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EDITORIAL

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Cognitive control of attention and action: Issues and trends

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The present special issue deals with the control of cognitive processes. Modern cognitive psychology has been quite successful in analyzing and capturing the basic characteristics of all sorts of processes, ranging from those taking care of perceptual information to memory, from reasoning to the planning and execution of action. Experimental analyses of these processes require people to carry out particular tasks, tasks in which the investigated process, or its products, play a crucial role. How these tasks are implemented is very transparent from the experimenter's point of view. One typically presents an aural or written instruction, asks the subject whether he or she has understood, probably adds some more explanation, and the experiment is ready to begin. However, from the subject's point of view, things are much less transparent. True, the subjective experience commonly mirrors the experimenter's impression. One tries understanding the instruction, probably asks a few more questions, prepares oneself for the task, and is ready to go. And yet, the *how* of this goal-directed preparation is very poorly understood. In some way, people must be able to configure and re-configure their cognitive system in a way that task-relevant information is picked up, maintained and stored efficiently, and that appropriate actions are prepared, planned, and then executed in the light of the available information. But we are only beginning to understand, how this configuration works.

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A renaissance of cognitive control

Fortunately, research on how people set up and direct processing streams to achieve intended goals has seen a renaissance in the last decade or so. Yet, the middle ages preceding this renaissance were long-lasting and followed a short-lived beginning. Back in the late 1800s and early 1900s, in the heyday of introspective psychology, cognitive control was a major ingredient of psychological consideration, such as in the works of William James (1890) or Narziss Ach (1910). The expression of personal goals and interests was commonly attributed to two (still!) dominating faculties: *attention*, which takes care of the selection and preferred processing of goal-related environmental events, and the *will*, which is responsible for organizing movement elements to bring about the intended goal event. Most research efforts were directed towards characterizing the phenomenological outcome of attention and will, such as the increase in vividness of images of attended objects or the experience of commitment for self-intended actions. But the processing side was not ignored entirely. In fact, Ach (1910, 1935) and his colleagues devised many new experimental paradigms to investigate the interaction of, and conflict between, overlearned habits and intentional processes, such as his "combined method" (see Hommel, 2000a). Very soon, however, cognitive psychology lost interest in goals and their impact on information processing, and left this field to motivational and occupational psychology. The dark ages closed upon cognitive control, which was of little conceptual use for the behavioristic account of human action.

The renaissance of cognitive control can be dated back to the papers of Atkinson and Shiffrin (1968) and Shiffrin and Schneider (1977), who re-introduced the distinction between automatic and control(led) processes (Ach's habits and intentional processes) into psychological theorizing. This distinction has shown to be of considerable use in many areas of cognitive psychology, as witnessed by the contributions to this issue by LaBerge, Godijn and Theeuwes, Hommel and Eglau, Ridderinkhof, and Burle et al. However, as LaBerge rightly warns us, the distinction was not always well defined in early control accounts and its implications are not always obvious. In particular, terms like "attention" (which often comprises the semantics of the outdated "will" as well) are frequently used to characterize both the *product* (or "expression", in LaBerge's terminology) of goal-related selectivity as well as the *cause* of it; this means mixing up what is controlled and what does the controlling – not a good basis for understanding how control is actually carried out (Allport, 1980; Neumann, 1987). To avoid problems of this sort, more recent models are not only more specific than earlier ones with regard to mechanisms, they also tend to restrict their focus explicitly on *either* the cause of control *or* its consequences. For instance, authors such as Baddeley (1986) or Logan and Gordon (2001) follow the explicit strategy to treat the cause of control while trying to nail down the specifics of its effects on information processing. In contrast, authors such as Cohen (Cohen, Braver, & O'Reilly, 1998; Cohen, Dunbar, & McClelland, 1990) or Meyer and Kieras (1997) are concentrating more on modeling the (main) cause of control itself. Whatever strategy one may prefer, much progress has been made in very recent years, especially in the context of task-switching and dual-task performance, and in behavioral and neurophysiological analyses of working-memory functions (for overviews, see Monsell & Driver, 2000; and D'Esposito, Postle, & Rypma, 2000, respectively). The present selection of papers provides an up-to-date spotlight on these and related developments by bringing together views and opinions from a wide variety of research domains. However, although the domains covered are varied, the contributions to this special issue do converge to form a coherent picture; a picture that we think is representative of our current understanding of cognitive control as a whole. In particular, two basic take-home messages are emerging, which we will briefly discuss in turn.

