The Roles of Observation and Manipulation in Learning to Use a Tool

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Acknowledgments:

Eszter Somogyi was supported by the "Research in Paris" grant from the City of Paris.

J. Kevin O'Regan gratefully acknowledges the support of ERC grant 323674 "FEEL".

We also thank all of the families for their participation.

Abstract

We investigated how repeated, five-minute familiarization sessions occuring once a week over a 6-week period influenced 14 to 15 1/2 month-old infants' ability to use a rake-like tool to retrieve an out of reach object. We found that infants, who were not allowed to touch the rake, but only to observe an adult retrieve an object with it, improved their performance. On the other hand, infants who were allowed to manually manipulate the rake and touch and move other objects with it did not improve their performance. The results, which were also replicated in a string-pulling task, suggest that cognitive rather than motor, limitations are mainly what prevent infants from succeeding in such tool-use tasks. Furthermore, infants can

overcome these cognitive limitations with only a few, very brief demonstrations spaced over several weeks.

1. Introduction

The general definition of tool use is the ability to use one object to extend the boundaries of our physical body in order to act upon another spatially independent object (Beck, 1980). The earliest step towards tool use in development is when infants display means-end behavior to retrieve a distant object that is connected to a within-reach support (Piaget, 1952; Willatts, 1999). From 10 months of age, infants become increasingly successful at solving string- and cloth-pulling problems by correctly ignoring strings or cloths not in contact with the object (e.g., Aguiar & Baillargeon, 2000 for the cloth task; Brown, 1990; Richardson, 1932 for the string task). Similarly, by the end of their first year, infants are able to retrieve an out-of-reach object when it is visibly connected to a handle or to a string (Bates et al., 1980; Chen et al., 1997), demonstrating their understanding of connectivity. On the other hand, when the handle or string is not visibly connected to the desired object, that is, when there is a spatial gap between the tool and the object, the task becomes more difficult, and infants begin to succeed only during their second year (van Leeuwen et al.,1994; Fagard et al., 2012; O'Regan et al., 2011; Rat-Fischer et al., 2012, see also Brown, 1990; Chen & Siegler, 2000; Esseily et al., 2010; Keen, 2011 for similar observations).

In older infants and young children, the limiting factor shifts towards the overall complexity (procedural and structural) of the tool use task and thus the failure to understand the functionality of a tool. As Bates (1980) explains, infants fail because "anticipatory imagery is necessary to perceive the tool function" (p. 137). Towards the end of their second year, children start to vary their learning strategies according to the difficulty of the tool use problem. For instance, Bauer and Kleinknecht (2002) manipulated procedural complexity by changing the number of action steps involved across a series of tool-use trials. They found that with the easier two-step tasks, 20-month-old children chose one single strategy, either imitation (reproducing both the means and the ends of the demonstration) or emulation (reproducing only the ends but not the means). On the other hand, in the harder three-step condition, the children tended to use a mixture of the two strategies across trials (see Call & Carpenter, 2002, for description of social learning strategies). Gardiner et al. (2012) systematically varied the structural complexity of the objects involved across a variety of tool choice tasks. They found that although haptic experience was sufficient for children aged 2-3 years to choose the correct functional tools in the easier tasks, children relied on demonstrations when solving the harder tasks, where the affordances of the objects were less apparent (the moveable parts of the apparatuses were hidden).

Indeed, to explain how infants overcome tool use difficulties two learning strategies emerge in the literature: observational learning and spontaneous manipulation (Greif & Needham, 2011). We shall first review research supporting one and the other approach, and then continue with the few studies that compared the two.

1.1 Learning to use tools through observation

Children spend considerable time observing how others interact with objects and readily acquire tool-use knowledge by watching others use tools (van Leeuwen et al., 1994; Want & Harris, 2001; Whiten & Flynn, 2010). The causal structure of observable tool use behavior is often inaccessible or cognitively ‘opaque’ to infants as human tools mostly have less evident affordances, possess multiple possible functions and because the infant might not understand the intention of the demonstrator. Csibra and Gergely (2009, 2011) and Gergely and Csibra (2005) propose that observational learning and imitation are core components of natural pedagogy, which has evolved as Mother Nature’s ‘trick’ to overcome the difficulties of learning and teaching cognitively ‘opaque’ cultural knowledge. They suggest that children are sensitive to communicative and referential cues from adults that indicate instances of teaching and that by late infancy they observe demonstrations with an assumption that adults provide relevant and new information.

Preschool children are also predisposed and motivated to learn about the causal structure of events (Király et al., 2013) and are known to selectively engage in more exploratory play when the causal structure of events is ambiguous (Schulz & Bonawitz, 2007; Schulz et al., 2007). This epistemic motivation leads children to not only imitate adult tool use with a high degree of precision (Gardiner et al., 2011), but also to 'overimitate', that is to faithfully reproduce relevant as well as apparently irrelevant steps of demonstrated action sequences (Horner & Whiten, 2005; Lyons et al., 2007; Lyons et al., 2011; Kenward, 2012; Király et al., 2013). For example Kenward (2012) shows that preschoolers imitate actions that they already discovered to be unnecessary to achieve an outcome because they conceive them as norms.

What prompts children to rely on a demonstrator to learn about the function of a tool rather than relying on themselves? Studies suggest an inverse relationship between the degree of cognitive opacity within the observational learning context and whether children will apply their own understanding of causal relationships and emulate or defer to a demonstrator and learn by observation. For instance, Williamson et al. (2008) tested whether prior experience with a task affects learning strategies in 3-year-old children. They found that children who previously failed to use a tool, and thus had difficult prior experience, were more likely to imitate the precise tool use of an adult than children who had easy prior experience. In a study by Hopper et al. (2010), preschool children have been found to learn much less about a complex tool-use task when they only saw the parts of the apparatus move 'by themselves' (ghost condition) than when they observed a live demonstrator using the tool, which lead the authors to suggest that for complex or cognitively opaque tasks children require a live model for any form of learning to occur. Finally, in a recent study by Gardiner (2014) cognitive opacity was manipulated by the transparency/opacity of the apparatus on which the demonstrator acted. When 3-4-year-olds observed a demonstrator acting on a transparent apparatus and could thus see the physical effects of its moveable parts, they reproduced only the demonstrator's goal and determined the action sequence on their own. Conversely, when the demonstrator acted on an opaque apparatus with causally ambiguous physical structure, the children relied on the demonstration, reproducing the demonstrator's action sequence rather than figuring out the process on their own.

