Dissecting children's observational learning of complex actions through selective video displays

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Abstract

Children can learn how to use complex objects by watching others, yet the relative importance of different elements they may observe, such as the interactions of the individual parts of the apparatus, a model's movements, or desirable outcomes, remains unclear. One hundred and forty 3-year-olds and one hundred and forty 5-year-olds participated in a study in which they observed a video showing tools being used to extract a reward item from a complex puzzle box. Conditions varied according to the elements that could be seen in the video: (i) the whole display including the model's hands, the tools and the box, (ii) the tools and the box but never the model's hands, (iii) the model's hands and the tools but not the box, (iv) only the end-state with the box opened, and (v) no demonstration. Children's later attempts at the task were coded to establish whether they imitated the hierarchically-organised sequence of the model's actions, the action details and/or the outcome. Children's successful retrieval of the reward from the box, and the replication of hierarchical-sequential information were reduced in all but the "whole display" condition (i). Only once a child had attempted the task, and witnessed a second demonstration, did the display focused on the tools and box (ii) prove to be better for hierarchical-sequence information than displays that focused on the tools and hands only (iii).

Dissecting children's observational learning of complex actions through selective video displays

Observational learning allows a child to acquire much adaptive information from his or her cultural environment, and several different processes of learning underpin the assimilation of the critical aspects of what is witnessed. Tomasello, Kruger and Ratner (1993) distinguished different forms of observational learning including mimicry, in which the actions of another individual are copied with little thought to the resulting outcome, and imitation, where an individual instead reproduces the outcome, as well as the actions that lead to the outcome. Whiten and Ham (1992, page 250) defined imitation more simply as a process in which "B learns some aspect(s) of the intrinsic form of an act from A". By contrast in emulation an observer focuses on the mechanics of a scene, potentially learning about the affordances of the objects concerned (Byrne, 1998), for example that an object can be moved in a certain manner (object movement re-enactment, Custance, Whiten, & Fredman, 1999), or that a certain goal can be achieved (goal emulation, Whiten & Ham, 1992).

Dissecting imitation versus emulation

There has been a recent drive in both comparative (Whiten, Horner, Litchfield, & Marshall-Pescini, 2004) and developmental psychology (Want & Harris, 2002; Whiten, McGuigan, Marshall-Pescini and Hopper, 2009) to dissect these different mechanisms within the observational learning process to establish the importance of each (see Hopper 2010 for a review). To do this, a number of ingenious paradigms have been developed, two of which are particularly relevant to the current study: two-action tasks and ghost controls.

In two-action tasks (Dawson & Foss, 1965) the same outcome is achieved by a model or models using either of two alternative methods, such as pushing a lever versus pulling a lever. Replication of the method a participant saw a model use to achieve the outcome then implies imitation. Achieving the outcome witnessed, but not using the method observed, implies result or goal emulation. Research using such two-action tasks has been extremely fruitful, showing that young children often imitate, copying the means they see others use to achieve a desirable outcome (McGuigan, Whiten, Flynn, & Horner, 2007; Nielsen & Tomaselli, 2010; Tennie, Call, & Tomasello, 2006). However, in some contexts children have also been shown to be selective learners, either not copying all the actions they have witnessed or replicating the outcome but using alternative means (Bekkering, Wohlschläger, & Gattis, 2000; Carpenter, Akhtar, & Tomasello, 1998; Flynn, 2008; Meltzoff, 1995; Wood, Kendal, & Flynn, 2012).

