The Effect of Evoked Conflict on Executive Control in a Realistic Task

Tomasz Smolen (t.smolen@up.krakow.pl)
Psychology Department, Pedagogical University of Krakow
Podchorazych 2, 30-084 Krakow, Poland

Adam Chuderski (adam.chuderski@gmail.com)
Institute of Philosophy, Jagiellonian University in Krakow
Grodzka 52, 31-044 Krakow, Poland

Abstract

Existing so-called conflict-based models of executive control aim to explain how an agent, without constantly controlling its own processing (what is both cognitively costly and inefficient), can know when to apply strong control, but when to withdraw it. These models predict that the strength of control is adjusted proportionally to the level of conflict among competing stimuli/response tendencies. However, so far the conflict-based models were verified with the use of relatively simple experimental paradigms, like the Stroop task. In the present study, we extended the effect of evoked conflict on the strength of executive control, exerted by participants, to a more realistic task (the search of information in a portal-like browser). The results indicate that also semantic conflicts (incompatible meaning of subsequent messages) can mobilize executive control, and help people to cope with experienced distraction and difficulty.

Introduction

A crucial human mental faculty that is intensively studied in cognitive science/neuroscience is executive control (also called cognitive control). It allows humans to direct and coordinate their thoughts and actions in a flexible and novel way, in order to reach adopted goals, even in face of conflicting stimulation and strongly learned but inadequate response tendencies. The important role of control in human behavior becomes clearly visible in situations when such a control has been disrupted (e.g., due to illness, aging, etc.), and agents are no longer able to inhibit intruding thoughts or responses, prevent perseveration, overcome salient distraction, switch between alternative tasks, or plan their actions (Chuderski & Nęcka, 2010; Monsell & Driver, 2000).

Recent research efforts aim to explain how the mind/brain is able to internally control its own cognitive processes, without positing any vague and homuncular constructs like *will*, *person*, or *self*. One important conclusion from this line of research states that cognitive control most likely is not a function of one dedicated cognitive subsystem, but it seems to emerge from the complex interactions between diverse mechanisms/processes (Egner, 2008) that can be precisely specified in terms of formal models (Kieras & Meyer, 1997). Work on various executive control functions spans from motivational psychology (Bargh, Gollwitzer, & Oettingen, 2010), through cognitive modeling (Cohen, Dunbar, & McClelland; Gray, 2007), to cognitive neuroscience (Alexander & Brown, 2011). What integrates all those efforts is the view that a crucial role in coordinating cognition and behavior is played by goal representations (Austin & Vancouver, 1996).

However, highly controlled (goal-focused) processing is cognitively and energetically costly (Bargh et al., 2010), and sometimes (in cases of highly skilled actions) it is counter-effective. Thus, an agent should exert control only when it is really necessary to perform a task (the minimum control principle; Taatgen, 2007). However, how an agent, without constantly controlling its own processing, can know when to apply strong control, and tightly focus on goal-relevant processes, but when to withdraw it, and rely primarily on well-learned action schemata?

One solution to this paradox assumes that an agent just monitors some simple global signal (simple enough not to require any complex processing), which acts as a heuristic for the evaluation of how strong control is needed in a particular situation. It has been proposed that such a signal can rely on various measures of *conflict* (incongruency, incompability) between thoughts/actions that can be potentially applied in a given situation (Berlyne, 1960).

Since very beginnings of psychological research, the role of conflict in mediating control was studied in natural settings (henceforth we will call such settings *realistic tasks*). For example, Kurt Lewin (1935) was one of the first to investigate the conflicts between so called helping and hindering forces acting on a person, moving her or him either toward or away the adopted goal (the approach-avoidance conflicts). Lewin's student, Festinger (1957), formalized the level of conflict (dissonance in his terminology) between incongruent psychological entities, identifying three factors affecting the perceived conflict level: (i) the magnitude of dissonance, (ii) its importance for a person, and (iii) how difficult to resolve is a particular dissonance. Motivation to counteract the causes of dissonance was a positive function of the level of conflict expressed in such a way. Festinger (and his followers) explained many real-world psychological phenomena by using the above conceptualization of conflict.

