



Controlled information processing, automaticity, and the burden of proof

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Abstract

Cognitive psychologists often distinguish between voluntary and involuntary/automatic processes in attention and cognitive control. Dedicated experimental paradigms have been developed to isolate involuntary information processing, but these paradigms tend to assume a rigid and inflexible process that is either stimulus-driven or built up through simple repetition. In contrast, voluntary information processing is often assumed when processing is in line with arbitrarily defined task-specific goals. Here I review evidence from multiple cases suggesting that ostensibly goal-directed cognitive processes may not be so voluntary and controlled. It is argued that automatic processes can be conditionalized to reflect the task relevance of the stimuli and selection history in a variety of ways, rapidly and flexibly adjusting in order to facilitate future goal-directed behavior. As a result, many studies assumed to have measured a voluntary cognitive process have likely measured an amalgam of voluntary and automatic processes, thus blurring the distinction between the two. Automaticity may be much broader and more sophisticated than has previously been thought, which has wide-reaching implications for our conception of human cognitive control.

Keywords Cognitive control · Automaticity · Selective attention · Goal-directed

In the field of cognitive psychology, an established burden of proof must be met before a cognitive process can be said to be involuntary or automatic. In its most general form, the cognitive process must unfold in response to a task-irrelevant stimulus or stimulus dimension (e.g., the meaning of a word in the classic Stroop task; Stroop, 1935), in a context in which either it is not to the participant's advantage to engage that process or, ideally, engaging the process is explicitly counterproductive to the task at hand (Kahneman & Treisman, 1984). A case in point can be found in the paradigms frequently employed to test for involuntary attentional capture. Participants search for a target stimulus as defined by task-specific goals, often communicated via verbal instruction. For example, participants may be asked to search for a target of a particular shape and report something about that stimulus, such as the orientation of a bar contained within it. On a subset of trials, one of the nontargets is manipulated to be potentially attention-grabbing—for example, by making it salient in its physical

characteristics (such as a unique color; Theeuwes, 1992). Attending to this distractor would be explicitly counterproductive to the task at hand, since the target and not the distractor needs to be selected in order to determine the correct behavioral response (see Fig. 1A). When the presence of the distractor impairs performance under such conditions, it can be said to have been processed involuntarily. An entire literature is devoted to using this approach to examine the conditions under which attentional selection is automatic (e.g., Theeuwes, 2010).

On the other hand, no such burden of proof is typically invoked when attributing a cognitive process to voluntary control mechanisms. Instead, when participants engage cognitive processes that support the realization of task-specific goals, these processes are assumed by default to be voluntary. Returning to the attentional capture example, although the selection of a salient but irrelevant distractor is held to be involuntary, selection of the target is typically assumed to reflect a volitional process, especially when the response to the target is contingent on a changing task context (see Fig. 1B). In fact, this presumed coupling between voluntary processes and goal-directed behavior is so pervasive that most experimental designs used in the attention and cognitive-control literatures take it for granted. Studies that are not

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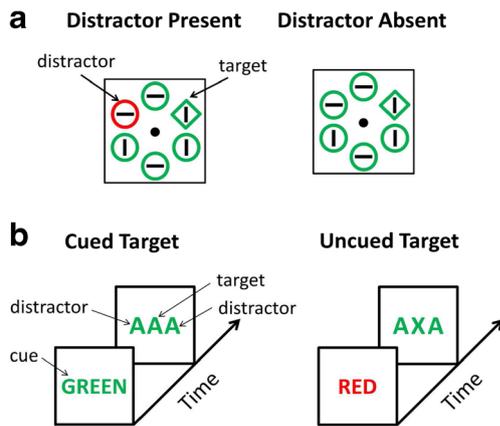


Fig. 1 Example experimental paradigms. (A) In the additional-singleton paradigm, participants search for a shape-defined target and report the orientation of a bar within it with a keypress. On a subset of trials, one of the nontargets is rendered in a unique color (referred to as the *distractor*). Color is entirely irrelevant to the task, and participants are explicitly informed of this. Processing of the distractor under such conditions is generally held to be automatic, because it conflicts with the goals of the task; such processing can be inferred from a variety of measures, including a slowing of response time on distractor-present trials, more frequent eye movements to the distractor, and distractor-evoked brain activity. (B) In this modified version of the flanker paradigm, participants only report the identity of the center letter (with a keypress) if its color matches that of the cue at the beginning of the trial. The cued color switches unpredictably across trials (variable mapping of color to response demands). Under these conditions, it is tempting to assume that the cue-contingent processing of the target and corresponding response information (whether and how to respond) reflects a voluntary and controlled cognitive operation. The effect of the task-irrelevant flankers (distractors) on performance, however, suggests otherwise: Flanker compatibility affects response time differently, depending on whether the flankers are rendered in the cued color (standard compatibility effect: faster for compatible than for incompatible trials) or the uncued color (reverse compatibility effect: faster for incompatible than for compatible trials), suggesting that stimuli are processed automatically in relation to the response contingencies of the task

explicitly interested in examining automatic processes give little if any consideration to the idea of automaticity when interpreting the results. In studies explicitly testing for automaticity, a competition between goal-directed and automatic information processing is assumed, such that the goal-directed and putatively voluntary process (e.g., target selection) may or may not be disrupted by the hypothesized automatic process (e.g., distractor selection). If this assumption were to be violated, such that the performance demands of the task failed to engage voluntary control mechanisms or engaged them only minimally, it would become difficult to claim that any observed influence of task-irrelevant stimuli was truly automatic insofar as it was robust to competing goal-directed influences.

That a cognitive process is successful in achieving an explicit goal of the participant is not sufficient to conclude that the process is volitional. Involuntary processes could still be engaged that would facilitate the realization of task goals, limiting the need for volitional control in certain

circumstances. In the context of attentional-capture studies, for example, the target conceivably could also capture attention involuntarily, even though participants might have the intention of attending to it. Without explicitly ruling out an automatic component, it is difficult to know with confidence the degree to which goal-contingent behavior is in fact volitional.

Considerations surrounding the definition of automaticity

Classical definitions of automaticity emphasize both the involuntary nature of the mental process in question and the process's freedom from capacity-limited mental resources. Specifically, an automatic mental process should be triggered by a stimulus without specific intention and without the ability to stop that process, once triggered (i.e., it is executed involuntarily; Kahneman & Treisman, 1984). An automatic process should also be immune to dual-task interference, operating independently of the mechanisms supporting goal-directed cognition and action (Kahneman & Treisman, 1984).

