https://doi.org/10.1016/j.newideapsych.2022.100980

A System for Describing Mechanisms Underlying the Congruency Sequence Effect or the Proportion Congruency Effect

Michael Sprengel[1], Mike Wendt[2], Thomas Jean Hosang[1], and Thomas Jacobsen[1]

[1]Experimental Psychology Unit, Helmut-Schmidt-University/University of the Federal Armed Forces Hamburg, Holstenhofweg 85, 22043 Hamburg, Germany

[2]Faculty of Life Sciences, Medical School Hamburg, Am Kaiserkai 1, 20457 Hamburg, Germany

Author Note

Correspondence concerning this article should be addressed to Michael Sprengel, Helmut-Schmidt-University/University of the Federal Armed Forces Hamburg, Experimental Psychology Unit, Holstenhofweg 85, 22043 Hamburg, Germany.

Email: sprengem@hsu-hh.de

Abstract

The congruency sequence effect (CSE) and the proportion congruency effect (PCE) are typical findings in experimental conflict protocols. Given the ever-increasing number of, in part, radically different mechanisms proposed to explain either effect, a unified system for describing candidate mechanisms appears desirable. In this article, we show that such a system can be derived by focusing on functional similarities among all mechanisms capable of explaining either effect. The latter perspective reveals the adaptive dynamic that all such mechanisms share. This shared dynamic allows describing each mechanism by addressing the same questions about how this dynamic is implemented. We contend that this description system facilitates comparisons between mechanisms, and relating the discourse on the CSE and PCE to other lines of discourse. First, we introduce the adaptive dynamic and the questions about its implementation. Then, we answer these questions for exemplary cases. Finally, we discuss the utility of the proposed system.

Keywords: Congruency sequence effect (CSE), proportion congruency effect (PCE), mechanism, description, system

A System for Describing Mechanisms Underlying the Congruency Sequence Effect and the Proportion Congruency Effect

Experimental conflict protocols, such as the Stroop task (Stroop, 1935; see MacLeod, 1991, for an overview), the Simon task (Simon, 1990) or the Eriksen flanker task (Eriksen & Eriksen, 1974; see Eriksen, 1995, for an overview), are commonly used to investigate behavior optimization under changing environmental conditions. In such protocols, behavioral performance is typically worse in incongruent trials, where task-irrelevant stimuli indicate an incorrect response, than in congruent trials, where such stimuli indicate the correct response. This *congruency effect* tends to be smaller when the immediately preceding trial is incongruent than when it is congruent (*congruency sequence effect; CSE; also known as Gratton effect*; e.g. Gratton et al., 1992). It also tends to be smaller when an extended sequence of preceding trials contains mostly incongruent trials than when such a sequence contains mostly congruent trials (*proportion congruency effect; PCE*; e.g. Gratton et al., 1992; Lindsay & Jacoby, 1994; Logan, 1980; Logan & Zbrodoff, 1979; Lowe & Mitterer, 1982; West & Baylis, 1998).

Competing explanations attribute these modulations of the congruency effect to different mechanisms (e.g. Bugg, 2017; Bugg & Crump, 2012; Schmidt, 2013b, 2019). The longstanding debate whether top-down control or bottom-up associative mechanisms are better supported remains unresolved (e.g., Schmidt, 2013b, 2019). There have been attempts to integrate both perspectives, for example by “grounding cognitive control in associative learning” (Abrahamse et al., 2016, p. 693). Apart from such a potential mechanistic integration, both types of mechanisms are united in their function, as Egner emphasized in 2014. He identified “the matching of incoming stimulation (external states) to memories (internal states) in the service of producing fast, goal-conducive action” as their “common principle and goal” (Egner, 2014, pp 1-2).

In our view, this describes an adaptive dynamic that not only all hitherto discussed but all mechanisms share that are capable of explaining the CSE or PCE. This shared dynamic allows describing each mechanism by addressing the same questions about how functional aspects of this dynamic are implemented. The spectra of answers to these questions can be regarded as dimensions of a theoretical space in which every mechanism can be located. Locating mechanisms in this space, instead of categorizing them as types, may inspire new types of comparisons within and across the borders of the conflictual top-down-bottom-up dichotomy. At the same time, serving as a neutral, common frame of reference, this space may facilitate a more equitable treatment of non-control mechanisms, which are often regarded as mere confounds (Braem et al, 2019).