However, one disadvantage of studying the relationship between perceived conflict and executive control is the fact that realistic tasks usually do not provide sufficient experimental control required to carry out more fine-grained cognitive and neurofunctional research, and in particular – to verify precise computational models of control. Thus, this type of research usually uses simpler laboratory tasks, like the Stroop task and its variants (MacLeod, 1991). This task consists of presenting bivalent stimuli (e.g., colored words that themselves name colors), which include a less-learned (non-dominant) aspect (i.e., a color) and a more-learned (dominant) aspect (i.e, a name of a color), and require participants to process and respond to the non-dominant aspect (i.e., naming colors), while ignoring the dominant one (i.e., not reading color names).

The crucial observation in Stroop, called the congruency effect, consists of increased response latency in incongruent trials, for example when the color denoted by a word mismatches the ink color, compared to RT in neutral trials, for instance when the color of a color-unrelated string, like 'XXXXX', has to be named. The effect is even larger if the incongruent trials are compared to trials in which ink color and the word meaning match (to congruent trials). Because of its simplicity (simple stimuli displayed, and only a few vocal/manual responses required), the Stroop task (and similar tests) have been widely used to examine the theories and models (i.e., *conflict-based models of executive control*; e.g., Botvinick, Braver, Barch, Carter, & Cohen, 2001; Davelaar, 2008; Smolen & Chuderski, 2010; Verguts & Notebaert, 2008) suggesting that the perceived level of conflict affects the strength of executive control, and the congruency effect is inversely proportional to that strength.

Two experimental effects found in Stroop studies were especially interpreted as resulting from differences in the evaluated conflict level. The Gratton effect (Gratton, Coles, & Donchin, 1992) shows that the congruency effect decreases in trials presented after incongruent stimuli, in comparison to trials following congruent stimuli (i.e., in the former case, the incongruent trials become faster, often accompanied by slower congruent trials). The Gratton effect was explained (Botvinick et al., 2001) as resulting from a higher strength of control passing from *(N-1)th* incongruent trial (where it is adjusted by the conflict between alternative responses to a color and to a word) to *Nth* trial. In contrast, when *(N-1)th* trial is congruent, no additional control is exerted when *Nth* trial occurs, so the resulting level of control in the latter trial is lower overall, and it yields a longer response latency (and so a larger congruency effect). Thus, Gratton effect reflects phasic changes in control.

Moreover, the congruency effect can be decreased by an increasing proportion of incongruent trials in the sequence (Tzelgov, Henik, & Berger, 1992). This effect is interpreted in terms of tonic strength of control, which is permanently increased due to frequently occurring incongruent trials, which prevent control from decay (Botvinick et al., 2001). In general, the conflict-based models of executive control explain these two effects as reflecting the adaptation of control processes to the perceived level of conflict.

Goals of the study

The aim of the present study is to show that the above mentioned relationship between conflict and control can also be found in a more complex and ecologically valid test of executive control, that is, in a realistic task. At the same time, this task will still be computer-administered, thus potentially allowing for precise manipulations of task parameters (e.g., proportions of certain stimuli, presentation times, the nature of evoked conflict, feedback, etc.).

First, if conflicts evoked within such a task affect the indices of executive control performance, this fact will imply that the predictions of conflict-based models of executive control observed so far can be generalized onto more complex and higher-level processes, supporting the psychological plausibility of these models. Also, the novel knowledge about operation of executive control in realistic tasks will allow us to design such tasks in a better way (e.g., in a way in which they impose less load on executive control or working memory), so it will have important practical implications.

Second, the conflicts evoked in our task will consist of the semantic incongruency between presented stimuli, whereas these incongruent stimuli will not yield incompatible motor responses (they will just lead to cognitive dissonance). As so far most of conflict-based models of control accounted only for conflicts at the stimulus (Davelaar, 2008) or response level (Botvinick et al., 2001; Verguts & Notebaert, 2008), a potential observation of semantic conflicts influencing the strength of control will substantially extend the scope of theories of control based on conflict evaluation.

