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The point of no return: A fundamental limit on the ability to control thought and action

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Bartlett (1958. *Thinking*. New York: Basic Books) described the point of no return as a point of irrevocable commitment to action, which was preceded by a period of gradually increasing commitment. As such, the point of no return reflects a fundamental limit on the ability to control thought and action. I review the literature on the point of no return, taking three perspectives. First, I consider the point of no return from the perspective of the controlled act, as a locus in the architecture and anatomy of the underlying processes. I review experiments from the stop-signal paradigm that suggest that the point of no return is located late in the response system. Then I consider the point of no return from the perspective of the act of control that tries to change the controlled act before it becomes irrevocable. From this perspective, the point of no return is a point in time that provides enough "lead time" for the act of control to take effect. I review experiments that measure the response time to the stop signal as the lead time required for response inhibition in the stop-signal paradigm. Finally, I consider the point of no return in hierarchically controlled tasks, in which there may be many points of no return at different levels of the hierarchy. I review experiments on skilled typing that suggest different points of no return for the commands that determine what is typed and the countermands that inhibit typing, with increasing commitment to action the lower the level in the hierarchy. I end by considering the point of no return in perception and thought as well as action.

Keywords: Point of no return; Stop signal; Response inhibition; Cognitive control; Hierarchical control

Sir Frederic Bartlett introduced the point of no return to psychology in his 1958 book, *Thinking* (Bartlett, 1958). His thesis in the book was that thinking is a skill, and he applied concepts and methods from studies of skilled performance to characterize aspects of thinking. One of the concepts was the point of no return, which he borrowed from the aviators he knew from his applied work. They thought of it as the point at which they were committed to reach a destination because they no longer had enough fuel to return to the base. Bartlett saw a similar irrevocable commitment to action in the expression of skill:

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> Skilled performance reaches a stage beyond which the further input of signals cannot produce a result because it fails to be noticed, or does not produce a result because it is ignored. Alternatively, the new signals lead to a belated attempt to modify action and error follows. (Bartlett, 1958, pp. 17–18)

Preceding the point of irrevocable commitment, Bartlett saw a more gradual increasing commitment to action:

> I come constantly upon instances of how people start developing an argument sequence, perhaps rather tentatively, and reach a stage at which it is very much easier to go on than to go back. A little beyond this there comes a stage when, if they do make an effort to go back, they become hesitant, ineffective, and very often incoherent. (Bartlett, 1958, p. 185)

It is easy to see why Bartlett would want to look for the point of no return in thinking. We can learn a lot about how a process is controlled by asking how commitment to the resulting action increases and finally becomes irrevocable. When we ask where the point of no return is, we must specify the architecture and the anatomy of the process in enough detail to distinguish different loci. When we ask how the commitment to action grows before it becomes irrevocable, we must specify how the process and the information it uses evolve over time. When we ask where and when a process is controlled, we must specify the process that controls it, describing the conditions that trigger the control process and the latency of the act of control.

These questions about the point of no return are important because they are pretheoretical and empirical. The answers require a theory of the controlled act and the act of control that governs it, but the questions apply to all theories and all processes. The questions can be used to assess current theories and to guide the development of new ones. They can be used to understand control in familiar processes or to explore control in new ones. They apply most clearly to actions and skills, but they can easily be extended to perception and memory and, as Bartlett speculated, thinking.

Bartlett did not say much about the point of no return in his book. The term appears three times in the index, and the quotes above comprise 23% of the words he said about it. He thought, "The experimental evidence is conclusive. It has been shown by many investigators and for many different types of skilled response . . . " (Bartlett, 1958, p. 18). Unfortunately, Bartlett did not review the evidence for the point of no return. My goals in this article are to provide that review, focusing on simple actions and action sequences, and to explore the implications of the concept.

The point of no return can be viewed from many different perspectives. I address three in this article. First, the point of no return can be viewed from the perspective of the controlled act, as a point in processing beyond which a response is inevitable. From this perspective, *the point of no return is a locus* in the structure and the anatomy of the controlled act. Second, the point of no return can be viewed from the perspective of the process trying to enact control, as the *lead time* it needs to implement a change before the action takes place. From this perspective, *the point of no return is a point in time*, like a deadline. Any acts of control instigated after the point of no return will finish too late to affect the action. Third, the point of no return can be viewed from the perspective of *hierarchical control*, where different processes go on at different levels at the same time. From this perspective, *there may be many points of no return*. Complex skills require many acts of control at different levels with different latencies, and each may have its own point of no return. The gradually increasing commitment to action may result from passing points of no return at successively lower levels of a hierarchy.

THE LOCUS OF THE POINT OF NO RETURN IN COUNTERMANDING

The countermanding or stop-signal paradigm provides a natural operational definition of the point of irrevocable commitment to an action. The paradigm was developed by Margaret Vince in 1948 at the Applied Psychology Unit in Cambridge, and it is now widely used to study inhibitory control (for reviews, see Logan, 1994; Verbruggen & Logan, 2008). The paradigm asks subjects to inhibit a planned action. If they manage to inhibit the action, they were not irrevocably committed to it. The paradigm is simple and easy to implement. It has been used with monkeys, rodents, and a variety of human subject populations, including college students, the young and the old, and patients with psychiatric and neurological disorders. The paradigm is well understood theoretically and open to a broad range of experimental manipulations, so we have the techniques we need to locate the point of no return in the processing structure. The paradigm prescribes punctate events, which make it easy to record neural activity during performance with a variety of measures, from single neurons to functional magnetic resonance imaging (fMRI). We have the techniques we need to locate the point of no return anatomically.

The locus of the point of no return in the processing structure

The countermanding paradigm involves two kinds of trials, randomly intermixed. The majority—typically 75%—are *go trials*, in which a go stimulus is presented, and subjects are asked to respond to it as quickly and accurately as possible. The minority are *stop trials*, in which the go stimulus is followed by another stimulus (the *stop signal*) that instructs subjects to withhold the go response on that trial. The go stimulus is usually visual, and the go task usually involves choice between two or more responses. The stop signal is usually auditory, but the same pattern of results is found with auditory and tactile stimuli, as well as with go tasks that involve simple detection, and visual and even tactile stop signals (for reviews, see Logan, 1994; Verbruggen & Logan, 2008). The go trials prevent subjects from anticipating the stop signal and provide baseline data for model-based calculations. The stop trials provide the critical data relevant to locating the point of no return: the probability that subjects respond when given a stop signal, which indicates how irrevocable the response was.

The most important independent variable in the countermanding paradigm is the delay between the onset of the go stimulus and the stop signal, which is called *stop-signal delay*. The plot of the probability of responding on stop-signal trials against stop-signal delay is called the *inhibition function*, and inhibition functions typically increase monotonically as stop-signal delay increases, as illustrated in Figure 1A. The second most important independent variable in the countermanding paradigm is reaction time (RT) on the go task. For a given stop-signal delay, the longer the RT, the lower the probability of responding on a stop-signal trial. Graphically, increases in go RT shift the inhibition function to the right, as illustrated in Figure 1A.

The effects of stop-signal delay and go task manipulations on inhibition functions can be understood as the consequences of a race between a *go process* that responds to the go stimulus and produces a response, and a *stop process* that responds to the stop signal and inhibits a response (Logan & Cowan, 1984; Logan, Van Zandt, Verbruggen, & Wagenmakers, 2014). If the stop process finishes before the go process reaches the point of no return, the go response is inhibited. If the stop process finishes after the go process reaches the point of no return, inhibition fails, and the response is executed. Stop-signal delay handicaps the race in favour of one process or the other. Short stop-signal delays favour the stop process, making it more likely to finish before the go process reaches the point of no return, so the probability of responding given a stop signal is low. As stop-signal delay increases, the stop process is less likely to win the race, and the probability of responding given a stop signal increases monotonically. Manipulations that affect go RT also handicap the race. If go RT is long, the go process is unlikely to reach the point of no return before the stop process, so the probability of responding is low. If go RT is short, the go process is likely to reach the point of no return before the stop process finishes, so the probability of responding given a stop signal is high.