Thus, while it may seem counter-intuitive, we believe that abstracting from differences (of implementation) between mechanisms, and thereby identifying general functional dimensions they share, yields a system that allows for a nuanced description of the mechanisms and their differences. In our view, the discourse may benefit from the description of mechanisms based on underlying functional dimensions in a similar way as, for example, personality psychology benefits from dimensional descriptions of personality.

First, we introduce the adaptive dynamic and the questions about its implementation. Then, we answer these questions for exemplary cases. Finally, we discuss the utility of the proposed description system.

1. The Adaptive Dynamic

To demonstrate that all mechanisms capable of explaining either effect share the adaptative dynamic, we derive the latter from necessary and sufficient conditions for both effects, which we introduce first.

1.1 Necessary and Sufficient Conditions

The CSE and PCE are congruency level repetition advantages: Performance is better when the most recent/recently more frequent congruency level repeats in the current trial than when it does not. This description expresses the interaction that each effect constitutes independently of main effects.

Figure 1

CSE and PCE Independent of Main Effects

Note. “Cong (n)” stands for congruency in trial n, “Inc” and “Con” stand for incongruent and congruent, respectively.

As Figure 1 shows, this interaction provides two indications for a difference between the congruency levels that are independent of main effects. One indication is that congruent trials are affected differently than incongruent trials by the most recent/recently more frequent congruency level. The other indication is that the latter factor has an effect on each trial type.

While not necessary, it is most parsimonious to assume only one relevant difference between the congruency levels[1]. For simplicity, we also assume that this difference concerns a parameter that is instantiated in every trial[2]. Under these assumptions, a necessary condition for both the CSE and the PCE is:

- The congruency levels differ in the distribution of a parameter X.

The only other condition required for a CSE is:

- The cognitive system is more adapted to (i.e., its state is better suited to processing) X-values from either congruency-level-dependent distribution immediately after processing an X-value from that distribution than immediately after processing an X-value from the respective other distribution.

The only other condition required for a PCE is:

- The cognitive system is more adapted to X-values from either congruency-level-dependent distribution immediately after processing a sequence of X-values mostly sampled from that distribution than immediately after processing a sequence of X-values mostly sampled from the respective other distribution.

1.2 The Adaptive Dynamic

The adaptive dynamic is implied in each of the latter two conditions. According to both, information about from what distribution one or more preceding X-values were

[1] To our knowledge, all proposed explanations make this assumption.
[2] Assuming that the respective parameter is not instantiated in every trial does not change the relevant characteristics of the conditions.

sampled, influences current performance. Clearly, this information must have been acquired in the past and stored until the present. In the present, it influences how adapted the cognitive system is to particular X-values. One aspect of this influence is to what specific value(s) the cognitive system is more adapted, and how this is determined. Other aspects are what configuration of the cognitive system constitutes this adaptedness, and how it arises.

As we have seen, the adaptive dynamic is implied in a necessary condition for each effect. Therefore, every mechanism capable of explaining either effect must share this dynamic.

1.3 The Questions

Above, we have described the adaptive dynamic in terms of functional aspects. While these aspects are not necessarily all implemented independently, they could be. Therefore, it is useful to address each individually, by answering the following questions:

- To what parameter does the cognitive system adapt (i.e., what is parameter X)?
- How does the cognitive system acquire and store information about this parameter?

  Depending on one's definition of the term, information storage could be described as a form of memory. For example, we would even consider the persisting activation of processing pathways underlying priming effects, as a form of memory.
- How does this information influence to what parameter value(s) the cognitive system is more adapted?

  Based on the stored information about preceding parameter values, it somehow has to be determined to what value(s) the system "should be" more adapted. Conceptually, though not necessarily practically, this question is independent of what state ultimately constitutes the adaptedness to this value (fourth question) or through what process it is achieved (fifth question). For example, assuming parameter X is color, a conceivable albeit extremely counter-intuitive result of the determination process would be that the system should be most adapted to the color it has least recently encountered (i.e., the opposite of bottom-up color priming).