During observational learning of tool use, children also take into account social information, such as the intentions of the demonstrator when selecting which actions to imitate. By 3 years of age, they imitate unnecessary actions when a demonstrator performs them intentionally but not when she performs them accidentally (Gardiner et al., 2011, see also Carpenter, Akhtar, & Tomasello, 1998). Understanding the intentions of the demonstrator also reduces the cognitive opacity of tool use situations and helps infants to learn tool use by observation. In Esseily et al.'s (2013) study, infants who were shown the intention of the experimenter before the demonstration (she stretched out her arm in an effort to grasp an out-of-reach object) succeeded more in using a rake to retrieve a toy.

1.2 Learning to use tools through manipulation

The second, motor-based approach to tool use is present in early studies that describe the changes in motor patterns that characterize, for instance, the development of the use of a spoon (Connolly & Dalgleish, 1989). According to Lockman (2000), "tools alter the properties of effector systems" (p. 137), and early exploration and manipulation is necessary for the infants to gain knowledge about the affordances of their environment.

The idea that motor development influences cognitive development is not new. Piaget described motor skills as a mechanism that drives development in other domains by generating new sensorimotor experiences (Piaget, 1953, 1954). A more recent formulation of this idea is Gibson's ecological theory, stating that perceptual experience and cognition are shaped by action execution and are therefore ‘embodied’ or grounded in the body (Gibson, 1988).

The impact of active experiences on early development has been studied across ‘sticky mittens’ experiments where infants who could not yet reach for objects themselves were fitted with Velcro-covered mittens allowing the infants to catch toys and move them merely by swiping at them (Needham, Barrett, & Peterman, 2002; Sommerville et al., 2005). These studies showed that training with ‘sticky mittens’, but not passive reaching experiences (Libertus & Needham, 2010), facilitated exploration behavior and action understanding. Similarly, in object retrieval tasks, where children rarely succeed before 2-3 years of age in selecting the appropriate tool for retrieving a toy (Brown, 1990; Chen & Siegler, 2000), success increases over trials as children learn through their own interactive experience with the tools (Chen & Siegler, 2000).

In fact, the experience children have with objects, without necessarily using them as tools, can play an important role in how they perform in tool use tasks in general. Gredlein and Bjorklund (2005) observed 3-year-old children during free play and found that the amount of time children, especially boys, spent with object-oriented play (stacking, securing together, or connecting two or more objects or laying against or putting objects together in close proximity) predicted their success at choosing functional tools in a toy retrieval task. Preschool children also use haptic exploration to determine tool function when it is the most appropriate for discovering affordances relevant to a particular task. In a study by Klatzky et al. (2005) children were asked whether spoons of various sizes could be used to transport candies and sticks of varying rigidity could be used for stirring sugar and gravel. Instead of directly performing the tasks in order to judge whether the tool would be adequate, children made judgments about transport after visual inspection of the spoon, and judgments about rigidity after haptic exploration of the stick.

1.3 Comparing observation and manipulation

Only few studies so far have directly compared the roles of observation and manipulation in tool-use learning, but these agree on the advantage of observational learning over object manipulation in older children for tools that are difficult for their age. Two of these compared the frequencies of the two learning modes on the group level, investigating how preschool children learn from each other in naturalistic settings, such as the microculture of their classroom (Flynn & Whiten, 2010; Whiten & Flynn, 2010). The authors used the 'seeding' paradigm, where a single child was taught an extraction method: how to manipulate a tool or a puzzle box in order to retrieve an object. In both studies, the authors found that when the apparatuses were brought into the children's playgroup to freely interact with, the majority of learning instances were observational: most children used the method of extraction they had seen their classmates use. Two further studies confirmed the advantage of observational learning in children 3-7 years old for a task that required them to manufacture tools to retrieve objects from containers (Beck et al., 2011; Cutting et al., 2011). While children had difficulty creating tools themselves within a 1-minute time limit, they were easily able to solve the task when provided with demonstrations. Finally, Gardiner et al.'s (2012) study, cited above, compared the roles of observation and haptic experience in a more controlled and systematic fashion. Here, children 2-3 years old were presented with six toy-retrieval tasks that were designed to be easy, moderately difficult, or hard to achieve. The easy tasks involved pushing a toy out of a transparent tube, whereas the hard tasks involved cylindrical containers with hidden components that had to be pulled forward with a tool. For each task, children could choose from a set of tools, both functional and non-functional. Tool choice and tool use was evaluated across four learning conditions: (1) haptic experience, (2) observation, (3) haptic experience and observation, and (4) control. As mentioned above, the structural complexity of each object limited the efficacy of individual learning. But more importantly from the point of view of our present investigation, the authors also found that children learned about tools better by observation than by individual manual exploration or by both haptic and observational experience.

With the present study, we wished to test the applicability of the observational- versus the motor-based approaches in infants aged 14-15½ months, an age group in which the two learning modes have not yet been compared. We also wished to study tool use learning in a more naturalistic setting, where infants observe tool use repeatedly or have several opportunities to explore and manipulate task materials. It is possible that with repeated exposure, observational or manual, the relative efficiency of the two strategies would change as compared with studies where infants encounter the tools only on one occasion.

We compared the development of the infants' ability to retrieve an out-of-reach object with a rake (Rake Task) in a longitudinal pre- and post-test design, allowing repeated exposure to tools in two familiarization conditions. In one condition, infants received purely visual familiarization with the functionality of the tool (Visual Familiarization); in the second condition, they received only manual familiarization with the tool itself as an object (Manual Familiarization) – that is, they were allowed to manipulate the tool and to bring it into contact with other objects.

For both visual and manual familiarization, we designed brief sessions (about 5 minutes each), spaced out at 1-week intervals over a 6-week period. Pilot work showed that this amount of familiarization should suffice to show an effect.

We chose to study infants over the period of 14 to 15½ months because we knew from previous work that infants younger than 16 months do not succeed in the rake task when the rake is not connected to the desired toy and the two are separated by a large spatial gap (O'Regan et al., 2011; Rat-Fischer et al., 2012). Therefore, any improvement by 16 months captured in our study must be the effect of the familiarization conditions.

In order to ensure that any difference we found between our Visual and Manual Familiarization conditions was not a group effect, we included a control tool-use task for each infant, where Visual and Manual Familiarization were switched. This second task, approximately equal in difficulty to the Rake Task, would also allow us to extend the generality of our potential findings. For these purposes, we chose the String Task. Infants were shown four strings with one being connected to an out-of-reach toy. Infants are known to be able to pull a string to retrieve an object attached to it starting from the age of 10 months (Richardson, 1932). However, when presented with four strings, with only connected to the toy (the other three separated by a clearly visible spatial gap), even 16-month-olds often fail to pull the connected string, instead pulling any string at random (Rat-Fischer et al., 2011; Rat-Fischer et al., submitted).