We can use the effects of stop-signal delay and go RT on the inhibition function to localize the point of no return. Manipulations that increase the duration of stages of the go process after the point of no return should have no effect on the inhibition function. Manipulations that

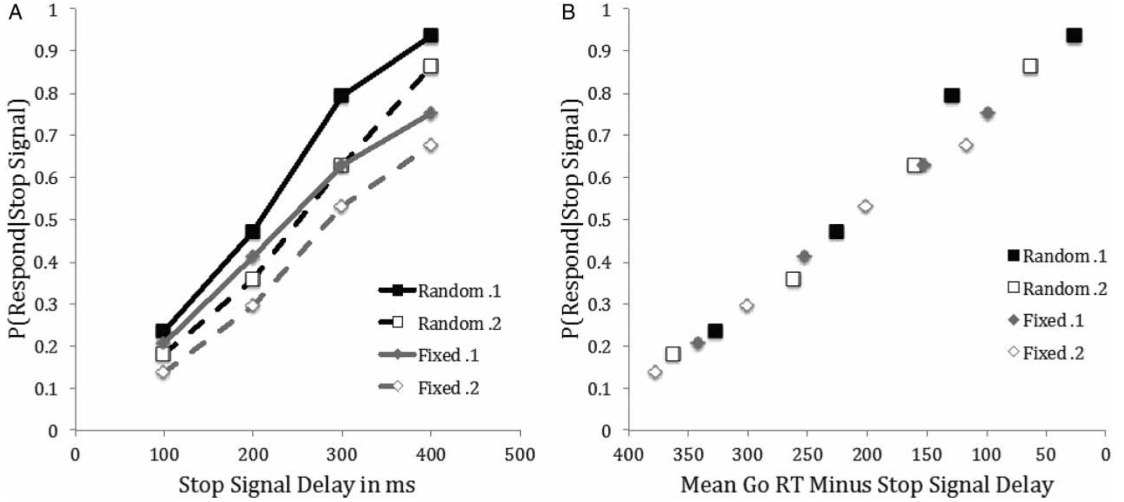

Figure 1. *Logan (1981) Experiment 1: (A) Probability of responding given a stop signal as a function of stop-signal delay in an experiment that varied the probability of a stop signal (.1 vs. .2) and varied whether stop-signal delay was random or fixed for a block of trials. Go reaction time (RT) increased strategically with stop-signal probability, and it increased when stop-signal delay was fixed, increasing more the longer the stop-signal delay. (B) Probability of responding given a stop signal from (A) plotted as a function of the time between the onset of the stop signal and the onset of the response (mean go RT minus stop-signal delay). Data points are means across subjects in each condition.*

increase the duration of stages of the go process before the point of no return should shift the inhibition function to the right, decreasing the probability of responding given a stop signal at each stop-signal delay. The race model makes a stronger prediction: The shift in the inhibition function should equal the increase in go RT. We can test this prediction by plotting inhibition functions against go RT minus stop-signal delay. If the shift in the inhibition function equals the increase in go RT, the inhibition functions should be aligned when plotted against go RT minus stop-signal delay. This alignment should occur for manipulations that affect the duration of go processes before the point of no return but not for manipulations that affect the duration of go processes after the point of no return.

Studies that use this logic to locate the point of no return have found that it is located very late in the go process, in the stage of response execution. Inhibition functions from different strategies (Logan, 1981; Figure 1B), tasks (Logan, Cowan, & Davis, 1984; Logan & Irwin, 2000; Figures 2B and 3B), and subjects (Figures 2B and 3B) align when plotted against go RT minus stop-signal delay. Logan (1981) prolonged the durations of perceptual and response selection stages in a go task by manipulating discriminability and stimulus–response compatibility. These variables had additive effects on go RT, suggesting that they affect different stages (Sternberg, 1969). They also had additive effects on the inhibition functions (Figure 4A). The inhibition functions for all four conditions were aligned when plotted against go RT minus stop-signal delay (Figure 4B), suggesting that the point of no return was located after perception and response selection (also see Osman, Meyer, & Kornblum, 1990).

The anatomical locus of the point of no return

Hand movements

De Jong, Coles, Logan, and Gratton (1990) searched for the point of no return in a countermanding task in which subjects squeezed force transducers with their left or right hand to indicate which shape appeared on a screen. They defined the point of no return as the locus at which all movement-related activity was suppressed on

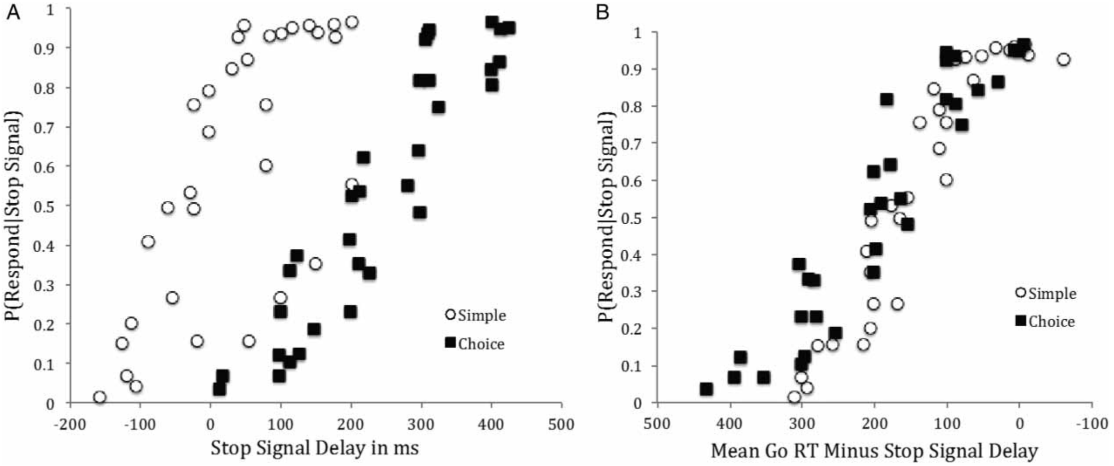

Figure 2. *Logan et al. (1984): (A) Probability of responding given a stop signal as a function of stop-signal delay for a simple (open circles) and choice (filled squares) go task. Go RT was substantially shorter in the simple task. (B) Probability of responding given a stop signal as a function of mean go RT minus stop-signal delay for simple and choice tasks. Data points are individual subject means in each condition.*

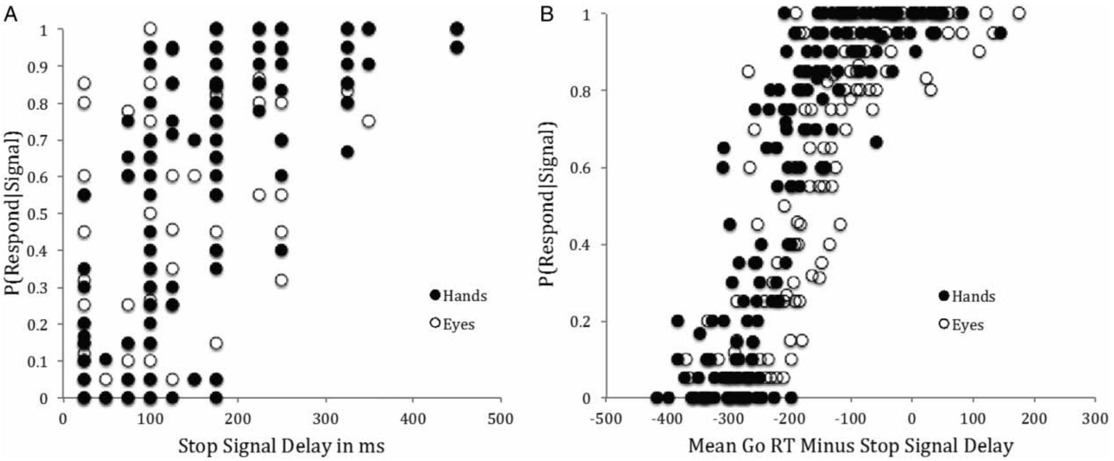

Figure 3. *Logan and Irwin (2000): (A) Probability of responding given a stop signal for eye movements (open circles) and keypresses with the hands (filled squares) in a go task in which subjects responded to a cued location (left or right). (B). Probability of responding given a stop signal plotted as a function of go reaction time (RT) minus stop-signal delay. Data points are individual subject means in each condition.*

successful stop trials, as if the go signal had never been presented. They sought the point of no return in motor cortex, in the muscles of the responding hand, and in the force exerted on the force transducer.