"Ghost control" experiments instead remove the agent from the display witnessed, so that it takes a "ghostly" form, offering participants the opportunity to recreate the outcome they witnessed through emulation, as the pertinent parts of the apparatus move but the absence of an agent offers no possibility of imitation. Such displays have been engineered through use of a remote control (Thompson & Russell, 2004), by the discreet use of fishing line (Hopper, Lambeth, Schapiro, & Whiten, 2008; Hopper, Flynn, Wood, & Whiten, 2010; Tennie *et al.*, 2006) or by digitally altering a video display (Huang & Charman, 2005). Children as young as 17 months have been found to learn from displays that present only information about the interactions of objects, without the model's movements being seen (Huang & Charman, 2005). By contrast, Tennie *et al.* (2006) found that 18-month-olds did not match the pushing or pulling of a door when it was displayed within a ghost control, whereas they did match the method witnessed when the model was included in the scene. Twenty-four month-olds matched the method witnessed in both conditions. Finally, Hopper and colleagues tested slightly older children's (three- and four-year-olds) learning with (i) a simple bi-directional task in which a door could be moved to the left or right (Hopper *et al.*, 2008), and (ii) a more complex tool use task, in which a tool could be used to remove an obstructing block, both resulting in the release of a reward (Hopper *et al.*, 2010). For the bi-directional door task children matched the response they witnessed on the first trial. But when all responses were considered, only children who witnessed a whole demonstration or an "enhanced" ghost control (in which another child was present but did not manipulate the apparatus) matched the direction that they witnessed the door moved above chance levels. The enhanced control provided a social element to draw the participant's attention to the display, working under social facilitation to control for mere presence effects (Akins, Klein, & Zentall, 2002; Fawcett, Skinner, & Goldsmith, 2002; Klein & Zentall, 2003). Children who witnessed a standard ghost control, with no other child present, did not match the direction of the door movement. The tool use task produced similar results, with children who witnessed a whole demonstration showing the best performance, and children in a ghost control showing better performance than children who witnessed no demonstration.

In the present study we developed a new approach to dissecting such elements by creating videotapes that revealed different aspects of the execution of a complex task. We compared the level of success on this task and the specific components of a witnessed demonstration that were copied when children were presented with information focussed only on the affordances or movement of the apparatus (addressing the role of information that underpins emulative learning), or on the end-state of the task (addressing the role of information that underpins goal emulation), or on the physical actions made by a model (addressing the role of information that underpins the imitation of body movements). During observational learning observers may process one or several aspects within such a scene. By presenting displays that isolate different aspects within a scene, at the detriment of access to other forms of information, we can establish how these drive different social learning processes, and as a result can establish how important each aspect is to a child's success and his/her adoption of aspects of the demonstration. For example, in a ghost control demonstration children are presented with all the functional information with regard to an object's affordances and the inter-relations between objects and, objects and tools. In an end-state condition, an observer can see the result that can be achieved, but must infer how to achieve this end-state through their own endeavour. In one of our conditions children witness the hands of a model using a series of tools but never see the tools connect with the main apparatus, thus presenting body movements and tool manipulations (but not allowing access to information about the tool to object connection); thus assessing how much children's success is through observation and replication of the bodily actions. Each of these conditions is compared to a whole display in which an observing child sees the model, the tools and the task during the demonstration. Comparisons with this whole display allow one to examine the driving power of each of these elements (object manipulations, end-state, body movements) in a child's observational learning. For example, if a similar level of successful retrieval of a reward or fidelity to specific elements within the display is achieved in one of the manipulated displays compared to the whole display, then we can be sure that this form of information, and the learning process it allows (tools and box only, emulation; tools and hands only, bodily imitation; end-state, goal emulation), is a significant driver in observational learning. Further, by comparing the different manipulated displays, we can establish whether one is more influential in children's observational learning than another.

