Biologically Inspired Cognitive Architectures xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Biologically Inspired Cognitive Architectures

journal homepage: www.elsevier.com/locate/bica

Research article

Cognitive control explains the mutual transfer between dimensional change card sorting and first-order false belief understanding: A computational modeling study on transfer of skills

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A R T I C L E I N F O

Article history:
Received 3 November 2016
Revised 1 March 2017
Accepted 1 March 2017
Available online xxxx

Keywords:
False belief reasoning
Cognitive control
Transfer of skills
Computational cognitive modeling
Cognitive development
PRIMs

A B S T R A C T

While most 3-year-olds fail both in the false belief task of theory of mind and Dimensional Change Card Sorting task of cognitive control, most 4-year-olds are able to pass these tasks. Different theories have been constructed to explain this co-development. To investigate the direction of the developmental relationship between false belief reasoning and cognitive control, Kloo and Perner (2003) trained 3-year-olds on the false belief task in one condition and on the Dimensional Change Card Sorting task in another condition. They found that there is a mutual transfer between the two tasks, meaning that training children with the Dimensional Change Card Sorting task with feedback significantly improved children's performance on the false belief task and vice versa. In this study, we aim to provide an explanation for the underlying mechanisms of this mutual transfer by constructing computational cognitive models. In contrast to the previous theories, our models show that the common element in the two tasks is two competing strategies, only one of which leads to a correct answer. Providing children with explicit feedback trains them to use a strategy of control instead of using a simpler reactive strategy. Therefore, we propose that children start to pass the false belief and cognitive control tasks once they learn to be flexible in their behavior depending on the current goal.

Introduction

There are many hilarious videos on the Internet showing 2- and 3-year-olds' failure on the *hide and seek* game and on the *marshmallow* test. On the other hand, most 4-year-olds are able to hide themselves at a place where the seeker cannot find them immediately in the *hide and seek* game. In the *marshmallow* test, most 4-year-olds are able to wait for the experimenter to come back to the room in order to get more marshmallows instead of eating one marshmallow right away. The key element of success in the *hide and seek* game is to be able to take the perspective of the seeker and the key element is in the *marshmallow* test is to have self-control.

In line with these videos, a number of correlational studies have shown that there is a relation between children's development of *theory of mind* and *cognitive control* (Henning, Spinath, & Aschersleben, 2011; Müller, Zelazo, Imrisek, 2005; Perner & Lang, 1999). Theory of mind can be defined as a general term for perspective taking by reasoning about others' representational mental states such as beliefs, desires and knowledge (Premack & Woodruff, 1978). Cognitive control, which is an important component of executive functions, can be defined as the ability to flexibly select actions in the furtherance of chosen goals, instead of inflexibly reacting to the environment while ignoring the current goal. Therefore, cognitive control requires selecting appropriate information related to the current goal for processing and inhibiting inappropriate information and responses. For example, to succeed in the *marshmallow* test, children have to inhibit the urge to eat the marshmallows right away and have to consider the current goal, which is waiting for the experimenter in order to receive a larger award. Similarly, if an agent's initial goal is to find another agent who has blue eyes and if the current goal is finding an agent who has brown shoes, then the agent should ignore the eye color of other agents and attend to the agents' shoe color.

There are three main theories about the relation between theory of mind and cognitive control.[1] The *Cognitive Complexity and Control-revised* theory (CCC-r; Zelazo, Müller, Frye, &

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[1] see (Carlson, Moses, & Hix, 1998; Leslie & Polizzi, 1998; Carlson, Moses, & Breton, 2002) for other theories that are related to the role of other components of executive functions, such as inhibition and working memory.

http://dx.doi.org/10.1016/j.bica.2017.03.001
2212-683X/

Please cite this article in press as: Arslan, B., et al. Cognitive control explains the mutual transfer between dimensional change card sorting and first-order false belief understanding: A computational modeling study on transfer of skills. *Biologically Inspired Cognitive Architectures* (2017), http://dx.doi.org/10.1016/j.bica.2017.03.001

Marcovitch, 2003) suggests that the common component between theory of mind and cognitive control is representational and also related to the activation and inhibition of rules. According to this theory, theory of mind and cognitive control tasks develop together because they both require a child to reason by using embedded *if-if* rules and both need inhibition of rules. The second theory suggests that being able to take the perspective of others improves children's cognitive control abilities, meaning that there is transfer of skills from theory of mind to cognitive control (Perner, 1998). On the contrary, the third theory suggests that the direction of transfer is from cognitive control to theory of mind (Russell, 1996 as cited in Kloo & Perner, 2003).