In the context of human cognitive control, the distinction between a voluntary and an involuntary cognitive process has an intuitive quality to it: If a cognitive process is triggered by a stimulus regardless of the will of the participant to engage that cognitive process at that particular moment in time (i.e., if it is stimulus-driven), such a process can be clearly distinguished from one that is willfully and endogenously engaged in the support of an explicit goal. It is in this respect that I focus my arguments here concerning the distinction between controlled and automatic processes. Freedom from capacity-limited mental resources assumes a strict duality in which automatic mental processes are not shaped by, or otherwise conditionalized on, the currently activated goal states, which by definition require some measure of intentional control to engage. As will be discussed, if one broadens the concept of automaticity to include automatic processes that are contingent upon task-specific goals, the extent to which cognition can be said to be controlled and volitional becomes much more limited. However, even under the strict assumptions of this duality, the extent to which automaticity can support goal-consistent task performance is still underappreciated.

The more liberal definition of automaticity adopted here, focusing on involuntary cognitive processes that are stimulus-driven, raises an important distinction between the manner in which an individual prepares for a task and the manner in which an individual actually executes behavior consistent with that state of preparedness. Although the former process may be volitional, the latter may be distinctly nonvolitional and is the focus of this article. Under most experimental conditions, mental activity is inherently ambiguous with regard to the latter, because cognition is only probed using a stimulus

that participants are motivated to process in the service of performing the task goal (i.e., a critical target), which could elicit automatic responses. As will be described in more detail below, experiments that include explicitly task-irrelevant stimuli to probe the volitional nature of cognition suggest that goal-consistent information processing may not be so volitional.

In the context of the arguments made in this article, the examples of automatic processes that are provided include both the automatic allocation of attention and the automatic activation of stimulus–response mappings. Although obvious theoretical distinctions can be made between the two, for the purposes of this argument they are treated in the same way. Specifically, both can exhibit characteristics of volitional cognitive control in a variety of experimental tasks, ostensibly supporting the realization of task goals. In this regard, the focus of this article is on the different aspects of goal-consistent task performance that can be supported by involuntary mental processes.

On the scope of automaticity

As was stated in the opening section of this article, a cognitive process that operates in the service of completing the task goals need not be a voluntary cognitive process. This dissociation between voluntary and goal-directed cognition may not be particularly problematic when interpreting whether the mechanisms governing task-related performance are volitional and controlled, provided that the scope of automaticity is limited in clearly defined ways. Highly influential theoretical models of cognition have tended to assume that this is indeed the case. Automatic behavior is held to be rigid, inflexible, and built up through protracted habit learning (Schneider & Shiffrin, 1977; Shiffrin & Schneider, 1977; see also Jiang & Swallow, 2013; Kyllingsbaek, Schneider, & Bundesen, 2001; Kyllingsbaek, Van Lommel, Sorensen, & Bundesen, 2014; Lenartowicz, Verbruggen, Logan, & Poldrack, 2011; Qu, Hillyard, & Ding, 2017; Verbruggen & Logan, 2008). Under these assumptions, controlled processing is necessary to flexibly adjust how information is selected and translated into behavior to accommodate a task's goals. Specifically, controlled processing is recruited when an effective automatic response has not yet developed through repetition, or to override automatic information processing under conditions in which the automatic mode no longer produces the desired outcome. A brief experiment involving only a few hundred trials, and especially an experiment in which the correct responses are dictated by specific contingencies within the task (rather than consistent stimulus–response mappings), can effectively rule out the role of automaticity when interpreting the processes responsible for the realization of goal-consistent behavior.

As will be argued in this article, we now have much reason to doubt these foundational assumptions about the scope of automaticity. Automatic modes of information processing can develop much more rapidly than has previously been thought, being evident within a single experimental session and undergoing trial-by-trial modulation. They are also much more flexible than has previously been thought, able to adjust immediately to changes in the task relevance of stimuli. Nor does the development of automaticity necessarily reflect a history of having performed a particular behavior more frequently than competing behaviors, but can instead arise merely from associative learning. Once automatic processing has been configured or shaped by these factors, it is poised to facilitate future goal-directed behavior. Such automatic cognitive processes could affect performance in most any experimental context, including those that are often assumed to require voluntary and effortful cognition. Below, I present several cases that illustrate these features of automaticity.

Flexibility of automatic information processing

The idea that involuntary cognitive processes can be conditionalized on the goal state of the observer has a rich tradition. One classic case can be found in the well-documented phenomenon of (goal-)contingent attentional capture (Folk & Remington, 1998; Folk, Remington, & Johnston, 1992; Folk, Remington, & Wright, 1994): When observers search for a stimulus defined by a particular feature property, such as the color red, stimuli that possess this searched-for property involuntarily capture attention when presented as task-irrelevant distractors (e.g., irrelevant by virtue of their timing, location, and object identity). This is typically measured as a significant cuing effect generated by such distractors in a spatial-cuing paradigm (e.g., Folk & Remington, 1998; Folk et al., 1992; Folk et al., 1994) or as an attentional blink in a rapid serial visual presentation (RSVP) paradigm (Folk, Leber, & Egeth, 2002, 2008). These attentional effects can be contrasted with nonsignificant orienting toward otherwise equivalent distractors that do not share a defining feature with the target (e.g., Eimer & Kiss, 2008, 2010; Folk & Remington, 1998).

Goal-contingent attentional capture possesses characteristics often associated with controlled, volitional mechanisms of information processing. Like endogenous attentional orienting (Johnson & Yantis, 1995), goal-contingent attentional capture reflects a graded allocation of processing resources rather than a ballistic orienting response (Anderson & Folk, 2010): The more the distractor resembles the target (at least in color), the more strongly it is processed by the attention system (Anderson & Folk, 2010). Also like endogenous attentional orienting, goal-contingent attentional capture can operate flexibly. When the target-defining feature is cued unpredictably from trial to trial, goal-contingent attentional capture

can still be observed (Lien, Ruthruff, & Johnston, 2010). Although this finding is not without controversy (see Belopolsky, Schreij, & Theeuwes, 2010), the rapid instantiation of automatic yet goal-contingent information processing as a principle is robust in other domains of human cognition.

One such domain is the inhibitory control of behavior. A common approach to examining the ability to inhibit a behavior involves a task in which participants execute speeded responses to particular stimuli. Occasionally, a stop or no-go signal is presented that requires that a prepared behavior be canceled or otherwise withheld (e.g., Aron, Fletcher, Bullmore, Sahakian, & Robbins, 2003; Aron & Poldrack, 2006; Logan, 1983; Logan & Cowan, 1984). Because the stop/no-go signal is task-relevant and the corresponding inhibition of planned behavior is dictated by the task goals, it is tempting to conclude that such inhibition reflects a voluntary act of cognitive control. As with attentional selection, however, goal-contingent automaticity is also evident in the domain of response inhibition.