Cognitive control as an emergent property

One of the above-mentioned messages is that cognitive control functions should not necessarily be considered as basic mental functions, supported by specific dedicated systems or neural circuits – as implied by earlier models (e.g., Norman & Shallice, 1986) – but might well be conceived of as *emergent properties*, being established by the configuration and tailoring of existing subordinate processes in such a fashion that 'new', unique functions emerge. In the contributions to this special issue, this message comes in various flavors and with respect to various types of sources. Indeed, factors that interact, and sometimes compete, to produce cognitive control can be categorized with respect to at least two dimensions. First, control commonly reflects the joined influence of *internal factors*, such as goal-related attentional control settings (Folk, Remington, & Johnston, 1992) and *external factors*, such as salient stimulus events (Theeuwes, 1994). This joined influence is especially obvious in visual attention, as pointed out in depth and with reference to the underlying neural machinery, in the paper of LaBerge. But it also plays a role in the control of response selection and dual-task performance, as discussed in the contributions of Ridderinkhof, Burle et al., and Hommel and Eglau. Thus, as anticipated by Ach (1910), perceiving a perceptual event and selecting an appropriate action is usually the outcome of a dynamic conflict between stimulus-driven tendencies and habits, on the one hand, and goal-related cognitive sets, on the other. (For an analysis of the dynamics of control in such conflicts, see Ridderinkhof, 2002). Second, control is unlikely to be divided into pure input selection and pure output selection but, rather, seems to emerge from the interaction of *perceptual and response-related* selection processes. This is implicated by the findings of Godijn and Theeuwes, who demonstrate that and also how the visual search for a particular target stimulus can be affected by oculomotor programming, as well as by Magen and Cohen, who show that response requirements have a direct impact on what stimulus information is selected for further processing. These observations speak against a sharp separation of perceptual and action-related stages and, instead, suggest that selection in perception and action planning takes place in a common representational medium (Hommel, Müsseler, Aschersleben, & Prinz, in press).

Delegating control

Another related take-home message is that internal control *delegates* and, therefore, is always relative in several respects (Hommel, 2000b). Indeed, if cognitive control is about goals and interests, it should be concerned with behavioral outcomes, not (necessarily) the details of the processes actually producing them. A good reason for delegating control to sub-ordinate processes is that internal higher-level control processes seem to be slow and inert. Accordingly, they do not seem to monitor and steer task-related processes too closely but, rather, merely enable and parameterize (then) autonomously-running processes, and only re-adjust them from time to time. Altman discusses this characteristic with regard to task-switching performance. In his framework, control is mainly exerted by means of storing a task goal into working memory. As soon as this is achieved, the active impact of control processes stops, so that success or failure in performing the correct task is a direct function of forgetting, hence, of the attributes of processes to which control has been delegated.

Tombu and Jolicœur report evidence from experiments and simulations suggesting that people are able to distribute their processing capacity among concurrent tasks in a graded fashion. Once the distribution parameter is set, further processing is shared accordingly without further ado and adjustment, thus reflecting again delegation of control to sub-ordinate processes. Similarly, Burle et al. and Ridderinkhof discuss two types of control-by-adjustment; one triggered by the presence of response conflict and operating on a trial-bytrial basis (and sometimes even within trials), and another triggered by learning factors and working on a slower, task-related time scale- comparable to that implied by Tombu and Jolicœur's model. Although with differing emphasis, Ridderinkhof, Burle et al., and Tombu and Jolicœur deal with the "circularity" of control, that is, the fact that internal control factors do not only pre-set parameters for future action but re-adjust parameters as a reaction to the registered success or failure of a performed action. In a sense, this can also be regarded as joint control by internal and external factors.

How some of these iterative re-adjustments might be triggered is investigated more closely in Jennings and van der Molen's paper. They show that perceiving response conflict or negative feedback leads to characteristic changes in heartbeat frequency and other "autonomic" reactions. These changes work back by supporting central processes that resolve the conflict and re-adjust the faulty action, thereby creating a kind of optimization loop in which central control processes use sub-cortical systems to steer cognitive task processes. But delegating control has also a temporal aspect, as exemplified in the contribution of Botvinick and Plaut. They suggest that more complex action sequences are represented in a distributed fashion and by integrating goal states (i.e., task context) into an action's cognitive representation. This has several advantages for performance on later occasions. Not only does the composed nature of the representation facilitate transfer to other, similar novel actions, the integration of the goal states also allows for the automatic, context- or goal-induced activation of action skills. In other words, integrating action representations with information about what purposes they serve and what intentions they satisfy represents a way to delegate later control to automatic processes; internal and external circumstances are thereby enabled to do the selection previously achieved by higher-level control processes.

Looking ahead

In summary, we feel that this special issue provides a lively, representative picture of current states of affairs in the area of cognitive control. It is to be expected that this field will progress fast and reveal new insights very soon. Two of the trends that emerge from the current literature in cognitive neuroscience are likely to play a leading role in this development.

