to record horizontal movements of the left eye only. Eye position was sampled once every millisecond. A bite bar with dental impression compound was used to keep the subject's head

Table 1
**Mean Reaction Time (RT; in Milliseconds), Percentage
of Correct Responses (% Correct) to the Go Signal, and
Estimated Reaction Time to the Stop Signal (SSRT;
in Milliseconds) as a Function of Response Type, Pro Versus
Anti Task, and Central Versus Peripheral Stimulus Presentation**

	Central		Peripheral	
	Pro	Anti	Pro	Anti
Go Task				
Hands				
RT	364	360	306	352
% Correct	95	94	97	95
Eyes				
RT	326	331	235	293
% Correct	97	95	98	97
Stop Task				
Hands				
SSRT	217	215	233	221
Eyes				
SSRT	195	183	151	180

steady during the experiment. The subjects completed a calibration sequence (described later) before every experimental trial. The accuracy of the eyetracker under these conditions is ±0.3º.

During the experiment, the subjects were positioned 57 cm from the display. At this viewing distance, the total display area subtended a visual angle of 12º horizontally and 10º vertically. At the beginning of each trial, three fixation crosses were presented on the display, aligned horizontally. These crosses subtended 0.2º vertically and horizontally, and they were separated from each other by 4.0º.

The central (< or >) and peripheral (X) stimuli also subtended 0.2º vertically and horizontally. The stop signal consisted of three boxes centered at the location of the three fixation crosses; each box subtended 1º vertically and horizontally and consisted of eight dots (i.e., a 3 × 3 dot matrix with no center dot).

The experimental chamber was illuminated by overhead fluorescent lights. The luminance of the display screen was 68 cd/m². The effective luminance of the stimulus display was 552 cd/m². This luminance was obtained by measuring the luminance of a 31 × 31 dot matrix plotted within an 8 × 8 mm area that was refreshed every millisecond.

Design

There were eight experimental conditions, defined by response type (eyes vs. hands), stimulus condition (peripheral vs. central), and task (pro vs. anti). Each subject completed two practice blocks and 10 experimental blocks of 40 trials each in each of the eight conditions. Response type, stimulus condition, and task were held constant in each block of trials.

The 12 blocks of each condition were completed in succession. Condition order was balanced across subjects, with the exception that the eye-movement version of each combination of stimulus condition and task was completed before the buttonpressing version. We used this order to ensure that our subjects would produce good eye-movement data. Eye-movement data take longer to gather and are harder to analyze than buttonpress data.

Procedure

On each trial, three plus signs were presented on the display, separated by 4.0º. The subject was instructed to fixate the center plus sign carefully. Following an interval of 1,000, 1,250, or 1,500 msec, the stimulus was presented. On central-stimulus trials, the center plus sign turned into an angle bracket (< or >). On peripheral-stimulus trials, one of the peripheral plus signs turned into an X.

In separate blocks of trials, the subjects responded by pressing a button or by moving their eyes. In the pro task, the subjects responded to the position indicated by the X or the angle bracket; if the left plus sign turned into an X or the angle bracket pointed left, they moved their eyes to it or they pressed the button held in the left hand. In the anti task, the subjects responded to the position opposite to the one indicated by the central or peripheral cue. Thus, if the left plus sign turned into an X or if the angle bracket pointed left, they moved their eyes to the rightmost plus sign or pressed the button held in the right hand.

The subjects were instructed to respond as quickly but as accurately as possible. They were also told that, on some trials, "stop boxes" would appear around all three stimulus locations and that they should try to withhold their response whenever that occurred. They were told that some stop boxes would occur so early that they would always be able to stop, whereas others would occur so late that they would rarely be able to stop; thus, they should always try to stop if they could, but they should not worry if they could not. The instructions stressed that the most important thing was for them to perform the go task as quickly and as accurately as possible and not let the stop boxes interfere with their performance.