Especially, our own computational model (Smolen & Chuderski, 2010) assumes that conflicts can occur at almost each stage of cognitive processing (conceptual, semantic, memorial). So, the expected observation will support this model to a large extent, in comparison to alternative models, predicting that only events at a stimulus/response stage matter for the evaluation of control strength.

One challenge for a study of executive control in natural settings is the design of a realistic task that, on one hand, can be applied using a computer, and requires relatively simple reactions (e.g., with a mouse), whereas on the other hand it is still 'realistic', in the sense that it resembles activities that most of people do for a certain part of a day at their work or at home. Our choice was a tool that requires both searching and reading the short portions of information (both textual and graphical) within a simplified internet portal, in order to fulfill a task of gathering as much relevant knowledge on a given (realistic) problem as possible, and eventually answering one precise question regarding that problem. The crucial manipulation in such a task consists of introducing a certain amount of semantic incompatibility between target passages of text (some passages negate others). We expected increased semantic incompatibility (i.e., the conflict on a conceptual level) to increase the strength of exerted control, which in effect would help to deal with a higher distraction – a factor that likely would affect negatively the goal-relevant performance, if not prevented by strong executive control.

Method

Participants

A total of 46 women and 36 men participated (82 people). All of them were recruited via adds on social networking webpages. Mean age was 22.8 years (*SD* = 3.38, range 18 – 38). For a two-hour session each participant received the equivalent of ten euro in local currency. All participants had normal or corrected-to-normal vision.

Materials and design

The screen in the task was composed of 3 × 3 matrix of locations. The task consisted of four problems. In a particular problem, the initial screen consisted of nine messages. Each message was placed in one of the matrix cells. In subsequent cycles, every 5 s, a random message was substituted with another message. In total, 100 messages were presented in one problem (including the initial messages).

Messages could belong to one of four categories. *Regular target messages* were short passages of text (not shorter than 120 characters) providing an information relevant for a problem to be solved (see below). For instance, a regular target message A could state that 'company X expects more sales next year and prepares for that fact'. However, a certain number of target messages (*conflicting target messages*) negated regular target messages that directly preceded them (e.g., message B: 'X expects less sales next year and will cut costs', directly following – that is, not separated by any other target message – message A).

Another category were *distractor messages*, which were text messages (30%) which conveyed information superficially associated with the problem, but in fact irrelevant for it (e.g., 'sales employees of X won soccer cup in the 2013 sales departments competition'), attractive graphics (30%; either funny cartoons or erotic images of young pretty women/handsome men), or text jokes (40%). Distractor messages were intended to capture attention of participants, what might result in missing target messages, as the latter disappeared from the screen after certain time (depending on the number of cycles that it was displayed for).

The last category were *noise messages*, which conveyed either text information irrelevant for the problem, but in no way conflicting or distracting (e.g., 'several national parks have been founded in Poland in recent years'), or images of supposedly not distracting objects and landscapes. The use of both the distractor and noise messages made the contents of the task relatively similar to internet portals, which usually contain a lot of irrelevant textual and graphical information. The example screen of the task, including all types of messages, is presented in Fig. 1.

The task of each participant was to monitor and read messages that can be potentially informative with regard to the problem presented to her or him in an instruction. Participants were also instructed that they have to confirm with the computer mouse the fact that a certain message is a message conveying an important knowledge on the problem (by clicking on that message). At the beginning of the experiment, the participants were informed that after the computerized part of the test they would be provided with messages they chose, and they would have to answer a question about presented problems. Answering the question consisted of providing the subjective probability of the confirmative answer to this question.

