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Getting that thing out of the box: The contribution of self-regulation in innovation processes in human children (Homo sapiens) and a non-human primate species (Sapajus spp.)

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Abstract

The capacity to innovate is regarded as one major cause for explaining the rise of the human species. But how does innovation develop in human ontogeny? Which basic skills are needed to act innovatively? And how do we differ from other species? In our project, we use an interdisciplinary comparative approach and pursue three aims. First, we investigate innovative tool use in preschool children taking a process perspective that allows for a more detailed analysis of why young children may fail. Second, we study potential relations between the process of tool innovation and self-regulation, because self-regulation allows for flexible adaptation to different situations and might be crucial when it comes to solving a problem innovatively. Third, we compare preschool children's performance to the behavior of capuchin monkeys in an analogue paradigm. The present report describes our project in more detail and outlines the current project state as well as the next steps.

Keywords

Innovation; preschoolers; non-human primates; self-regulation

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Getting that thing out of the box: The contribution of self-regulation in innovation processes in human children (Homo sapiens) and a non-human primate species (Sapajus spp.)

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1 Introduction

Each human generation has come up with novel tools to solve problems: from Oldowan tools that were first built about 2.5 million years ago to contemporary smartphone technologies. Our capacity of being innovative is regarded as one major cause for explaining the rise of the human species. We are able to adapt flexibly and quickly to new environments. But our world becomes also more and more complex. In such a highly complex and rapidly changing world, the ability to innovate becomes increasingly important. It is seen as one of the most crucial competences in the 21st century and should be promoted. To make it possible to establish educational programs supporting creative problem-solving and innovation from early, as this is demanded even by primary school curricula (Theurer et al. 2012), it is necessary to know more about the development of innovation. Therefore, it is crucial to better understand the essential capacities necessary for showing innovative behavior, and the potential of young children to show innovation.

How does innovation develop during human ontogeny? How do we differ from other species? Which basic skills are needed to innovate? These questions remain largely unexplored until today. To help fill this gap we study innovative tool use in 3- to 5-year-old children and capuchin monkeys (a non-human primate taxon), and want to relate this capacity to self-regulation processes (i.e. executive functions, EF) as potentially relevant processes for innovation. We thus take an interdisciplinary comparative approach to investigate the cognitive prerequisites of innovation.

Only recently, developmental researchers have started to investigate tool innovation in young children (Beck et al. 2011; Cutting et al. 2014; Nielson et al. 2014; Nielson 2013; Rawlings et al. 2016; Sheridan et al. 2016). In all of these studies a task was used that had originally been developed to test New Caledonian crows' capacities to innovate. In this task, subjects need to create a hook tool enabling them to reach a reward that is placed in a small bucket inside a vertical plexiglass tube (Weir et al. 2002). Results consistently showed a remarkable difficulty of children until the age of 8 years to innovate a functional tool in this task, despite their ability to select an appropriate tool or to build a functional tool after having seen a demonstration. Task characteristics such as time and social pressure, offering only one possible solution, using a difficult manufacturing strategy, and considering only innovation success as dependent variable may provide potential explanations for children's failure to succeed.

Another reason for this difficulty may lie in the "ill-structuredness" of the problem (Cutting et al. 2011; Cutting et al. 2014). While starting and end conditions of the problem are clear, the way to the solution (i.e. the actions that are required) is unknown. Young children seem to struggle to retrieve and coordinate relevant knowledge to spontaneously execute the relevant transformations. Solving an ill-structured problem requires broadening one's attention in order to consider multiple alternatives (divergent thinking) and focusing attention to select the most promising strategy and avoid distractions (convergent thinking). Adult research shows that both, divergent and convergent thinking, are linked with executive-function capacities (EF) (Benedek et al. 2014; Benedek et al. 2012; Chermahini/Hommel 2010; Lee/Therriault 2013; Radel et al. 2015). Hence, children's poor performance in previous studies may result from children's limited self-regulation capacities, i.e. skills such as divergent, convergent thinking and EF.

Executive functions (EF) can be seen as "higher-order" self-regulation processes helping to organize thoughts and actions to enable goal-directed behavior (Blair 2016; Garon et al. 2008; Zelazo et al. 1997). Since EF undergo substantial development during childhood, especially during toddlerhood and preschool years (e.g. Carlson 2005; Garon et al. 2008), it is possible that these improvements influence the development of divergent and convergent thinking, and in the end children's innovative behavior.