- What configuration of the cognitive system constitutes this adaptedness?

  To continue the counter-intuitive example, the concrete state of the system that makes it better suited to processing the least recent color could be a lower activation threshold for the corresponding semantic unit (than for other color-related semantic units).

- How does this adaptedness arise?

  Crucially, this lower activation threshold could not be explained purely in terms of bottom-up processing, as the simplest forms of priming can. Assuming the same passive decay of preceding bottom-up activation over time, for every instance of preceding activation, bottom-up processing could only explain better adaptedness to the most recent color(s). Therefore, a different process would have to be proposed to explain how the above described state of adaptedness arises.

1.4 Answering the Questions

The answers to the above questions are intended to characterize a mechanism in the context of an explanation of the CSE or PCE. Therefore, in our view, they should reflect how the respective mechanism explains that the cognitive system is more adapted to X-values from either congruency-level-dependent distribution after processing an X-value/mostly X-values from that distribution. To our knowledge, all proposed mechanisms rely on the following principle:

- At any moment, there is one X-value to which the cognitive system is most adapted. The expected value of the parameter that represents this optimal X-value is biased towards more recently and, in some cases, towards more frequently sampled X-values.
- The cognitive system is more adapted to a given X-value the closer this value is to the optimal X-value.

In combination with the assumption that the congruency levels differ in the expected value of X, this principle gives rise to a general deductive argument for congruency level repetition advantages, visualized in Figure 2. To our knowledge, every proposed explanation of the CSE or PCE provides an instantiation of this argument. Thus, when they reflect this principle, the answers to the above questions capture all aspects of how the respective explanation provides this instantiation. At the same time, they characterize the implementation of all functional aspects of the underlying adaptive dynamic that we consider most relevant to the current discourse.

Figure 2

General Deductive Argument for Congruency Level Repetition Advantages

Note. The propositions to which the arrows point follow logically from the conjunction of the propositions immediately above the respective arrow. The spatial arrangement of the propositions does not reflect any relations (e.g., temporal succession) but the logical ones described.

2. Exemplary Cases

As an illustration, we answer the introduced questions for a top-down control and for a bottom-up associative mechanism. For simplicity, we consider only one version of each account. For the same reason, these are not the most recent or most sophisticated versions.

2.1 Conflict Monitoring Theory

- To what parameter does the cognitive system adapt (i.e., what is parameter X)? According to the Conflict Monitoring Theory (CMT; Botvinick et al., 2001), the cognitive system adapts to response conflict, which indicates the level of concurrent response activations.
- How does the cognitive system acquire and store information about this parameter? A monitoring unit located in the anterior cingulate cortex registers conflict in each trial. The computational implementation of the CMT suggests that all information concerning registered conflict levels is stored in a single parameter. This parameter, the current (need-for-)control signal, is a linear transformation of a (recency-biased) exponentially weighted moving average (EWMA) of all registered conflict levels (Botvinick et al., 2001). Due to its nature, this EWMA of registered conflict levels is

biased towards more recently and towards more frequently registered conflict levels.

- How does this information influence to what value(s) the cognitive system is more adapted?

  The EWMA of registered conflict levels is the level to which the cognitive system is most adapted.

- What configuration of the cognitive system constitutes this adaptedness?

  A degree of processing selectivity that correlates strongly positively with the current (need-for-)control signal, constitutes the adaptedness (Botvinick et al., 2001). Due to this strong positive correlation, the cognitive system is more adapted to a given conflict level the more similar this level is to the optimal level.

- How does this adaptedness arise?

  Botvinick et al. (2001) did not specify how this adaptedness arises.

2.2 Contingency Learning

- To what parameter does the cognitive system adapt (i.e., what is parameter X)?

  According to the response-contingency learning account (Schmidt & Besner, 2008), the cognitive system adapts to the distractor-specific identity of the (co-occurring) response.

- How does the cognitive system acquire and store information about this parameter?

  Apart from describing the learning process as implicit, Schmidt & Besner (2008) did not specify how information about co-occurrences of distractors and responses is acquired and stored, but presumably through some form of association learning. Due to the nature of association formation, association strength reflects the recency and frequency of co-occurrence.

