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Preschool children's use of perceptual-motor knowledge and hierarchical representational skills for tool making

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A R T I C L E I N F O

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A B S T R A C T

Although other animals can make simple tools, the expanded and complex material culture of humans is unprecedented in the animal kingdom. Tool making is a slow and late-developing ability in humans, and preschool children find making tools to solve problems very challenging. This difficulty in tool making might be related to the lack of familiarity with the tools and may be overcome by children's long term perceptual-motor knowledge. Thus, in this study, the effect of tool familiarity on tool making was investigated with a task in which 5-to-6-year-old children ($n = 75$) were asked to remove a small bucket from a vertical tube. The results show that children are better at tool making if the tool and its relation to the task are familiar to them (e.g., soda straw). Moreover, we also replicated the finding that hierarchical complexity and tool making were significantly related. Results are discussed in light of the ideomotor approach.

1. Introduction

Tools play an important role in human culture, and children develop inside this tool-rich environment. Beginning in their early months, infants are able to use tools (such as a spoon) with a specific aim (Connolly & Dalgleish, 1989), or to reach a target through seeing the complementary relation between the tool and the target, such as fetching a toy with a stick, especially after the first year of age (Bates, Carlson-Luden, & Bretherton, 1980; McCarty, Clifton, & Collard, 1999). Although tool use is an early developing skill, preschool children are poor at multi-step[2] tool-related tasks, such as tool innovation and tool manufacture (Cutting, Apperly, & Beck, 2011; Nielsen, 2013; but see Reindl, 2017), which is surprising especially considering that similar tool-related problems can be solved by other animals (Auersperg, Borasinski, Laumer, & Kacelnik, 2016; Uomini & Hunt, 2017; Weir, Chappell, & Kacelnik, 2002). In other words, preschool children have difficulty in making novel tools spontaneously (tool innovation, multi-step tool-related behavior) to solve some problems until the end of their seventh year (Beck, Apperly, Chappell, Guthrie, & Cutting, 2011), unless children are given longer times and more than one manufacturing method to solve the problem (Voigt, Pauen, & Bechtel-Kuehne, 2019) or the problem is facilitated by some triggering of their perceptual-motor repertoire related to the tools (Neldner, Mushin, & Nielsen, 2017; Whalley, Cutting, & Beck, 2017). Beyond that, before the age of five, they also have difficulty in making tools even after observing action information socially regarding the steps necessary to create the target tool, namely tool manufacture (Chappell, Cutting, Apperly, & Beck, 2013; Gönül, Takmaz, Hohenberger, & Corballis, 2018). Even though children can find innovative solutions to *single-step* tool use tasks in which they do not intentionally need to change the shape of the tool (Reindl, Beck, Apperly, & Tennie, 2016), tool making to solve a multi-step task is challenging for preschool children. Their immaturity in tool making might be related to their perceptual-motor tool and task knowledge (e.g., familiarity) and also developing cognitive abilities

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[2] In broad terms, here we define (i) single-step tool-related behavior if the subject needs to use a tool as-it-is (or just detach a tool from a surface without further modification on it) to reach the goal in a single (or almost single) step, and (ii) multi-step tool-related behavior, if further manipulations are made on the tool, or a set of tools with distinct actions, are required to get the target (Goldenberg, Hartmann-Schmid, Sürer, Daumüller, & Hermsdölrfer, 2007; Hunt & Gray, 2003; Shumaker, Walkup, & Beck, 2011).

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(Rawlings & Legare, 2021). Considering their inexperience and developing representational abilities, without prior long term social and perceptual-motor information about the tools, tool making might be challenging for preschool children (Legare & Nielsen, 2015). Experience with the tools might help children to construct the relation between movements with the tools and their possible sensory effects, and this action-effect coupling might help facilitate voluntary action processes with concurrent problems even when children's representational capacities are limited (Hommel, 2013; Paulus, 2012, 2014). Thus, in this study, we focus on the possible effect of tool familiarity and the role of hierarchical representation on children's tool making process.

One of the tasks that is extensively used to measure children's tool making ability is the hook task (Beck et al., 2011). This task, in which children are required to bend a pipe cleaner and retrieve a bucket from a long vertical tube to obtain a sticker, has proven to be very challenging for preschool children (Beck et al., 2011). Some children could solve it only after observing how to manipulate the tool properly or seeing the ready-made tool (tool manufacture); that is, they relied on social learning (Cutting et al., 2011; Frick, Clément, & Gruber, 2017). These results might indicate the crucial role of social learning in children's tool making, as a number of authors have suggested (see Buttelmann, Carpenter, Call, & Tomasello, 2008; Price et al., 2010; Tennie, Call, & Tomasello, 2009). Nevertheless, beyond social learning, recent studies and theoretical approaches also considered the facilitatory role of sociocultural information (Neldner et al., 2019), motor diversity (Griffin & Guez, 2014), and perceptual information (Neldner et al., 2017) regarding the materials in tool making and tool use. It was also recently shown that increasing the time that children engage in the hook task increases their tool making performance (Voigt et al., 2019).

1.1. Tool making: familiarity, anticipation, and action-effect relation

Studies have clearly shown that prior experience and familiarity are crucial factors in tool use in infants and children (Barrett, Davis, & Needham, 2007; Bechtel, Jeschonek, & Pauen, 2013; Gardiner, Bjorklund, Greif, & Gray, 2012), and haptic exploration of the materials facilitates anticipation of tool-use in 5-year-old children (Kalagher, 2015). Recent studies indicate that some contextual factors impinge upon tool making, e.g., the type of tool and the tool-making action or the time limit for the task (Breyel & Pauen, 2021; Voigt et al., 2019). Moreover, prior experience with the properties of a tool facilitates novel tool making, e.g., seeing a hooked pipe cleaner before solving the hook task or haptic exploration of the particular properties of the pipe cleaner (Cutting, Apperly, Chappell, & Beck, 2014; Whalley et al., 2017), and making the affordance of the tool clearer eases tool making in preschool children (Neldner et al., 2017). These studies suggest a role for the affordance and effect learning in tool making and tool use, in which perception of tools triggers action, by anticipating the possible effects of the tool on the target, in children and infants (Paulus, 2012). For instance, in the hook task, children can anticipate the immediate relation between the tool and the goal (Chappell et al., 2013). After four years of age, they can select functional tools (e.g., more rigid tools) over non-functional ones before inserting the tool(s) into the tube (Beck et al., 2011; Nielsen, Tomaselli, Mushin, & Whiten, 2014). If young children are given both straight and hooked pipe cleaners, most of them select the hooked one (Beck et al., 2011). In other words, their difficulty in the hook task is not realizing the causal relation between the tool and the goal, or anticipating the effects of their actions, but making a hook with the pipe cleaner.