None of the aforementioned studies investigated tool innovation in children in relation to divergent and convergent thinking, and executive functions. Exploring correlations between these constructs may help us to find out more about relevant cognitive process for innovation and on the long run enable us to discover possible starting points to help foster this important ability during childhood.

Another promising and complementing way to deepen our understanding about the underlying mechanisms of innovation is a comparative approach between different primate species. Where can we see parallels, where differences in innovative behavior between human children and distantly related non-human primates? Is the advantage of humans over other species regarding innovative tool-manufacture related to differences in underlying cognitive mechanisms? For several reasons, capuchin monkeys (*Sapajus* spp.) are an ideal taxon to compare with children in order to understand the phylogeny of innovation. Innovative behaviors in animals occur especially in non-human primates (Reader/Laland 2003). Besides apes, the taxon in which flexible tool use and innovative behaviors are most probable to occur is the capuchin monkey (i.b.). These New World monkeys are known to be very explorative and manipulative (Fragaszy et al. 2004). Capuchins have a relatively long juvenile period and their brain size to body mass ratio is very high compared to other primates. Wild capuchins use tools in highly adaptive and flexible ways which closely resemble those of chimpanzees (Visalberghi/Addessi 2013; Visalberghi et al. 2009). As preschoolers, capuchins show some degree of planning abilities such as the ability to organize their actions in a hierarchically correct sequence using tools differing in their properties (Sabbatini et al. 2014). Moreover, recent findings demonstrate that the opportunity to experience action–outcome contingencies in the absence of extrinsic rewards promotes capuchins' exploration and facilitates learning processes (Polizzi di Sorrentino et al. 2014).

The present project therefore compares innovative behaviors in preschool children aged 3, 4, and 5 years with those of capuchin monkeys in a tool-innovation task to learn more about possible phylogenetic precursors of innovation in humans. In addition, potentially underlying cognitive processes (i.e. divergent and convergent thinking, and EF) and their relations to innovative tool-manufacture are examined.

2 Project report (proposed goals and current status)

The project was planned as a pilot project using a correlational design. Our main goal was to design a suitable task to measure innovation outcome and process in young children and capuchin monkeys (Goal 1). With this newly developed task we wanted to collect data to evaluate innovation behavior in 3- to 5-year-old children and capuchin monkeys (Goal 2). In addition to innovation, we wanted to measure divergent thinking (in children and monkeys), as well as convergent thinking and executive functions (in 3- to 5-year-old children only) (Goal 3).

The project has been supported by initial funding from the Field of Focus 4 (Heidelberg University) from October 2014 to November 2016. Below, the projects' aims will be described, followed by reports about achieved goals, steps that still need to be done, and newly developed goals.

2.1 Proposed Goal 1: Developing appropriate methods to compare innovation between human children (3- to 5-year-olds) and capuchin monkeys

To assess innovation behavior two new tool-manufacture paradigms were developed that encourage participants to create a novel tool for obtaining a reward from a selection of materials available. Some task elements serve as distractors. In contrast to previous studies more than one solution is possible. In addition to success, latency until finding a solution is measured, as well as number and quality of solution attempts. This enables to get information not only about the outcome, but about the innovation process. A comparable task was developed for capuchin monkeys.

Innovation task A. To generate first pilot data and to test the practicability of a tool-manufacture task and necessary context conditions for innovation in young children, a pilot task was developed. This task has been conducted with 5-year-old children. It consists of two different trials in which children must solve a problem: (1) a reward must be removed from a transparent vertical tube with only one opening on top of the tube, and (2) a reward has to be obtained from a transparent horizontal tube.

In both cases, children received the same materials placed in a box with several compartments and must innovate and manufacture a functional tool. In each trial some materials serve as distractors and are not suitable to manufacture a helpful tool. Materials that are functional in one trial, are not useful in the other trial. Among the functional materials there are four different strategies that can be used to obtain a suitable tool: (a) a functional tool can be *detached* from the material box, (b) one part can be removed from an object to get a functional tool (*substract*), (c) two pieces of material can be put together (*add*), or (d) material can be deformed (*reshape*) as in the case of previous innovation studies with children (e.g. forming a hook out of a straight pipe cleaner).

In both trials, children had up to ten minutes to solve the task. The experimenter did not interact with the children during this time, but sat in the corner of the room and pretended to work on something. The order of the trials is counterbalanced over all tested children.