Models of cognitive control: verbal versus formal models

While descriptive models of cognitive control (e.g., Baddeley, 1986; Norman & Shallice, 1986; Shiffrin & Schneider, 1977) have been most influential in generating conceptual and empirical hypotheses concerning control functions, recent models tend to be increasingly (anatomically and/or computationally) explicit about the recruitment and/or intervention of control and organization of basic cognitive processes (e.g., Cohen et al., 1990; Kimberg & Farah, 1993). For instance, in Cohen et al.'s (1990) model of Stroop task performance, control is exerted by a module that specifies the relevant task (in this case, color naming), and that biases the flow of information processing. While these properties are shared with the supervisory attentional system in Norman and Shallice's (1986) descriptive model, for instance, the specific benefit of formal computational modeling is that it can quite accurately simulate a host of benchmark phenomena.

Another attractive feature of formal models is that contextual information (i.e., about the relevant task) is represented in the same way as the other information (as a pattern of activation across a set of units and their interconnections), so that the control module has no special status in the model. In order to deal with the homunculus problem, the cognitive system may determine the need for control through the monitoring for conflicts in information processing that occur, for instance, when a stimulus affords two competing response tendencies (e.g., Botvinick et al., 2001). Conflict is computed as a simple, multiplicative function of the activation in competing response pathways. Detecting conflict, an evaluative control function, leads then to the recruitment of attentional/executive control processes or, even more simply, to the consultation of a contextual or goal state. Models along these lines may easily account for systematic variations in control, such as the observation that the Stroop effect (Logan & Zbrodoff, 1979) and the Simon effect (Hommel, 1994) are reduced if incongruent trials are more frequent than congruent trials or after an error has been committed (cf. the contributions of Ridderinkhof and Burle et al. to the present volume).

Failures of cognitive control

Interference effects, typically taken to result from intrinsic limitations of the efficiency of cognitive control functions, might alternatively reflect failures to consistently recruit or utilize cognitive control functions (e.g., Duncan et al., 1996). For instance, residual switch costs in task switching (the increase in reaction-time associated with task-alternation as compared to task-repetition trials, despite the opportunity to prepare for the up-coming change of task) appears to demonstrate intrinsic limitations to the ability to achieve a prepared state by fully endogenous means. Alternatively, however, De Jong (2000) suggested (on the basis of reaction-time mixture-distribution analyses) that while on most trials people do engage the cognitive control processes necessary in the preparation for a new task, on some proportion of trials they fail to do so. Thus, on switch trials responses are not slower than on repetition trials unless the subject fails to initiate the adaptive control process required to prepare for the new task. Other interference effects that have been attributed, at least in part, to probabilistic (as opposed to intrinsic) control failures include the Stroop effect (De Jong, Berendsen, & Cools, 1999) and the increased latency of antisaccades (Nieuwenhuis et al., 2000).

Effective recruitment of cognitive control requires an explicit goal or intention (i.e., to exert control) to be added to the basic goal structure that governs task performance, and retrieval and the carrying out of this intention at the proper time (cf. the contribution of Botvinick & Plaut to the present volume). Failures of this process may result in a behavioral phenomenon called *goal neglect*, defined by Duncan et al. (1996) as disregard of a task requirement even though it has been understood and remembered. This phenomenon is characteristic of laboratory-task as well as daily-life performance in patients with frontal lobe damage. Control failures may play a role in many performance deficiencies, and may provide a new research venue within the area of cognitive neuroscience.

In closing

The impetus to compose this special edition came from an international expert meeting on cognitive control that we organized in Amsterdam in May/June 2001, an Academy Colloquium sponsored by the Royal Netherlands Academy of Arts and Sciences (KNAW in its Dutch abbreviation) and co-sponsored by the Dutch organization for scientific research (NWO). The success of the meeting inspired us to compile a set of invited papers, which in most part stem from participants to the colloquium. We encouraged the authors to include provocative or even speculative discussions in their empirical or theoretical work; nevertheless, the papers underwent regular peer review to ascertain that the high quality standards of *Psychological Research* are met. We wish to express our gratitude to the referees, who gave generously of their time to help improve the caliber of the manuscripts contained in this volume, and to Peter Frensch, who spontaneously supported this project from the start.

References

Ach, N. (1910). *Über den Willensakt und das Temperament*. Leipzig: Quelle & Meyer.

Ach, N. (1935). Analyse des Willens. In E. Abderhalden (Ed.), *Handbuch der biologischen Arbeitsmethoden* (Vol. VI). Berlin: Urban & Schwarzenberg.

Allport, D. A. (1980). Patterns and actions: Cognitive mechanisms are content-specific. In G. Claxton (Ed.), *Cognitive psychology* (pp. 26–63). London: Routledge.

Atkinson, R. C., & Shiffrin, R. M. (1968). Human memory: A proposed system and its control processes. *Psychology of Learning and Motivation,* 2, 89–195.

Baddeley, A. D. (1986). *Working memory*. Oxford: Oxford University Press.