De Jong et al. (1990) measured activation in motor cortex with the lateralized readiness potential (LRP), which measures the difference in electrical potential between left and right motor cortices and so reflects the relative activation of the left versus right response. The LRP rose from baseline to a peak value just before the response on go trials and failed stop trials, as expected. However, the LRP rose significantly above baseline on successful stop trials as well, indicating some activation of the go response (also see De Jong,

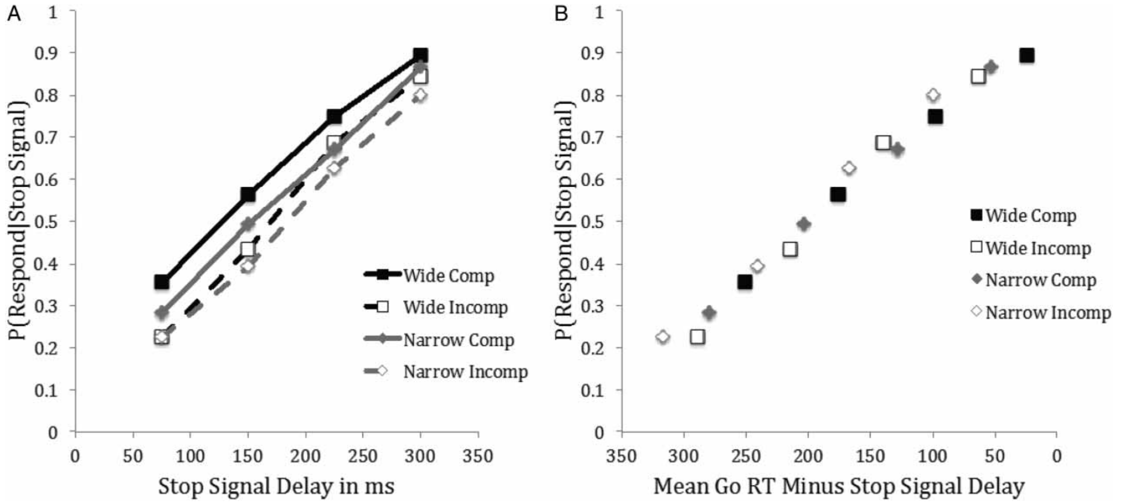

Figure 4. *Logan (1981) Experiment 2: (A) Probability of responding given a stop-signal delay in an experiment that varied discrimination difficulty (wide vs. narrow spacing) and stimulus–response compatibility. Go reaction time (RT) increased with discrimination difficulty and with stimulus–response compatibility, but there was no interaction between them, suggesting that they affected different processing stages. (B) Probability of responding given a stop signal as a function of the interval between mean go RT and stop-signal delay. Data points are means across subjects in each condition.*

Coles, & Logan, 1995). De Jong et al. (1990) concluded that the point of no return is after the motor cortex.

De Jong et al. (1990) measured electromyographic activity in the agonist muscles that squeezed the transducer and found some activation in the go response on successful stop trials, suggesting that the point of no return was after muscle activation. They measured the force exerted on the transducers and found partial squeezes on successfully stopped trials. Altogether, the results led De Jong et al. to conclude that the point of no return is very late, after the response begins.

De Jong et al. (1990) required subjects to exert a lot of force in the go task. They set the threshold for a response for each subject at 75% of the maximum force the subject could exert on the dynamometer, which one critic suggested might be enough to induce a hernia. Ko, Alsford, and Miller (2012) measured force in a stop-signal experiment that required much smaller and possibly more typical forces, around what is required to press a key on a computer keyboard. They, too, found that some force was exerted for the go response on successfully inhibited trials, corroborating a late locus for the point of no return.

Eye movements

Hanes, Patterson, and Schall (1998) looked for the point at of no return in the frontal eye fields of monkeys performing a saccadic countermanding task, defining the point of no return at the point at which neural activity modulates on successful stop trials. They recorded from movement-related neurons whose activity rises from a baseline until it reaches a threshold, and an eye movement is released. They found no modulation of these neurons on unsuccessful stop trials. Activity reached the same threshold as that on no-stop-signal trials. However, on successful stop trials, movement-neuron activity increased on the same trajectory but then decreased sharply before reaching threshold, just before the estimated stop-signal reaction time (SSRT). Paré and Hanes (2003) found similar results recording from movement-related neurons in superior colliculus while monkeys performed the saccadic countermanding task. These results suggest that responses become inevitable at the point at which movement-related neurons reach threshold, as if their threshold is the point of no return. However, movement-related neurons are part of a larger network that implements the go process, extending from cortex to brainstem, and the whole network may represent the point of no return (Boucher, Palmeri, Logan, & Schall, 2007; Logan, Yamaguchi, Schall, & Palmeri, in press).

Site and source of inhibition

Studies of electrophysiology tend to focus on single loci for the point of no return. fMRI studies reveal an extensive network of brain areas involved in stopping responses, including motor cortex, premotor cortex, supplementary motor area, anterior cingulate cortex, inferior frontal cortex, basal ganglia, and subthalamic nucleus (Aron et al., 2007; Rae, Hughes, Weaver, Anderson, & Rowe, 2014; Ridderinkhof, van den Wildenberg, Segalowitz, & Carter, 2004; Swick, Ashley, & Turken, 2011; Zandbelt, Bloemendaal, Hoogendam, Kahn, & Vink, 2013). These studies suggest that it is important to distinguish between the *site* and *source* of inhibition: The site is the locus at which go responses are actually inhibited, and the source is the locus at which the significance of the stop and go stimuli is apprehended and from which the command to inhibit is propagated. Electrophysiological methods addressing to the point at which responses become irrevocable reveal the site of inhibition; imaging studies addressing the broader network involved in stopping responses reveal the source of inhibition. De Jong et al. (1990) suggest several possible sites of inhibition, from motor cortex to the muscles, though the response only becomes inevitable after the last site is passed.

Behavioural data and modelling results suggest that later sites of inhibition must have stronger effects. Suppression in earlier structures must cascade through later structures, slowing the rate at which the later structures accumulate information, lengthening go RT on trials where inhibition fails (Boucher et al., 2007; Logan et al., in press). If there is enough early suppression, go RT may be longer when inhibition fails than when there is no stop signal (and therefore no suppression to slow the rate of accumulation). The data resoundingly falsify this prediction. Go RT is typically shorter when inhibition fails than when there is no stop signal, following the predictions of the independent race model (Logan & Cowan, 1984; Logan et al., 2014). Modelling analyses show that rate changes must be late and potent, occurring near the end of the SSRT interval (Boucher et al., 2007; Logan et al., in press).

A likely possibility is that motor cortex and later sites are part of a single circuit that extends through basal ganglia and the brainstem, so that all sites in the circuit are suppressed at the same time, except for small differences for synaptic transmission time (Aron et al., 2007; Boucher et al., 2007; Logan et al., in press). Thus, the modulation at several sites reported by De Jong et al. (1990) might reflect modulation of a single circuit.

Causes and consequences of inhibition

These studies also suggest that it is important to distinguish between the *causes* and the *consequences* of inhibition: Neurons or networks that cause inhibition should be active before SSRT; neurons or networks whose activity is a consequence of inhibition should be active after SSRT (Hanes et al., 1998). In theory, both sources and sites cause inhibition, so both should be active before SSRT. Regions that become active after SSRT cannot be sources or sites. Since SSRT is of the order of 200 ms, fine temporal resolution is required to evaluate this distinction. Electrophysiology provides the necessary resolution.

In single-cell recordings from monkeys performing a saccadic countermanding task, Hanes et al. (1998) and Paré and Hanes (2003) found modulation before SSRT on successful stop trials in movement neurons and fixation neurons in frontal eye fields and superior colliculus. This suggests that movement and fixation neurons may be part of the circuit that causes response inhibition. Similarly, De Jong et al. (1990) and De Jong et al. (1995) found modulation of the LRP before SSRT on successful stop trials, suggesting that the motor cortex may be part of the circuit that causes response inhibition. However, recordings from other areas show later modulation on successful stop trials: Stuphorn, Taylor, and

Schall (2000) found modulation after SSRT in neurons in supplementary eye field, and Ito, Stuphorn, Brown, and Schall (2003) found modulation after SSRT in neurons in anterior cingulate cortex. These structures may control the go process but do not implement it directly (Schall, Stuphorn, & Brown, 2002). Kok, Ramautar, de Reuter, Band, and Ridderinkhof (2004) found modulation of human event-related potential components (N2 and P3) before and after SSRT, suggesting that these components reflect both causes and consequences of stopping.

THE POINT OF NO RETURN AS LEAD TIME

The point of no return has a locus in the processing structure and anatomy of the controlled task, near the response end. The response can only be revoked if the act of control intervenes at or before the point of no return, for example, to change the rate of accumulation in movement-related neurons (Boucher et al., 2007; Logan et al., in press). The act of control must take time. It is implemented in the same cognitive architecture and brain structures as those for the controlled task, so it must operate on the same principles (Logan et al., 2014). The act of control begins with some stimulus, like an error, a change of mind, or a stop signal, and ends with some action, like revoking a response. The control system must detect the stimulus and respond to it, and detection and responding take time. The latency of the act of control imposes a further limitation on our ability to control controlled tasks: The act of control must be instigated with enough lead time to compensate for its latency, so it can alter processing before the controlled task reaches its point of no return.

The concept of lead time was familiar to Bartlett from the applied problem that antiaircraft gunners faced when shooting enemy aircraft. The shell took time to travel from the gun to the aircraft, and gunners had to compensate for that time by anticipating the location of the plane at the time the shell would reach it. All commands take some time to be communicated and implemented, and that latency imposes a temporal point of no return on the control system. Acts of control that are not initiated with enough lead time will fail.