Beyond anticipating future actions, children may also imagine possible divergent solutions in the hook task. For example, observational results from previous studies demonstrate that some children can directly say or gesticulate the ideational solution for the hook task in some rare cases (Cutting, 2013; Gönül et al., 2018). They may draw a hook shape in the air or tell the experimenter that a hooked cane (or a soda straw) would work, although they may not implement these ideational solutions into the tool at hand. These examples are in line with the ideomotor approach that aims "to explain how the cognitive representation of an intended action – an 'idea' – can move one's body in such a way that the action is actually carried out, that is, results in motor activity" (Hommel, 2013, p. 114). The ideomotor approach emphasizes that actions are represented in terms of their possible effects, and there is a bidirectional relation between them. In goal-directed actions, bidirectional relations between the body movements and their sensory effects are gained by long term experience (Elsner & Hommel, 2001; Hommel, 2013). The possible relation between action anticipation and tool use from an ideomotor perspective has been argued both on empirical and theoretical grounds (see Badets, Koch, & Philipp, 2016; Badets & Osiurak, 2017). If children could produce ideational solutions for the hook task, and if the difficulty they are experiencing is in making the tool at hand, then children may be better at solving the hook task if their perceptual-motor repertoire triggers the solution.

In the literature on the evolution and development of tool-related behaviours, it is indicated that preschool children's physical understanding to use and make tools for multi-step problems may be comparable to that of chimpanzees, New Caledonian crows, and Goffin's cockatoos (Clayton, 2015; Pepperberg, 2019). In a recent study, Lamon et al. (2018) demonstrated that chimpanzee novel tool modification mostly consists of functional improvements of known techniques and materials. Considering the similarity between preschool children's and chimpanzees' physical understanding (Clayton, 2015), preschool children might also need perceptual-motor knowledge in tool making. In line with this reasoning, it might be easier for children to solve the hook task with a familiar tool such as a bendable soda straw. For instance, as children have the perceptual-motor knowledge of the relation between bendable straws and beverage receptacles, it may be easier for them to use a soda straw to solve the hook task although they need to use the tool in a different way. That is, it may be easier for children to construe relations between the elements of the task and required actions based on a goal with the soda straw rather than some other functional tools.

1.2. Hierarchical structuring and tool making

During tool making, children and adults construct the relation between tools and the task based on the goal (Stout, 2011). This goal-directed action planning might require representing the events and elements in a hierarchical fashion (Maffongelli, D'Ausilio, Fadiga, & Daum, 2019; Miller, Galanter, & Pribram, 1960; Uomini & Meyer, 2013). Hierarchical representation ability is considered to be one of the most crucial factors in making tools (Stout, 2011). Greenfield (1991) argues that managing hierarchically complex manual combinations might have triggered technical understanding in tool use and object construction during evolution. More generally, it is claimed that one of the distinctive capacities of human cognition is the ability to form higher-level representations necessary for imitating hierarchically structured patterns and actions (Byrne & Russon, 1998; Greenfield, 1991). Children who are better at constructing hierarchically complex shapes were found to be good at constructing the hierarchical relation between the tools, task, and social information in the hook task (Gönül et al., 2018). Greenfield and Schneider (1977) showed that children become better at making hierarchically complex tree-like constructions with small sticks after age five.

Constructing complex hierarchical representations might be crucial for both hierarchical structuring, in which sequencing actions according to hierarchical shapes is required (Greenfield, 1991; Greenfield & Schneider, 1977), and tool manufacture and innovation in which "increasing hierarchical complexity, in turn, favours the emergence of technical innovations by providing greater latitude for the recombination of action elements and sub-assemblies" (Stout, 2011, p. 1055). Beyond constructing action and tool elements, hierarchical representation might also facilitate social learning (Byrne & Russon, 1998). For instance, children can overcome complex tool use problems if their level of information is systematically increased, for example by watching an older person demonstrating complex action patterns with the tool in a hierarchically organized way (Flynn & Whiten, 2008).

1.3. This study

In this study, first, we aimed to investigate the effect of tool and task relation familiarity on tool making in children. Second, we also aim to explore the role of hierarchical representation in tool making.

We hypothesized that preschool children's tool making might be facilitated by their tool familiarity and by their perceptual-motor knowledge (tool-task relation familiarity). Thus, we specifically predicted that children would be better at tool making with a bendable soda straw (familiar tool, and familiar tool-task relation) in the hook task compared to other tools, namely wooden sticks (familiar tool, but unfamiliar tool-task relation) and a pipe cleaner (novel tool, unfamiliar tool-task relation). Note that bendable soda straws are very common in the target culture in which we collected the sample (Turkey). Considering the affordance of a bendable straw, children can anticipate that bending the straw results in a curvature. This curvature is functional to the same extent – but in different ways – for drinking and hooking. Most importantly, the soda straw is used in an upright position for drinking and the mouth contacts it at its upper opening. However, it needs to be turned upside-down for hooking and manipulated with the hand. This change in direction (upside, down) and effectors (mouth, hand) is part of the newly constructed action-effect relation. Thus, considering the action-effect relation in more detail, there are three sequential enabling actions each with their particular action effects in the hook task: (1) bending the soda straw resulting in a functional hook shape, (2) turning the soda straw such that the hook is at the lower end of the straw,[3] and (3) inserting the hook into the jar, hooking the little bucket with the sticker inside, and finally pulling it up. While the first action effect – bending – is familiar to children, the second and third ones – turning the straw and using it as a hook – are novel and therefore require some cognitive effort. Although Whalley et al. (2017) and Neldner et al. (2017) investigated the effect of prior experience on tool making, their results are based on the immediate effect of perceptual learning. However, our study focuses on the effect of children's long term perceptual-motor knowledge on tool making. Similar to the arguments in the evolution of material culture (see Gibson, 1993), we evaluated tool making as a process ranging from individual learning (tool innovation) to social learning (tool manufacture). To test the generalizability of our first hypothesis in a different cultural context, we also compared our results with an unpublished study that used exactly the same design and two of the tools that were used in this study (Cutting, 2013; with permission from the author).

Secondly, we also aim to test the generalizability of the findings of Gönül et al. (2018) with regards to the relation between hierarchical complexity and tool making, for two main reasons. First, their results were based on only one type of tool, the pipe cleaner, which is a very novel tool in children's cultural context, in a rather young age group. Gönül et al. (2018) showed that 50- to 67-months-old children's tool manufacturing performance was positively predicted by the complexity of their hierarchical representations measured by the tree task. In this study, we tested the tool-task relation with different tools and in an older age group (59 to 81 months old) of primary school children. Moreover, their design focused only on tool making after a process of social demonstration. However, as Greenfield and Schneider (1977) indicate, the construction of hierarchical patterns develops especially after the fifth year of age, and 5-to-6-years of age seems to be a transition period for different types of tool making behavior (see Beck et al., 2011; Cutting et al., 2014). Thus, it would make sense to test this relation with different tool making behaviours in 5-to-6-year-old children.