The Task

Many observational learning studies have been concerned with establishing *how early* children begin to replicate observed information, and so have used actions applied to rather simple tasks, like placing a block into a hole or opening a box by sliding a door left or right. While an analysis of observational learning in these contexts can tell us much about such processes in infants, it is also essential to understand how observational learning occurs as children develop and experience more complex action sequences. Thus the current study extended previous research by addressing how different forms of information affect a child's ability to learn to complete a complex task. The task used was an "artificial fruit" (Whiten, 1998), designed as an analogue of a tool-based naturalistic food processing task faced by apes and children alike. Our "Keyway Fruit" (KW, see Figure 1) was a puzzle box requiring the execution of sixteen consecutive actions to extract a reward held inside. The new and critical aspect of our study was that we showed children video displays that differed in terms of the type of information available. Some children witnessed the whole display with the KW, tools and hands of the model manipulating the tools (thus providing a benchmark from which to comparing to other conditions), in a second condition children saw only the KW being manipulated with the tools but no hands were ever seen (thus the bodily movements had to be inferred), while in a third condition children saw the hands manipulating the tools, but never saw the KW (thus the mechanical causality needed to be inferred). In a fourth condition, children saw a video of the end-state of the manipulation of the KW, with all the apparatus visible as it would be after a successful extraction of the reward. These four conditions were compared to a no-information condition in which children were simply presented with the KW and no other information, thus allowing a baseline of asocial learning to be established.

Figure 1 about here

Like conventional ghost conditions, our ghost control condition removed the agent from the image, but in a more naturalistic way. In a ghost condition, objects move in a "ghostly" way that might strike children as rather odd. In our experiment, children instead saw a tightly focused video view which tracked around the KW to display the critical aspects of the scene while the agent moving the tools was simply out of the frame; such images are similar to the kind children often see on television. For all the video displays the camera moved around the pertinent parts, and children could see previously completed actions, as well as to be completed actions. We developed this as a simpler and more natural use of video images than digitally removing agents, the approach favoured by Huang and Charman (2005). Children as young as 18-months can imitate behaviour they have seen in televised demonstrations, even when no narration is presented (Simcock, Garrity, & Barr, 2011), demonstrating that young children can take information from symbolic media and apply it to real-world objects (Barr & Hayne, 1999) and by 36 months children's abilities to imitate multistep sequences from television demonstrations approaches that of live demonstrations (McCall, Parke, & Kavanaugh, 1977).

Copying hierarchical structure of actions versus style details

As explained above, a child's copying of a series of actions after witnessing a display is often only partial; thus one can ask what influences which features of the display are copied? By manipulating the type of information observed we can establish whether witnessing certain forms of information facilitates the copying of specific types of behaviour. For example, children who witness displays that focus on a model's bodily actions, without the same level of functional information as presented in a ghost control condition, may be more likely to copy action styles (in the present study, whether a model tapped or twisted a tool) as this is a main focus of what has been witnessed.

The two main aspects of action structure we investigated were the hierarchical, sequential structure of the actions (Byrne & Russon, 1998; Flynn & Whiten, 2008; Whiten *et al.*, 2006) and the action "style" (Flynn & Whiten, 2008; Hobson & Lee, 1999). With respect to the first of these, the KW box was designed to allow an examination of the program-level copying of hierarchical action structure; that is the "copying the structural organization of a complex process (including the sequence of stages, subroutine structure, and bimanual coordination), by observation of the behaviour of another individual, while furnishing the exact details of actions by individual learning" (Byrne & Russon, 1998, p. 677). In line with previous studies using the KW, this task allowed an investigation of the imitation of sequential structuring within actions of appropriate complexity (as in copying a series of acts A,B,C versus C,B,A); and (ii) imitation of hierarchical structuring, that goes beyond mere replication of linear sequences, recognizing instead the way in which lower level elements of behaviour are embedded within a higher-level organization. For successful extraction of a reward from the KW, sixteen actions could be performed in multiple ways, but in the displays used in the current study the actions were presented in either of two different hierarchically organised sequences ("hierarchical sequences", for short), that we call the "Row" versus "Column" approaches (Flynn & Whiten 2008; Whiten *et al.*, 2006; see the Methods section for further details). Presenting these two alternative hierarchical sequences allowed us to establish whether the different viewing conditions facilitated or inhibited the acquisition of this type of information. The hierarchical sequence of operation was discernible in all the conditions except the end-state and no information conditions. We predicted, in line with ghost control studies in which a whole display produced the most faithful copying performance, that children who witnessed the whole display would show a higher level of adoption of the witnessed hierarchical sequential structure than children who witnessed other viewing conditions. Further, in line with evidence on a simpler task (Huang & Charman, 2005) we predicted that when the interactions of the tools and apparatus were presented, more copying of hierarchical actions would occur than in conditions that presented information about hands and tools only.