SSRT as a temporal point of no return in countermanding

Lead time is a major factor in the countermanding paradigm, where SSRT imposes a temporal point of no return. The need for lead time can be seen in the plot of inhibition functions against RT minus stop-signal delay from Logan et al. (1984), replotted in Figure 5. Inhibition fails almost all the time when the stop signal coincides with the response (i.e., when RT minus stop-signal delay equals 0). In order to inhibit successfully half of the time, stop signals must be presented about 200 ms before the response (see Figure 5). The same relations appear in the other plots of probability of responding against mean go RT minus stop-signal delay (see Figures 1B, 3B, and 4B). They all require about 200 ms of lead time to inhibit successfully half of the time. This lead time defines SSRT, the time required to detect

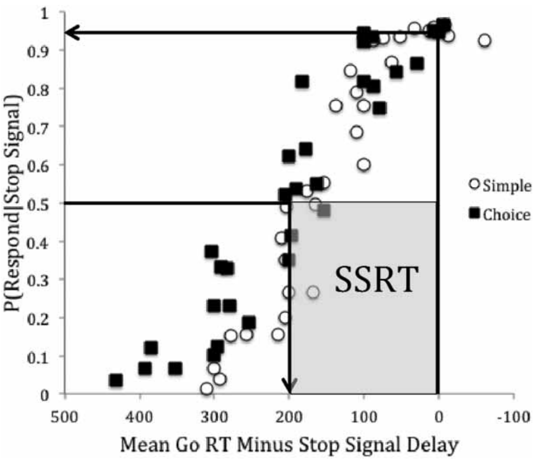

Figure 5. *Logan et al. (1984): Probability of responding given a stop signal in a simple or choice reaction time (RT) task as a function of go RT minus stop-signal delay. The probability of responding is near 1.0 when mean minus delay equals 0. A lead time of nearly 200 ms is required in order to inhibit 50% of the time. This lead time represents stop-signal reaction time (SSRT).*

the stop signal and stop the go response (Logan & Cowan, 1984; Logan et al., 2014). Thus, SSRT represents a temporal point of no return in the countermanding paradigm.

SSRT is not directly observable. If response inhibition succeeds, we know that SSRT plus stop-signal delay must have been shorter than the latency of the go process up to its point of no return, but we do not know when it occurred. If response inhibition fails, we know that SSRT plus stop-signal delay must have been longer than the observed go RT, but we do not know how much longer. To estimate SSRT, we need a mathematical model. Fortunately, several models provide measures of SSRT. The simplest model is the Logan and Cowan (1984) independent race model, which makes no assumptions about the nature of the underlying processes and allows SSRT to be estimated from calculations on the observed data. More complex models make assumptions about the underlying processes, allowing estimates of the distribution of SSRT. Logan et al. (2014) modelled the stop and go processes as racing diffusions. Estimated distributions of SSRT from one of their fits appear in Figure 6. Matzke, Dolan, Logan, Brown, and Wagenmakers (2013) assumed that the stop and go distributions were ex-Gaussian and presented Bayesian methods for recovering the parameters of the SSRT distribution. However, their model is a measurement model rather than a process model. They make no assumptions about the nature of the processes that generate the ex-Gaussian distributions.

SSRT is short. It is of the order of 200 ms in healthy young adults across a wide variety of tasks, modalities, conditions, and strategies (Logan & Cowan, 1984; Verbruggen & Logan, 2008). It is longer in young children and becomes shorter with development. It is shortest in young adulthood and early middle age and lengthens in old age. Data from a lifespan development study by Williams, Ponesse, Schachar, Logan, and Tannock (1999) are plotted in Figure 7. Other studies show larger deficits in old age (e.g., Kramer, Humphrey, Larish, Logan, & Strayer, 1994). SSRT is longer in many kinds of psychopathology, including attention deficit hyperactivity disorder (Schachar & Logan, 1990) and schizophrenia (Thakkar, Schall, Boucher, Logan, & Park, 2011). It is longer in many neurological disorders, including frontal damage (Ornstein et al., 2009) and Parkinson's disease (Gauggel, Rieger, & Feghoff, 2004).

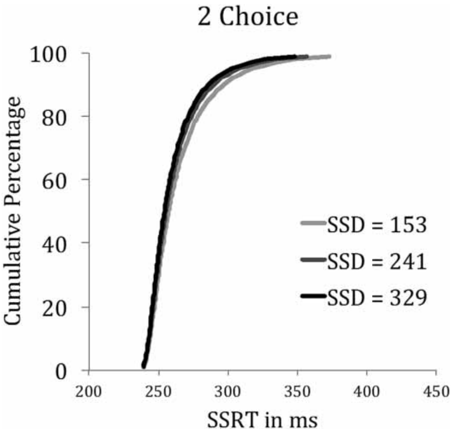

Figure 6. *Logan et al. (2014): Distributions of stop-signal reaction time (SSRT) estimated by fitting a diffusion race model to data from two-choice reaction time experiment (SSD = stop-signal delay).*

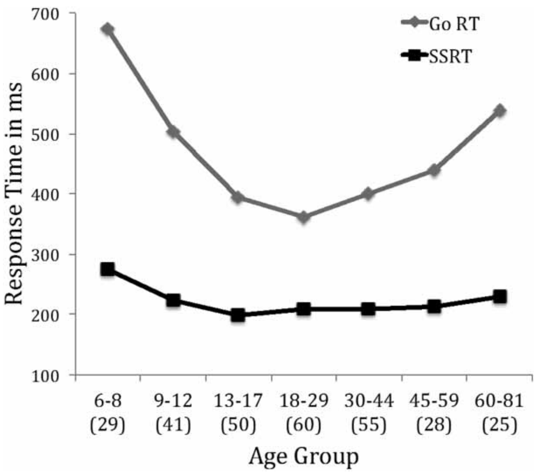

Figure 7. *Williams et al. (1999): Mean go reaction time (go RT) and stop-signal reaction time (SSRT) as a function of age group. The number of subjects in each group is in brackets.*

SSRT seems unaffected by the demands of the go task. It does not vary with the difficulty of the go task (Logan, 1981; Middlebrooks & Schall,

2014) or the number of choice alternatives in the go task (Logan et al., 2014; Rae et al., 2014). Yamaguchi, Logan, and Bissett (2012) examined SSRT when the go task involved performing two tasks in rapid succession, in the classic "psychological refractory period" procedure (Pashler, 1994; Welford, 1952). They had subjects stop the first or the second response in dual task conditions and stop one response in single task conditions. They found the same SSRT in all three conditions. There was no decrement from the single task to the dual task condition, and there was no decrement from the easy dual task (the first response) to the hard dual task (second response) condition (also see Logan & Burkell, 1986). This immunity of SSRT to the demands of the go task is interesting, in contrast to the strong effects of the demands on the go task. It suggests that acts of control are not subject to the same capacity limitations as the controlled acts they modify. It is not clear whether this immunity is specific to the act of control underlying response inhibition or a characteristic of acts of control in general.

THE POINT OF NO RETURN IN HIERARCHICAL CONTROL

The point of no return is straightforward in the simple controlled acts addressed in the countermanding paradigm. There is not much to control: A stimulus must be detected and discriminated, and a response must be selected and executed. The go task can be performed as a *prepared reflex*, in which a task set establishes a chain of processes that is triggered when an appropriate stimulus appears and produces a response with no further online control (Cohen-Kdoshay & Meiran, 2009; Hommel, 2000; Logan, 1978). The go response can be inhibited if the stop process beats it to the muscles. The increasing commitment to a response can be modelled as stochastic accumulation of evidence to a threshold (Logan et al., 2014; Ratcliff, 1978; Ratcliff & Smith, 2004).

The point of no return is not so straightforward in more complex, hierarchical tasks, which are more typical of the skills Bartlett was thinking about (Cooper & Shallice, 2000; Lashley, 1951; Miller, Galanter, & Pribram, 1960; Vallacher & Wegner, 1987). There is a lot to control in hierarchical tasks. Several processes may be going on concurrently at different levels, and each may have its own point of no return.

For the past few years, my colleagues and I have been searching for points of no return in skilled typewriting. Skilled typing recruits processes of perception, attention, memory, and motor control and requires them to work together in a coordinated fashion at a high speed. The individual processes are well understood in standard laboratory experiments (e.g., on prepared reflexes) but the combination is not. Seminal work by Henry Shaffer at Exeter in the 1960s and 1970s (e.g., Shaffer, 1976; Shaffer & Hardwick, 1968), corroborated in more recent investigations (Logan & Crump, 2011; Rumelhart & Norman, 1982; Salthouse, 1986; Sternberg, Knoll, & Turock, 1990), suggests that typists coordinate the component processes by controlling them hierarchically. There is strong evidence for at least two nested control loops in typing: an outer loop that begins with language comprehension or generation and ends with a series of words to be typed, and an inner loop that begins with a word to be typed and ends with a series of keystrokes (Logan & Crump, 2011). Thus, we can ask whether the point of no return is in the outer loop, the inner loop, or both.

The point of no return in skilled typing

The two-loop theory assumes that the outer loop processes words, and the inner loop processes letters. Thus, we can locate the point at which responses become inevitable by asking skilled typists to stop typing words in response to a stop signal. If the point of inevitability is in the outer loop, words should be typed ballistically, without interruption, until they are finished. Typists should not be able to stop typing in the middle of a word. If the point of inevitability is in the inner loop, letters should be typed ballistically, and typists should be able to stop typing in the middle of a word. Three sets of data suggest they can.