2. Method

2.1. Participants

The final sample included 75 children from Ankara and Muğla (Turkey), all attending various kindergartens. For the sample size rationale, see Supplementary Material 1. They were assigned to one of the following groups according to the material made available: bendable straw (n = 25, 10 girls, M_{age} = 68 months 1 week, *Range* = 63-76 months), wooden sticks (n = 27, 11 girls, M_{age} = 68 months 2 weeks, *Range* = 60-81 months), and pipe cleaner (n = 23, 11 girls, M_{age} = 68 months 1 week, *Range* = 59-79 months). Age-in-months was not significantly different between groups, $F(2, 74) = 0.534$, $p = .589$, and genders, $t(73) = 0.927$, $p = .357$. Two additional children who were able to solve the hook task without making a functional tool were excluded. Participants were tested in a quiet room in their kindergarten. Before the experiment, the kindergarten teachers asked children not to tell other children about the game in order to make the game a surprise for everyone. The data were collected in parallel with the study of Gönül, Hohenberger, Corballis, and Henderson (2019). Note that the wooden sticks group (see below) was the same in this study and in the study of Gönül et al. (2019). The study was approved by the ethics committee of Middle East Technical University. Informed consent was taken from legal guardians. Informed consent was taken from the participants for the pilot testing with adults (see Supplementary Material 1).

2.2. Materials, experimental design, and procedure

2.2.1. Hook task

For the evaluation of the tool making abilities, the hook task (see Beck, Williams, Cutting, Apperly, & Chappell, 2016; Cutting et al., 2011) was used. For this task, a tall transparent plastic tube (15 or 22 cm according to the size of the tool) with an opening at the top was used. The opening was partially closed by a 6-cm diameter cardboard circle with a 4-cm diameter internal opening to prevent getting the bucket at the bottom of the tube out without a functional tool (a hook). This tube was vertically stuck onto a square wooden board with 30 cm edges. Inside, at the bottom of this tube, there was a small bucket of 1 cm depth, 3.2 cm diameter and a 9.5 cm long handle (see Fig. 1). Inside the bucket, there was a small sticker as a reward.

Four types of tools were used in the study: a bendable straw (length

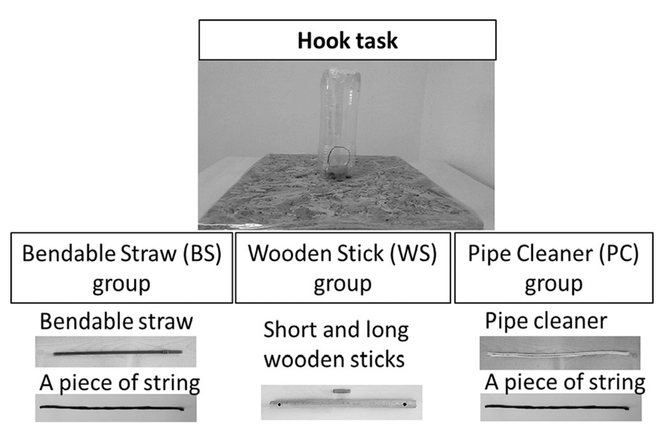

Fig. 1. The hook task, tools and experimental groups.

[3] Sub-actions (1) and (2) can be carried out in alternate order as well, i.e., the straw can first be turned upside-down and then the hook can be formed. The fact that the straw must also be turned upside-down may, at first sight, appear as hindering the finding of the solution. At second sight, however, it may also be beneficial with respect to discriminating the different usage of the straw for a different purpose. Hence, the turning action may help overcome functional fixedness.

= 22 cm), a long wooden stick (length = 27.5 cm, diameter = 1.5 cm) with two holes (diameter = 0.7 cm) that were 1.5 cm from both endpoints, a pipe cleaner (length = 29 cm), and a piece of string (29 cm). One side of the straw (soda straw) had a 1 cm flexible and bendable part that was 2 cm below the endpoint. The long wooden stick was presented together with a 3.5 cm short wooden stick. The surface of the short stick was knurled (around 0.1 cm), which made the short stick perfectly fit into either of the holes in the long stick without much effort (see Fig. 1).

There were three groups (between-subjects) of children according to the main tools they received: bendable straw group, wooden sticks, and pipe cleaner. A piece of string was also given only to the pipe cleaner and bendable straw groups to present them with a similar (but non-functional) tool of less rigidity. A piece of string was not used in the wooden sticks group to keep the number of tools the same in each group.

The experimenter showed the *hook task* and said "*Do you see the sticker inside? If you get the sticker, you can have it*". Then, the tools were brought out by the experimenter and the experimenter said, "*You can use these ones*". Participants had one minute to solve the task (Phase 1: tool innovation phase). If the children could not solve the task in the first phase, the experimenter encouraged them to put the materials down on the board and then showed a ready-made functional tool for around 2 s (a hooked tool, i.e., a bent straw, the combined long and short wood sticks, and a bent pipe cleaner, respectively). Again, the children were encouraged to solve the task and were given 30 s (Phase 2: end-state tool demonstration phase). If they still could not solve the task, the experimenter demonstrated how to make a hook with the tool(s) and the children were given 30 s (Phase 3: action demonstration condition). Note that the experimenter did not show how to solve the task in any of the phases. All the children got a sticker at the end of the study, regardless of their performance in the task. Based on the results of a preparatory pilot study, children in the hook task got 25-30 s warm-up (they explored the long and the short stick). Moreover, we conducted a preparatory study with adults mainly to evaluate whether the tools were familiar in the cultural context from an adult perspective. Familiarity of the tools from an adult perspective was as follows, from most to least familiar: soda straw, wooden sticks, and pipe cleaner. Additionally, adults evaluated the pipe cleaner as the most functional one to solve the hook task, and the soda straw as the least functional one. For further information about these pilot testing studies, see Supplementary Material 1.

2.2.2. Hierarchical structuring task

Following Gönül et al. (2018), in this task, children were asked to engage in a simplified version of the *hierarchical structuring task* (Greenfield & Schneider, 1977), in which they needed to copy a tree-like shape with sticks. In these studies, the term "hierarchical complexity" is operationalized based on graph theory, which is also adopted in this study. An A4-sized photo of the end-state of the tree-like shape was shown during this task (see Fig. 2, target shape). Children were given 10 pieces of 4-cm long sticks (similar to matchsticks) and asked to form the same shape demonstrated in the photo on the table. This task is used to measure the hierarchical representation abilities of children.