- How does this information influence to what value(s) the cognitive system is more adapted?

  While Schmidt and Besner (2008) did not specify this influence, they assumed that the cognitive system expects the response which has (recently) most often cooccurred with the presented distractor. Assuming that association strength determines how likely a response is the expected one, the probabilities of being the expected response correspond to the co-occurrence probabilities that the association strengths reflect.

- What configuration of the cognitive system constitutes this adaptedness?
  A lower activation threshold of the expected response constitutes the adaptedness (Schmidt & Besner, 2008). The cognitive system is more adapted to a required response that is identical, and therefore more similar, to the expected response than to one that is not.
- How does this adaptedness arise?
  Schmidt and Besner (2008) did not specify how this adaptedness arises, possibly through the spreading of activation from the activated distractor representation.

3. Utility

3.1 Comparability

The spectra of answers to the introduced questions can be regarded as dimensions of a theoretical space in which all mechanisms underlying the CSE or PCE can be located. Locating each mechanism on each dimension provides information of variability within categories of mechanisms that prototype systems like the traditional top-down-vs-bottom-up dichotomy lack. Moreover, locating prototypes themselves on each dimension enriches their representations. Thus, the proposed “dimensional” description facilitates more nuanced comparisons between mechanisms, irrespective of whether they are prototypical representatives of categories or not. At the same time, a dimensional description lacks categories (across dimensions), which are often useful, however. Therefore, in our view, the proposed description system is most useful as a complement to categorical systems. Indeed, information about variability within categories may induce further differentiation of categories into subcategories, and thus refine category systems.

3.2 Falsifiability and Communication

The proposed description system may increase falsifiability. As the examples illustrate, the implementation of some functional aspects may not have been (explicitly) addressed, in the case of some mechanisms. The proposed system encourages theorists to address each aspect, at least tentatively. This would increase the specificity of theoretical notions and thereby their falsifiability.

Systematically describing the mechanisms by addressing the same questions, in each case, may increase transparency in communicating their working principles, especially but not exclusively to non-experts.

The generality of the adaptive dynamic at the foundation of the proposed system may facilitate relating the discourse on the CSE and PCE to other lines of discourse concerned with adaptive behavior. This generality stems from the generality of the effects themselves. Repetition advantages can be regarded as quintessential indicators of adaptation in general. How would one demonstrate that an organism has adapted to a type of environment if not by demonstrating that the organism performs better when this type of environment recurs than when the organism is confronted with another type of environment? Indeed, in the most directly related line of discourse, the central finding are task switch costs (e.g., Kiesel et al., 2010; Koch et al., 2018) – or in other words, task repetition advantages.

References

Abrahamse, E., Braem, S., Notebaert, W., & Verguts, T. (2016). Grounding cognitive control in associative learning. *Psychological Bulletin*, *142*(7), 693–728. https://doi.org/10.1037/bul0000047

Botvinick, M. M., Braver, T. S., Barch, D. M., Carter, C. S., & Cohen, J. D. (2001). Conflict monitoring and cognitive control. *Psychological Review*, *108*(3), 624–652. https://doi.org/10.1037/0033-295X.108.3.624

Braem, S., Bugg, J. M., Schmidt, J. R., Crump, M. J., Weissman, D. H., Notebaert, W., & Egner, T. (2019). Measuring adaptive control in conflict tasks. *Trends in Cognitive Sciences*, *23*(9), 769–783. https://doi.org/10.1016/j.tics.2019.07.002

Bugg, J. M. (2017). Context, conflict, and control. In T. Egner (Ed.), *The Wiley handbook of cognitive control* (pp. 79–96). New Jersey: John Wiley & Sons.

https://doi.org/10.1002/9781118920497.ch5

Bugg, J. M., & Crump, M. J. (2012). In support of a distinction between voluntary and stimulus-driven control: A review of the literature on proportion congruent effects. *Frontiers in Psychology*, *3*(367). https://doi.org/10.3389/fpsyg.2012.00367