Although correlational studies have shown that children's theory of mind and cognitive control abilities co-develop, as reflected in the second and third theories, there is no consensus on the direction of this relationship. In order to investigate the direction of the relationship, Kloo and Perner (2003) conducted a training study with children by using a theory of mind task and a cognitive control task. We provide the details of these tasks in the following subsection. Kloo and Perner's results showed that there is a mutual transfer between cognitive control and theory of mind, meaning that training children with a cognitive control task with feedback significantly improved children's performance on a theory of mind task and vice versa.

Based on these findings, Kloo and Perner propose that the common component between the two tasks is representational. Differently from CCC-r theory, they argue that the problem 3-year-olds encounter is related to failure in redescribing an object or situation and that training children with explicit feedback helps them to understand that an object or certain situation can be described differently from different perspectives. However, Kloo and Perner stated that the exact nature of transfer effect remains to be determined.

The main goal of the current study is to provide an explanation for the nature of the mutual transfer between cognitive control and theory of mind by constructing computational cognitive models.

How does training children help transfer of skills? According to the *primitive information processing elements* theory (PRIMs; Taatgen, 2013), there are two explanations for the transfer of skills that can be modeled with the same mechanism. According to Explanation 1, skills can transfer from one task to another when those tasks have a substantial overlap in their procedural knowledge. For example, multi-column multiplication shares knowledge with multi-column addition, and many other pen-and-paper arithmetic algorithms. Acquiring this knowledge is a relatively slow process. On the other hand, Explanation 2 assumes that the knowledge for both tasks is already present in memory: it just has to be mobilized at the right moment. Suppose a particular task has two possible strategies, A and B, and suppose B is superior to A, but A is simpler. If parts of strategy B, in particular the parts that are necessary to select B, are trained in another task, it becomes more likely that strategy B will be chosen over strategy A. Our models are based on Explanation 2, because the training time in the experiment is relatively short.

In the following subsection, we first present the details of the theory of mind and cognitive control tasks that were used in Kloo and Perner's training study together with a summary of the design of the study, in order to provide a sufficient background to understand our computational cognitive models and to interpret the simulation results.

Kloo and Perner's training study

Kloo and Perner's training study (Experiment 2) tested a sample of 44 children between the ages three and four (M = 45.1 months, SD = 4.9 months) at four different sessions almost one week apart from each other: (i) pre-test, (ii) training day 1, (iii) training day 2, and (iv) post-test.

At the pre-test and post-test sessions, children were tested with a standard theory of mind task and a cognitive control task together with a verbal intelligence task.

As a theory of mind task, Kloo and Perner used a standard false belief task (FB; Wimmer & Perner, 1983), which is one of the most commonly used tasks to assess young children's development of theory of mind. During the FB task, children listened to a story

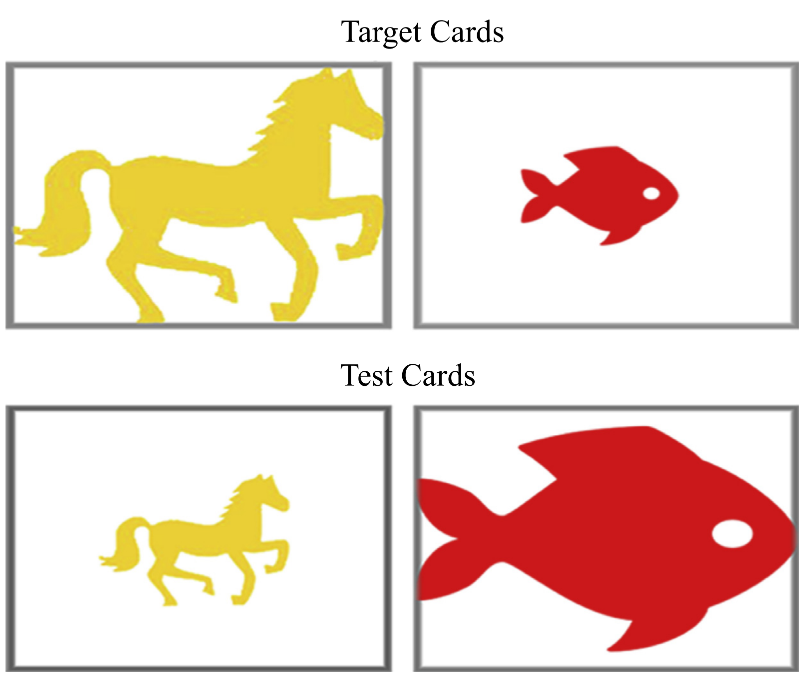

Fig. 1. An example of the DCCS task. In this example, if the game is an "Animal" game, children are expected to sort the test card "small horse" by pointing to the target card "big horse", which is on the left and to sort the test card "big fish" by pointing to the target card "small fish", which on the right. If the game is a "How-Big" game, children are expected to sort the test card "small horse" by pointing to the target card "small fish", which is on the right and to sort the test card "big fish" by pointing to the target card "big horse", which is on the left.