Our study also considered children's adoption of "styles" of specific subsidiary actions, in this case tapping or twisting the tools, based on the viewing condition witnessed. For this it was appropriate to compare only the whole display with the hands-and-tools-only condition, as action styles were present only in these conditions. Bekkering *et al.* (2000) found that, depending on context, different elements of a display can take precedence. For example, action "style" can become the focus of a series of actions in contexts in which the end-state is not emphasised: in conditions in which a child witnessed a demonstration of a mouse hopping and then being placed inside a house, versus a mouse hopping to the same location with no house present, children were more likely to reproduce the hopping when the house wasn’t there (Carpenter, Call, & Tomasello, 2005). We predicted that children would be more likely to copy the action style in the condition in which they saw the hands and tools only, as these action styles would have been a main focus, compared to the whole display that incorporated multiple goals, including these action styles.

Method

Participants

One hundred and forty 3-year-olds and one hundred and forty 5-year-olds participated in this yoked design study. Children within each age group were matched across different conditions according to verbal mental age, as measured by the British Picture Vocabulary Scale (BPVS, Dunn, Dunn, Whetton, & Pintilie, 1997), so that there was no more than three months difference between them and their yoked participants in the other conditions. The mean difference between the yoked participants was one month. Descriptive statistics for the participants in each of the conditions are shown in Table 1; within each age group comparisons across the conditions show no significant difference in chronological age, 3-year-olds, $F(4, 140) = .46$, *ns*., 5-year-olds, $F(4, 140) = .45$, *ns.*

Table 1 about here

Design

A between-group design was used, in which children were assigned to one of several experimental conditions or to a no information control. The four main types of experimental condition differed in the form of information provided in a demonstration video (see Figure 2): (i) the “whole display” showed the KW, tools and hands of the demonstrator (presenting full information), (ii) the “box-and-tools-only display" showed only the KW and tools being manipulated and never showed the demonstrator or the demonstrator's hands (presenting emulation information), (iii) the "hands-and-tools-only display" showed the demonstrator's hands manipulating the tools, but the KW box was never seen (presenting bodily movement imitation) and (iv) the "end-state display" condition showed the KW and tools as they would be after it had been opened, but showed no moves towards this end-state. The final condition was a no information control condition in which no information was given before a participant was presented with the KW. For the video displays, the camera tracked around the hands and/or box so that the pertinent parts of the scene, in line with the display being observed (e.g., a shape being inserted into the front of the lid or the tools being tapped), were presented (videos can be viewed in the Supplementary Material). The displays presented as much of the scene as was possible without including the part of the display that was to be obscured; thus the displays allowed the sequence of actions to be seen as children saw the result of a previous action, as well as the following apparatus to be manipulated (e.g., that there was a space for a tool to be inserted; or that there was a shape into which a tool was yet to be inserted). Also, the final scenes of the video reflected the information being presented, with the whole display and box-and-tools-only display showing the KW open with the keys assembled (details below) next to the box, while the hands-and-tools-only display ended after the image showed the model's hands moving to lift the lid off of the KW.

Figure 2 about here

The whole display, box-and-tools-only and hands-and-tools-only conditions were divided further at two separate levels. For each of these conditions children saw one of two types of display, Row or Column, which differed according to the hierarchical sequence of the actions undertaken. Both the Row and Column displays incorporated the same set of twelve operations on the box (the twelve actions are a result of the sixteen actions minus the four actions on a missing tablet, described later), but these elements were organised into alternative hierarchical sequences. The second level of division related to the manner in which the tools were manipulated; in half of the displays the tools were tapped and in the other half the tools were twisted into tablets as described below. These differences resulted in fourteen different conditions for each age group, as illustrated in Table 1. Videos for each of the video displays can be found in the supplementary material.