The number of conflicting target messages and the number of distractor messages were two crucial task parameters. In the *no-conflict condition*, there were 30 regular target messages defined for a particular problem, but no conflicting target messages were presented. In the *conflict condition*, half of 20 regular target messages (randomly picked up from the pool of 30 messages) was followed by the corresponding conflicting target message (so, there were also 30 targets in total, but some their pairs were mutually incompatible semantically). In the *low-distraction condition*, there were 10 distractor messages/ images in a run, whereas in the *high-distraction condition* as much as 60 such messages/images were presented. In order to obtain the 100-message/image sequences, in the former condition 60 noise messages/images were used, whereas in the latter – 10 such messages/images were included. For each participant and problem, the distractor and noise messages/images were picked up on random from a pool of 1186 distractor and 1500 noise messages/images.

The problems were formulated as follows: 'On a basis of information provided in a task, please …':

- analyze new investment of IT company X in a mobile phone system, and judge the probability that X will increase its headcount due to this investment;
- describe how the human cortex works;
- tell how computer processor works;
- evaluate what factors have the most important role in supporting the existing political system in Ukraine.

Noteworthy, in order to be maximally interesting for participants, the problems pertained to diverse topics.

Thus, in the present experiment, the independent variables were: semantic conflict (either present or absent), and distraction (either low or high). For each participant, all possible problems and conditions were combined on random, resulting in the 2 × 2 'within-subjects' design. First, we expected that distraction would significantly decrease performance accuracy (i.e., people will be looking at erotic pictures or jokes instead of selecting the target messages). Second, we expected that the magnitude of the distraction effect (i.e., accuracy on low distraction minus high distraction condition) in the no-conflict condition would be attenuated by increased control in the conflict-condition (i.e., people, after detecting conflicts, would focus more on the task, and would better ignore distractors). Thus, we expected the two-way interaction analogous to the Gratton effect in Stroop.

Procedure

Participants were tested in a large, dimly lit room, in groups of up to ten people. Standard PC workstations with 17' LCD monitors were used for the test. Each participant occupied a visually isolated desk, and she or he was asked to adopt the most comfortable sitting position.

The primary dependent variable (DV) was the proportion of missed regular target messages (i.e., error rate) in each problem, corrected (i.e., increased) by the weighted proportion (with the weight reflecting the ratio of targets to non-targets; i.e., noise and distractor messages) of incorrectly identified non-targets (see Snodgrass & Corwin, 1988). The correction was meant to reflect the individual response tendencies of participants (i.e., people who generally tended to respond more often had also a larger chance to hit the target). Where explicitly indicated, analyses additionally pertain to data about the conflicting target messages.