A stop signal was presented on 25% of the trials, sequenced randomly. Five different stop-signal delays (or stimulus onset asynchronies between cue onset and stop signal onset) were used for each subject. These varied somewhat across subjects and conditions, with most subjects experiencing stop-signal delays of 25, 100, 175, 250, and 325 msec. Slightly different ranges were chosen for some subjects and conditions on the basis of performance in the practice blocks to ensure that all of the stop signals did not occur too early or too late.

Each trial ended when the subject responded or when 600 msec elapsed from cue onset without a response. The eyes were considered to have moved if eye velocity exceeded 50º/sec and eye position changed by at least 0.5º from the initial fixation point. The point in time at which this occurred defined the latency of the eye-movement response. No feedback about response accuracy was given. The initiation of each trial was controlled by the subject. During eye-movement blocks, each trial began with a calibration routine during which a calibration point (a plus sign) stepped across the display at three locations separated by 4.0º. Each point was presented for 1,500 msec, and the subject was instructed to fixate each carefully. Eye position at each location was sampled (at a rate of 1000 Hz) for 100 msec near the middle of this interval. These recordings served to calibrate the output of the eyetracker against spatial position.

RESULTS

Go Task

Mean RTs and percentage of correct responses to the go signal were computed for each subject and were submitted to 2 (response type: eyes vs. hand) × 2 (task: pro vs. anti) × 2 (stimulus presentation: central vs. peripheral) analyses of variance (ANOVAs). The means across subjects are presented in Table 1.

As we expected, all of the main effects were significant: The subjects responded 50 msec faster with the eyes than with the hands [$F(1,7) = 40.01$, $MS_e = 965.04$, $p < .01$]; they responded 49 msec faster to peripheral stimuli than to central stimuli [$F(1,7) = 69.31$, $MS_e = 548.64$, $p < .01$]; and they responded 26 msec faster in the pro (compatible)
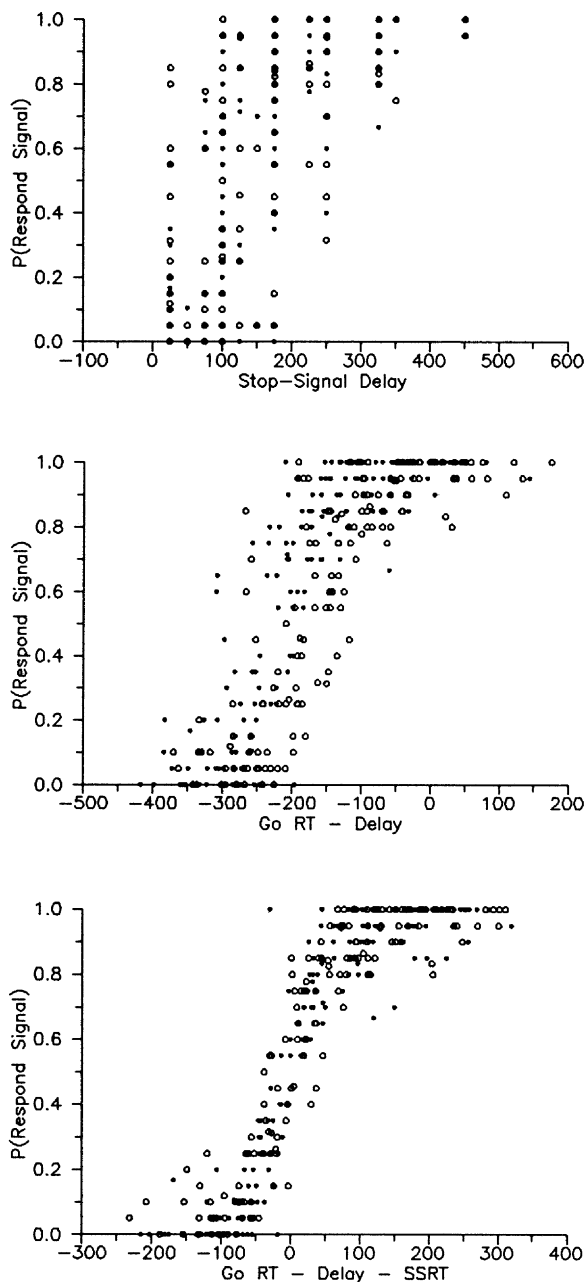
Figure 1. The probability of responding given a stop signal as a function of stop-signal delay (top panel), mean go reaction time (RT) minus stop-signal delay (middle panel), and mean go RT minus both stop-signal delay and stop-signal RT (SSRT; bottom panel). Each subject contributed 40 points to each panel. Open circles represent data from the eyes; filled circles represent data from the hands.