Materials

The task used in this study, the “Keyway Fruit” (KW, see Figure 1) was almost completely transparent and explicitly designed to study the imitation of hierarchically-structured, complex actions sequences (Flynn & Whiten, 2008, Whiten *et al.*, 2006). A lid was fitted to the box in the manner of a shoe-box lid held in place by four skewers running through both lid and box. The skewer ends did not protrude so could not be removed by fingers alone. On top of the lid was a row of four hollows of different shapes; each hollow contained a different coloured plastic tablet of the same shape. By stabbing a stick-tool into a hole in each tablet, the tablet could be lifted up. The “key” thus formed could then be inserted into a correspondingly-shaped hollow at the front of the lid, thus pushing backwards one of the skewers that protruded into the hollow. The other end of the skewer could then be grasped and removed. As an incentive to open the KW, a capsule that contained a reward (a sticker) was placed inside.

Procedure

Each participant was seen twice. During the first session children were tested using the BPVS. From this test children's verbal mental ages were calculated and the participants were yoked according to these verbal mental age scores across the conditions. During the second testing session each participant in the experimental conditions sat next to an experimenter in front of a laptop computer. The child was told, "You sit here and watch what happens on the computer because I'm going to let you have a go (pointing to the KW, which was covered with a cardboard box) in a minute." The child proceeded to watch one of thirteen video displays, which showed opening of the KW, or the "end-state display" only.

The video displays differed in three ways, (i) the type of information presented ("whole display", "box-and-tools-only display", "hands-and-tools-only display" or "end-state display"), (ii) the hierarchical order of actions used to open the box (Row or Column), and (iii) the manner in which the tool was inserted into each tablet (twisted or tapped). The videos differed from "ghost control" video displays (Huang & Charman, 2005) that were digitally altered so that the whole scene was presented but certain elements were removed (for example, a block might be seen to float into a hole as the model's hand and arm have been digitally removed). We presented what we see as a more ecologically-valid display by simply focusing the camera on the appropriate part, so that only the box and tools could be seen, or only the hands and tools and not the KW. Such an approach meant that the size of certain elements on the laptop screen were slightly different for each viewing condition (as can be seen in Figure 2), but (and as the results will show) seeing a larger version of certain elements did not necessarily mean that it was more likely to be copied.

In the “Column” approach to the task, a key was made with the first tablet and inserted in the corresponding hollow, then the skewer and the key were removed (picture b in Figure 1). This “Column” of procedures was then repeated with each tablet in turn. In the alternative “Row” displays, the actions were completed consecutively along each row (picture c in Figure 1). Thus, tools were first inserted into all tablets, then all keys into hollows, after which all skewers were removed, followed by all keys. Both the Column and Row video displays had two versions, one which showed the tools being twisted into the holes in the tablets, and one which showed the tools being tapped into the holes in the tablets, by holding it with one hand and tapping down on top with the other hand. The Row/Column distinction allowed hierarchical-sequence imitation to be investigated and the tap/twist distinction allowed the investigation of the imitation of action style.

If a child appeared distracted while watching the video, s/he was told, “Watch carefully because you are going to have a go in a minute.” No reference was made to the KW or the goal of extracting the capsule, in line with previous studies which have used the KW (Flynn & Whiten, 2008; Whiten *et al.* 2006). As with previous studies, after the display finished, each child was presented with the KW and simply told, “Now it’s your turn.” If the child did not interact with the KW, or asked for help, s/he was asked, “What do you think you do? Can you show me?” If the child was still reluctant to continue the experimenter said, “You’re doing really well. Can you show me what you think you do next? Walk all the way round the box and have a look to see if there is anything that you think you do.” After the child’s first attempt, whether successful or not, each child was told, “Let’s watch the video again and then you can have another go.” We intended to use a proviso that children would be discounted if they did not attend to the videos after such prompts; however, it was not necessary to use this rule as all children attended to the videos. The KW was reassembled out of sight and the procedure began again; thus, all participants in the experimental conditions attempted to open the KW twice, and both attempts were preceded by a viewing of the same demonstration.