Egner, T. (2014). Creatures of habit (and control): A multi-level learning perspective on the modulation of congruency effects. *Frontiers in Psychology*, *5*, Article 1247. https://doi.org/10.3389/fpsyg.2014.01247

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*(1), 143–149. https://doi.org/10.3758/BF03203267

Eriksen, C. W. (1995). The flankers task and response competition: A useful tool for investigating a variety of cognitive problems. *Visual Cognition*, *2*(2–3), 101–118. https://doi.org/10.1080/13506289508401726

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*(4), 480–506. https://doi.org/10.1037/0096-3445.121.4.480

Kiesel, A., Steinhauser, M., Wendt, M., Falkenstein, M., Jost, K., Philipp, A. M., & Koch, I. (2010). Control and interference in task switching—A review. *Psychological bulletin*, *136*(5), 849–874. https://doi.org/10.1037/a0019842

Koch, I., Poljac, E., Müller, H., & Kiesel, A. (2018). Cognitive structure, flexibility, and plasticity in human multitasking—An integrative review of dual-task and task switching research. *Psychological Bulletin*, *144*(6), 557–583. https://doi.org/10.1037/bul0000144

Lindsay, D. S., & Jacoby, L. L. (1994). Stroop process dissociations: The relationship between facilitation and interference. *Journal of Experimental Psychology: Human Perception and Performance*, *20*(2), 219–234. https://doi.org/10.1037/0096-1523.20.2.219

Logan, G. D. (1980). Attention and automaticity in Stroop and priming tasks: Theory and data. *Cognitive Psychology*, *12*(4), 523–553. https://doi.org/10.1016/0010-0285(80)90019-5

Logan, G. D., & Zbrodoff, N. J. (1979). When it helps to be misled: Facilitative effects of increasing the frequency of conflicting stimuli in a Stroop-like task. *Memory & Cognition*, *7*(3), 166–174. https://doi.org/10.3758/BF03197535

Lowe, D. G., & Mitterer, J. O. (1982). Selective and divided attention in a Stroop task. *Canadian Journal of Psychology/Revue canadienne de psychologie*, *36*(4), 684–700. https://doi.org/10.1037/h0080661

MacLeod, C. M. (1991). Half a century of research on the Stroop effect: An integrative review. *Psychological Bulletin*, *109*(2), 163–203. https://doi.org/10.1037/0033-2909.109.2.163

Schmidt, J. R. (2013). Questioning conflict adaptation: Proportion congruent and Gratton effects reconsidered. *Psychonomic Bulletin & Review*, *20*, 615–630. https://doi.org/10.3758/s13423-012-0373-0

Schmidt, J. R. (2019). Evidence against conflict monitoring and adaptation: An updated review. *Psychonomic Bulletin & Review*, *26*(3), 753–771. https://doi.org/10.3758/s13423-018-1520-z

Schmidt, J. R., & Besner, D. (2008). The Stroop effect: Why proportion congruent has nothing to do with congruency and everything to do with contingency. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *34*(3), 514–523. https://doi.org/10.1037/0278-7393.34.3.514

Simon, J. R. (1990). The effects of an irrelevant directional cue on human information processing. In R. W. Proctor & T. G. Reeve (Eds.), *Stimulus–response compatibility* (pp. 31–86). North-Holland. https://doi.org/10.1016/S0166-4115(08)61218-2

Stroop, J. R. (1935). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology*, *18*(6), 643–662. https://doi.org/10.1037/h0054651

West, R., & Baylis, G. C. (1998). Effects of increased response dominance and contextual disintegration on the Stroop interference effect in older adults. *Psychology & Aging*, *13*(2), 206–217.