task than the anti (incompatible) task [$F(1,7) = 10.76$, $MS_e = 1,039.13, p < .01$].

The main effects were modulated by two interactions: First, the difference between central and peripheral stimuli was greater for eye responses (64 msec) than for hand

responses (33 msec) [$F(1,7) = 8.52, MS_e = 458.75, p < .01$], suggesting that peripheral eye movements were more reflexive than compatible hand movements. Second, the difference between pro and anti tasks was negligible with central stimuli (1 msec) but substantial with peripheral stimuli (52 msec) [$F(1,7) = 48.15, MS_e = 223.56, p < .01$]. This suggests that peripheral stimuli elicited reflexive or automatic responses, whereas central stimuli did not (for similar results with central stimuli, see Proctor, Van Zandt, Lu, & Weeks, 1993, Experiment 5).

The accuracy data mirrored the RT data, suggesting no speed–accuracy tradeoff. The only significant effect in the ANOVA on percent correct was the main effect of stimulus presentation (central vs. peripheral) [$F(1,7) = 5.57, MS_e = 4.69, p < .05$].

Stop Task

Inhibition functions. The probability of responding when given a stop signal [$p(\text{respond} | \text{signal})$] was computed for each subject in each combination of stop-signal delay, response, stimulus condition, and task, yielding 40 points for each subject. These data are plotted in Figure 1.

According to the race model, the $p(\text{respond}|\text{signal})$ depends on go RT, SSRT, and stop-signal delay, which jointly determine the opportunity the subject has to detect the stop signal and respond to it before executing the go response (Logan & Cowan, 1984). The race model predicts that inhibition functions should become more regular and consistent as more predictors are added to the measure of opportunity. The top panel of Figure 1 plots $p(\text{respond} | \text{signal})$ as a function of stop-signal delay and shows considerable scatter. The middle panel plots $p(\text{respond} | \text{signal})$ as a function of mean go RT minus stop-signal delay, reducing the scatter somewhat. The bottom panel plots $p(\text{respond} | \text{signal})$ as a function of mean go RT minus stop-signal delay and SSRT, reducing the scatter by a considerable amount. These data suggest that the race model provides a good account of performance, allowing us to compare estimates of SSRT for the eyes and the hands.

SSRT. The most important data for our purposes are the estimates of SSRT. The race model provides four ways to estimate it, and we used the most general one. This method treats SSRT and go RT as random variables, with density functions $f_s(x)$ and $f_g(x)$, respectively. The probability of responding given a stop signal, $P_r(t_d)$, at stop-signal delay, t_d, is

$$P_r(t_d) = \int_{t < u + t_d} f_g(t) f_s(u) dt \, du. \qquad (1)$$

Equation 1 can be treated as a distribution function, because $P_r(T_d)$ increases monotonically from 0 to 1 as t_d increases from $-\infty$ to $+\infty$. Its density function, $\phi(t_d)$, is the derivative of Equation 1,

$$\phi(t_d) = \frac{dP_r(t_d)}{dt} = \int_{-\infty}^{\infty} f_s(u) f_g(u + t) du. \qquad (2)$$