If 14 to 15½ month-old infants already privilege observational learning when facing a tool use task difficult for their age, then familiarizing infants with the tools' function by showing them an adult retrieving a toy with the tool should help infants learn how to use the tool. Note that simply providing such familiarization only once prior to attempting the task would not be sufficient, since the studies cited above, showing that infants do not learn how to solve such tasks by observation at this age, used only one demonstration (Chen & Siegler, 2000; O'Regan et al., 2011; Rat-Fischer et al., 2012, see also Brown, 1990; Chen & Siegler, 2000). Therefore, the possibility exists that repeated observations over an extended period of several weeks might have an effect.

If manual control of the tool is what drives 14 to 15½ month-old infants' success in difficult tool use tasks, then providing the infant with a purely visual familiarization of the functionality of the tool should not appreciably help the infant learn how to use it. However, opportunities for manipulating the tool should develop the infant's skills in tool use.

In summary, with the experimental design and two tasks we chose, our hypotheses were the following.

(1) If failure to understand the functionality of the tool (rake or string) in conditions with spatial gap is due to lack of motor skills necessary to manipulate the tool, then the Manual Familiarization condition should improve infants' performance by 16 months, following the 6-week familiarization period.

(2) If, by contrast, lack of representational abilities is the main impediment to understanding the functionality of the tool (rake or string) in conditions with spatial gap, then demonstrating the tool's functionality in the Visual Familiarization condition should improve infants' performance by 16 months, following the 6-week familiarization period.

2. Method

2.1 Participants

Eighteen infants were followed from the age of 14 months (range 13mo 19d to 14mo 15d, 13 females) over 6 weeks. Two additional infants (males) were excluded due to parental error or inability to come back to the university laboratory for the last session. Infants were recruited from a list of local families who had expressed interest in participating in studies in infant development. Families were middle to upper class. Parents gave their informed consent before participating in the study. Infants were randomly assigned to one of the two groups:

(1) Visual Familiarization with Rake / Manual Familiarization with String (VisRakeManString) group: n=10

(2) Manual Familiarization with Rake / Visual Familiarization with String (ManRakeVisString) group: n=8

Please see Table 1 for the descriptive data of the participants.

Insert Table 1 about here.

2.2 Materials

Rake Task: A pool of eight small, attractive toys (average size 3 cm x 2 cm x 2 cm) and two different rake-like tools were used, the same for the two groups. The rake used in the lab was a T-shaped object made of white cardboard; it was constructed for this experiment. The handle was 20 cm long and the head 20 cm wide. It was designed to be visually plain, so as not to distract the infants. The rakes used in the infants' homes were plastic rakes of similar size commonly found in toy stores. We used different rakes in the lab and for the home sessions in order to ascertain whether any improvement in the infants' performance could be attributed to learning about the rake's function and the use of rake-like objects in general, and not to learning about one particular object used in the study. If during the sessions the infants did not show interest in a toy proposed for retrieval, it was replaced with another toy from the pool.

String Task: The same pool of eight toys, a support board and four woolen strings (each 20 cm long) were used. The support board was made of white cardboard and was used for arranging and proposing the four strings and one toy (attached to one of the strings) to the infant. Again, if the infant did not show interest in a proposed toy, it was replaced with another.

Figure 1 illustrates the materials used for the two tasks.

Insert Figure 1 about here.

2.3 Procedure

Infants took part in seven sessions, held at regular intervals, once a week, over a period of 6 weeks on average (as the date of the laboratory visit sometimes had to be adjusted to fit a family's schedule, +/- 3 days were allowed). The first and last sessions took place in the university laboratory; the sessions in between (Sessions 2 through 6) took place in the infants' homes. For all sessions, infants were seated on one parent's lap or in a high chair in front of a table. The experimenter or the demonstrating parent was seated across the table, opposite the infant. We video recorded all laboratory sessions as well as the home sessions that were conducted by an experimenter.

2.3.1 Testing infants' performance in the Rake Task and the String Task

We tested all infants for their ability to use the rake and the string during the first session (Rake $\text{Test}_{\text{before}}$, String $\text{Test}_{\text{before}}$) and the last session (Rake $\text{Test}_{\text{after}}$, String $\text{Test}_{\text{after}}$). Figure 2 shows the time line of the study.

Insert Figure 2 about here.

Tool-use studies generally capture infants' learning in two ways: (1) by evaluating spontaneous performance, and (2) by testing the ability to learn in a facilitated or scaffolded setting (Brown, 1990; Chen & Siegler, 2000; Rat-Fischer et al., 2012). Scaffolding in tool-use tasks might mean either (a) facilitated conditions with reduced spatial gap between tool and toy, or (b) demonstrations by an adult of the tool's use. In order to obtain data that are comparable to the results of existing studies, we also used both measures and adopted Rat-Fischer et al.'s (Rat-Fischer et al.) procedure for the scaffolded conditions. This way, beyond comparing the infants' ability to use the rake following the familiarization period, we could also capture any differences in their propensity to learn from a scaffolded setting after the familiarization period. For the present study, we will use the terms (1) Rake $\text{Test}_{\text{before}}$ and Rake $\text{Test}_{\text{after}}$ for the evaluation of spontaneous performance in the Rake Task, and the term

(2) Rake $\text{Test}_{\text{after/Scaffold}}$ to refer to infants' performance following an opportunity to learn from a scaffolded setting.

The String Task served as a control task allowing us to make sure that there were no differences between our two familiarization groups and to test whether any performance patterns observed in the Rake Task could be generalized. Therefore a scaffolded setting was not devised for this task, and infants' spontaneous performance only was evaluated.

Rake Tests, Rake $\text{Test}_{\text{after/Scaffold}}$ and String Tests were conducted as described below.

Rake Tests: Identical tests were conducted before and after the familiarization period (Rake $\text{Test}_{\text{before}}$ and Rake $\text{Test}_{\text{after}}$). The experimenter placed the toy in front and out of reach of the infant, approximately 70 cm from the infant. She then placed the rake near the infant's hand. Thus, from the infant's point of view, the toy was behind the rake and there was a large spatial gap between tool and toy. The experimenter then said, "Look at the (toy name); do you want to play with it? How can you get it?" If the infant failed to retrieve the toy, the test ended after a 60-second period starting when the infant first touched the rake or stretched his or her hand out toward the toy. If, within this test period, the infant became discouraged after having tried but failing to retrieve the toy, the experimenter encouraged the infant once by touching the toy and saying, "Go ahead; how can you get that toy?" If the infant threw the rake away, the experimenter placed the rake near the infant once more and another 60-second test period began. The actions that the infants produced during this test period were later scored for analyses. Parents were asked to restrain their infants if they tried to crawl onto the table to get the toy.