The execution of motoric inhibition in response to a stop signal does not require conscious awareness of the stop signal, suggesting automatic activation of inhibitory processes by a goal-defined stimulus (van Gaal, Ridderinkhof, Scholte, & Lamme, 2010; van Gaal, Ridderinkhof, van den Wildenberg, & Lamme, 2009). By presenting entirely task-irrelevant stimuli possessing a feature (e.g., color) shared with a no-go stimulus, a strong test of an involuntary component to goal-contingent response inhibition can be provided. Using such an approach in the context of an Eriksen flanker task (Eriksen & Eriksen, 1974), Anderson and Folk (2012) showed that when task-irrelevant flankers are presented in a color associated with the need to withhold a response, they evoke a reverse compatibility effect consistent with the inhibition of their associated response; that is, responding to a target was slowed when a compatible flanker was presented in the no-go-associated color.

Goal-contingent involuntary response inhibition is not restricted to instances in which the stimulus feature associated with the need to withhold a response is consistent across trials. Rather, such conditional automaticity can be adjusted flexibly under conditions in which the feature indicating the need to withhold a response changes unpredictably from trial to trial (Anderson & Folk, 2014; Anderson, Folk, & Courtney, 2016; Anderson, Folk, Garrison, & Rogers, 2016). Such flexibility provides compelling evidence that, once established, the goal of withholding a response to a particular stimulus can be executed automatically, triggered by a match between intentions and the stimulus input. In this way, the response inhibition elicited by a goal-defined but otherwise arbitrary stop or no-go stimulus need not reflect an act of volitional cognitive control.

Further evidence for cue-elicited acts of goal-contingent information processing has come from conflict adaptation.

In a response conflict task, such as the flanker task, suppression of irrelevant and conflicting response information is typically more efficient on the trial after an individual has successfully resolved such conflict (Botvinick, Braver, Barch, Carter, & Cohen, 2001; Gratton, Coles, & Donchin, 1992). Such conflict adaptation effects are evident in motor-evoked potentials even when the prior and current trials required no behavioral response, and thus when no conflict in response selection required resolution, consistent with the idea that the response associations of the stimuli (which were arbitrary and defined by the task goals) were processed automatically in a cue-driven fashion (Cona, Treccani, & Umiltà, 2016).

Automaticity and associative learning

When performance is motivated by the prospect of a reward outcome, performance-related improvements and information-processing biases are frequently observed. For example, rewarded targets are located more quickly than less-rewarded or unrewarded targets (e.g., Kiss, Driver, & Eimer, 2009; Kristjánsson, Sigurjónsdóttir, & Driver, 2010) and evoke a stronger response in visual areas of the brain, indicative of a reward-motivated bias in visual processing (Kiss et al., 2009; Kristjánsson et al., 2010; Serences, 2008). Similar biases can be found in perceptual sensitivity measures (Serences & Saproo, 2010).

Preparatory cognitive control likely plays a role in such motivational effects on information processing. When rewards are available for certain trials in a particular context, a broad sharpening of performance is observed, mediated by a sustained increase in activity in the fronto-parietal attention network (Jimura, Locke, & Braver, 2010; Locke & Braver, 2008; Pessoa & Engelmann, 2010). These sustained influences of motivation are coupled with modulations of the transient signals evoked by reward-related stimuli and tasks (Jimura et al., 2010; Pessoa & Engelmann, 2010), mirroring the just described benefits observed for reward-associated stimuli (e.g., Kiss et al., 2009; Kristjánsson et al., 2010; Serences, 2008). One interpretation of these findings is that such motivation effects reflect volitional adjustments in task engagement, resulting in attention being better focused on task-related stimuli (e.g., Esterman et al., 2016; Esterman, Poole, Liu, & DeGutis, 2017; Esterman, Reagan, Liu, Turner, & DeGutis, 2014).

Elevated attentional priority for previously reward-associated stimuli was shown to persist into periods of extinction (Della Libera & Chelazzi, 2009), calling the purely volitional nature of reward-related effects on attention into question. In a compelling demonstration of the automaticity of reward's influence on attention, Anderson, Laurent, and Yantis (2011) showed that previously reward-associated stimuli capture attention during periods of extinction, even when they are explicitly task-irrelevant and physically nonsalient,

reflecting what the researchers termed *value-driven attentional capture* (see Anderson, 2016, for a recent review). Le Pelley, Pearson, Griffiths, and Beesley (2015) further demonstrated that such reward effects do not even depend on the prior task relevance of the rewarded stimuli during learning, but instead reflect the consequences of simple associative mechanisms linking visual features with a reward outcome. Likewise consistent with an associative-learning account, simply providing a reward incentive for attending to certain stimuli is not sufficient to produce subsequent value-driven attention, but rather, the stimuli need to provide predictive information concerning the magnitude of the reward available (i.e., serve as a reward cue; Sali, Anderson, & Yantis, 2014).

Reliably pairing a stimulus with a reward outcome also has consequences for cognitive processes tied more directly to response selection. When currently associated with reward, stimuli generate stronger response signals. In the Stroop task, the naming of colors associated with reward when they were correctly reported was subject to less Stroop interference than the naming of unrewarded colors (Krebs, Boehler, Egner, & Woldorff, 2011; Krebs, Boehler, & Woldorff, 2010). Taken alone, this finding is consistent with a purely voluntary motivational effect, with reward enhancing the processing of task-relevant information. However, these same authors demonstrated corresponding increases in the interference generated by written words that spelled the high-value colors (Krebs et al., 2011; Krebs et al., 2011), suggesting a reward-mediated bias that is not restricted to task-relevant information.

Using an Eriksen flanker task (Eriksen & Eriksen, 1974), Anderson, Laurent, and Yantis (2012; see also Anderson, Folk, Garrison, & Rogers, 2016; Mine & Saiki, 2015) demonstrated that previously reward-associated stimuli persistently generate greater response interference even into periods of extinction, in which these stimuli are entirely task-irrelevant. Furthermore, this persisting response bias occurred even though the response mapping was new to participants (i.e., not the same response mapping used during reward training), suggesting that the mere association between features and reward was sufficient to modulate the response codes generated by stimuli.