The mean of the inhibition function, treated as a distribution, is

$$\overline{T}_d = \int_{-\infty}^{\infty} t\phi(t_d)\,dt = \int_{-\infty}^{\infty} t \int_{-\infty}^{\infty} f_s(u)f_g(u+t)\,du\,dt = \overline{T}_g - \overline{T}_s. \quad (3)$$

According to Equation 3, the mean SSRT, $\overline{T}_s$, can be estimated by calculating the mean of the inhibition function, $\overline{T}_d$, and subtracting it from the mean go RT, $\overline{T}_g$ (for further details, see Logan & Cowan, 1984). We estimated SSRT by fitting a cumulative normal distribution to each subject's inhibition function, calculating its mean, and subtracting it from their mean go RT, following Equation 3. The SSRT estimates were submitted to a 2 (response type: eyes vs. hands) $\times$ 2 (task: pro vs. anti) $\times$ 2 (stimulus presentation: central vs. peripheral) ANOVA. The means across subjects are presented in Table 1.

The subjects stopped their eye movements 45 msec faster than they stopped their hand movements. Moreover, SSRT for hand movements was largely unaffected by task or stimulus presentation—the fastest and slowest hand SSRTs differed only by 16 msec. By contrast, SSRT for eye movements was 29 msec faster in the peripheral pro condition than in any other condition, and the other conditions did not differ much from each other. The largest difference between the other conditions was 15 msec. These data confirm both of the predictions we derived from the hypothesis that the eyes and the hands were stopped by separate processes: SSRT was faster for the eyes than for the hands, and SSRT for the eyes and the hands was affected differently by task and stimulus conditions.

These conclusions were supported in the ANOVA. The main effect of response type was significant [$F(1,7) = 28.16$, $MS_e = 1{,}130.07$, $p < .01$], and the interactions involving response type were either significant or marginally significant: for the response type $\times$ stimulus presentation interaction [$F(1,7) = 7.63$, $MS_e = 639.80$, $p < .05$]; for the response type $\times$ task interaction [$F(1,7) = 4.66$, $MS_e = 208.12$, $p < .07$]; and for the response type $\times$ stimulus presentation $\times$ task interaction [$F(1,7) = 4.27$, $MS_e = 587.87$, $p < .08$]. In addition, the stimulus presentation $\times$ task interaction was marginally significant [$F(1,7) = 4.49$, $MS_e = 223.00$, $p < .08$]. The main effects of stimulus condition and task were not significant ($F < 1.0$).

We tested the significance of the differences between stimulus presentation and task conditions within each response type by computing Fisher's LSD, using the error term from the highest order interaction (587.87). The value for $p < .05$ was 29 msec. This analysis showed that, for eye movements, SSRT in the peripheral pro condition was significantly faster than in any other condition, and that, for hand movements, none of the conditions differed significantly from any of the others.

Finally, we analyzed each response type separately in 2 (stimulus condition: peripheral vs. central) $\times$ 2 (task: pro vs. anti) ANOVAs. The critical interaction between stimulus condition and task was significant in the eye response ANOVA [$F(1,7) = 11.69$, $MS_e = 285.89$, $p < .05$]. No effects were significant in the hand-response ANOVA.

DISCUSSION

The go-task results replicate standard effects in the literature. However, their interpretation is somewhat ambiguous. They are consistent with the hypothesis that go responses for the eyes and the hands are controlled by the same mechanisms and with the contrary hypothesis that they are controlled by separate mechanisms that are affected in the same way by manipulations of task and stimulus presentation. The larger effect of pro versus anti task with eye movements may reflect different control processes, or it may reflect a greater degree of compatibility between eye movements and peripheral stimuli than between hand movements and peripheral stimuli. The eyes actually moved to the positions of the peripheral stimuli, suggesting a high degree of "dimensional overlap" between stimuli and responses (Kornblum et al., 1990). By contrast, the hands moved to corresponding but nonidentical positions, suggesting a lower degree of dimensional overlap. We were more concerned with the similarities and differences between stop processes than between go processes, so we did not try to resolve these uncertainties.