The KW in the video displays differed slightly to the KW in the testing sessions because in the displays the third tablet (the “T” shaped tablet as shown in Figure 1) was always absent, but when the child was presented with the KW all the tablets were present. Introducing the “missing” tablet in this way tested whether a child was merely copying a chain of actions, in which case the new tablet was predicted to be left until last or ignored. If a child had acquired the hierarchical sequence, the new tablet would be assimilated to a hierarchical order and dealt with during the third position.

In the no information control condition each child was shown the KW and the experimenter said, “Can you see this box? What do you think you do with it? Can you show me?” Then the child was allowed to interact with the KW. If the child didn’t interact with the KW the experimenter followed the same series of prompts as in the experimental conditions.

Coding

All trials were videotaped for later coding. A number of behaviours were of interest: the number of transitions between consecutive actions (the movement from manipulation of a pertinent part of the KW to the manipulation of another pertinent part of the KW) that occurred either along rows or down columns (as described below), the number of tablets into which tools were tapped or twisted, time taken on the task (from the child’s first touch of the box to his/her last touch, success or refusal to participate after prompts) and the position of the manipulation of the tablet that had been missing in the demonstration. Row-wise transitions occurred when a child progressed from one action to the same kind of action on a similar object, such as stabbing a tool into one tablet, then stabbing another tool into a further tablet (one row transition) or removing one skewer, then a second and a third (two row transitions). Column-wise transitions occurred when a child completed consecutive actions concerning the same tablet. Thus, stabbing a tool into a hole in a tablet, placing the key thus made into the front hollow, then removing the key followed by the skewer consisted of three column-wise transitions. The percentage of row-wise transitions for each child was calculated by dividing the number of row transitions by the sum of row and column transitions and then multiplying by 100. Similar calculations were performed for column transitions and for tapping and twisting (tapping moves divided by the number of tapping and twisting moves). An index of the imitation of the hierarchical sequence was calculated by dividing the number of transitions made which were faithful to the method a child had witnessed by the number of total transitions made. A similar calculation was used to provide an index of “action style” imitation. Inter-rater reliability for the sequence of actions for 85 attempts selected at random (16% of the total attempts) produced a Cohen’s kappa of 0.93 for the Row moves and 0.95 for the Column moves. Nearly all discrepancies occurred within the no information control condition.

Results

Four questions were investigated: (i) was there evidence of observational learning and what effect did the different forms of information presentation have on children’s subsequent levels of success?; (ii) did children copy the hierarchical sequence they observed?; (iii) did children incorporate a missing tablet, and if so where?; and (iv) did children copy the action style they witnessed (comparing the whole-display condition and hands-and-tools-only conditions, as no action detail was observed in the box-and-tools-only condition)? Each question was addressed in relation to age effects (3- versus 5-year-olds) and the type of information presented. As there was no effect of gender this is not considered further.

Repeated-measures analyses of variance (ANOVA) showed that the main difference between the children's first and second attempts at the KW was that children made significantly more transitions in their second attempt (M = 5.99) than their first attempt (M = 4.80), $F(1, 259) = 45.13$, $p < .0001$, partial $\eta^2 = .15$. For economy the following analysis will concentrate on the first attempt, with the results of the second attempt only being reported when additional effects were found.

Was there evidence of observational learning and how important was the type of information witnessed for a child's level of success?

Figure 3 shows the percentage of children who successfully opened the KW according to age (3- versus 5-year-olds) and the type of information (whole-display, hand-and-tools- only, box-and-tools-only, end-state and no information control) witnessed. Five-year-olds were more successful at opening the KW than 3-year-olds, $\chi^2(1, N = 280) = 14.55$, $p < .0001$; and children who watched the whole-display were significantly more successful than children in all the other conditions, χ^2 ranged from 10.43 to 35.34, N ranged from 100 to 160, all ps < .001. Children in the box-and-tools-only condition were significantly more successful than children in the hands-and-tools-only condition, $\chi^2(1, N = 160) = 6.94$, $p < .05$. There were no other significant differences.