Automaticity, the repetition of cognitive operations, and the maintenance of task goals

Many common experimental paradigms in the field of cognitive psychology utilize a design in which the target-defining features and stimulus–response mappings remain consistent across trials, likely adopted for the sake of simplicity and to ensure that participants have adequate opportunity to enact appropriate control settings. One consequence of this approach is that cognitive operations are frequently repeated in response to the same stimulus. A wealth of research has

demonstrated an automatic bias to process information in the same manner in which it was processed very recently (e.g., Kristjánsson & Campana, 2010; Maljkovic & Nakayama, 1994). The consequences of such intertrial priming effects on the interpretation of putatively goal-mediated effects of automaticity (i.e., contingent attentional capture; Theeuwes, 2010, 2013) are well documented. The same logic can be applied to putatively voluntary acts of cognitive control, as well. When a participant attends to a target stimulus and generates a corresponding response, if the same processes were performed in response to the same stimulus on a recent trial, the cognitive and underlying neural mechanisms may reflect the exercise of volitional control, the unfolding of an automatic mode of information processing (i.e., priming), or some combination of the two. Stimulus-specific priming, for example, has been shown to contribute substantially to conflict adaptation effects traditionally interpreted as reflecting executive control processes (Mayr & Awh, 2009; Mayr, Awh, & Laurey, 2003; Nieuwenhuis et al., 2006).

Intertrial priming can be influenced by motivation-related factors, also in a manner outside the volitional control of the participant. The reward that accompanies the performance of a cognitive operation, such as selecting a target, modulates the magnitude of priming observed on the next trial (Hickey, Chelazzi, & Theeuwes, 2010a, b; Hickey, Keiser, & Peelen, 2015). Such reward-mediated priming remains robust even when participants are motivated to switch to the nonprimed mode of processing, and it occurs when the rewards are randomly determined (Hickey et al., 2010a). Even on the level of a single trial, the ability for reward information to automatically configure future information processing can be observed.

Goal-directed cognitive control presumably requires that the task goals be maintained in an active state. However, maintaining stimulus-specific information in working memory has been shown to automatically bias attention toward the remembered stimulus (Kumar, Soto, & Humphreys, 2009; Olivers, 2009; Olivers, Meijer & Theeuwes, 2006; Olivers, Peters, Houtkamp, & Roelfsema, 2011). This occurs even when participants know that the contents of working memory are unrelated to the intervening task in which the bias is measured (e.g., Olivers et al., 2006).

Rethinking the distinction between goal-directed and automatic information processing

The examples above are not intended to be an exhaustive list, but rather are intended to support the claim that automatic processes are not restricted to processes repeated heavily under consistent mapping conditions. Even under variable mapping conditions and at the level of a single trial, the realization

of task goals is supported by the execution of automatic, cue-triggered processes. Through activating a particular set of intentions or expectations, the selection of which may itself reflect a voluntary and controlled mental process, individuals can preconfigure information processing to automatically follow a particular path, in a form of conditional automaticity (Bargh, 1989). Certain sources of information—such as reward value, the contents of working memory, and the recent trial history—automatically get incorporated into these modes of information processing. The result is a case in which automatic modes of information processing possess some of the hallmarks of what has traditionally been assumed to reflect volitional and controlled information processing: rapid and flexible instantiation that does not depend on repetitive behaviors.

Three broader implications of these findings for the study of cognition need to be considered. The first concerns the interpretation of goal-oriented task performance, the second concerns the standards that are applied when considering the degree to which a cognitive process is controlled or automatic, and the third concerns the nature of the distinction between these two modes of information processing. Each of these implications is further discussed in turn.

A source of ambiguity

Many paradigms that are used in the study of cognitive control utilize a consistent mapping between stimuli and motor responses, in spite of the fact that such conditions are known to be open to automatic effects arising from selection history (e.g., Shiffrin & Schneider, 1977) and intertrial priming (Kristjánsson & Campana, 2010; Maljkovic & Nakayama, 1994). The more sophisticated paradigms used to study cognitive control involve variable mapping—for example, via the task goals that are cued trial by trial (e.g., Anderson & Folk, 2014; Anderson, Folk, & Courtney, 2016; Anderson, Folk, Garrison, & Rogers, 2016; Lien et al., 2010; Schneider & Shiffrin, 1977), if–then response rules (e.g., Carter et al., 1998; Locke & Braver, 2008; Rosvold, Mirsky, Sarason, Bransome, & Beck, 1956), and hierarchical rule structures (e.g., Badre & D’Esposito, 2007; Badre, Kayser, & D’Esposito, 2010; Koechlin, & Jubault, 2006)—circumventing the influence of classical sources of automaticity. However, as I have argued in this article, even these conditions are not immune to the influence of automatic sources of information processing on the execution of goal-consistent cognitive processes.

In fact, it is difficult to imagine any explicit task structure that is not subject to the potential influence of automaticity. It appears that the simple act of establishing a set of expectations or behavioral contingencies (e.g., press the right-hand response key if you see a red X) is sufficient to allow for certain stimuli to evoke an automatic response contingent on those

expectations. Merely providing participants with task instruction, even instructions that are unpredictably cued on a trial-by-trial basis, is sufficient to shape automatic behaviors.

Although the study of automaticity has arisen as a specific area of investigation, with dedicated experimental paradigms that are optimized for isolating automatic influences of information processing, this is generally not the case for the volitional control of information processing. Rather, volitional control is often assumed from the ability to process information in line with arbitrarily defined, task-specific goals. In light of the evidence described above, this assumption seems questionable. Automatic processes have been identified that could achieve the same ends. Likely, many cases of goal-contingent information processing reflect some combination of controlled and automatic components. There is an inherent ambiguity in the interpretation of performance data in experiments of cognitive control involving stimulus-specific goals, which reflect the vast majority of all experiments in this research area (although see the following section for a counterexample).

This ambiguity is often peripheral to the main research question addressed by any one study. In many cases, the answer to the research question at hand does not depend on whether the components of the process in question are controlled or automatic. Rather, researchers are simply interested in the nature of the process more generally and in distinguishing it from other hypothetical processes (controlled or not) that would be expected to operate differently and thus make different predictions concerning the pattern of performance and/or the underlying brain activity. Even in these cases, however, the (often implicit) assumption that the ability to process information in line with arbitrarily defined task goals is a controlled process remains prevalent, which has strongly shaped the theoretical landscape. For example, studies of the role of prefrontal cortex in cognitive control tend to assume a volitional mode of processing (e.g., Badre & D’Esposito, 2007; Courtney, 2004; Roth, Serences, & Courtney, 2006), and motivated information processing and volitional control are often conceptualized as going hand in hand (e.g., Jimura et al., 2010; Locke & Braver, 2008; Padmala & Pessoa, 2011; Pessoa & Engelmann, 2010). The term “executive control” is replete with connotations of a volitional, controlled underlying mechanism (e.g., Baddeley, 1996). The result is a somewhat distorted view of the nature of cognitive control, and it is difficult to know just how distorted this view is without a more rigorous approach to assessing the degree of control involved.

Shifting the burden of proof

Throughout this article, it has been argued that (1) there is currently no burden of proof for claiming that an act of cognitive control is volitional and controlled, (2) there is good reason to suspect that components of even sophisticated

goal-directed processes are in fact automatic, and (3) the absence of such a burden of proof has engendered a view of the control of information processing that is likely to some degree distorted. Controlled information processing should not be considered the default mode of processing underlying the performance of an experimental task. Ideally, claims concerning controlled information processing would be held to the same standard that claims concerning automaticity are held to, with an explicit effort to quantify and assess the level of control involved.