The stop-task results are consistent with the hypothesis that eye and hand movements are inhibited by separate processes that are governed by similar principles (i.e., the race model). First, SSRT was faster with the eyes than with the hands. Second, stimulus and task conditions had different effects on SSRT to the eyes and hands. Estimates of SSRT for hand movements were unaffected by stimulus conditions (central vs. peripheral) and task (pro vs. anti). The null effect of task replicates previous results with inhibiting manual responses (Logan, 1981). By contrast, SSRT for eye movements was especially fast in the peripheral pro condition, suggesting a substantial advantage for the stop process in that condition.

Our results are consistent with electrophysiological investigations of the inhibition of eye and hand movements. De Jong and colleagues (De Jong, Coles, & Logan, 1995; De Jong et al., 1990) recorded the *lateralized readiness potential* with scalp electrodes placed over the motor cortex in humans, and they found that the magnitude of the potential was reduced substantially when subjects inhibited hand responses successfully. This suggests that the motor cortex is involved in stopping hand movements. De Jong et al. (1995; De Jong et al., 1990) suggested that the motor cortex was not the only structure involved in inhibiting hand movements, because the lateralized readiness potentials on stop trials exceeded a criterion that predicted overt responses on trials with no stop signal. They proposed two stop processes—a central one measured by the lateralized readiness potential and a peripheral one produced by midbrain structures—to account for their data (also see Jennings, van der Molen, Brock, & Somsen, 1992).

Hanes, Patterson, and Schall (1998) recorded from single cells in the frontal eye fields of macaque monkeys during an oculomotor stop task, and they found two types of cells that appeared to be involved in stopping eye movements—saccade cells and fixation cells. The firing

rate for saccade cells increased monotonically after the go signal, reaching a maximum when the saccade began. On stop-signal trials, the firing rate for saccade cells followed the same pattern up to a point and then dropped precipitously. Estimates of SSRT derived from the monkey's behavior predicted the point of divergence. The firing rate for fixation cells dropped after the onset of the go signal and reached a minimum during the saccade. On stop-signal trials, the firing rate followed the same pattern up to the estimate of SSRT and then diverged, increasing as it would during a fixation.

The Hanes et al. (1998) data provide convincing evidence of the validity of the methods for estimating SSRT. Together with the De Jong et al. (1995; De Jong et al., 1990) data, they suggest that the eyes and the hands are inhibited by different anatomical structures, converging on the conclusions we reached from analysis of our behavioral data. The fact that the race model fits both the Hanes et al. data and the De Jong et al. data suggests that the different anatomical structures are governed by the same principles of processing: those described abstractly by the race model.

An interesting question for future research is whether other response systems (e.g., vocal gestures, eye blinks, leg movements) are controlled by the same processes as the eyes or the hands. Possibly, each distinct response modality is controlled by its own pathway, but each inhibitory control system functions according to the same race-model principles.

REFERENCES

ABRAMS, R. A., MEYER, D. E., & KORNBLUM, S. (1990). Eye-hand coordination: Oculomotor control in rapid aimed limb movements. *Journal of Experimental Psychology: Human Perception & Performance*, **16**, 248-267.

BEKKERING, H., ABRAMS, R. A., & PRATT, J. (1995). Transfer of saccadic adaptation to the manual motor system. *Human Movement Science*, **14**, 155-164.

DE JONG, R., COLES, M. G. H., & LOGAN, G. D. (1995). Strategies and mechanisms in nonselective and selective inhibitory motor control. *Journal of Experimental Psychology: Human Perception & Performance*, **21**, 498-511.

DE JONG, R., COLES, M. G. H., LOGAN, G. D., & GRATTON, G. (1990). Searching for the point of no return: The control of response processes in speeded choice reaction performance. *Journal of Experimental Psychology: Human Perception & Performance*, **16**, 164-182.