Rake $\text{Test}_{\text{after/Scaffold}}$: Following Rake $\text{Test}_{\text{after}}$, we proposed further retrieval tasks to the infants, in which the spatial gap between tool and toy was reduced, i.e., toy inside and against the rake part of the tool (C2: no spatial gap), toy inside the tool but not against it (C3: small spatial gap). If infants succeeded in these two easier conditions, they were again tested in the first setting with the toy to the side of the tool, now referred to as C4 (large spatial gap). If infants failed to retrieve the toy on two of three trials, even in the C2 and C3 conditions, parents were asked to give two consecutive demonstrations of the failed condition. Each test ended with a final condition where the toy was in the middle of the table and the tool was directly held out to the infant by the experimenter (C5: effectively a very large spatial gap). We only scored infants' actions in conditions C4 and C5, as the toy could move by pure contingency in conditions C2 and C3. (In other words, these two conditions served as a learning opportunity, but obviously infants' understanding of connectivity could not be scored here.) We used exactly the same procedure as Rat-Fischer et al. (2012) in order to be able to compare the performance of our infants with a group of 16-month-olds who had not been familiarized at all with the tool before testing.

String Tests: Again, tests conducted before and after the familiarization period (String $Test_{before}$ and String $Test_{after}$) were identical. The experimenter placed the cardboard support on the table where the four strings and a toy were arranged beforehand, with the toy in front and out of reach of the infant, approximately 70 cm away. She then said, "Look at the (toy name); do you want to play with it? How can you get it?" If the infant became discouraged or hesitated, the experimenter encouraged the infant once by touching the toy and saying, "Go ahead; how can you get that toy?" The test was repeated four times in order for the string connected to the toy to cover all four positions and also to allow the infants to try their own strategy.

2.3.2 Familiarization procedures

All infants were familiarized with both the rake and the string, along the following crossed design:

1. VisRakeManString group: The 10 infants assigned to this group regularly observed

one of their parents or another adult retrieve an out-of-reach object using a rake (Visual Familiarization with Rake) and had the opportunity to regularly manipulate four strings, one of which was attached to a toy (Manual Familiarization with String).

2. ManRakeVisString group: The 8 infants in this group had the opportunity to regularly manipulate a rake (Manual Familiarization with Rake) and regularly observed one of their parents or another adult retrieve an out-of-reach object attached to a string (Visual Familiarization with String).

Infants had six familiarization sessions. The first familiarization took place during the infants' first session in the laboratory and the remaining five (Sessions 2 through 6) took place in their homes. Parents were asked to perform familiarization sessions exactly as they had observed in the laboratory. They also received detailed verbal and written instructions to perform the sessions preferably on the same day every week, to conduct the sessions in a spontaneous way, to avoid explicit teaching, and to ensure that their child was attentive and interested when presented with the tool and toys for manual familiarization or when watching their demonstration. One of the experimenters visited the families every other week in order to conduct a session, which she videotaped. This way, about half of the home sessions were standardized. We also telephoned the families a day before each home session as a reminder and to check that they understood the procedure. The familiarization procedures, illustrated by Figures 3 and 4, were conducted as described below.

Insert Figures 3 and 4 about here.

Visual Familiarization with Rake: The rake was placed on the table on the right side of the parent or experimenter, who used it to bring a toy toward the infant, without any comments, in order to avoid explicit teaching. This action was repeated five times with a different toy each time. In order for the familiarization to remain strictly visual, infants were not allowed to touch the rake.

Manual Familiarization with Rake: The rake was placed on the table in front of the infant with three different toys. The infant was allowed five minutes to freely manipulate the items. No instruction or demonstration was given. In order for the familiarization to remain strictly manual, infants in this group never observed the use of the rake.

Visual Familiarization with String: Four strings, one connected to a toy, were placed on the table on the right side of the parent or experimenter, who used the connected string to bring the toy toward the infant, without any comments. This action was repeated five times with a different toy each time. In order for the familiarization to remain strictly visual, infants were not allowed to touch the strings.

Manual Familiarization with String: Four strings, one connected to a toy, were placed and arranged in a roughly parallel manner on the table in front of the infant, who was allowed five minutes to freely manipulate the items. No instruction or demonstration was given. In order for the familiarization to remain strictly manual, infants in this group never observed the use of the strings.

2.3.3 Data analysis

Behavioural categories were established for the analysis of the infants' behaviours in both the Rake and the String Tests.

Rake Tests and Rake Test$_{after/Scaffold}$: Since complete success is rare at this age (O'Regan et al., 2011; Rat-Fischer et al., 2012), a score from 1 to 4 was assigned for each action based on whether the infant did or did not manipulate one or both objects; did or did not make a connection between the toy and the rake without necessarily retrieving the toy; and whether they ultimately retrieved the toy using the rake.

Score 1: Interested mainly in toy or tool alone. In this category, infants produced the following actions: pointed to toy refusing or ignoring tool; pointed to toy, grasped tool then pointed again toward toy with other hand; grasped tool, discarded it and pointed to toy; pointed to toy, then grasped tool and played with it; grasped tool, swiped table with it, and swept toy away by accident; grasped tool, played with it and then rejected it, possibly interested in toy again.

Score 2: Interested in tool in connection with toy. In this category, infants grasped tool and touched or pushed toy with it or infants pointed to toy, then grasped tool and touched or pushed toy with it.

Score 3: Interested in tool for retrieval, understands connection between the rake and the toy: trial and error, difficult or partial success. Here, infants grasped tool, moved tool, tried to retrieve toy, but failed; grasped tool after being encouraged, moved tool and retrieved toy with it; grasped tool, made awkward movements to bring toy to hand, and succeeded; grasped tool and retrieved toy after several attempts.

Score 4: Interested in tool for retrieval, solid understanding of connection between the rake and the toy: intentional full success. Infants in this category grasped tool directly, moved tool behind toy to retrieve it, and succeeded.

During the Rake Tests, we recorded the score of the highest-rated action during the 60-second test periods and used this score for analyses. During Rake Test$_{\text{after/Scaffold}}$ all of the infants' actions in C4 and C5 were rated and the average of these scores was used for analyses.