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.

Cohen, J. D., Braver, T. S., & O'Reilly, R. C. (1998). A computational approach to prefrontal cortex, cognitive control, and schizophrenia: Recent developments and current challenges. In A. C. Roberts, T. W. Robbins & L. Weiskrantz (Eds.), *The prefrontal cortex: Executive and cognitive functions* (pp. 195–220). Oxford: Oxford University Press.

Cohen, J. D., Dunbar, K., & McClelland, J. L. (1990). On the control of automatic processes: A parallel distributed processing account of the Stroop effect. *Psychological Review*, 97, 332–361.

D'Esposito, M., Postle, B. R., & Rypma, B. (2000). Prefrontal cortical contributions to working memory: evidence from event-related fMRI studies. *Experimental Brain Research*, 133, 3–11.

De Jong, R. (2000). An intention-activation account of residual switch costs. In S. Monsell & J. Driver (eds.), *Control of cognitive processes: Attention and performance XVIII* (pp. 357–376). Cambridge, MA: MIT Press.

De Jong, R., Berendsen, E., & Cools, R. (1999). Goal neglect and inhibitory limitations: Dissociable causes of interference effects in conflict situations. *Acta Psychologica*, 101, 379–394.

Duncan, J., Emslie, H., Williams, P., Johnson, R., & Freer, C. (1996). Intelligence and the frontal lobe: The organization of goal-directed behavior. *Cognitive Psychology*, 30, 257–303.

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.

Hommel, B. (1994). Spontaneous decay of response code activation. *Psychological Research*, 56, 261–268.

Hommel, B. (2000a). Intentional control of automatic stimulus-response translation. In Y. Rossetti & A. Revonsuo (eds.), *Interaction between dissociable conscious and nonconscious processes* (pp. 223–244). Amsterdam: John Benjamins Publishing Company.

Hommel, B. (2000b). The prepared reflex: Automaticity and control in stimulus-response translation. In S. Monsell & J. Driver (eds.), *Control of cognitive processes: Attention and performance XVIII* (pp. 247–273). Cambridge, MA: MIT Press.

Hommel, B., Müsseler, J., Aschersleben, G., & Prinz, W. (in press). The theory of event coding (TEC): A framework for perception and action planning. *Behavioral and Brain Sciences*, 24.

James, W. (1890). *The principles of psychology*. New York: Dover Publications.

Kimberg, D. Y., & Farah, M. J. (1993). A unified account of cognitive impairments following frontal lobe damage: The role of working memory in complex, organized behavior. *Journal of Experimental Psychology*: General, 122, 411–428.

Logan, G. D., & Gordon, R. D. (2001). Executive control of visual attention in dual-task situations. *Psychological Review*, 108, 393–434.

Logan, G. D., & Zbrodoff, N. J. (1979). When it helps to be misled: Facilitative effects of increasing the frequence of conflicting stimuli in a Stroop-like task. *Memory & Cognition*, 7, 166–174.

Meyer, D. E., & Kieras, E. D. (1997). A computational theory of executive cognitive processes and multiple task performance: Part 1, Basic mechanisms. *Psychological Review*, 104, 3–75.

Monsell, S., & Driver, J. (2000). (Eds.), *Control of cognitive processes: Attention and performance XVIII.* Cambridge, MA: MIT Press.

Neumann, O. (1987). Beyond capacity: A functional view of attention. In H. Heuer & A. F. Sanders (Eds.), *Perspectives on perception and action* (pp. 361–394). Hillsdale, NJ: Erlbaum.

Nieuwenhuis, S. N., Ridderinkhof, K. R., de Jong, R., Kok, A., & van der Molen, M. W. (2000). Inhibitory inefficiency and failures of intention activation: Age-related decline in the control of saccadic eye movements. *Psychology and Aging*, 15, 635–647.

Norman, D. A., & Shallice, T. (1986). Attention to action: Willed and automatic control of behaviour. In R. J. Davison, G. E. Schwartz, & D. Shapiro (Eds.), *Consciousness and self-regulation* (Vol. 4, pp. 1–18). New York: Plenum.

Ridderinkhof, K. R. (2002). Activation and suppression in conflict tasks: Empirical clarification through distributional analyses. In W. Prinz & B. Hommel (Eds.), *Common Mechanisms in Perception and Action: Attention & Performance*, Vol. XIX (pp. 494–519). Oxford: Oxford University Press.

Shiffrin, R. M., & Schneider, W. (1977). Controlled and automatic human information processing: II. Perceptual learning, automatic attending, and a general theory. *Psychological Review*, 84, 127–190.

Theeuwes, J. (1994). Stimulus-driven capture and attentional set: Selective search for color and visual abrupt onsets. *Journal of Experimental Psychology: Human Perception and Performance*, 20, 799–806.