Innovation task B. The pilot task (Innovation task A) was modified to enable testing in 3- to 4-year-old children (the youngest age group in all previous studies on innovation in children) and capuchin monkeys. Therefore, the number of materials per trial was reduced whereas the number of trials increased.

Subjects receive no distracting materials. All materials are suitable for the problem in a given trial. Among these helpful materials children can use the same strategies as in Innovation task A (*detach*, *substract*, *add*, or *reshape* material). The reward must be removed from a transparent apparatus that has three possible entries for a tool: (1) a horizontal tube, (2) a vertical tube, and (3) a slot leading from the top of the horizontal tube to the top of the box. All three ways cross and a reward is placed in the middle of all three ways.

There are three trials. In each trial, the subject receives functional material for one way only (e.g. in one trial only tools for the use of the slot can be built, in the next only tools for the vertical tube, and in the last trial only tools for the horizontal tube). Again, in each trial the children were given up to ten minutes to find a solution. The experimenter did not interact with them but pretended to work in the corner of the room.

Since both tasks work well and enable to answer different questions concerning innovation behavior and flexibility, testing is continued with both tasks with different age groups (5-year-olds: Innovation task A; 3- to 4-year-olds: Innovation task B).

All testing is video-taped and data is coded offline by two independent coders.

2.2 Proposed Goal 2: Data collection of *N*=18 capuchin monkeys and *N*=50 3- to 5-year-old children

Study 1 (Innovation task A). So far, data of *N* = 74 5-year-old children has been collected with Innovation task A (including piloting). The current sample consists of *N* = 55 children. Innovation behavior has been coded so far on the outcome level (i.e. success/failure and duration until success). Coding of the innovation process is still ongoing.

Study 2 (Innovation task B). *N* = 78 3- and 4-year-old children and *N* = 18 capuchin monkeys have been tested with Innovation task B (including piloting). The present sample comprises *N* = 39 children (*n* = 12 3-year-olds and *n* = 27 4-year-olds) and *N* = 16 capuchin monkeys. Also in this case, innovation success and duration until success, as well as further outcome variables (e.g. materials used to succeed) have been coded, whereas the fine coding of the innovation process is still underway.

In both studies, data collection will be continued to balance gender, material arrangements and trial order (goal: balanced sample sizes of *N* = 60 each). In study 2, much more 4-year-olds than 3-year-olds have been tested so far. This is due to the fact that 3-year-old children became frustrated and refused to cooperate more often than 4-year-old. In the older age group almost no encouragement was needed.

2.3 Proposed Goal 3: Data collection of divergent and convergent thinking, and executive functions to investigate correlations between these higher-order cognitive processes and innovation.

In both studies, divergent (div-T) and convergent thinking (conv-T), as well as executive functions (EF) have been measured in children. Due to the limited duration of the project, only the divergent thinking task was conducted in addition to the innovation task in capuchin monkeys. Children in both samples (5-year-olds and 3- and 4-year-olds) have received all tasks (div-T, conv-T, and EF) after having completed the innovation task.

Divergent thinking has been assessed by using the Unusual Box Task (UBT, see Bijvoet-van den Berg/Hoicka 2014). This task had already been validated for young children to asses flexible object manipulation and exploration of new artifacts as indicators of divergent thinking (i.b.; Hoicka et al. 2016). The same task was used with capuchin monkeys. This was the first time this task was used with non-humans.

To examine convergent thinking, a planning task for children, the co-called Monkey Jumping Game (Carlson et al. 2004; Welsh 1991), an adaptation of the Tower of London task (see Bull et al. 2004; Krikorian et al. 1994) was used for 5-year-old children. Since piloting showed that this task and further adopted versions of planning tasks (e.g. the Truck Loading task, Carlson et al. 2004) were too complex for 3- to 4-year-old children, we developed a new planning task based on the Truck Loading task that proved suitable for this age group.

Executive functions are commonly divided into three components: working memory (WM), inhibition (INH), and attention shifting (SHF) (e.g. Diamond 2013; Garon et al. 2008; Miyake et al. 2000). These three components were measured by validated tasks. Simple working memory has been assessed by the Corsi-Block task (a spatial WM task, Kessels et al. 2000). For inhibition, the Day-Night task has been used (Gerstadt et al. 1994). Attention shifting has been evaluated by the Dimensional Change Card Sort task (Zelazo 2006).