String Tests: A score from 1 to 3 was assigned for each action based on whether the infant pulled a string randomly or not, did or did not look at the toy before pulling a string; and whether the infant pulled the connected string or not.

Score 1: Pulls any string randomly without looking at the out-of-reach toy.

Score 2: Looks at the toy before and while pulling a string, but does not pull the connected string first. This score was also attributed when infants pulled two strings simultaneously, one in each hand.

Score 3: Looks at the toy before and while pulling directly the connected string.

The scores for each infant were averaged over the four trials and this average score was used for analyses.

2.4 Scoring reliability

Infants' behaviours were coded from the videotapes, and 6 infants (30%) were coded independently by a second observer to assess inter-observer reliability. Reliability between the two observers was 90%.

3. Results

Rake Tests: We performed a repeated measures analysis of variance (ANOVA) on the highest scores obtained on the Rake Tests as a function of Test time (highest score in Rake $Test_{before}$ and Rake $Test_{after}$) and Familiarization condition (Visual or Manual). The analysis yielded a significant within-subjects effect of Test time ($F(1,16) = 11.92$, $p = .003$, $\eta 2 = .33$) and a significant interaction between Test time and Familiarization condition ($F(1,16) = 7.85$, $p = .013$, $\eta 2 = .54$), indicating that Familiarization had different effects in our two groups. Paired t-tests were used to compare mean scores in Rake $Test_{before}$ and Rake $Test_{after}$. A correlated-samples t-test revealed a significant improvement in the performance of the Visual Familiarization group ($m_{Visual/before} = 1.7$, $m_{Visual/after} = 2.9$), $t(9) = -3.67$, $p = .005$). Manual Familiarization did not have an effect on infants' scores ($m_{Manual/before} = 2$, $m_{Manual/after} = 2.13$, $t(7) = -1$, $p = .35$). An independent-samples t-test confirmed the significant difference between the performances of the two Familiarization groups in Rake $Test_{after}$ ($m_{Visual/after} = 2.9$, $m_{Manual/after} = 2.13$, $t(16) = 2.09$, $p = .05$). There was no difference in the means of the two Familiarization groups at the onset of the study in Rake $Test_{before}$ indicating that the two samples were comparable ($m_{Visual/before} = 1.7$, $m_{Manual/before} = 2$, $t(16) = -1.25$, $p =.229$). Please see Table 2 for participant scores and Figure 5 for a summary of results in Rake Tests.

Insert Table 2 and Figure 5 about here.

Rake Test$_{after/Scaffold}$: The mean score of actions produced in C4 and C5 conditions was calculated for each infant. We performed a repeated measures analysis of variance (ANOVA) on the scores obtained on the Rake Tests as a function of Test time (highest score in Rake Test$_{before}$ and mean score in Rake Test$_{after/Scaffold}$) and Familiarization condition (Visual or Manual). The analysis yielded a significant within-subjects effect of Test time ($F(1,16) = 15.98$, $p = .001$, $\eta 2 = .43$) and a significant between-subjects effect of Familiarization condition ($F(1,16) = 9.89$, $p = .006$, $\eta 2 = .35$). Test time by Familiarization condition interaction was also significant ($F(1,16) = 17.54$, $p = .001$, $\eta 2 = .43$), indicating that Visual and Manual Familiarization had different effects on infants' propensity to learn from a scaffolded setting. Paired t-tests were used to compare mean scores in Rake Test$_{before}$ and Rake Test$_{after/Scaffold}$. A correlated-samples t-test confirmed the significant effect of Visual Familiarization ($m_{Visual/before} = 1.7$, $m_{Visual/after/Scaffold} = 3.5$), $t(9) = -6$, $p = .004$). This shows a significant increase in performance following learning from a scaffolded setting (reduced spatial gap and demonstrations) for infants in the Visual Familiarization condition. Manual Familiarization did not have an effect on the infants' scores ($m_{Manual/before} = 2$, $m_{Manual/after/Scaffold} = 1.96$, $t(7) = 0.13$, $p = .9$). An independent-samples t-test confirmed the significant difference between the performances of the two groups in Rake Test$_{after/Scaffold}$ ($m_{Visual/after/Scaffold} = 3.5$, $m_{Manual/after/Scaffold} = 1.96$, $t(16) = 4.79$, $p = .0002$). Please see Table 2 for participant scores and Figure 5 for a summary of results in Rake Test$_{after/Scaffold}$.

String Tests: We performed a repeated measures analysis of variance (ANOVA) on the scores obtained on the String Tests as a function of Test time (Score in String $Test_{before}$ or Score in String $Test_{after}$) and Familiarization condition (Visual or Manual) The analysis yielded a significant within-subjects effect of Test time ($F(1,16) = 11.06$, $p = .004$, $\eta 2 = .29$) and a significant interaction between Test time and Familiarization condition, confirming through this control task that Visual and Manual Familiarization had different effects in our two groups. Subsequent paired t-tests were used to compare mean scores in String $Test_{before}$ and String $Test_{after}$. These revealed a significant improvement in the performance of the Visual Familiarization group ($m_{Visual/before} = 1.07$, $m_{Visual/after} = 2.13$), $t(7) = -4.68$, $p = .002$). Manual Familiarization did not have an effect on the infants' scores ($m_{Manual/before} = 1.45$, $m_{Manual/after} = 1.6$, $t(9) = -0.55$, $p = .6$). An independent-samples t-test confirmed the significant difference between the performances of the two groups in String $Test_{after}$ ($m_{Visual/after} = 2.13$, $m_{Manual/after} = 1.6$, $t(16) = 4.79$, $p = .046$). There was no difference in the means of the Visual Familiarization group and the Manual Familiarization group at the onset of the study in String $Test_{before}$ either, indicating that the two samples were comparable ($m_{Visual/before} = 1.07$, $m_{Manual/before} = 1.45$, $t(16) = 1.24$, $p =.232$) regarding their baseline performance in this task as well. Please see Table 2 for participant scores and Figure 6 for a summary of results on the String Task.

Insert Figure 6 about here.

Observation and manipulation behaviour during home sessions: We analysed infants' behaviour during the two home familiarization sessions that were conducted by one of the experimenters. In the Visual Familiarization conditions all infants watched as the experimenter used the tool (rake or string) to bring an object closer to them. In the Manual Familiarization conditions all infants touched and manipulated (moved or held) the tool (rake or string).