Countermanding typing

Logan (1982, Experiment 1) had skilled typists perform a countermanding task while typing three-, five-, and seven-letter words. The inhibition functions for the first and last letter in each word length are plotted in Figure 8A. Figure 8B plots the same data as a function of keystroke latency minus stop-signal delay. The inhibition functions align nicely, consistent with the alignment that I showed earlier in simpler RT tasks. The alignment on the occurrence of the response suggests that typists can stop typing in the middle of a word, up to the point of making a keystroke. Thus, the point of no return is in the inner loop.

Another way to ask whether typists can stop typing in the middle of a word is to plot the distribution of the number of keystrokes they type after a stop signal. Figure 9 plots the distribution from a study in which professional typists typed sentences (Logan, 1982, Experiment 3). Its mean is 1.87, which is smaller than the shortest word in the sentence. The same figure plots data from an unpublished experiment by Patrick Bissett (unpublished), in which skilled undergraduate typists stopped typing five-letter words. Their distribution is very similar. Its mean is 1.80, suggesting that modern typists, like the professional typists of yesteryear, can stop typing in the middle of a word (also see Salthouse & Saults, 1987).

Error detection in typing

Errors in typing are natural stop signals. The goal of typing is to produce perfect text, so errors have to be fixed. Typists normally stop typing when they make an error, in order to correct it. Crump and Logan (2013) suggested that the post-error slowing seen in skilled typists reflects the cost of

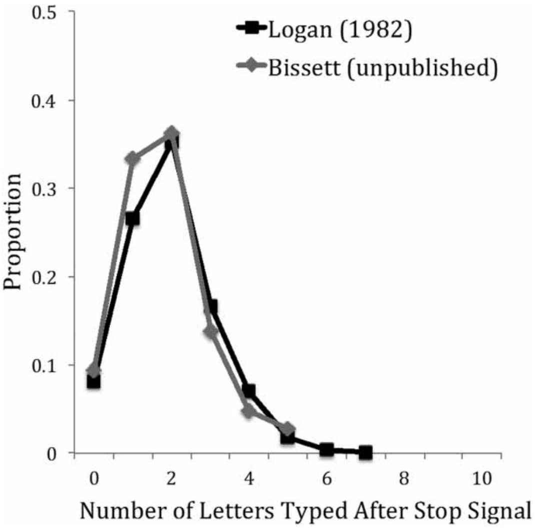

Figure 9. *Number of keystrokes typed after a stop signal in professional typists (Logan, 1982) and modern university students (Bissett, unpublished).*

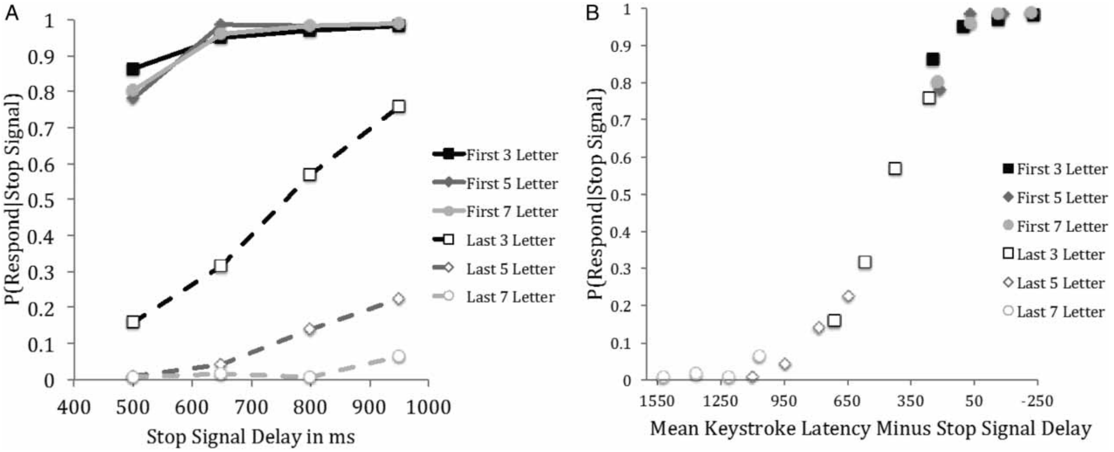

Figure 8. *Logan (1982): (A) Probability of responding as a function of stop-signal delay for the first and last keystrokes of 3-, 5-, and 7-letter words typed by skilled typists. (B) Probability of responding as a function of keystroke latency minus stop-signal delay. Data points are means across subjects in each condition.*

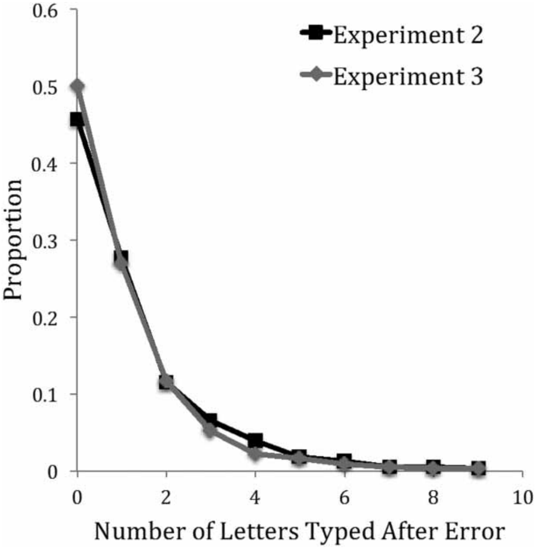

Figure 10. *Crump and Logan (2013) Experiments 2 and 3: Number of keystrokes struck between making an error and detecting it when skilled typists type text.*

inhibiting the automatic tendency to correct the error, which is not allowed in most experiments. When typists are allowed to correct their errors, the number of keystrokes they type following the error reflects the latency of the detection process and indicates whether typists can stop typing in the middle of a word. Figure 10 plots the distributions of the number of keystrokes typed after an error from two experiments (Crump & Logan, 2013, Experiments 2 and 3). The mode of both distributions is 0, suggesting that skilled typists can stop typing in the middle of a word (also see Long, 1976; Rabbitt, 1978).

Interrupting typing with a second task

Yamaguchi, Logan, and Li (2013) tested skilled typists in the psychological refractory period procedure (Welford, 1952), in which the first task was to type a three-, four-, or five-letter word, and the second task was to report the pitch of a tone, saying "high" if it was high and "low" if it was low. When the two tasks overlapped, RT to the tone increased with word length, indicating that the response selection process chose letters rather than words and suggesting that the

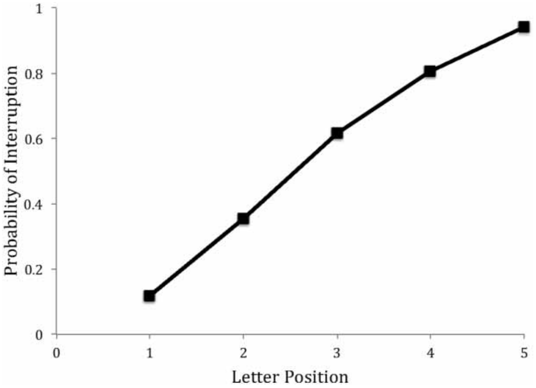

Figure 11. *Yamaguchi et al. (2013): Probability of interrupting the typing of the first through fifth letters of a word to make a vocal response to a secondary tone (stimulus onset asynchrony = 50 ms).*

bottleneck was in the inner loop and not in the outer loop. The data also indicated a strong tendency to interrupt typing to report the tone. The probability of responding to the tone before typing a letter increased with word length and with the position of the letter in the word (see Figure 11). Thus, skilled typists can stop typing in the middle of a word.

The point of no return is in the inner loop

All of these data suggest the point at which responses become inevitable in skilled typing is in the inner loop, probably at the fingertips. But typing is hierarchical. There may be points of no return at other levels of the hierarchy.

COMMANDS AND COUNTERMANDS

Hierarchical skills like typing are vehicles for expressing our intentions. Our intentions result in commands to the motor system that cause our actions. There is some debate about the causal status of intentions, primarily from reports that actions can occur without intention, and intentions can occur without action (see Wegner, 2002; also see Logan & Crump, 2010), but these are rare cases. More often, we act when we intend to act, and do not act unless we intend to. The association between intention and action may not be perfect, but it is strong enough to support our actions in everyday life. Indeed, I am relying on it as I type this article.

From the perspective of intentional action, hierarchical control relies on commands as well as countermands. Higher level processes control lower level processes by providing them with instructions that tell them what to do. In skilled typing, the outer loop chooses a word to be typed, and the word tells the inner loop which keys to strike (Logan & Crump, 2011; Shaffer, 1976). Words command the inner loop, and keystrokes command finger movements. Commands and countermands are both acts of control, instigated by an intention and some triggering condition, resulting in changes in the processing system (Logan et al., 2014). Countermands are simple: Stop whatever is happening. Commands are more complex: Actions must be chosen, sequenced, and fitted to the constraints of the actor's goals and the structure of the environment. Commands may be more common than countermands: Skilled performance depends on the fluent execution of many commands at many levels, often for sustained periods. Skilled performers "in the zone" let the commands take care of themselves, countermanding only after errors or big changes in goals.