Such efforts must go beyond the manipulation of arbitrary task goals using a variable mapping procedure (Schneider & Shiffrin, 1977). It may be tempting to assume that conditions involving task switching, in which the task goals must be updated in response to unpredictable and arbitrarily mapped cues, necessarily tax volitional cognitive processes. Although this may be true of the decision to switch tasks, at least before the cue–task mapping is well learned, the actual execution of the task goals (e.g., selecting a target, generating or inhibiting a response to a particular stimulus) may be nontrivially automatic under such conditions. Even the canonical Posner cuing task (Posner, 1980), in which a cue indicates the likely spatial position of an upcoming target, cannot be assumed to elicit a purely volitional cognitive process (in this case, a shift of attention), since the cue will come to be associated with a corresponding response (shifting attention) that could be triggered automatically with learning. Such an automatic response is immediately evident when the cue is an overlearned stimulus, such as an arrow (e.g., Bonato, Priftis, Marenzi, & Zorzi, 2009; Hommel, Pratt, Colzato, & Godijn, 2001) or a series of numbers mapped onto space (see Fischer, Castel, Dodd, & Pratt, 2003). Given the speed with which associative learning can come to automatically bias attention (e.g., Anderson et al., 2011; Le Pelley et al., 2015; Sali et al., 2014), and given the influence of intertrial priming (Kristjánsson & Campana, 2010; Maljkovic & Nakayama, 1994; Theeuwes, 2013), it would seem that any arbitrary cue could elicit similar behavior.

If a burden of proof for putatively voluntary components of cognitive control is needed, what might be done to implement such a burden of proof? One potential approach would be to establish conditions under which behavior can only be explained by a voluntary cognitive process and to apply such conditions when a distinctly voluntary process is of interest. Alternatively, one could attempt to empirically assess the degree of volitional control under a particular set of task conditions. With respect to the latter technique, empirically defining conditions for a voluntary act of cognitive control is not straightforward, because the inverse of the conditions for automaticity imply a negative result. Specifically, we could reason that a voluntary act of cognitive control should *not* be observable in response to an explicitly task-irrelevant stimulus, in a manner that is not conducive to task performance.

Behavioral effects could be contrasted between task-relevant and task-irrelevant stimuli, and the neural response to task-irrelevant stimuli could be subtracted from that of task-relevant stimuli. However, the validity of this approach assumes that the task-irrelevant stimulus condition provides a fair test of automaticity—that it could have measured robust automatic information processing if such processing were relevant to the task at hand. This assumption would be difficult to verify, although such an approach might provide some insight into the degree of automaticity involved if it is addressed programmatically across a range of experiment contexts.

If the isolation of distinctly voluntary cognition is desired, one especially promising approach would be to design experimental situations in which participants engage a particular cognitive process not in response to a specific stimulus in accord with task instructions (which could act as a cue/trigger for an automatic process), but rather in a purely endogenous manner. An elegant example of this approach was recently provided by Gmeindl et al. (2016), in which participants voluntarily decided when to shift attention between two locations, being instructed only to shift their focus of attention periodically throughout the course of the task. The actual act of shifting attention was decoded from lateralized brain activity in visual areas, allowing for the specification of the approximate point in time in which the voluntary act was executed. Brain activity that is correlated with this voluntary shift of attention in other regions (than the one used to define it) can be said to reflect a volitional control process. Note that this is different from having participants perform a cognitive operation in response to a stimulus event based on a voluntary decision made before the trial (e.g., picking which task rules to follow), because the performance of the main task could still be stimulus-driven, and indeed has been argued to reflect automatic processing under certain conditions (e.g., Belopolsky et al., 2010). That is, the cognitive operation itself (not the prior decision to prepare for it) needs to be endogenously generated.

Reevaluating the dichotomy

A more fundamental question that can be posed in light of the evidence discussed here concerns the distinction between controlled and automatic information processing. If so many ostensibly goal-directed cognitive processes indeed have automatic components that contribute to their execution, is it worthwhile to maintain the dichotomy implied by the terminology? Theoretical dichotomies that distinguish between a voluntary and an involuntary mode of processing have increasingly been called into question—for example, in the context of affective cognition (Pessoa, 2013) and the mechanisms of attentional orienting (Awh, Belopolsky, & Theeuwes, 2012). The same type of criticism can be applied here. It

would appear that controlled and automatic components of cognitive control often contribute to the same overarching mental process (e.g., selecting a target and generating a corresponding response), making attempts to classify a given process as either controlled/volitional or involuntary/automatic perhaps misguided. Instead, it may be more fruitful to consider the degree to which a cognitive process is controlled or automatic and how the different components of that process work together to (1) allow for online adjustments in how information is processed due to changes in the goal state (the more controlled side) and (2) offload the execution of task goals to more stimulus-driven modes of information processing (the more automatic side).

With that said, in my opinion more care needs to be taken in interpreting the nature of goal-consistent cognitive processes. The degree to which human cognitive control is volitional and controlled remains an important theoretical question, the answer to which requires explicit assessment of the degree of control involved. There is likely substantial variation in the degree to which goal-consistent information processing, as measured in typical experimental paradigms, is in fact volitional and controlled, variation that has been largely ignored in the literature. In this respect, a more systematic approach to probing the nature of goal-consistent cognitive processes along the lines described above has value, regardless of whether a dichotomy or a continuum is assumed.

Conclusions

Controlled information processing is often assumed when this processing is in line with task-specific goals. This is especially the case under variable mapping conditions, in which the same stimulus can require a different behavioral response under different task conditions. Emerging research suggests that this assumption is not tenable. Many studies examining putatively voluntary cognitive processes have likely measured some amalgam of voluntary and automatic information processing. As a consequence, the contribution of automaticity to human cognitive processes is likely to some degree understated and underappreciated.

It is not the intent here to call into question a vast array of findings or theoretical perspectives in the domain of cognitive control. Many conclusions and theories are agnostic as to the relative contributions of automatic and controlled processes. Nonetheless, the distinction is absolutely fundamental to our broader view of cognitive control and is replete with both theoretical and practical implications for how we characterize and address ineffective or inappropriate behaviors.

There are two important takeaways from the issues raised in this article. The first is that, as a field, we need to be more careful about assumptions that are made concerning the nature of human cognitive control. A reexamination of the breadth and extent of automaticity in goal-directed cognitive processes

is in order. The second is that, in order to facilitate this investigation, it will be important to establish a burden of proof against which a putatively voluntary process can be measured. Such a burden of proof has a rich tradition in the study of automaticity, and a comparably rigorous burden of proof needs to become more routine in the study of goal-directed cognitive control.