4. Discussion

Complex tool use is a distinguishing characteristic of the human species (Semaw, 2000), a characteristic that may have caused adaptive pressure for strategies that facilitate efficient tool-use learning. Several studies have described how manual dexterity develops when infants learn to use a tool (Brown, 1990; Rat-Fischer et al., 2012). Other studies relate tool-use learning to the procedural complexity of the task (Bauer and Kleinknecht, 2002), to the relational properties of the objects involved (Bates et al., 1980; van Leeuwen et al., 1994) or their structural complexity (Gardiner et al., 2012). Only a few studies, however, have investigated the relative importance of cognitive and motor factors, and these have involved mostly preschool infants (Williamson et al., 2008; Whiten & Flynn, 2010; Flynn & Whiten, 2010; Beck et al., 2011; Cutting et al., 2011; Gardiner et al., 2012), allowing no comparison with earlier stages of development.

The present longitudinal study aimed to address this gap in the literature, to investigate how young infants learn about the function of a tool and how they come to understand a tool as an extension of the body's reach.

Interestingly, without familiarization, infants learn to use tools such as the rake or the string only around the age of 18 months. Before this age, they do not learn from demonstration either (Chen & Siegler, 2000; Esseily et al., 2013). This might be interpreted in two different ways. Cognitive limitations may prevent infants at this age from understanding the function of the tool and thus its usefulness. On the other hand, motor execution of such tasks may be too difficult and may add an attentional load that inhibits task execution. The goal of the study presented here was to examine which hypothesis was more likely to explain infants' failure. We hypothesized that if mainly cognitive factors are responsible, then brief repeated visual exposure to the function of the tool, without manipulation or explicit demonstration, should advance the age of success. By contrast, if manipulating the tool prevents success by putting an attentional load on the task, then manual familiarization with repeated opportunities to manipulate the tool should relieve the task of this difficulty and advance the age of success.

We followed the development of infants aged 14-15½ months in their ability to use a rake or a string to retrieve out-of-reach objects. One group of infants received purely visual familiarization with the functionality of the rake and manual familiarization with the string; the other received only manual familiarization with the rake itself as a manipulable object, and purely visual familiarization with the function of the string. There was no difference between infants' performance on the Rake and String Tasks at the onset of the study, which shows that the differences in tool use can only be attributed to the different familiarization conditions.

The results indicated the advantage of observational learning over manipulation for both tasks. Concerning the Rake Task, at the onset of the study, all infants (aged 14 months) focused their attention either on the toy or on the rake. This corresponds to the responses infants gave in Rat-Fischer et al.'s (2012) study in the same task at the same age. However, 6 weeks later, only those infants who received visual familiarization with the rake's function shifted their attention to the combination of both the toy and the rake, making a connection between the two and eventually succeeding at the task. Those infants in the manual familiarization group did not make this connection. Visual familiarization with the function of the rake therefore proved to be more effective in bringing about successful rake use than manual familiarization. In Rat-Fischer et al.'s cross-sectional study (2012), in which there was no familiarization, infants at this age were more likely to focus their attention on the toy (pointing to or reaching for it), often ignoring or discarding the tool, further supporting the advantage of functional familiarization that the infants received.

The infants' performance in the String Task reproduced this pattern. At the onset of the study, infants pulled the strings mostly at random or did not pull the connected string in order to retrieve the attached toy. However, 6 weeks later, those infants in the visual familiarization group pulled on the correct string significantly more often than those in the manual familiarization group.

We can therefore conclude that infants already in their second year rely more on observation than their own motor experiences when learning to use tools that are relatively complex for their age. This conclusion extends the results of earlier studies involving older age groups (Williamson, 2008; Whiten & Flynn, 2010; Flynn & Whiten, 2010; Beck et al., 2011; Cutting et al., 2011; Gardiner et al., 2012).

We have also shown that even with longer and repeated opportunities for children to explore and manipulate task materials, the advantage of observational learning did not disappear. Infants in the visual familiarization conditions did not touch the tools during the familiarization period and still learned better than the manual groups, which suggests that manual control of the tool was not the main factor in learning to use the tool in our case. This does not mean that manipulation and haptic experience is ineffective or unimportant. Instead, it is likely that cognitive and motor factors play different roles at different points in development. Experience may be crucial for infants at early stages of tool use before they can benefit from observation (Sommerville et al., 2008; Sommerville & Woodward, 2005). As pointed out by Gardiner et al. (2012), it may also be that, besides age, the complexity of the task also influences which strategy infants rely on. It seems possible that when the task is less complex and does not involve problem solving (procedural simplicity) or one of the objects is stationary (structural simplicity), spontaneous learning might happen (Kahrs et al., 2012). In the context of tool-use learning, manual exploration may be more important to refine both children's understanding of the affordances of a tool and their motor strategies when manipulating the tool.

One reservation to consider is that infants in the manual familiarization sessions simply did not spontaneously perform the manual gestures necessary to improve their performance later. From a motor perspective, however, spontaneous manual exploration in itself, without any direct teaching of the necessary movements, should allow for infants to detect a tool's affordances and to gain manual control over it. A further point might be that manual familiarization, in order to be effective, needs to be more intense than 5-minute sessions at weekly intervals.

Even still, the important point remains that purely visual exposure is sufficient to provide a very strong facilitating effect. Further to this effect, an additional important question should be discussed. How can it be that such significant improvement was achieved with only six visual demonstrations, each only 5 minutes long, over a 6-week period, without any attentional directives given to the child, and without any explicit pedagogical stance being taken? This is in contrast to the fact that extended, laborious scaffolding and demonstrations with pedagogical stance completely fail to help infants accomplish the task when these demonstrations are done intensively in one single session at 16 months (Rat-Fischer et al., 2012; O'Regan, 2011).

To understand this finding, consider the child's understanding of the goal of a demonstration. Teaching an infant to perform a task by demonstration first requires the infant to understand the goal of the demonstration. When an infant at 16 months observes an adult performing the task without prior familiarization in a single half-hour experimental session in the laboratory, the infant may be preoccupied with his own goal of retrieving the toy, or may have abandoned hope of retrieving the toy altogether. Infants may therefore not understand that the adult's demonstration is relevant to their own goal and may not be able to espouse the adult's goal as their own. Indeed, the child may not even see that the adult's goal is to retrieve the toy. Esseilly et al.'s (2013) study supports this idea, confirming that in conditions where the child is more likely to espouse toy retrieval as the goal of the demonstration, the demonstration becomes much more effective. In these experiments, infants succeeded more at retrieving a toy with a rake when they were shown the goal of the action before the demonstration (i.e., the experimenter extended her hand towards the toy, but could not reach it). The advantage of repeated observational learning over repeated manual experience in our study may therefore be explained by the fact that children were learning different types of information about the involved objects and the task goals in each of the conditions. They may have learned about the objects' physical properties in the manual familiarization condition and about the end-goal of using a tool in the visual familiarization condition. Still, exploring the physical properties of the tool itself was not sufficient for discovering the possible goals that could be achieved with it.