Beyond these two tasks, children in the wooden sticks group got another predictor task (divergent thinking task) after the hook task and the hierarchical structuring task for the purpose of another study (also see 'participants' Section 2.1). However, results of the divergent thinking task are not reported in this study (see Gönül et al., 2019). As the divergent thinking task was given as the last task, this task could not have impinged upon the results of the hook task and the hierarchical structuring task.

2.3. Coding, data analyses and data reduction

In the hook task, the success criterion for tool making was to create a hook and raise the bucket with the hook. Children could get descending ordinal scores from 4 to 1 according to their success in one of the three phases or in none of the phases (Phase 1, Phase 2, Phase 3, none of the phases), respectively. There are two reasons why we relied on descending scores rather than having three different dependent variables of tool making success. First, it allows us to include the whole sample size into one model, thus increasing its power. Second, tool making might be a cumulative learning process ranging from individual learning (success in Phase 1: tool innovation condition) to social learning (success in Phase 2 or Phase 3, end-state condition, or action demonstration condition, respectively). As children gained more information about the hook task over the phases in our experimental design, this facilitatory effect of learning could be represented by descending scores.

Following Gönül et al. (2018), the hierarchical complexity measure was computed based on graph theory (Greenfield & Schneider, 1977) in which a score was given to each node according to the number of units in each node, and then summed up. Mathematical graph theory explores graphs, which consist of points and lines, and their relations (Wilson, 1996). Nodes, on the other side, are the junction of more than one line, which may have different degrees (e.g., join of the two lines are degree 2). In this study, graph theory allows us to find an appropriate way to measure children's competence in creating tree diagrams, as it is possible to consider both the number of sticks that were used and also the number of nodes that were created in the same calculation. The hierarchical complexity measure is calculated based on the sum of the degrees squared (see Fig. 2, right shape), by which complex nodes get larger weight (Greenfield & Schneider, 1977). In Greenfield and Schneider (1977), the scores that can be received from nodes with one, two and three units are 1, 2^2, 3^2, respectively. The only difference to our measure concerned the middle junction, for which children could obtain a score of 3^3 (see Fig. 2) and not a score of 3^2, as in Greenfield and Schneider (1977) since the triple node had to be created in the middle of a stick, instead of joining three sticks at one node. This difference was due to the fact that we used a smaller, structurally somewhat different shape than Greenfield and Schneider (1977). Please see 'Supplementary

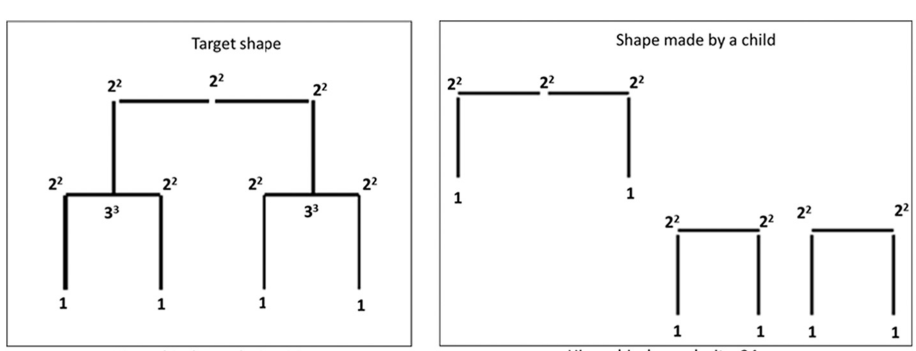

Fig. 2. Schematic drawing of the target (left) and an example (right) shape of the hierarchical structuring task and complexity scores for each node.

Material 2' for examples of hierarchical structures made by children.

As the tool making scores were ordinal, we used ordinal regression with a Generalized Linear Model (GLM) (McCullagh & Nelder, 1983). For further details about the ordinal regression, please see Supplementary Material 1. Based on our first hypothesis, we selected the bendable straw group as the comparison group.

Exploratory (or preliminary) tests before the main GLM models were calculated. In these tests, we looked at the possible effect of gender and age-in-months. The data of the hierarchical structuring task of one child in the pipe cleaner group were excluded since she refused to do the task. We further compared our results with an unpublished study (see Cutting, 2013, Chapter 3, p. 69), which used the wooden stick ($n = 43$) and pipe cleaner ($n = 45$) with the hook task with 4-to-7-years-old children (with the permission from Nicola Cutting). This would help us to investigate how robust our findings are, and also see the generalizability of the findings in a different culture (for a detailed description, see Supplementary Material 1). Note that they also used another task and also other tools, which, however, are not included in our analyses. Please see Supplementary Material 1 for the details of this comparison. Data were analyzed using SPSS-25. The data can be found in the following Open Science Framework link: https://osf.io/g2peh/?view_only=9798d959ff8e4e91aed23e0037191cf9

3. Results

3.1. Preliminary analyses

Children could get descending ordinal scores from 4 to 1 for tool making success. A preliminary analysis in terms of gender showed that boys obtained significantly higher tool-making scores ($Mdn = 42.89$) than girls ($Mdn = 31.06$), $U = 467$, $p = .016$, $r = -0.279$, in the hook task. Further exact tests revealed that while there was no gender difference in the pipe-cleaner group ($U = 59.5$, $p = .695$), and bendable-straw group ($U = 47.5$, $p = .129$), boys were significantly better in tool making in the wooden-sticks group ($U = 45$, $p = .046$, $r = -0.40$). Hierarchical complexity results were not significantly different between genders, $U = 545$, $p = .099$, and groups, $H(2) = 2.167$, $p = .338$.

There was a significant positive Spearman correlation (two-tailed) between age-in-months and hierarchical complexity, $r = 0.344$, $p = .003$. Furthermore, age-in-months and tool-making scores were also significantly and positively correlated (Spearman's *rho*, two-tailed), $r_s = 0.295$, $p = .003$. However, it should be noted that there was a ceiling effect and there were many influential cases in hierarchical complexity scores. We did not include the gender effect in the following models as we do not have a specific hypothesis about the effect and also considering that the effect was significant only in one group (wooden sticks). Results were very similar when the effect of gender was included. See Supplementary Material 3 for all possible models with the main effects, and the interactions, including the effect of gender.