If commands are acts of control, they must have their own points of no return, defined by the structural and anatomical loci at which they have their effects and by the lead times they require to cause those effects at those loci. The point of no return for commands may differ from the point of no return for countermands in locus, timing, and degree of commitment to action.

Commands must occur at all levels of the hierarchy. The intention to type brings us to the keyboard. The idea we want to express suggests sentences and phrases, which suggest words, which suggest keystrokes. Typing involves executing commands at all these levels. Countermands have their strongest effects on the lowest level. Typists are able to inhibit individual keystrokes, stopping in the middle of a word (see above).

Commands have various lead times that depend on their position in the hierarchy. Higher level commands take longer to execute. They pass through more levels of the hierarchy before they are expressed in action, and that takes more time. Often, a single higher level command creates several lower level commands, as chunks are broken into their constituents. Larger chunks will take more time to execute. Countermands have a short lead time, of the order of 200 ms, perhaps reflecting the importance of stopping. Countermands undo commands, so they should happen quickly.

Commands engender less commitment to action than countermands, especially at higher levels in the hierarchy. A high-level intention to act may be the ultimate cause of an action (Sperry, 1966; Vallacher & Wegner, 1987), but the commitment to action is not completely irrevocable until it reaches the muscles (see above). High-level commands are often general, specifying the goal but not the means to achieve it; there is a commitment to act but no commitment to a particular action. Lower level commands specify the action more completely, committing to more details at lower levels in the hierarchy, until finally the action is executed, and commitment is irrevocable (Rosenbaum, Inhoff, & Gordon, 1984). Commitment grows progressively as the action evolves over time, increasing as it passes points of no return at successively lower levels of the hierarchy.

The contrast between commands and countermands is sharpest when they address different levels in the hierarchy. The literature reviewed so far suggests that countermands occur at the level of keystrokes in the hierarchy that controls typing. I now review experiments that suggest that the explicit commands in typing cannot be keystrokes and must be words, and I show how words command keystrokes when they pass the point of no return.

Explicit commands in skilled typing cannot be keystrokes

Typing is a deliberate, conscious activity that expresses our explicit knowledge. We know what we want to say, and we sit at the keyboard until it appears in print on the screen. This explicit knowledge forms the commands that drive the motor system to type. We can discover the nature of the explicit commands by asking skilled typists to make explicit judgements about aspects of typing. Then we can determine whether their explicit knowledge is accurate enough to support skilled typing. If it is not, that knowledge cannot be the explicit command that drives typing. We can ask whether keystrokes are explicit commands by asking whether typists know where the keys are on the keyboard and know which hand and finger strikes which key.

Typists have poor explicit knowledge of key locations

Skilled typists whose fingers dance across the keyboard have poor explicit knowledge of the locations of the keys relative to the keyboard or relative to each other. Following Morton (1967), Snyder, Ashitaka, Shimada, Ulrich, and Logan (2014) tested explicit knowledge of key locations on the keyboard. They gave typists a blank keyboard and had them fill it in, writing the letters in their proper locations. On average, typists got half of them right, got a quarter of them wrong, and missed a quarter of them. However, the same typists were 95% correct in a typing test, indicating good implicit knowledge of key locations despite poor explicit knowledge. Liu, Crump, and Logan (2010) tested explicit knowledge of relative location, having typists imagine themselves standing on one key (e.g., F) facing one direction (e.g., the space bar) and then point to the location of another letter (e.g., W). Their absolute pointing error was 47°, which was much larger than their pointing error when they could see the keyboard (28°). These typists were also accurate on the typing test, suggesting good implicit knowledge but poor explicit knowledge. If implicit knowledge is more accurate than explicit knowledge, then explicit knowledge cannot be the basis of the explicit commands that drive typing. Skilled typists' explicit commands do not specify key locations.

Typists have poor explicit knowledge of what their hands are doing

There is evidence that skilled typists do not know explicitly which hand and which finger types which letter. Logan and Crump (2009) had typists type paragraphs normally, with both hands, or by typing only the letters they would type with their left hand and omitting the letters they would type with their right hand (or vice versa). Typists typed normally very quickly and accurately, averaging 80 words per minute and 6% errors. They typed the left-hand (or right-hand) letters much more slowly and less accurately, averaging 14 words per minute and 30% errors. A control experiment suggested that the problem was in knowing which hand typed which letter, not in breaking up familiar movement sequences. Typists typed single words in which the left-hand letters were coloured red, and the right-hand letters were coloured green. They were told to type only the red letters (or only the green ones). Their typing was as fast as in a control condition in which all letters were red (or green), suggesting that disrupting familiar movement sequences was not the problem.

On the basis of these results, we concluded that typists normally do not have explicit knowledge of which hand types which letter. We suggested that they acquired explicit knowledge by monitoring their fingers and inhibiting the movement if the finger was on the wrong hand. Snyder and Logan (2013) asked whether simply monitoring the fingers was enough to disrupt typing. We compared a "monitor and inhibit" condition, like Logan and Crump's (2009), in which typists had to omit keystrokes typed with a particular finger, with a "monitor" condition, in which typists just had to say whether they used that finger after the trial. The mean interkeystroke interval, plotted in Figure 12, was longer in the monitor-and-inhibit condition than in the control condition, replicating Logan and Crump. Mean interkeystroke interval was also longer in the monitor condition than in the control condition, suggesting that simply monitoring a finger is enough to disrupt skilled typing. The disruption was larger in the monitor-and-inhibit condition than in the monitor condition, suggesting an extra cost to inhibiting. We interpret this as a lead time effect: Typists must slow down their typing to have enough time to monitor the finger and to inhibit the finger movement when

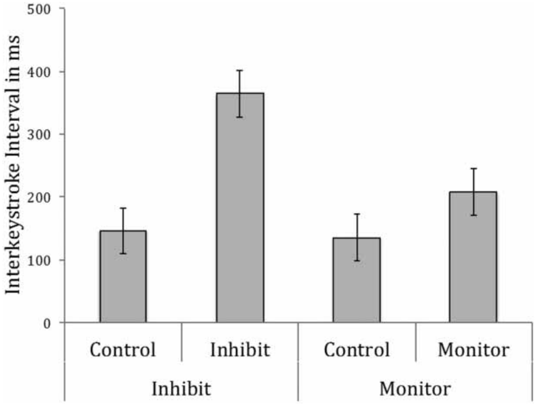

Figure 12. *Snyder and Logan (2013): Mean interkeystroke intervals in typing words in which no keystrokes were inhibited or monitored (*control*), in words in which single keystrokes had to be inhibited (*inhibit*), and in words in which typists had to report whether they typed a particular single keystroke (*monitor*).*

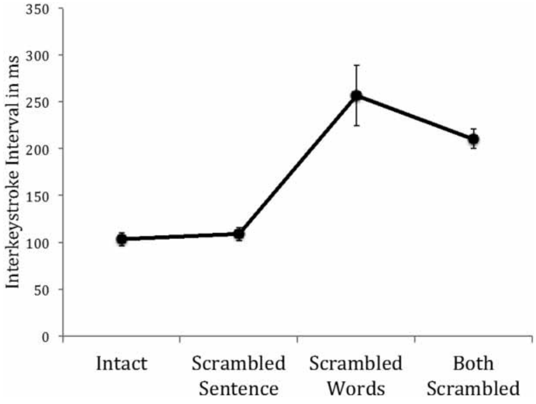

Figure 13. *Yamaguchi (unpublished): Interkeystroke interval for typing "the instance theory is right" (*intact*), "right the is instance theory" (*scrambled words*), "hte ticsenan htoyre si ithgr" (*scrambled letters*), and "trghi het si taesncin tyhore" (*both scrambled*) in 9 skilled typists.*

necessary. Typical SSRTs are of the order of 200 ms (Logan & Cowan, 1984; Verbruggen & Logan, 2008), so disruption should be at least that large. By contrast, in the monitor condition, typists only have to slow down enough to take note of which finger they use.

The Logan and Crump (2009) and Snyder and Logan (2013) results suggest that skilled typists' explicit commands cannot specify the hand or finger used to type each letter, because acquiring that knowledge produces so much disruption. The Snyder et al. (2014) and Liu et al. (2010) results suggest that skilled typists' explicit commands cannot specify the location of the key to be struck, because they have poor explicit knowledge of absolute and relative key locations. Together, these results suggest that commands and countermands in skilled typing address different units at different levels of the control hierarchy and so may have substantially different points of no return.