All EF tasks are currently being coded by two independent persons. Performance in conv-T task has been coded by one person so far. Half of the collected data of the div-T task has been coded by one person, the other half, as well as a second coding of the div-T and conv-T tasks are underway.

2.4 Goal 4: Developing a micro-coding system to investigate the innovation process

During piloting and further data collection we realized that we needed a much more fine-grained coding system if we wanted to investigate not only whether subjects innovated, but also why some of them succeeded and other failed. Therefore, we developed a micro-coding system that allows us to classify all actions occurring during a trial in the innovation task on more than twenty dimensions (e.g. functionality such as exploration, or attempt to solve the task; or repetitions with same material, material modifications, use of distractors).

Since it is probable that higher-order cognitive processes will be associated differently with different aspects of the innovation process (e.g. WM may be correlated negatively with the number of repetitive unsuccessful solution attempts shown, div-T positively with the number of solution attempts shown), this micro-coding system may allow us to get a more precise picture of these associations. In addition it may allow us to find out more about the challenging elements during the innovation process.

We have developed a micro-coding system that can be used in both children and capuchin monkeys. Currently, micro-coding of all data is still underway, because it is very time-consuming (2.5 hours per child). A second coding of a major part of the data is extremely important to evaluate inter-coder reliability for this new coding system.

3 Preliminary results and next steps

First results concerning innovative tool-manufacture showed that almost all 5-year-olds (Bechtel-Kuehne et al. 2016a) as well as the majority of 4-year-old children were able to find a solution without help (Bechtel-Kuehne et al. 2016b). However, in both studies and in all trials most of the subjects used the easiest manufacture strategy (*detach*) in which an already functional tool must be detached from the material box.

In Innovation task B (i.b.) some children also used other ways to solve the task beyond the expected ones. First analyses of the capuchin's behaviors reveal a similar pattern. The first problem the children encountered seemed to be the most difficult one for them. This seems plausible, because the second and third problem are not as new as the first one. The child already knows that a tool can be manufactured by using the given materials and also the task setting is clear to the child.

As outlined above, further data collection is needed to balance all possible problem orders and to compare the performance of 4-year-olds to 3-year-old children. All codings must be finished before correlations among all tasks can be reliably examined. The micro-coding may offer promising opportunities of analysis in this vein.

Pilot data from the project will be used to apply for project grant from the German Research Foundation (DFG).

4 Conference contributions resulting from the project

4.1 Talks

Bechtel-Kuehne, Sabrina / Voigt, Babett / Pauen, Sabina / Visalberghi, Elisabetta / Sabbatini, Gloria (2016):Wie krieg' ich das Ding nur da raus? Innovative Werkzeugherstellung bei Kindern und Kapuzineraffen, Talk at the Young Scientist Workshop „Multidisciplinary approaches to socio-cognitive development", Westfälische Wilhelms-Universität Münster, Germany.

Bechtel-Kuehne, Sabrina / Voigt, Babett / Pauen, Sabina (2016): Creative problem solving in childhood: Do executive functions matter?, Talk at the Workshop "Executive Functions in Early Childhood – Measurement and Relations to Play and Creative Problem Solving", Field of Focus 4, Heidelberg University, Germany.

4.2 Poster

Bechtel-Kuehne, Sabrina / Voigt, Babett / Pauen, Sabina / Visalberghi, Elisabetta / Sabbatini, Gloria (2016): Getting that thing out of the box: divergent thinking and innovative tool manufacture in preschool children (Homo sapiens) and capuchin monkeys (Sapajus spp.), Poster presented at the interdisciplinary workshop „Rational Animals", Ruhr-Universität Bochum, Germany.

Bechtel-Kuehne, Sabrina / Voigt, Babett / Pauen, Sabina (2016): Getting the mouse out of the box: Preschoolers' convergent and divergent thinking and innovative tool manufacture, Poster presented at the BCCCD16, Budapest, Hungary.

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Bechtel-Kuehne, Sabrina / Voigt, Babett / Pauen, Sabina / Visalberghi, Elisabetta / Sabbatini, Gloria (2016b): Getting that thing out of the box: divergent thinking and innovative tool manufacture in preschool children (Homo sapiens) and capuchin monkeys (Sapajus spp.), Poster presented at the Interdisciplinary Workshop "Rational Animals" Ruhr-University, Bochum, Germany.

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