3.2. Confirmatory analyses

Our predictors were group (factor) and hierarchical structuring (covariate). A GLM with a multinomial (ordinal) distribution and complementary log-log link function was calculated to predict descending (from 4 to 3, 2, 1) tool-making scores. The overall model was significant compared to the intercept only model, $LR\ |^2 (3) = 15.654$, $p = .001$. Results demonstrated that the group, $LR\ |^2 (2) = 6.638$, $p = .036$, and the covariate hierarchical complexity, $LR\ |^2 (1) = 8.772$, $p = .003$, were significantly related to tool making. The order of the tool making scores were descending (see Figs. 3 and 4); thus, the beta values in parameter estimates should be interpreted accordingly. Parameter estimates indicated that children in the bendable straw group got significantly higher scores compared to the children in the wooden sticks group, $\beta = 0.824$, $SE = 0.354$, *95% Profile Likelihood CI* [0.198, 1.460], $Wald\ |^2 = 5.428$, $p = .020$. There was no significant difference between bendable straw and

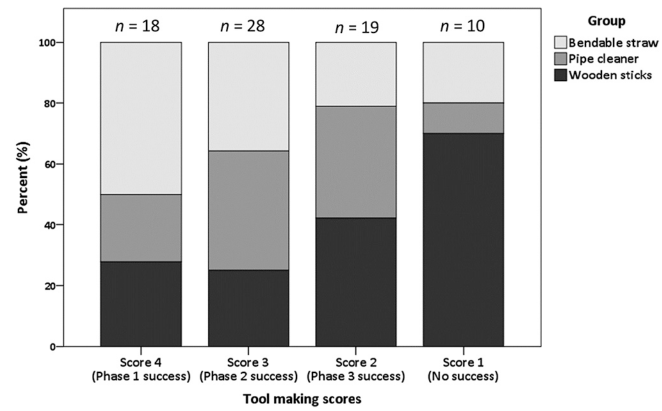

Fig. 3. Percentage of tool making scores in each group. Bars represent the total percentage of the tool-making score according to groups.

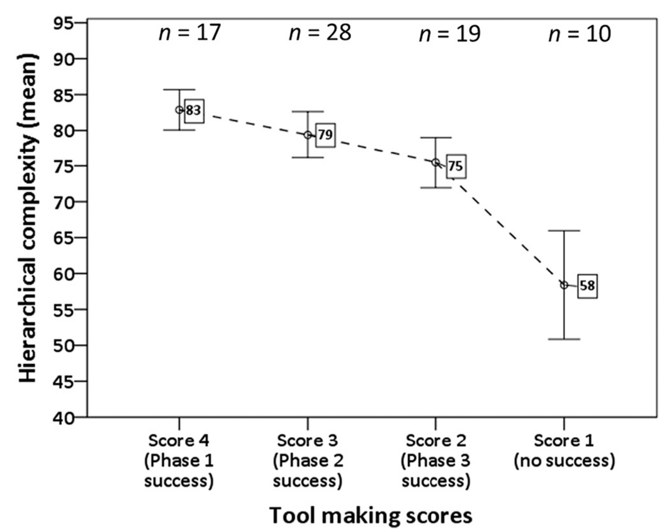

Fig. 4. The relation between tool making scores and hierarchical complexity. Error bars represent ± 1 Standard Error.

pipe cleaner groups, $p = .152$ (Fig. 3, and Table 1). A follow-up model to compare pipe cleaner and wooden sticks groups (wooden sticks as the comparison group) indicated that the difference between these two groups was not significant, $\beta = -0.327$, $SE = 0.303$, *95% Profile Likelihood CI* [−0.997, −0.198], $Wald\ |^2 = 1.164$, $p = .281$. Fig. 3 shows the

Table 1
The success of tool making in phases between groups. Percentages for success in each phase and in each group are shown in parentheses. Results of the current study and the study by Cutting (2013) are shown.

Study	Groups	N	Success			
			Successful			No success (Score 1)
			Phase 1 (Score 4)	Phase 2 (Score 3)	Phase 3 (Score 2)	
Current study: 5-to-6-year-olds	Bendable straw	25	9 (36%)	10 (40%)	4 (16%)	2 (8%)
	Pipe cleaner	23	4 (18%)	11 (48%)	7 (30%)	1 (%4)
	Wooden sticks	27	5 (18%)	7 (26%)	8 (30%)	7 (26%)
Cutting (2013): 4-to-7-year-olds	Pipe cleaner	45	5 (11%)	18 (40%)	11 (24.5%)	11 (24.5%)
	Wooden sticks	43	5 (12%)	6 (14%)	17 (39%)	15 (35%)

percentage of children from the various groups (bendable straw, pipe cleaner, wooden sticks) who passed the task in Phases 1-4, e.g., children who passed the task in Phase 1 (Score 4) consisted mostly of children from the bendable straw group but children who did not pass the task (Score 1, No success) consisted mostly of children from the wooden stick group. Hierarchical complexity and tool-making scores decreased together, β = -0.016, *SE* = 0.005, *95% Profile Likelihood CI* [-0.025, -0.005], *Wald* $|^2$ = 8.609, p = .004. (Fig. 4). As Fig. 4 shows, there is a moderate decline in hierarchical complexity scores from Phase 1-3, however, a steep decline between Phase 3 and No success, indicating that children who did not pass the task had particularly low hierarchical complexity scores as compared to children who succeeded in any of the other phases. Considering the statistical suggestions of Simmons, Nelson, and Simonsohn (2011) indicating that those models including a covariate should also be given without the covariate, we also calculated a follow-up model without the covariate hierarchical complexity. Results indicated that the group was still a significant predictor of tool making scores, *LR* $|^2$ (2) = 7.071, p = .029.

As a further follow-up analysis, we checked the relation between tool-making scores and hierarchical complexity, after controlling for age-in-months, as age-in-months and hierarchical complexity were correlated. Non-parametric Spearman's partial rank correlation results indicated that there was still a partial correlation between tool making scores and hierarchical complexity after controlling for age in months, r_s = 0.281, p = .016, indicating that hierarchical complexity had a true, distinct relation with tool making, irrespective of children's age.

We also compared our data with those of Cutting (2013, unpublished manuscript). Please see Table 1 and Fig. 5 for the descriptive results. Their study also included wooden sticks and pipe cleaner groups with the hook tasks, and with the same design. Combined results indicated that children got significantly lower tool making results with the wooden sticks compared to pipe cleaners in both cultures (UK and Turkey). Please see Supplementary Material 1 for further details.