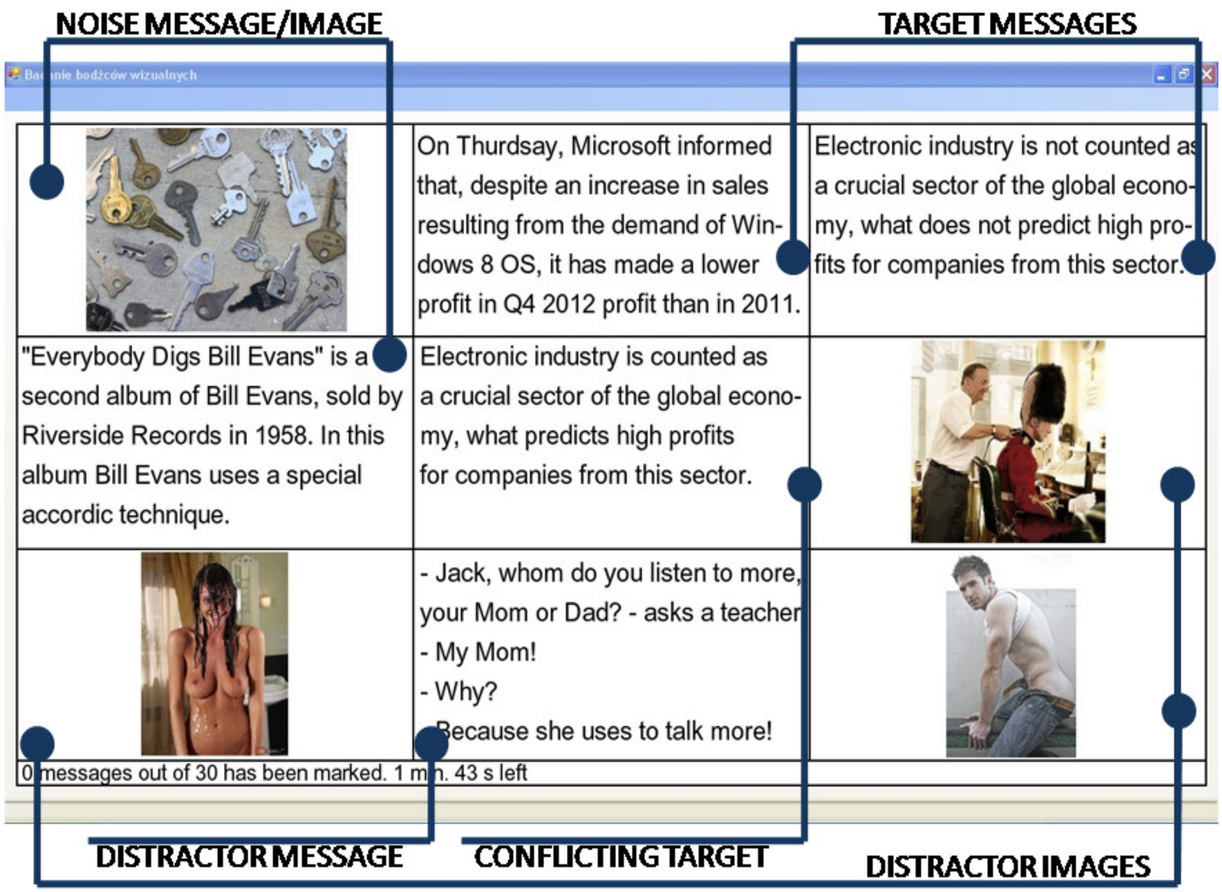

Fig. 1: A demonstration of a screen in the realistic task used in the experiment, with particular types of messages that were presented in the task marked with arrows (note that no arrows were shown in the original screens). Texts represent English translations of the original messages (in the experiment, the task was administered in Polish).

Results

The mean proportion of errors was .33 (*SD* = .11). It ranged from *M* = .15 to *M* = .64 for particular participants. This data indicates that participants generally understood and followed instructions for the task, and the individual differences in task performance were not substantial. Data for specific conditions of the task are presented in Table.

Distraction:	Low	High
No-conflict condition	.25 (.13)	.41 (.20)
Conflict condition	.31 (.14)	.36 (.15)
Conflicting targets in conflict condition	.46 (.24)	.45 (.22)

Table: Mean error rate (and *SD*) in all conditions of the task.

Data regarding regular target messages were submitted to ANOVA. In the case of errors, two factors yielded significant main effects. First, in the high distraction condition participants missed target messages more often (M = .39) than in the low distraction condition (M = .28), $F(1, 81) = 55.59$, $p < .001$, $\eta^2 = .41$. This fact implied that superficially similar texts, funny cartoons, and erotic images, originally aimed to capture people's attention, indeed diverted participants from fulfilling the task, and constituted the substantial source of interference for the executive system to cope with. Second, there was no significant difference in errors between the conflict and no-conflict conditions, $F(1, 81) = 0.12$, meaning that conflict did not affect the accuracy of recognition of regular target messages *per se*.

As expected, in the conflict condition participants missed the conflicting target messages more often (M = .46) than they missed the regular target messages (M = .31), $F(1, 81) = 58.80$, $p < .001$, $\eta^2 = .42$. This effect indicates that they indeed detected semantic incompatibility between consecutive target messages, and often decided that a incompatible message was irrelevant for the solution of the current problem (so they did not click on it).

In light of our hypotheses, the most important effects pertained to the two-way interactive effect of factors, which was significant $F(1, 81) = 15.24$, $p < .001$, $\eta^2 = .94$. Tukey's HSD test showed that high and low distraction conditions differed both in no-conflict ($p < .001$) and conflict ($p = .008$) conditions as well as conflict and no-conflict conditions differed both in low distraction ($p = .009$) and high distraction ($p = .009$) conditions. The interaction is presented in Figure 2.