References

- Anderson, B. A. (2016). The attention habit: How reward learning shapes attentional selection. *Annals of the New York Academy of Sciences*, 1369, 24–39.
- Anderson, B. A., & Folk, C. L. (2010). Variations in the magnitude of attentional capture: Testing a two-process model. *Attention, Perception, & Psychophysics*, 72, 342–352. <https://doi.org/10.3758/APP.72.2.342>
- Anderson, B. A., & Folk, C. L. (2012). Contingent involuntary motoric inhibition: The involuntary inhibition of a motor response contingent on top-down goals. *Journal of Experimental Psychology: Human Perception and Performance*, 38, 1348–1352.
- Anderson, B. A., & Folk, C. L. (2014). Conditional automaticity in response selection: Contingent involuntary response inhibition with varied stimulus–response mapping. *Psychological Science*, 25, 547–554.
- Anderson, B. A., Folk, C. L., & Courtney, S. M. (2016). Neural mechanisms of goal-contingent task disengagement: Response-irrelevant stimuli activate the default mode network. *Cortex*, 81, 221–230.
- Anderson, B. A., Folk, C. L., Garrison, R., & Rogers, L. (2016). Mechanisms of habitual approach: Failure to suppress irrelevant responses evoked by previously reward-associated stimuli. *Journal of Experimental Psychology: General*, 145, 796–805.
- Anderson, B. A., Laurent, P. A., & Yantis, S. (2011). Value-driven attentional capture. *Proceedings of the National Academy of Sciences*, 108, 10367–10371. <https://doi.org/10.1073/pnas.1104047108>
- Anderson, B. A., Laurent, P. A., & Yantis, S. (2012). Generalization of value-based attentional priority. *Visual Cognition*, 20, 647–658.
- Aron, A. R., Fletcher, P. C., Bullmore, E. T., Sahakian, B. J., & Robbins, T. W. (2003). Stop signal inhibition disrupted by damage to right inferior frontal gyrus in humans. *Nature Neuroscience*, 6, 115–116. <https://doi.org/10.1038/nm1003>
- Aron, A. R., & Poldrack, R. A. (2006). Cortical and subcortical contributions to stop signal response inhibition: Role of the subthalamic nucleus. *Journal of Neuroscience*, 26, 2424–2433. <https://doi.org/10.1523/JNEUROSCI.4682-05.2006>
- Awh, E., Belopolsky, A. V., & Theeuwes, J. (2012). Top-down versus bottom-up attentional control: A failed theoretical dichotomy. *Trends in Cognitive Sciences*, 16, 437–443. <https://doi.org/10.1016/j.tics.2012.06.010>
- Baddeley, A. (1996). Exploring the central executive. *Quarterly Journal of Experimental Psychology*, 49A, 5–28. <https://doi.org/10.1080/027249896392784>
- Badre, D., & D’Esposito, M. (2007). Functional magnetic resonance imaging evidence for a hierarchical organization of the prefrontal cortex. *Journal of Cognitive Neuroscience*, 19, 2082–2099.
- Badre, D., Kayser, A. S., & D’Esposito, M. (2010). Frontal cortex and the discovery of abstract action rules. *Neuron*, 66, 315–326.
- Bargh, J. A. (1989). Conditional automaticity: Varieties of automatic influence on social perception and cognition. In J. Uleman & J.