A second explanation concerns the limited efficacy of a single demonstration session in a laboratory setting. In such a demonstration, even if a child shares the goal of the demonstrator, and understands that he is being shown a demonstration, he may not be able to isolate the relevant, effective cue among the many possible cues that are available. Perhaps observing, albeit briefly, the use of the tool on several prior occasions provided more opportunities for the infant to see which of the many possible cues were relevant for successful object retrieval. As Hirata, Morimura, and Houki (2009) point out in their study of tool-use learning by observing a conspecific model in chimpanzees, learning by observation over a longer term has a different effect.

A third explanation for the surprising usefulness of brief but repeated observations over an extended period concerns imitation. Human children are known to be extraordinarily prone to imitation. They may not only be innately prone to do this (Meltzoff & Moore 1977, 1983, though see Jones, 2009 for a more recent review including studies that challenge this claim) but imitation is also an important component of human culture (e.g.: Meltzoff, 1988; Gergely et al., 2002; Nadel & Potier, 2002; Paulus, 2011), and babies are supremely encouraged to play imitation games as they grow up, unlike offspring in other species. Furthermore, imitation is known to occur entirely incidentally, without pedagogical or attentional directives being given (e.g.: Masur & Olson, 2008). It may be similar to the incidental learning of cultural gestures in adults, who, after an extended period of exposure, change their gestures to resemble those of their cultural environment (see van Baaren et al., 2009 for a review). If imitation is therefore a natural tendency in infants, it may be that repeated exposure to brief demonstrations of the tool may predispose infants to imitate the associated gestures at a later time. This would happen without pedagogical or attentional effort on the part of the adult. The way this mechanism might act would then be to favor the occurrence of imitation during the final test session. If this were true, however, it would imply that though the infants perform better, they do not necessarily succeed because they have actually acquired a better functional understanding.

In conclusion, our work has shown the surprising efficacy of repeated, brief, purely visual demonstrations, provided over an extended period of 6 weeks in improving an infant's ability to use a rake or string to retrieve an out-of-reach object.

The result, though not entirely rejecting the role of motor limitations in understanding tool use, emphasizes the importance of cognitive rather than motor limitations in determining infants' success at a rather difficult tool use task, already at a young age. Among the possible explanations for the surprising success of our extended but brief visual familiarization procedure might be that it sensitizes infants to better perceive the goal of an adult's demonstration, that it gives the child more time to isolate those cues in the demonstration that are the effective ones, and that it provides the opportunity, through imitative incidental learning, to acquire the correct gestures to perform the task.

Tables and Figures

Figure 1: Materials used for the Rake and String Tasks. Different rakes were used in the lab and for familiarization at home. A white cardboard rake was constructed for lab sessions and a plastic rake commonly found in stores was given to parents for home sessions.

6 weeks

	0	1st week	2nd we	3rd we	4th we	5th we	6th we
Age	14mo	14mo	14mo	14mo	14mo	15mo	15mo
Group 1	Tests1+ 1st Fam in lab	Familiarization at home Visual Rake, Manual String					Tests2
Group 2	Tests1+ 1st Fam in lab	Familiarization at home Manual Rake, Visual String					Tests2

Figure 2: The time line of the longitudinal design.

Figure 3: Different infants observing the function of the rake in the Visual Familiarization condition and manipulating the rake in the Manual Familiarization condition. No instructions were given; the familiarization sessions were kept spontaneous.

Figure 4: Different infants observing the function of the string in the Visual Familiarization condition and manipulating the strings in the Manual Familiarization condition. No instructions were given; the familiarization sessions were kept spontaneous.

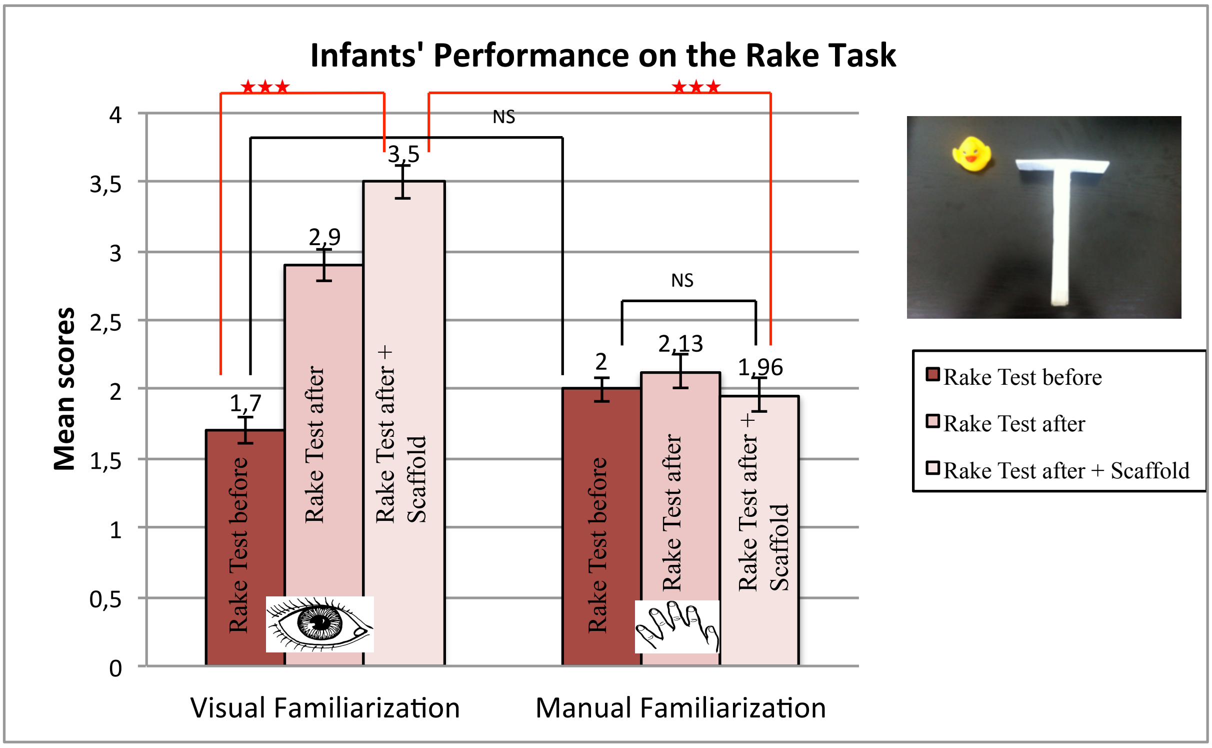

Figure 5: Infants' performance on the Rake Task before and after familiarization. Infants in the Visual Familiarization group, but not those in the Manual Familiarization group, improved significantly in their ability to use the rake. Infants in the Manual Familiarization group did not benefit from the scaffolded setting (reduced spatial gap, adult demonstration) either.