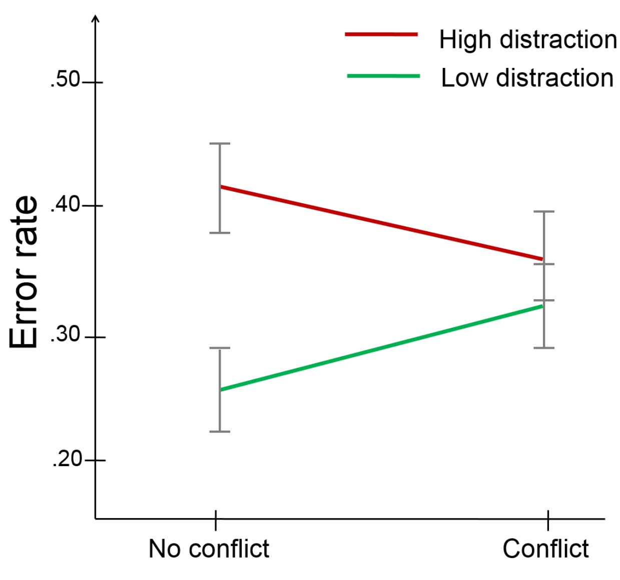

Fig. 2: Mean error rate of regular target message detection in the conflict versus no-conflict condition, for low- (green line) versus high-distraction (red line) conditions. Bars represent 95% confidence intervals.

Discussion

Our hypotheses assumed that increased perception of conflict, evoked by placing the semantically incompatible messages within the stream of information presented to participants, would affect the effects possibly yielded by factors that load executive control mechanisms, which might be responsible for dealing with our realistic task. We obtained strong evidence in favor of this hypothesis. Increased distraction made people to respond less correctly, but this effect was attenuated by increased conflict. In line with the conflict-based models of control, we attribute this interaction to additional strength of control, which was 'mobilized' and, thus, control became more effective when participants started facing semantic conflicts.

Thus, these results are pretty analogous to the Gratton effect observed in various tests of executive control. However, as far as we know, now for the first time they have been observed within a much more complex task than such tests, that is, within a task that in a way resembles natural situations of information acquisition and selection.

The theoretical implications of the present work pertain to the verification of the above mentioned conflict-based models of executive control. Extending their predictions to a (more or less) realistic task suggests that perceived conflict (in stimulation or between mental representations/response tendencies) may indeed be a type of signal that is evaluated for the sake of optimizing the strength of exerted control. Thus, our study seems to extend and generalize predictions of the conflict-based models of control. Especially, the results in some way support a key assumption of our own conflict-based model, which predicts that not only response- (see Botvinick et al., 2001) or stimulation-based conflicts (see Davelaar, 2008) modulate executive control, but it can also be influenced by conflicts regarding semantic or conceptual incongruency between cognitive processes (i.e., conflict related to memory/higher-level cognition).

However, it must be noted that conflicts may not be the only type of signal that can regulate executive control. Other accounts, for instance models that in regulating control rely on the learned (via reinforcement learning) likelihood of negative outcomes like errors or risky actions (Brown & Braver, 2007), or the discrepancy between predicted response outcomes and the outcomes that are actually experienced (Alexander & Brown, 2011), were proposed in literature, and successfully fitted to observed data regarding executive control. It is also likely that the human brain evolved to use various mechanisms that regulate executive control, and the comprehensive model of human control should integrate them all. For example, regulation based on reinforcement learning may be effective if an agent has a rich experience with a particular kind of situation (e.g., a risky one), that is, it had a lot occasions to learn. However, in completely novel situations, when learning was not possible yet, conflict-based regulation may be a better regulative mechanism to use.