It is important to compare the behaviour of children in the no information control and end-state conditions with the children in the experimental conditions at this point, as it is not possible to include these children in some of the future analyses because they did not witness a demonstration. There was a significant effect for the type of information a child witnessed (whole-display, hand-and-tools- only, box-and-tools-only, end-state and no information control) in terms of the number of moves made, ANOVA, $F(4, 280) = 10.50$, $p < .0001$, partial $\eta^2 = .13$. Children in the whole-display condition made significantly more moves (M = 6.33) than children in the hands-and-tools-only (M = 3.41), end-state (M = 2.85) and no information conditions (M = 3.90). Children in the box-and-tools-only condition (M = 5.16) made significantly more moves in their first attempt than children in the hands-and-tools-only and end-state conditions (all Bonferonni post hoc tests, $p < 0.05$). Importantly, children in the no information condition spent significantly longer manipulating the KW (M = 6 minutes) than children in the end-state (M = 3 minutes) and experimental conditions (M = 3½ minutes), ANOVA, $F(2, 267) = 27.16$ $p < .001$, partial $\eta^2 = .17$, Bonferonni post hoc $p < 0.05$; suggesting that the difference in the number of moves was not due to a lack of interaction with the KW.

Figure 3 about here

Did children copy the hierarchical sequence they observed?

Children who witnessed the Row demonstrations made significantly more row moves (M = 4.08) than children who witnessed the Column demonstrations (M = 1.87), ANOVA, $F(1, 239) = 30.97$, $p < .001$, partial $\eta^2 = .12$. Similarly, children who witnessed the Column demonstration made significantly more column moves (M = 2.81) than children who witnessed the Row demonstration (M = 1.18), ANOVA, F(1,

239) = 20.16, p < .001, partial η^2 = .08. Note that this second effect does not follow automatically from the first because children can perform moves other than Row and Column ones, for example, moving diagonally across the KW to manipulate a different piece.

Two levels of analysis for the imitation of the hierarchical sequence were carried out: (i) the absolute number of moves that were in line with the hierarchical order witnessed, and (ii) the percentage of moves that were in line with the hierarchical order witnessed. The initial analysis of the absolute number of moves made in line with the hierarchical sequence witnessed showed an effect for age, MANOVA, $F(1, 239) = 19.61$, p < .001, partial η^2 = .08, and the type of information witnessed (whole-display, hand-and-tools- only and box-and-tools-only), $F(2, 239)$ = 16.21, p < .001, partial η^2 = .12. Five-year-olds made significantly more moves in line with the hierarchical order witnessed (M = 4.37) than 3-year-olds (M = 2.51). Children who witnessed the whole-display made more moves in keeping with the hierarchical sequence they witnessed (M = 4.99) than children who witnessed the box-and-tools-only display (M = 3.28) or children who witnessed the hands-and-tools-only display (M =2.06; all Bonferroni post hoc tests p < .05). The second attempt produced the same effects, and in addition, children who witnessed the box-and-tools-only display made significantly more moves in keeping with the demonstration they had witnessed (M = 4.61) than children who witnessed the hands-and-tools-only display (M = 2.59), Bonferroni post hoc tests p < .05.

A measure of the percentage of moves in line with the hierarchical sequence witnessed was calculated (number of moves made which corresponded to the demonstration witnessed divided by the total number of row and column moves made, and multiplied by 100). There was no age effect for percentage of moves in line with the hierarchical sequence witnessed, MANOVA, $F(1, 205)= .83$, *ns*. An effect for type of information (whole-display, hand-and-tools- only and box-and-tools-only) witnessed approached significance at the initial attempt, M (whole-display) = 74% and M (box-and-tools-only) = 57%, $F(2, 205)= 3.03$, $p = .051$. At the second attempt, the lack of effect for the type of information remained, although it approached significance, MANOVA, $F(2, 219)= 2.74$, $p = .07$, but an age effect was found with 5-year-olds producing a higher percentage of hierarchical imitative moves (M = 73%) than 3-year-olds (M = 59%), $F(1, 219) = 7.49$, $p < 0.01$, partial $\eta^2 = .03$; although this effect was weak.