4. Discussion

The main aim of the study was to assess the effects of tool familiarity on success in tool making in 5-to-6-year-old children. Results indicated that children were more successful in tool making when the tool and the relation between the tool and the task were familiar (bendable soda straw) compared to wooden sticks, which was familiar but not related to the hook task at the perceptual-motor level. We also replicated the finding that hierarchical complexity and tool-making scores were significantly related. Moreover, in line with earlier findings, we demonstrated that tool innovation (phase 1 tool making) was very rare in preschool children. We compared our results with a study using the same design and two of the tools (wooden sticks and pipe cleaner) in the current study. Results between these two studies were in parallel, which shows the generalizability of our findings and claims to another culture, at least regarding the relation between wooden stick and pipe cleaner groups. Even though we evaluated the familiarity aspects of the tools based on adults' evaluations and assumed that children's familiarity with the tools would be similar to that of the adults with these tools considering the common knowledge and observations, we believe that this study will pave the way to even more systematic investigations into the effect of perceptual-motor factors on tool making in children.

Results showed that preschool children have great difficulty in tool innovation in all groups, but their tool making can be partially affected by long term perceptual-motor knowledge (tool-task familiarity and tool familiarity), social learning, and hierarchical structuring abilities. Children were better at tool making when using a highly familiar tool for the task, such as the bendable soda straw, compared to the wooden sticks (familiar tool but not related to the task). Since children have the knowledge of the relation between a straw and a bottle (familiar tool and tool-task relation), their tool making might have been facilitated by the perceptual-motor system in this case, allowing them to make the tool in the earlier phases of the task. As children are familiar with the action effects of the soda straw and its properties, they might have reasoned about the relation between the soda straw and the tube, although they needed to use the soda straw as a different means – to get the bucket out of the tube. We argue that these results are in line with the ideomotor approach. Considering the literature demonstrating that actions are represented in terms of their anticipated effects or, in other words, perception of outcomes and action planning are commonly represented (for a review, see Hommel, Müsseler, Aschersleben, & Prinz, 2001), it might be claimed that children can anticipate the very relation between the perceptual properties of the tool and the task elements with a familiar tool, when the tool and the task are perceptually and motorically related. Note that mere familiarity with the tool is not enough for children. Although wooden sticks are also familiar (from the adult perspective in the cultural context), it should be noted that children are not exposed to a direct perceptual-motor relation between the task and the wooden sticks.

4.1. Familiar tool-task relation and tool making

We argue that children's long term perceptual-motor experience with the tools in the experiment affects their technical understanding of the

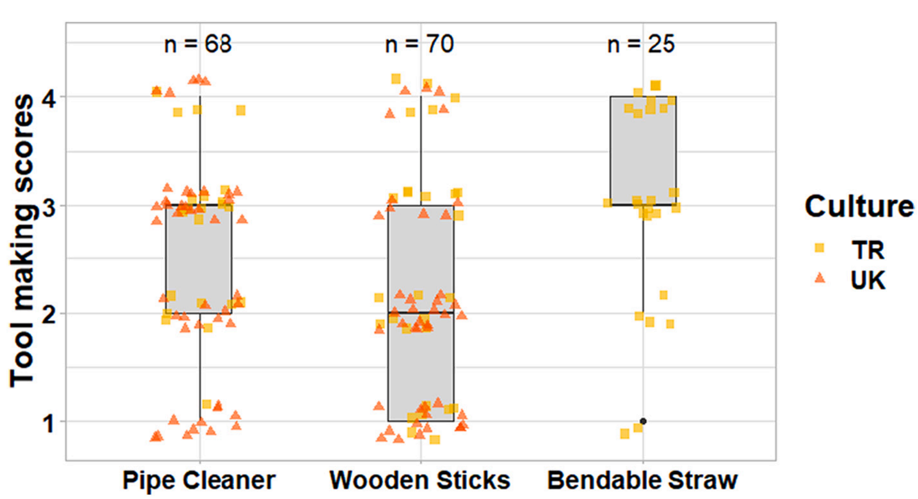

Fig. 5. Box plots with the data points between the three tool groups. The data from the current study and Cutting (2013) were collapsed for this plot. Two outliers (values between 1.5 and 3 times below the IQ range) are the data points closer to the black circle and both are in the bendable straw group.

hook task. In the bendable straw group, the (bending) action was familiar to children, as well as the relation between the straw and some receptacle, namely inserting the straw and getting something out of the receptacle. In an attempt at distinguishing the role of the anticipated action effect and the affordance of the tool, we may ask whether it was the action effect or the mere affordance properties of the soda straw that increased children's tool making success. In this respect, it should be noted that the resulting shape of a bent straw has different functionality in the original use for drinking as compared to the novel use as a hook, thus, the means-end relations are different in both cases. Consider that the resulting shape of the straw when being used for drinking and hooking is somewhat different and needs to be fine-tuned, requiring fine motor skills. For drinking, one needs a 90° or wider angle; however, for hooking, a smaller angle is more amenable. The bendable part of the soda straw must be rounded in order not to risk losing the bucket, which may slip off if the angle is too large. Observational results showed that most of the children were making the angle smaller, indeed, to get the bucket out.

From the ideomotor point of view, the action effect of the bent soda straw might be sucking some fluid out of some receptacle. The same action, bending, however, can also be used to reach a different action goal, i.e., the relation between action and effect is one-to-many. This is the case when the child bends the soda straw in order to hook up the bucket in the jar. Hence, the relation between the action and the new goal needs to be represented in a new form. Even the familiar action of bending, now in the service of a novel goal – hooking – needs to be slightly changed in order to obtain an optimal result. That is, the ultimate goal – getting the bucket out of the jar – shapes all parts of the action sequence and must therefore be represented continuously. Such continuity in representation is in line with Chambon and Haggard (2013) who criticize that ideomotor theory leaps from the idea directly to the goal state without considering the intermediate motor acts. They rather advocate a feed-forward prediction model that operates throughout the performance of the action and that allows for flexible adaptation of actions on the fly. Such continuous monitoring seems particularly suitable for explaining novel behavior that is not yet in the agent's action repertoire: if they do not have a sudden insight (which is a different pathway to innovation) children in the hook task may cumulatively assemble the sequential actions explained above prospectively – one at a time – check whether the result is in line with their prediction and so on until the gap to reaching the goal – having formed the hook – has been closed. With their feed-forward account, Chambon and Haggard also invoke another concept in the perception-action cycle – the (sense of) agency. Exploring the implications of agency from a developmental perspective, is a beneficial direction of future research.