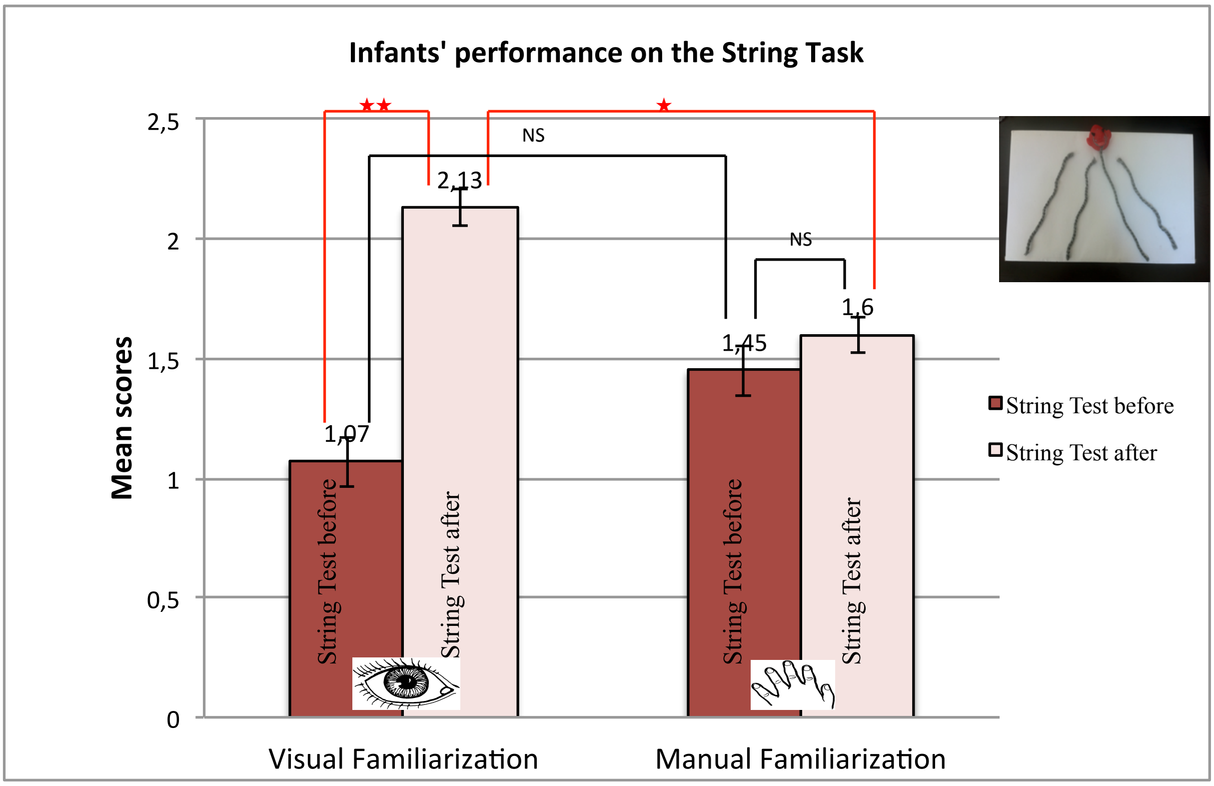

Figure 6: Infants' performance on the String Task before and after familiarization. The performance pattern found in the Rake Task was reproduced in this control task. Infants in the Visual Familiarization group, but not those in the Manual Familiarization group, improved significantly in their ability to use the string.

Familiarization condition	**Subject nr.**		**Age at onset (in weeks)**	**Gender**
VisRakeManString	**1**		62	f
	2		61	m
	3		62	f
	4		62	f
	5		61	f
	6		63	f
	7		63	m
	8		59	f
	9		61	f
	10		61	f
	Total	N	10	
		M	61,50	
		SD	0,37	
		Min.	59	
		Max.	63	
ManRakeVisString	**11**		61	f
	12		61	f
	13		62	m
	14		63	m
	15		62	f
	16		61	f
	17		61	f
	18		61	f
	Total	N	8	
		M	61,50	
		SD	0,27	
		Min.	61	
		Max.	63	
Total	N		18	
	M		61,50	
	SD		0,23	
	Min.		59	
	Max.		63	

Table 1: Descriptive data of participants.

Familiarization condition	Subject nr.		Test scores				
			Rake Test before	Rake Test after	Rake Test after/Scaffold	String Test before	String Test after
VisRakeManString	**1**		1	3	3,33	,63	1,75
	2		2	4	4,00	,38	2,00
	3		2	3	3,00	1,00	0,00
	4		2	2	3,33	1,63	1,50
	5		2	3	4,33	2,38	2,00
	6		1	3	3,50	2,13	2,00
	7		1	3	3,33	1,38	1,75
	8		2	3	4,33	1,00	2,00
	9		2	1	1,50	2,25	1,63
	10		2	4	4,33	1,75	1,38
	Total	N	10	10	10	10	10
		M	1,70	2,90	3,50	1,45	1,60
		SD	0,15	0,88	0,27	0,22	0,19
		Min.	1	1	1,50	,38	0
		Max.	2	4	4,33	2,38	2
ManRakeVisString	**11**		2	2	2,00	2,13	2,25
	12		2	2	1,67	1,88	2,50
	13		2	2	2,00	,63	2,25
	14		2	3	2,00	,63	2,50
	15		2	2	1,33	1,00	1,75
	16		1	1	3,00	,63	2,25
	17		3	3	2,00	,63	2,00
	18		2	2	1,67	1,00	1,50
	Total	N	8	8	8	8	8
		M	2,00	2,13	1,96	1,07	2,13
		SD	0,19	0,64	0,17	0,21	0,13
		Min.	1	1	1,33	,63	1,50
		Max.	3	3	3,00	2,13	2,50
Total	N		18	18	18	18	18
	M		1,83	2,56	2,81	1,28	1,83
	SD		0,12	0,86	0,25	0,16	0,13
	Min.		1	1	1,33	,38	0
	Max.		3	4	4,33	2,38	2,50

Table 2: Participant scores in the Rake and String Tests.

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