- Bargh (Eds.), *Unintended thought* (pp. 3–51). New York, NY: Guilford Press.
- Belopolsky, A. V., Schreij, D., & Theeuwes, J. (2010). What is top-down about contingent capture? *Attention, Perception, & Psychophysics*, *72*, 326–341. <https://doi.org/10.3758/APP.72.2.326>
- Bonato, M., Priftis, K., Marenzi, R., & Zorzi, M. (2009). Normal and impaired reflexive orienting of attention after central nonpredictive cues. *Journal of Cognitive Neuroscience*, *21*, 745–759.
- Botvinick, M. M., Braver, T. S., Barch, D. M., Carter, C. S., & Cohen, J. D. (2001). Conflict monitoring and cognitive control. *Psychological Review*, *108*, 624–652. <https://doi.org/10.1037/0033-295X.108.3.624>
- Carter, C. S., Braver, T. S., Barch, D. M., Botvinick, M. M., Noll, D., & Cohen, J. D. (1998). Anterior cingulate cortex, error detection, and the online monitoring of performance. *Science*, *280*, 747–749. <https://doi.org/10.1126/science.280.5364.747>
- Cona, G., Treccani, B., & Umiltà, C. A. (2016). Is cognitive control automatic: New insights from transcranial magnetic stimulation. *Psychonomic Bulletin & Review*, *23*, 1624–1630.
- Courtney, S. M. (2004). Attention and cognitive control as emergent properties of information representation in working memory. *Cognitive, Affective, & Behavioral Neuroscience*, *4*, 501–516. <https://doi.org/10.3758/CABN.4.4.501>
- Della Libera, C., & Chelazzi, L. (2009). Learning to attend and to ignore is a matter of gains and losses. *Psychological Science*, *20*, 778–784. <https://doi.org/10.1111/j.1467-9280.2009.02360.x>
- Eimer, M., & Kiss, M. (2008). Involuntary attentional capture is determined by task set: Evidence from event-related brain potentials. *Journal of Cognitive Neuroscience*, *20*, 1423–1433. <https://doi.org/10.1162/jocn.2008.20099>
- Eimer, M., & Kiss, M. (2010). Top-down search strategies determine attentional capture in visual search: Behavioral and electrophysiological evidence. *Attention, Perception, & Psychophysics*, *72*, 951–962. <https://doi.org/10.3758/APP.72.4.951>
- Eriksen, B. A., & Eriksen, C. W. (1974). Effects of noise letters upon the identification of a target letter in a nonsearch task. *Perception & Psychophysics*, *16*, 143–149. <https://doi.org/10.3758/BF03203267>
- Esterman, M., Grosso, M., Liu, G., Mitko, A., Morris, R., & DeGutis, J. (2016). Anticipation of monetary reward can attenuate the vigilance decrement. *PLoS ONE*, *11*, e0159741. <https://doi.org/10.1371/journal.pone.0159741>
- Esterman, M., Poole, V., Liu, G., & DeGutis, J. (2017). Modulating reward induces differential neurocognitive approaches to sustained attention. *Cerebral Cortex*, *27*, 4022–4032. <https://doi.org/10.1093/cercor/bhw214>
- Esterman, M., Reagan, A., Liu, G., Turner, C., & DeGutis, J. (2014). Reward reveals dissociable aspects of sustained attention. *Journal of Experimental Psychology: General*, *143*, 2287–2295.
- Fischer, M. H., Castel, A. D., Dodd, M. D., & Pratt, J. (2003). Perceiving numbers causes spatial shifts of attention. *Nature Neuroscience*, *6*, 555–556.
- Folk, C. L., Leber, A. B., & Egeth, H. E. (2002). Made you blink! Contingent attentional capture produces a spatial blink. *Perception & Psychophysics*, *64*, 741–753. <https://doi.org/10.3758/BF03194741>
- Folk, C. L., Leber, A. B., & Egeth, H. E. (2008). Top-down control settings and the attentional blink: Evidence for non-spatial contingent capture. *Visual Cognition*, *16*, 616–642. <https://doi.org/10.1080/13506280601134018>
- Folk, C. L., & Remington, R. (1998). Selectivity in distraction by irrelevant featural singletons: Evidence for two forms of attentional capture. *Journal of Experimental Psychology: Human Perception and Performance*, *24*, 847–858. <https://doi.org/10.1037/0096-1523.24.3.847>
- Folk, C. L., Remington, R. W., & Johnston, J. C. (1992). Involuntary covert orienting is contingent on attentional control settings. *Journal of Experimental Psychology: Human Perception and Performance*, *18*, 1030–1044. <https://doi.org/10.1037/0096-1523.18.4.1030>
- Folk, C. L., Remington, R. W., & Wright, J. H. (1994). The structure of attentional control: Contingent attentional capture by apparent motion, abrupt onset, and color. *Journal of Experimental Psychology: Human Perception and Performance*, *20*, 317–329. <https://doi.org/10.1037/0096-1523.20.2.317>
- Gmeindl, L., Chiu, Y.-C., Esterman, M. S., Greenberg, A. S., Courtney, S. M., & Yantis, S. (2016). Tracking the will to attend: Cortical activity indexes self-generated, voluntary shifts of attention. *Attention, Perception, & Psychophysics*, *78*, 2176–2184.
- Gratton, G., Coles, M. G. H., & Donchin, E. (1992). Optimizing the use of information: Strategic control of activation of responses. *Journal of Experimental Psychology: General*, *121*, 480–506. <https://doi.org/10.1037/0096-3445.121.4.480>
- Hickey, C., Chelazzi, L., & Theeuwes, J. (2010a). Reward changes salience in human vision via the anterior cingulate. *Journal of Neuroscience*, *30*, 11096–11103. <https://doi.org/10.1523/JNEUROSCI.1026-10.2010>
- Hickey, C., Chelazzi, L., & Theeuwes, J. (2010b). Reward guides vision when it's your thing: Trait reward-seeking in reward-mediated visual priming. *PLoS ONE*, *5*, e14087. <https://doi.org/10.1371/journal.pone.0014087>
- Hickey, C., Keiser, D., & Peelen, M. V. (2015). Reward guides attention to object categories in real-world scenes. *Journal of Experimental Psychology: General*, *144*, 264–273.
- Hommel, B., Pratt, J., Colzato, L., & Godijn, R. (2001). Symbolic control of visual attention. *Psychological Science*, *12*, 360–365.
- Jiang, Y. V., & Swallow, K. M. (2013). Spatial reference frame of incidentally learned attention. *Cognition*, *126*, 378–390.
- Jimura, K., Locke, H. S., & Braver, T. S. (2010). Prefrontal cortex mediation of cognitive enhancement in rewarding motivational contexts. *Proceedings of the National Academy of Sciences*, *107*, 8871–8876.
- Johnson, D. N., & Yantis, S. (1995). Allocating visual attention: Tests of a two-process model. *Journal of Experimental Psychology: Human Perception and Performance*, *21*, 1376–1390.
- Kahneman, D., & Treisman, A. (1984). Changing views of attention and automaticity. In R. Parasuraman & D. R. Davis (Eds.), *Varieties of attention* (pp. 29–61). Orlando, FL: Academic Press.
- Kiss, M., Driver, J., & Eimer, M. (2009). Reward priority of visual target singletons modulates event-related potential signatures of attentional selection. *Psychological Science*, *20*, 245–251. <https://doi.org/10.1111/j.1467-9280.2009.02281.x>
- Koechlin, E., & Jubault, T. (2006). Broca's area and the hierarchical organization of human behavior. *Neuron*, *50*, 963–974.
- Krebs, R. M., Boehler, C. N., Egner, T., & Woldorff, M. G. (2011). The neural underpinnings of how reward associations can both guide and misguide attention. *Journal of Neuroscience*, *31*, 9752–9759.
- Krebs, R. M., Boehler, C. N., & Woldorff, M. G. (2010). The influence of reward associations on conflict processing in the Stroop task. *Cognition*, *117*, 341–347.
- Kristjánsson, Á., & Campana, G. (2010). Where perception meets memory: A review of repetition priming in visual search tasks. *Attention, Perception, & Psychophysics*, *72*, 5–18. <https://doi.org/10.3758/APP.72.1.5>
- Kristjánsson, Á., Sigurjónsdóttir, Ó., & Driver, J. (2010). Fortune and reversals of fortune in visual search: Reward contingencies for pop-out targets affect search efficiency and target repetition effects. *Attention, Perception, & Psychophysics*, *72*, 1229–1236. <https://doi.org/10.3858/APP.72.5.1229>
- Kumar, S., Soto, D., & Humphreys, G. W. (2009). Electrophysiological evidence for attentional guidance by the contents of working memory. *European Journal of Neuroscience*, *30*, 307–317.