In conclusion, the present study in an original way combined the precise manipulation of factors possibly affecting the workings of human executive control mechanisms with the relatively complex, higher-level realistic task. Future steps in the present line of research should extend the examination of variables possibly influencing executive control, which are based on evoked conflict, to even more realistic settings. In this regard, the development of virtual reality platforms constitutes a very promising research tool that should be further exploited. Knowledge on factors negatively (or positively) affecting the internal control of human cognitive processing in natural settings may also help to design better human-computer interfaces, vehicle cockpits, etc.

Acknowledgments

This work was sponsored by the National Science Centre of Poland (grant no. 2011/01/D/HS6/00467). We are grateful to Jolanta Wójcik for designing the problems and conducting the experiment, and to Jaroslav Sadowsky for programming the experimental task.

References

Alexander, W. H., & Brown, J. W. (2011). Medial prefrontal cortex as an action-outcome predictor. *Nature Neuroscience, 14,* 1338-1344.

Austin, J. T., & Vancouver, J. B. (1996). Goal constructs in psychology: Structure, process, and content. *Psychological Bulletin, 120*, 338-375.

Bargh, J. A., Gollwitzer, P. M., & Oettingen, G. (2010). Motivation. In S. Fiske, D. Gilbert, & G. Lindzey (Eds.), *Handbook of Social Psychology* (pp. 268-316). New York: Wiley.

Berlyne, D. E. (1960). *Conflict, arousal, and curiosity.* New York: McGraw-Hill.

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.

Brown, J. W., & Braver, T. S. (2007). Risk prediction and aversion by anterior cingulate cortex. *Cognitive, Affective, & Behavioral Neuroscience, 7,* 266, 277.

Chuderski, A., & Nęcka, E. (2010). Intelligence and cognitive control. W: A. Gruszka, G. Matthews, B. Szymura, (Eds.), *Handbook on individual differences in cognition: Attention, memory, and executive control* (pp. 263-281). New York: Springer Verlag.

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

Davelaar, E. J. (2008). A computational study of conflict-monitoring at two levels of processing: reaction time distributional analyses and hemodynamic responses. *Brain Research, 1202,* 109-119.

Egner, T. (2008). Multiple conflict-driven mechanisms in the human brain. Trends in Cognitive Sciences, 12, 374-380.

Festinger, L. (1957). *A Theory of Cognitive Dissonance.* Stanford, CA: Stanford University Press.

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.

Gray, W. D. (2007). *Integrated models of cognitive systems*. New York: Oxford University Press.

Kieras, D. E., & Meyer D. E. (1997). A computational theory of executive cognitive processes and multiple-task performance: II. Psychological refractory period. *Psychological Review, 104(1)*, 3-65.

Lewin, K (1935). *A Dynamic Theory of Personality*. New York: McGraw-Hill.

MacLeod, C. M. (1991). Half a century of a research on the Stroop Effects: An integrative review. *Psychological Bulletin, 109,* 163-203.

Monsell, S., Driver, J. (2000), Banishing the control homunculus. In J. Driver, S. Monsell (Eds.), *Attention and Performance XVII* (pp.3-31). Cambridge, MA: MIT Press.

Smoleń, T., & Chuderski, A. (2010). Modeling strategies in Stroop with a general architecture of executive control. In S. Ohlsson, R. Catrambone (Eds.), *Proceedings of the 32nd Annual Conference of the Cognitive Science Society* (pp. 931-936). Austin, TX: Cognitive Science Society.

Snodgrass, J. G., & Corwin, J. (1988). Pragmatics of measuring recognition memory: Applications to dementia and amnesia. *Journal of Experimental Psychology: General, 117,* 34-50.

Taatgen, N.A. (2007). The minimal control principle. In Gray W. (Ed.), *Integrated Models of Cognitive Systems* (pp. 368-379). New York: Oxford University Press.

Tzelgov, J., Henik, A., & Berger, J. (1992). Controlling Stroop effects by manipulating expectations for color words. *Memory & Cognition, 20,* 727-735.

Verguts, T., & Notebaert, W. (2008). Hebbian learning of cognitive control. *Psychological Review, 115,* 518-525.