In line with our hypothesis and ideomotor explanation, children in the soda straw group were better at tool making than children in the wooden sticks group (also children were better at tool making with the pipe cleaner compared to the wooden sticks with the added sample from Cutting, 2013). As has been shown, active experience with tools eases tool use actions even in infants (Sommerville et al., 2008), and tool and action familiarity facilitates understanding means-end relations in preschool children (Umla-Runge et al., 2014; Wang, Fu, Zimmer, & Aschersleben, 2012). However, we could not find a difference between the soda straw and the pipe cleaner groups. With a bigger sample size, the picture may get clearer, as with the difference between pipe cleaner and wooden sticks. Nevertheless, the performance with the pipe cleaner was still better than the one with a more familiar tool: the wooden sticks. Pipe cleaners are very flexible and relatively novel tools compared to soda straws and wooden sticks, at least in the sample of children from Turkey. Although there is no direct perceptual-motor relation between the hook task and the pipe cleaner, 5-and-6-year-old children utilized social information over the phases (Phase 2 and 3) with the pipe cleaner. Although all children are explorative with novel tools, children older than 5-year-old might be better at learning the function of novel artefacts and tools socially and understanding the intended function (taking a design stance) of the objects in their tool use and technical understanding, compared to the younger children (Defeyter & German, 2003; Defeyter, Hearing, & German, 2009).

Overall, the children in the wooden sticks group found the task most difficult. Firstly, one reason for this may lie in the necessity of integrating more information while maintaining attention on the various parts of the tool (two sticks, holes), which might appear perceptually more complex. Note that the number of tools was kept the same among the groups, and children in the wooden stick group played with the wooden sticks briefly, prior to the experiment to make the groups comparable. Nevertheless, the long rigid stick might have still seemed 'sufficient' to solve the task and thus, hindered the consideration of the crucial function of the small stick. For example, in the study of Nielsen et al. (2014) children preferred more rigid tools, such as aluminium or wooden sticks, compared to flexible tools to solve the hook task as in the present study. Another possibility is that, when compared to the other tools, the bending (reshaping) action for the pipe cleaner and the straw might be easier than the combining (adding) action for the wooden sticks. Phylogenetic investigations show that a combining action is cognitively more demanding, as it is a type of composite tool making compared to manipulating, e.g., bending a single tool (McGrew, 1987; Oswalt, 1976; Wadley, 2010). In the unpublished study that we compared our results with (Cutting, 2013), which had the same experimental design as in the current study, more children made a functional tool in the first two phases with reshaping the pipe cleaner compared to attaching the wooden sticks. Thirdly, although the wooden sticks might be more familiar in the cultural context (based on adults' opinions), there is no direct perceptual-motor relation between the task and the wooden sticks, unlike the soda straw. Thus, they might have needed to overcome their functional fixedness (see Adamson, 1952) and/or, as suggested above, the perceptual-motor knowledge regarding rigid tools. Familiarity might sometimes be an inhibitory factor for novel problem solving (Adamson, 1952; Hanus, Mendes, Tennie, & Call, 2011). In fact, both relative novelty and the affordance of the pipe cleaner – compared to wooden sticks – might have made children immune to functional fixedness, as they are either not familiar with the intended use of the pipe cleaners (e.g., in Turkey), or they use it in a flexible way (e.g., arts and crafts in the UK). Thus, the novelty and affordance of a pipe cleaner might have helped children understanding the design stance, namely, the intended use of artefacts, in Phase 2 and Phase 3 (see German & Defeyter, 2000; German & Johnson, 2002).

4.2. Hierarchical structuring, age and tool making

Our results replicated the previous finding that forming hierarchical representations and tool making are related processes (see Gönül et al., 2018). However, there was a ceiling effect and many influential cases in the hierarchical structuring task in the present study. Future studies should use more complex patterns to measure hierarchical complexity to prevent any ceiling effect. We also found a positive relation between age-in-months (59 to 81 months) and hierarchical structuring. This relation is in line with the literature demonstrating that 5-to-6-years of age is a critical transition period for tool making as well as for complex hierarchical object manipulation (see Beagles-Roos & Greenfield, 1979; Greenfield, 1991; Greenfield & Schneider, 1977).

The crucial role of forming hierarchical representations in tool making has been emphasized in both ontogeny and phylogeny (see Corballis, 2014; Elias, 2012; Greenfield, 1991; Hoffecker, 2012). Considering the positive relation between the hierarchical complexity and the tool making scores, both abilities seem to underlie the development of technical understanding (Osiurak et al., 2016). It is most likely that being able to construct a unified hierarchical representation, as in creating hierarchical structures (Greenfield & Schneider, 1977), in the process of structuring sequential or visuospatial stimuli (Fitch & Martins, 2014; Martins, Laaha, Freiberger, Choi, & Fitch, 2014) or during new knowledge construction (Mounoud, 1996), is also critical for tool making and its evolution (Gibson, 1993; Greenfield, 1991; Moore, 2010). Tool innovation, manufacture, and use can be analyzed as processes with an underlying hierarchical structure and an overarching goal as well (Gönül et al., 2018). Constructing the tool – in our case, the hook – applying it to the objects involved in the task – inserting it into the jar, hooking up the bucket and pulling it out of the jar – are subgoals on the way to the final goal – obtaining the sticker. Each of these sub-goals is a structured object itself with smaller sub-goals nested within. Taken together, they form an action hierarchy that is mapped out in an ordered spatial-temporal sequence. It is this similarity of tool-related actions with Greenfield and Schneider's (1977) hierarchical structuring task that makes the hierarchical complexity a significant predictor of tool making scores.

4.3. Tool innovation

Although we did not specifically focus on tool innovation (Phase 1 tool making results), 5-to-6-year-old children's immaturity in spontaneous tool innovation is very obvious. Tool innovation is cognitively more demanding (Carr et al., 2016; Rawlings & Legare, 2021) compared to tool making after observing immediate modifications (e.g., ready-made tool demonstration or tool making action demonstration). In the hook task, children are able to select a functional tool – a hooked pipe cleaner (see, Beck et al., 2011), and in some rare cases, they talk about or make gestures regarding a functional solution, or as stated earlier, drawing a hook shape in the air with their fingers and saying "something like that would work" even though they are not asked to do so (Gönül et al., 2018). Recently it has also been shown that children select a hooked pipe cleaner compared to a straight one in their attempt to solve the hook task, even though the hooked tool was oversized, and children were not successful in making further modifications to the oversized tool (Cutting, Apperly, Chappell, & Beck, 2019 – Experiment 2). All these results may indicate that children can simulate a functional solution, but cannot implement these solutions with the tools at hand, as they may need further perceptual-motor and social information. It is known in the literature that the characteristics of tools and imagined actions with these tools are jointly represented in adults (Rieger & Massen, 2014). However, children might still not be ready to represent fine-grained details of the tools and combine them within the task. As the literature suggests, children can anticipate future needs and plan accordingly already at earlier ages than the children in our study (Caza & Atance, 2019). On the other hand, although children might *simulate a functional solution* for the presented hook task and *anticipate the possible solutions* with the imagined tool, they may not be ready for *converting these simulations* or *mental manipulations* into *fine-grained actions*. What may be needed is what Amati and Shallice (2007) call "sustained non-routine multi-level operations", i.e., the ability to support novel operations across levels of thought, e.g., supervisory operations acting flexibly on routine operations. This ability is supported by the prefrontal cortex and its connections with the parietal lobe, which is not yet mature enough in young children.