Explicit commands in skilled typing are words

For me, the most convincing evidence that words are the explicit commands in typing is my own experience. I write by talking to myself. I say words and I type them. This contrasts with my experience as a novice, when I typed by spelling. I would say a phrase or a sentence and then spell each word out, saying each letter, hunting for it, and striking the key. As my skill progressed, I spelled but I no longer needed to hunt. Finally, after typing my wife's dissertation (Zbrodoff, 1984), I could type without spelling. I could say a word and it would appear on the screen. Amazing.

Words are typed faster than nonwords

There is a lot of empirical evidence supporting the proposition that words are the explicit commands in typing. Scrambling the order of words in sentences has little effect on typing speed, but scrambling the order of letters within words has strong effects. This was first demonstrated by Fendrick (1937) and has been replicated many times (Salthouse, 1986). Figure 13 plots the results of a replication by Motornori Yamaguchi, now at Edge Hill University, in which nine typists typed *the instance theory is right* (intact text, and a perfectly true sentence), *right the is instance theory* (scrambled word order), *hte ticsenan htoyre si ithgr* (scrambled letter order), and *trghi het si taesncin tyhore* (scrambled word order plus scrambled letter order) just one time, with order randomized between typists (Yamaguchi, unpublished). The mean interkeystroke intervals, presented in Figure 13, replicate the standard results.

Yamaguchi's results and the classic effects suggest that words are the explicit commands that drive skilled typing. Higher level units cannot matter very much because scrambling word order destroys those units but leaves skilled typing intact. Words matter more because scrambling letter order destroys words and severely impairs skilled typing. Letters may also be commands, but the paucity of explicit knowledge that typists have about letter locations and hand and finger assignments suggests that this is unlikely.

Words activate their constituent keystrokes in parallel

More direct evidence that words are the explicit commands comes from experiments that demonstrate parallel activation of all the keystrokes in a word during typing. If the commands were single letters, then only one keystroke should be active at a time. Crump and Logan (2010) showed parallel activation of keystrokes in a priming experiment, in which skilled typists heard auditory primes and then typed a probe presented on the screen. The probe was the entire word that was primed, a single letter from the primed word (the first, middle, or last), or another single letter that was not in the primed word. If the word activated all of the prime's letters in parallel, then RT to single-letter probes should be longer for letters that were part of the prime than for letters that were not. If letters are activated serially such that only one letter is active at any time, and that letter remains active until it is typed, and the next letter becomes active, then only the first letter should be active before the word is typed. Thus, only first-letter probes should be primed. RT should be equally long for the other single-letter probes; middle- and last-letter probes should be no shorter than other-letter probes. The data, presented in Figure 14, support parallel activation: RT for first-letter probes was short, but RTs for middle- and last-letter probes were shorter than RTs for other-letter probes.

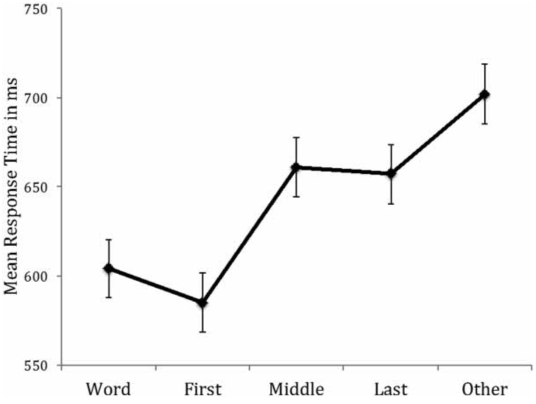

Figure 14. *Crump and Logan (2010): Response times to probes preceded by auditory primes. The probes required typists to type the primed word (*word*), the* first, middle, *or* last *letter of the primed word, or an* other *letter that did not appear in the word. Response times were longer for other letters than for letters that were part of the primed word.*

Logan, Miller, and Strayer (2011) used the LRP to assess parallel activation of keystrokes in the motor system. The LRP measures the difference in electrical potential between the left and right motor cortices; thus it should reflect the number of keystrokes that are activated in the left and right hands. We varied the number of active keystrokes in each hand by having typists type words like *rest,* in which all of the letters are typed with the same hand (the *all* condition), *swim,* in which the first two letters are typed with one hand, and the remaining letters are typed with the other (the *first two* condition), and *dump*, in which the first letter is typed in one hand, and all of the remaining letters are typed with the other (the *first* condition). If words are commands, and all keystrokes are activated at once, then the LRP for the first keystroke should decrease steadily from the all (*rest*) to the first two (*swim*) to the first (*dump*) condition because progressively more keystrokes will be activated in the opposite motor cortex, decreasing the difference between the cortices. However, if letters are commands, and only one keystroke is active at a time, the LRP to the first keystroke should not vary with condition. The data, plotted in Figure 15, show a steady decrease in the LRP across word conditions, supporting parallel activation.

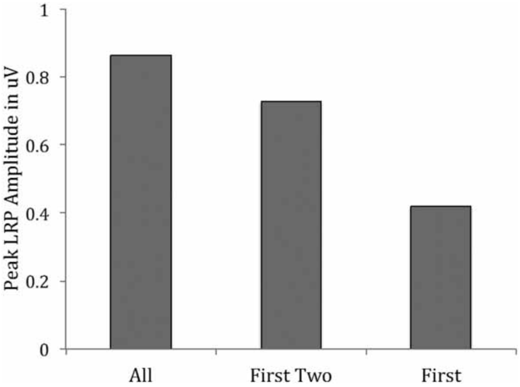

Figure 15. *Logan et al. (2011): Peak amplitudes of lateralized readiness potential (difference between C3 and C4 electrodes) for the first keystroke in words whose letters are all typed in one hand (*all, *e.g., rest), words whose first two letters are typed in one hand and the remainder typed with the other (*first two, *e.g., swim), and words whose first letters were typed in one hand and the remaining letters typed with the other (*first, *e.g. dump).*

A point of no return between words and letters

The evidence that words activate their constituent keystrokes in parallel suggests that passing a word to the motor system crosses a point of no return, significantly increasing the commitment to action. The word creates a pattern of activation that the motor system must contend with, whether it types the word or suppresses it to type something else. The commitment to respond is not yet irrevocable—responses can be inhibited even as they are executed (De Jong et al., 1990)—but it is significantly greater and more specific than the commitment in neutral activation at baseline. The commitment seems to change at the boundary between the outer and the inner loop. Before the outer loop passes a word to the inner loop, the inner loop is not committed. Once the outer loop passes a word, the inner loop is changed irrevocably. Specific keystrokes are activated, and they will influence what the inner loop does next, even if they do not determine it completely.

More generally, we might identify a point of no return as a locus or time at which the commitment to action increases substantially. Irrevocable commitment is a big increase in commitment. Large increases in commitment may also occur in earlier stages of processing at earlier points in time, from perception to memory to thinking itself. These increases should occur at the time and place where an act of control has its effect.

POINTS OF NO RETURN IN PERCEPTION

Identifying points of no return in perception involves taking a stand on the nature and purpose of perceptual representations. If the point of no return is defined as a commitment to action, then it should be found in the perceptual and memorial processes that support action. Some theorists might endorse the idea that all perceptual and memorial representations support action (e.g., Allport, 1987; Eriksen & Schultz, 1979; Gibson, 1979; Hommel, Müsseler, Aschersleben, & Prinz, 2001; Kolers & Roediger, 1984; Neumann, 1987), but others would not. It would be more inclusive to define the point of no return as an increased commitment to a representation whether or not it leads to action: Each process, perceptual or memorial, computes some representation from its input. We can ask where and when that representation is formed, how it is modified by an act of control, and what is the nature of the act of control that modifies it. Surely, this is what Bartlett (1958) intended when he suggested looking for points of no return in thinking.

Attention

The act of attending changes our commitment to act on the objects, features, and scenes that surround us. Processing at attended locations is enhanced, and processing at unattended locations is suppressed (Broadbent, 1957; Bundesen, 1990; Lavie, 1995; Logan, 2002; Lu & Dosher, 2008; Smith & Sewell, 2013; Treisman, 1969), increasing our commitment to represent the attended location and decreasing our commitment to represent unattended locations. We focus attention on the objects we act on, and that attention facilitates the action. In many theories, attention is the gateway to the motor system. When the gates are open, we are committed to the actions that flow through them.

The locus of the point of no return in attention

Classical theories, beginning with Welford (1952) and Broadbent (1957), addressed the locus at which attention operated by distinguishing between *preattentive* and *attentive* processes (Neisser, 1967), spawning the classical yet ongoing debate over early (Broadbent, 1957) versus late (Deutsch & Deutsch, 1963; Norman, 1968) selection. Cherry's (1953) experiments showing little awareness of the unattended channel supported early selection. Moray's (1959) discovery that subjects could respond to their own names in the unattended channel supported late selection. Over the years, both positions have gained support (Kahneman & Treisman, 1984). Now, it appears that early and late selection are both possible, and people choose between them according to task demands (Johnston & Heinz, 1978; Lavie, 1995). The boundary between preattentive and attentive processes does not appear to be as sharp as classical theorists thought (Van der Heijden, 1992).