- Kyllingsbæk, S., Schneider, W. X., & Bundesen, C. (2001). Automatic attraction of attention to former targets in visual displays of letters. *Perception & Psychophysics*, *63*, 85–98.
- Kyllingsbæk, S., Van Lommel, S., Sorensen, T. A., & Bundesen, C. (2014). Automatic attraction of visual attention by supraletter features of former target strings. *Frontiers in Psychology*, *5*, 1383:1–7. <https://doi.org/10.3389/fpsyg.2013.01383>
- Le Pelley, M. E., Pearson, D., Griffiths, O., & Beesley, T. (2015). When goals conflict with values: Counterproductive attentional and oculomotor capture by reward-related stimuli. *Journal of Experimental Psychology: General*, *144*, 158–171.
- Lenartowicz, A., Verbruggen, F., Logan, G. D., & Poldrack, R. A. (2011). Inhibition-related activation in the right inferior frontal gyrus in the absence of inhibitory cues. *Journal of Cognitive Neuroscience*, *23*, 3388–3399.
- Lien, M.-C., Ruthruff, E., & Johnston, J. V. (2010). Attentional capture with rapidly changing attentional control settings. *Journal of Experimental Psychology: Human Perception and Performance*, *36*, 1–16. <https://doi.org/10.1037/a0015875>
- Locke, H. S., & Braver, T. S. (2008). Motivational influences on cognitive control: Behavior, brain activation, and individual differences. *Cognitive, Affective, & Behavioral Neuroscience*, *8*, 99–112. <https://doi.org/10.3758/CABN.8.1.99>
- Logan, G. D. (1983). On the ability to inhibit simple thoughts and actions: I. Stop signal studies of decision and memory. *Journal of Experimental Psychology: Learning, Memory and Cognition*, *9*, 585–606.
- 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. <https://doi.org/10.1037/0033-295X.91.3.295>
- Maljkovic, V., & Nakayama, K. (1994). Priming of pop-out: I. Role of features. *Memory & Cognition*, *22*, 657–672. <https://doi.org/10.3758/BF03209251>
- Mayr, U., & Awh, E. (2009). The elusive link between conflict and conflict adaptation. *Psychological Research*, *73*, 794–802.
- Mayr, U., Awh, E., & Laury, P. (2003). Conflict adaptation effects in the absence of executive control. *Nature Neuroscience*, *6*, 450–452.
- Mine, C., & Saiki, J. (2015). Task-irrelevant stimulus-reward association induces value-driven attentional capture. *Attention, Perception, & Psychophysics*, *77*, 1896–1907.
- Nieuwenhuis, S., Stins, J. F., Posthuma, D., Polderman, T. J. C., Boomsma, D. I., & de Geus, E. J. (2006). Accounting for sequential trial effects in the flanker task: Conflict adaptation or associative priming? *Memory & Cognition*, *34*, 1260–1272.
- Olivers, C. N. L. (2009). What drives memory-driven attentional capture? The effects of memory type, display type, and search type. *Journal of Experimental Psychology: Human Perception and Performance*, *35*, 1275–1291. <https://doi.org/10.1037/a0013896>
- Olivers, C. N. L., Meijer, F., & Theeuwes, J. (2006). Feature-based memory-driven attentional capture: Visual working memory content affect visual attention. *Journal of Experimental Psychology: Human Perception and Performance*, *32*, 1243–1265. <https://doi.org/10.1037/0096-1523.32.5.1243>
- Olivers, C. N. L., Peters, J., Houtkamp, R., & Roelfsema, P. R. (2011). Different states in visual working memory: When it guides attention and when it does not. *Trends in Cognitive Sciences*, *15*, 327–334. <https://doi.org/10.1016/j.tics.2011.05.004>
- Padmala, S., & Pessoa, L. (2011). Reward reduces conflict by enhancing attentional control and biasing visual cortical processing. *Journal of Cognitive Neuroscience*, *23*, 3419–3432. https://doi.org/10.1162/jocn_a_00011
- Pessoa, L. (2013). Attention and emotion. In *The cognitive–emotional brain: From interactions to integration* (pp. 81–106). Cambridge, MA: MIT Press
- Pessoa, L., & Engelmann, J. B. (2010). Embedding reward signals into perception and cognition. *Frontiers in Neuroscience*, *4*, 17:1–8. <https://doi.org/10.3389/fnins.2010.00017>
- Posner, M. I. (1980). Orienting of attention. *Quarterly Journal of Experimental Psychology*, *32*, 3–25. <https://doi.org/10.1080/0033558008248231>
- Qu, Z., Hillyard, S. A., & Ding, Y. (2017). Perceptual learning induces persistent attentional capture by nonsalient shapes. *Cerebral Cortex*, *27*, 1512–1523.
- Rosvold, H. E., Mirsky, A. F., Sarason, I., Bransome, E. D., Jr., & Beck, L. H. (1956). A continuous performance test of brain damage. *Journal of Consulting Psychology*, *20*, 343–350.
- Roth, J. K., Serences, J. T., & Courtney, S. M. (2006). Neural systems for controlling the contents of object working memory in humans. *Cerebral Cortex*, *16*, 1595–1603.
- Sali, A. W., Anderson, B. A., & Yantis, S. (2014). The role of reward prediction in the control of attention. *Journal of Experimental Psychology: Human Perception and Performance*, *40*, 1654–1664. <https://doi.org/10.1037/a0037267>
- Schneider, W., & Shiffrin, R. M. (1977). Controlled and automatic human information processing: I. Detection, search, and attention. *Psychological Review*, *84*, 1–66. <https://doi.org/10.1037/0033-295X.84.1.1>
- Serences, J. T. (2008). Value-based modulations in human visual cortex. *Neuron*, *60*, 1169–1181. <https://doi.org/10.1016/j.neuron.2008.10.051>
- Serences, J. T., & Saproo, S. (2010). Population response profiles in early visual cortex are biased in favor of more valuable stimuli. *Journal of Neurophysiology*, *104*, 76–87.
- Shiffrin, R. M., & Schneider, W. (1977). Controlled and automatic human information processing: II. Perceptual learning, automatic attending, and general theory. *Psychological Review*, *84*, 127–190. <https://doi.org/10.1037/0033-295X.84.2.127>
- Stroop, J. R. (1935). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology*, *18*, 643–662. <https://doi.org/10.1037/0096-3445.121.1.15>
- Theeuwes, J. (1992). Perceptual selectivity for color and form. *Perception & Psychophysics*, *51*, 599–606. <https://doi.org/10.3758/BF03211656>
- Theeuwes, J. (2010). Top-down and bottom-up control of visual selection. *Acta Psychologica*, *135*, 77–99. <https://doi.org/10.1016/j.actpsy.2010.02.006>
- Theeuwes, J. (2013). Feature-based attention: It is all bottom-up priming. *Philosophical Transactions of the Royal Society B*, *368*, 20130055. <https://doi.org/10.1098/rstb.2013.0055>
- van Gaal, S., Ridderinkhof, K. R., Scholte, H. S., & Lamme, V. A. F. (2010). Unconscious activation of the prefrontal no-go network. *Journal of Neuroscience*, *30*, 4143–4150. <https://doi.org/10.1523/JNEUROSCI.2992-09.2010>
- van Gaal, S., Ridderinkhof, K. R., van den Wildenberg, W. P. M., & Lamme, V. A. F. (2009). Dissociating consciousness from inhibitory control: Evidence for unconsciously triggered response inhibition in the stop-signal task. *Journal of Experimental Psychology: Human Perception and Performance*, *35*, 1129–1139. <https://doi.org/10.1037/a0013551>
- Verbruggen, F., & Logan, G. D. (2008). Automatic and controlled response inhibition: Associative learning in the go/no-go and stop signal paradigms. *Journal of Experimental Psychology: General*, *137*, 649–672. <https://doi.org/10.1037/a0013170>