Tool innovation, thus, might require two crucial skills and their connection: simulation abilities, and controlled tool making. While 5-to-6-year-old children can be good at mental simulations/manipulations (Brandimonte, Hitch, & Bishop, 1992; even though some forms of more complex mental simulations/manipulations might represent more protracted development, see Reindl, Parkash, Völter, & Seed, 2021), controlling information hierarchically and implementing representations into actions might be challenging for preschool children without social learning. Stout, Toth, Schick, Stout, and Hutchins (2000) show that tool making activates brain areas responsible for spatial cognition, motor and multimodal processing, and visual associations. We claim that children's controlled mental manipulations precede controlled physical manipulations during innovative problem solving, which should be explored in the future.

5. Implications, future directions and conclusion

In the current study, we investigated the effect of long term perceptual-motor tool knowledge on the tool-making performance of preschool children. However, we did not specifically focus on tool innovation. First of all, tool innovation is a rare phenomenon in preschool children (and also among other animals), and bigger sample sizes might be needed to catch an effect of the familiarity-novelty dimension on tool innovation. Second, our results show that the overall tool-familiarity effect stems from the difference between the bendable soda straw and wooden sticks groups, however, there was no significant difference between the pipe cleaner and soda straw groups. Nevertheless, a bigger sample size with the added sample did demonstrate a difference between wooden sticks and pipe cleaner groups. It should be noted that there is a complex interaction among tool familiarity/novelty, the relation between the tool and task (tool-task familiarity/novelty), and the type of tool making action (e.g. bending, combining). It should also be noted that the UK sample did not include a soda straw group, which should be considered in future studies. We believe that this study, in accordance with other studies in the literature, will pave the way for more systematic investigations of the development of tool innovation and tool manufacture considering social and individual learning effects through the process of tool making in children. Even though a great interest in the topic arose in the last decade, results still were based on specific tasks, specific tools, and specific cultural groups (but see, Lew-Levy, Pope, Haun, Kline, & Broesch, 2021; Neldner et al., 2017, 2019). This shortcoming can only be resolved with multi-lab collaborations using different tasks, different tools, and various cultural groups. Moreover, even though we found some similarities between Turkey and UK samples (the overall trend was similar, and the tool/culture interaction was not significant), Turkish children were better in tool making compared to the children from the UK. We interpreted this finding based on the age-in-months distributions of the samples (5- to 6-year-olds in Turkey, and 4- to 7-year-olds in the UK). The only way to understand the real reason is to include wider and more heterogeneous samples, including samples from non-WEIRD (Western, Educated, Industrialized, Rich, Democratic) societies, via considering both similarities and differences in tool making performance and culture (Lew-Levy et al., 2021; Nielsen, Haun, Kärtner, & Legare, 2017).

Even though explorative, this study also found a gender effect with boys outperforming girls. Nevertheless, follow-up results indicated that the difference was only in the wooden sticks group, suggesting that the familiarity-novelty dimension might play a role in that effect. Tool making scores of girls and boys were very similar when only the pipe cleaner was considered, which is compatible with previous findings (e.g., Chappell et al., 2013; Cutting et al., 2011, 2014). The superiority of boys when handling wooden sticks may also be related to the 'combining' action. In a recent study, Neldner et al. (2019) showed that boys were more innovative than girls if the task required adding tools for its solution. However, Gönül et al. (2019) demonstrated that tool-making performance with the wooden sticks of boys and girls in the hook task was very similar in dyadic interaction (e.g., when two girls or boys try to solve the hook task together) in two relatively distinct cultures: New Zealand and Turkey. All these results indicate an intricate relation between tool making and gender, from experience with the tools to cultural differences. We suggest that future studies should more thoroughly consider gender as a variable in relation to familiarity-novelty of tools.

It should be also noted that we evaluated tool familiarity with adults (as a pilot study), not with children, as we were interested in the cultural frequency of these tools and assumed that adults would provide more clear-cut insight about the tools. However, even though soda straws are very common in Turkey (e.g., most of the small packed-milk and -juice has bendable soda straws attached to the pack) and children play with wooden tools in kindergartens, children's experience with tools might be different from adults. Additionally, in the pilot study, we evaluated tool-task familiarity in a 'forced choice' rating way. Future research may include more precise measures of familiarity and a set of tools based on these fine-grained familiarity results. Working on a comprehensive set of tools and tasks would be of interest to see the independent effects of tool-task familiarity, tool familiarity and the type of action. Also, adding a warm-up phase to the soda straw and pipe cleaner groups may help to see the potential effect of short-term experience with the tools on the tool making results. Finally, there was no soda straw group from the UK sample. Our results indicated that there was no significant difference between soda straw and pipe cleaner in the sample from Turkey. This may mean either that there is no actual difference between these two groups, or the sample size was not sufficient to catch an effect. To get a clearer picture, future studies should also include a tool that children have long term familiarity with and can connect to the task at the action level (tool-task familiarity) such as soda straw. One further issue is related to the possible distinction between tool modification and tool making. Even though we consider the individual learning (asocially or socially) aspect of tool making, children have culture-specific perceptual-motor information, especially about soda straws. Children needed to modify the known techniques in the soda-straw group at the beginning of the experiment, whereas in other groups (Turkey sample) children did not have this knowledge on the modification, or this modification knowledge was not related to the task. As indicated above, only multi-lab collaborations with various tasks, tools, and cultural groups may help to understand these open questions.

In conclusion, in this study, we investigated the role of the long term perceptual-motor aspect of tools (their familiarity) and representational abilities (hierarchical structuring) of children in the overall process of tool making. The results of the study show how 5-to-6-year-old children benefit from long term perceptual-motor knowledge for tool making. Namely, children are better at tool making if the tool, as well as the tool-task relation, is familiar to them at least in part as in the case of utilizing a bendable straw compared to wooden sticks and a pipe cleaner. If the tool is perceptually more complex, rigid, and requires a combining action, as in the case of wooden sticks, they have difficulty in tool making. We invoked the ideomotor account in order to clarify the relation between actions and their anticipated effects in novel action-effect learning. All children may profit from the demonstration of the ready-made tool and the tool making action during social interaction. Finally, we claim that children's difficulty in spontaneous tool innovation might be the result of their inability to implement their actions according to their simulations (mental manipulations), which requires both spontaneous creativity and simulation capacity, as well as multi-modal processing and hierarchical action control over physical manipulations.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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