FINLEY, G. (1985). A high-speed plotter for vision research. *Vision Research*, **25**, 1993-1997.

GRONER, R., GRONER, M. T., MULLER, P., BISCHOF, W. F., & DI LOLLO, V. (1993). On the confounding effects of phosphor persistence in oscilloscopic displays. *Vision Research*, **33**, 913-917.

HANES, D. P., & CARPENTER, R. H. S. (1997). Countermanding saccades in humans. *Society for Neuroscience Abstracts*, **23**, 797.

HANES, D. P., PATTERSON, W. F., & SCHALL, J. D. (1998). Role of frontal eye fields in countermanding saccades: Visual, movement and fixation activity. *Journal of Neurophysiology*, **79**, 817-834.

JENNINGS, J. R., VAN DER MOLEN, M. W., BROCK, K., & SOMSEN, R. J. (1992). On the synchrony of stopping motor responses and delaying heartbeats. *Journal of Experimental Psychology: Human Perception & Performance*, **18**, 422-436.

KEELE, S. W. (1986). Motor control. In K. R. Boff, L. Kaufman, & J. P. Thomas (Eds.), *Handbook of perception and human performance* (pp. 30-60). New York: Wiley.

KORNBLUM, S., HASBROUCQ, T., & OSMAN, A. (1990). Dimensional overlap: Cognitive basis for stimulus-response compatibility: A model and a taxonomy. *Psychological Review*, **97**, 253-270.

LOGAN, G. D. (1981). Attention, automaticity, and the ability to stop a speeded choice response. In J. Long & A. D. Baddeley (Eds.), *Attention and performance IX* (pp. 205-222). Hillsdale, NJ: Erlbaum.

LOGAN, G. D. (1982). On the ability to inhibit complex movements: A stop-signal study of typewriting. *Journal of Experimental Psychology: Human Perception & Performance*, **8**, 778-792.

LOGAN, G. D. (1985). Executive control of thought and action. *Acta Psychologica*, **60**, 193-210.

LOGAN, G. D. (1994). On the ability to inhibit thought and action: A users' guide to the stop signal paradigm. In D. Dagenbach & T. H. Carr (Eds), *Inhibitory processes in attention, memory, and language* (pp. 189-239). San Diego: Academic Press.

LOGAN, G. D., & COWAN, W. B. (1984). On the ability to inhibit thought and action: A theory of an act of control. *Psychological Review*, **91**, 295-327.

McGARRY, T., & FRANKS, I. M. (1997). A horse race between independent processes: Evidence for a phantom point of no return in the preparation of a speeded motor response. *Journal of Experimental Psychology: Human Perception & Performance*, **23**, 1533-1542.

OLLMAN, R. T. (1973). Simple reactions with random countermanding of the "go" signal. In S. Kornblum (Ed.), *Attention and performance IV* (pp. 571-581). New York: Academic Press.

OSMAN, A., KORNBLUM, S., & MEYER, D. E. (1986). The point of no return in choice reaction time: Controlled and ballistic stages of response preparation. *Journal of Experimental Psychology: Human Perception & Performance*, **12**, 243-258.

OSMAN, A., KORNBLUM, S., & MEYER, D. E. (1990). Does response programming necessitate response execution? *Journal of Experimental Psychology: Human Perception & Performance*, **16**, 183-198.

POSNER, M. I. (1980). Orienting of attention. *Quarterly Journal of Experimental Psychology*, **32**, 3-25.

PROCTOR, R. W., VAN ZANDT, T., LU, C., & WEEKS, D. J. (1993). Stimulus–response compatibility for moving stimuli: Perception of affordances or directional coding? *Journal of Experimental Psychology: Human Perception & Performance*, **19**, 81-91.

SCHALL, J. D. (1991). Neural basis of saccadic eye movements in primates. In A. G. Leventhal (Ed.), *Vision and visual dysfunction: Vol. 4. The neural basis of visual function* (pp. 388-442). London: Macmillan.