Figure 1

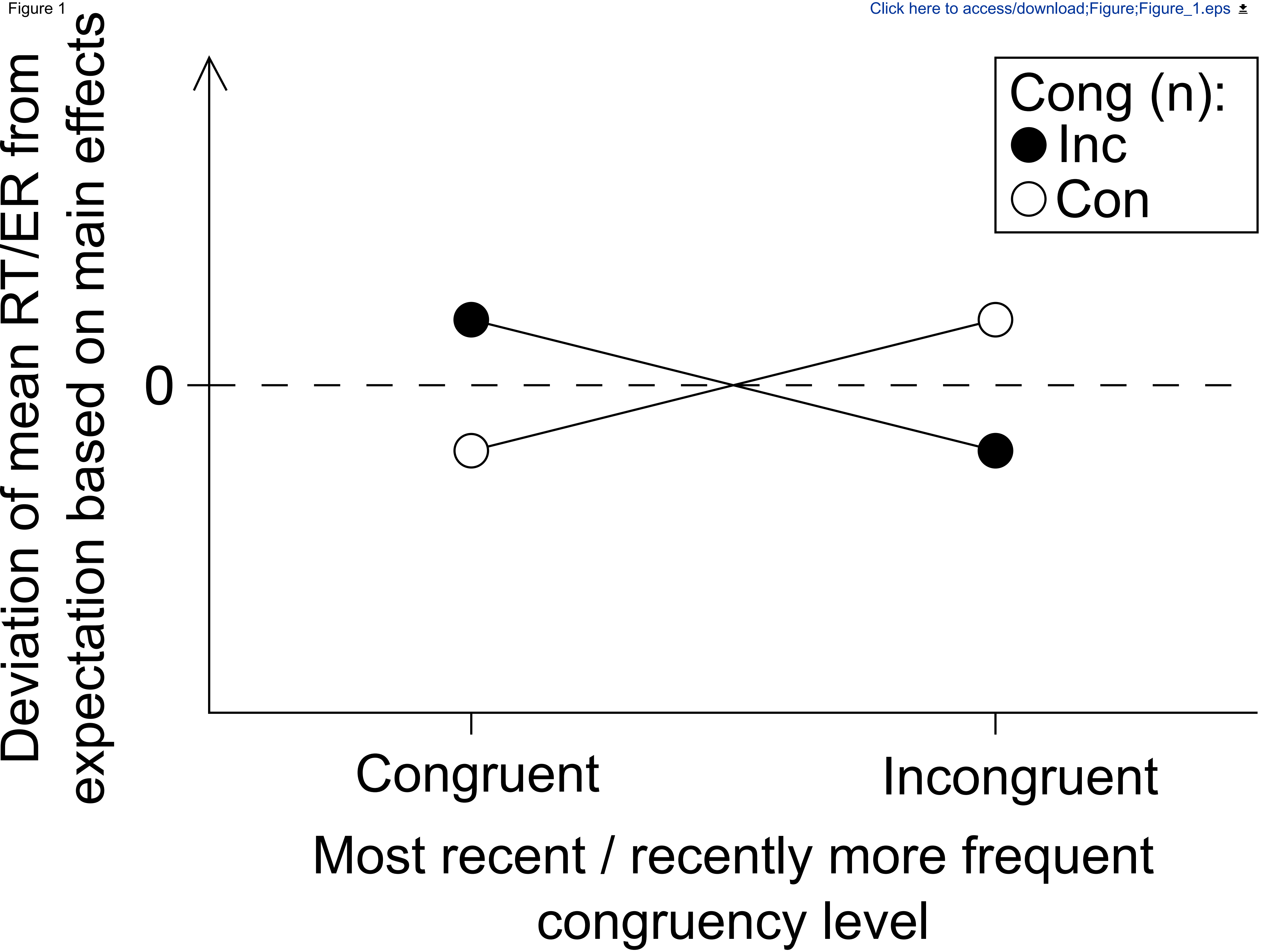
Deviation of mean RT/ER from expectation based on main effects
0
Cong (n):
Inc
Con
Congruent
Incongruent
Most recent / recently more frequent congruency level

Figure 2

The congruency levels differ in the expected value of X.

At any moment, there is one X-value to which the cognitive system is most adapted. The expected value of the parameter that represents this optimal X-vlaue is biased towards more recently and, in some cases, towards more frequently sampled X-values.

The expected value of the optimal X-value is more similar to the expected value of X associated with the current congruency level when the most recent/recently more frequent congruency level repeats in the current trial than when it does not.

The cognitive system is more adapted to a given X-value the more similar this value is to the optimal X-vlaue.

The expected value of the adaptedness of the cognitive system to the current X-value is higher when the most recent/recently more frequent congruency level repeats in the current trial than when it does not.