Studies of brain imaging and of awake behaving monkeys support this conclusion, showing evidence that attention modulates many brain structures including lateral geniculate nucleus and occipital, parietal, temporal, and frontal cortex (Schmolesky et al., 1998). The early studies with monkeys found attention effects in V4 (Moran & Desimone, 1985), but subsequent studies found them in earlier structures, including V1 (Luck, Chelazzi, Hillyard, & Desimone, 1997; Roelfsema, Lamme, & Spekreijse, 1998) and lateral geniculate nucleus (McAlonan, Cavanaugh, & Wurtz, 2008). Studies with humans have found attention effects from lateral geniculate nucleus (O'Conor, Fukui, Pinsk, & Kastner, 2002) to motor cortex to muscle activation (Gratton, Coles, Sirevaag, Eriksen, & Donchin, 1988). Thus, the point of no return for attention occurs at many loci (Treisman, 1969).

A temporal point of no return in switching attention

The data suggest that attention modulates perception at many levels and loci. The modulation is the result of an act of control that shifts attention, changing its parameters to focus on the location or the features of a new object (Logan & Gordon, 2001). Shifts in attention take time, and that imposes a temporal point of no return on the modulation they produce. The commitment to a response or a representation increases substantially when this point of no return is passed.

The time it takes to switch attention can be estimated from time course functions that plot changes in performance as a function of the delay between the onset of a cue that signals a shift of attention and the target display (Eriksen & Collins, 1969; Müller & Rabbitt, 1989). Performance improves as delay increases, eventually reaching asymptote. Sperling and Weichselgartner (1995) and Logan (2005) provided methods for estimating the distribution of switching times from time course functions. The mean of the distribution is around 50–100 ms.

If attention switching time is a temporal point of no return, there should be a large change in commitment when that point is passed. Eriksen, Webb, and Fournier (1990) measured this change in commitment by cueing attention to a location and changing the target in that location before and after attention shifted to it. RT to the target was unaffected when the target changed before attention shift but was strongly affected when the target changed after the attention shift, suggesting a large increase in the commitment to respond after the attention shift, consistent with a temporal point of no return (also see Shiffrin, Diller, & Cohen, 1996).

Task switching

The concept of task set is an important construct in theories of cognitive control. It refers to a state of readiness that people enter voluntarily to perform a certain task (Gibson, 1941; Schneider & Logan, 2014). It involves changes in perceptual, attentional, memorial, and motor processing that enable performance on the task (Logan & Gordon, 2001; Monsell, 1996). These changes alter people's responsiveness to the same stimuli. Figure 16 shows changes in RT to the digits 1–9

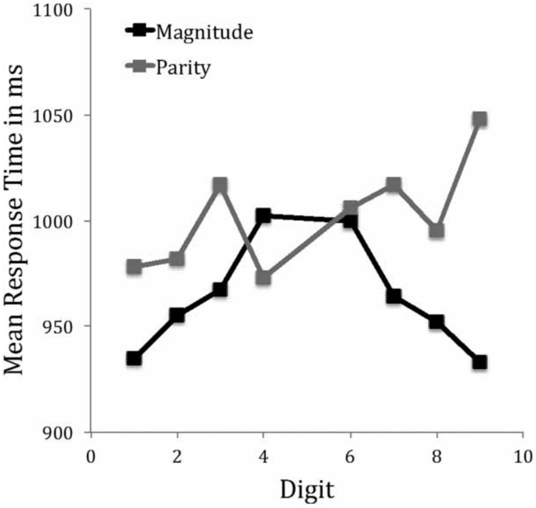

Figure 16. *Schneider and Logan (2005): Mean response time as a function of digit for magnitude and parity judgements.*

under task sets to judge magnitude (greater or less than 5) and parity (odd or even) in an experiment by Schneider and Logan (2005). For magnitude judgements, RT increased from 1–4 and decreased from 6–9; for parity judgements, RT increased slightly from 1–9 but was larger for odd digits than for even ones (see Logan & Schneider, 2010). These differences in RT can be viewed as reflecting changes in subjects' commitment to respond to the digits in particular ways, as if task set constitutes a point of no return. Like attention, task set operates at many structural and anatomical loci, and so entails many different points of no return. Schneider and Logan's (2005) experiment involved semantic judgements of visual stimuli, which were reported by pressing keys on a keyboard, changing commitment in perception, memory, and action.

Switching task sets is a voluntary process that is well described as an act of control. People switch tasks in response to external (Sudevan & Taylor, 1987) or internal cues (Jersild, 1927) or a combination of both (Rogers & Monsell, 1995). Sometimes they generate their own cues (Arrington & Logan, 2004) or retrieve them from memory (Logan, 2004). The response to the cue has a latency, like other acts of control. Logan and Bundesen (2003) developed methods for estimating the distribution of latencies from time-course functions generated by varying the interval between the onset of the cue and the onset of the target. The mean of the distribution was of the order of 350 ms. This task switching time represents the lead time required for the act of control and so constitutes a temporal point of no return.

Sudevan and Taylor (1987) showed that cues that signal tasks increase subjects' commitment to the task by presenting primes 2 s before the cues that either matched or mismatched the upcoming cues. When primes and cues matched, subjects responded quickly and appropriately. When primes and cues mismatched, subjects responded more slowly and less accurately, as if the prime committed them to one task, and they had to overcome the commitment when the cue appeared.

THINKING AND BEYOND

Following Bartlett (1958), I end by applying the concepts developed in my review of skilled performance to thought and communication. Thought can be construed as travel through mental space, transitioning from one state to another (Landauer, 1975). The set of states can be thought of as a problem space, where transitions between states result from the application of rules and operators (Newell & Simon, 1972). Thought is often more chaotic than logical, so transitions between states result from free association as much as rules or formal operations (J. R. Anderson, 2007; Landauer, 1975). Nevertheless, the concept of the point of no return applies to thought, as Bartlett (1958) anticipated.

The point of no return in thought may not have a distinct anatomical locus, as thinking is distributed throughout the brain, engaging language, perception, memory, and the motor system (J. R. Anderson, 2007). However, it may have distinct structural loci in the points of transition between mental states, as one state leads to another. The transitions between states are constrained by logic and habit, so one thought leads to the others that follow naturally from it. The spread of activation is automatic, so each state activates associated states, committing the thinker to a train of thought. The spread of activation is also determined by top-down goals and *schemas* (Bartlett, 1932), which suggest possible directions for the next step in the argument. Automatic and goal-directed thinking may converge, increasing the thinker's commitment to a single train of thought, or they may diverge, opening up new possibilities or dissolving into chaos, like many of my thoughts. In either case, there is an increasing commitment to a representation and the representations that follow from it. It may not lead irrevocably to action, but it affects subsequent thought and may be difficult to control (M. C. Anderson et al., 2004; Wenzlaff & Wegner, 2000).

Thought is often a social activity. We share ideas by acting and talking together and by writing and reading. My thoughts cross points of no return in your thinking as you read this. Together, we build a common representation of the state space underlying the topic of conversation. We build it iteratively, as my thoughts instigate your thoughts, and, if we are conversing, your thoughts instigate mine. The transfer of a thought from one person to another constitutes a point of no return: The speaker commits the listener to think certain thoughts, and those thoughts give rise to others through logic and association. The commitment can be dramatic. When one person says, "I love you", there is no turning back. The assertion may or may not lead to the desired actions, but the thoughts it causes are irrevocable. Relationships are never the same after those words are uttered.

Timing is also important in thinking, though it may be more important in enabling thoughts than committing to them. Some ideas build cumulatively and are better expressed in one order than another. Algebra before calculus. Sometimes we can feel thoughts building up to a solution, as in proving a theorem or designing a series of experiments. Other times the solution occurs with no premonition, in a sudden flash of insight (Metcalfe & Wiebe, 1987). But even with insight problems, the pieces have to be available in advance so we can see them in the right arrangement. Jokes are like insight problems: The set-up occurs before the punch line, and timing is critical. Good comedians commit their audiences to a train of thought and derail it at the right moment.

Thought is often shaped by hierarchical structures like schemas (Bartlett, 1932), frames (Minsky, 1975), and scripts (Bower, Black, & Turner, 1979). We often create narratives as a way of understanding people and events, attributing beliefs, desires, and rationality, and interpreting the behaviour we see as a coherent attempt to achieve some goal (Dennett, 1987). Thinking in terms of these structures commits us to representations, and the better the story we can construct, the stronger the commitment. Sometimes we misapply these structures, anthropomorphizing lower animals and inanimate objects, and seeing god's hand at work in natural phenomena. Once we go down that road, it is hard to turn back, as if we have passed personal and cultural points of no return.

CODA

Introducing the point of no return, Bartlett (1958) said,

> If we could devise experiments to show whether this occurs or not, and if it does under what conditions and with what results, it seems reasonable to hope that we might get some new light on the basic characters of error in thinking. (p. 18)

I hope the experiments reviewed in this article at least partially fulfil Bartlett's hope.

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