Did children incorporate the missing tablet into a hierarchically-organised approach?

Figure 4 illustrates the position in which children dealt with the missing tablet, allowing an investigation of whether children incorporated this new aspect of the task into a hierarchical sequence. 40% of the experimental groups (whole-display, box-and-tools-only and hands-and-tools-only) incorporated it at the “correct” third position, showing an effect significantly above chance (Binomial test with a test proportion of .25 as the likelihood of incorporating the piece at any of the four positions, $n = 280$, $p < .001$). Also, both 3- and 5-year-olds were more likely than chance to incorporate the third tablet at the “correct” third position, 3-year-olds, Binomial test, $n = 140$, $p < .05$; 5-year-olds, Binomial test, $n = 140$, $p < .05$.

Figure 4 about here

Did children copy the action styles they witnessed?

In order to establish whether there was imitation of style details, children's tool tapping or twisting manipulations were coded. At the first attempt only 16% of the children who witnessed the tools being tapped into the holes copied this tap, and 40% of the children who witnessed the tools being twisted into the holes copied the twist. Although less than half of children produced an action styles, when they did so it was overwhelming faithful to the action style witnessed, rather than adhering to a predisposed action style. Children who had witnessed the tapping, performed tapping, $\chi^2(1, n = 160) = 11.27$, $p < .01$, and children who had witnessed the twisting, performed twisting, $\chi^2(1, n = 160) = 23.33$, $p < .001$. There was no difference between the age groups (3- versus 5-year-olds) in the imitation of detailed actions, $\chi^2(1, n = 160) = .77$, *ns.*: 29% and 38% of 3-year-olds imitated detailed actions during the first and second attempts respectively, while 25% and 43% of 5-year-olds imitated detailed actions during the first and second attempts respectively. Similarly there was no effect for the type of information (whole-display and hand-and-tools- only) witnessed on the level of detail imitated, $\chi^2(1, n = 160) = .74$, *ns.*: 31% and 45% of children who witnessed the "whole-display" imitated detailed actions during the first and second attempts respectively, while 25% and 35% of children who witnessed the "hands-and-tools-only" display imitated detailed actions during the first and second attempts respectively. There was no association between children's ability to open the KW and their adoption of the detailed actions for the different age groups, 3-year-olds, $\chi^2(1, n = 80) = .41$, *ns.*; 5-year-olds, $\chi^2(1, n = 80) = 1.17$, *ns.*, or in the type of information witnessed, whole-display, $\chi^2(1, n = 80) = .27$, *ns.*; hands-and-tools-only, $\chi^2(1, n = 80) = .12$, *ns.*.

Discussion

Our aim was to establish the role of different aspects of what children witness during witnessing completion of a complex task on their subsequent imitation of hierarchical-sequence information and action style, as well as their success at completing the task. Importantly, our new approach to video manipulation successfully allowed us to address these questions.

Dissecting imitation versus emulation

Considering the level of success alone, children who witnessed a display which contained all the information were significantly more successful at opening the KW than children who witnessed other displays; and children who witnessed the box-and-tools-only information (which provided emulative information about how the objects could be moved, but lacked information about the bodily movements necessary to make such movements) were significantly more successful at opening the KW than children who witnessed hands-and-tools-only information (which provided imitative information about how the hands could be moved in relation to the tools, but lacked the emulative information about how the tools and box interacted). Such findings are in line with previous research with younger children on simpler tasks, and extends this work to more a more complex task (Hopper, *et al.* 2010; Tennie, *et al.* 2006). Thus in terms of general success none of our manipulated forms of information provided the same level of support to the learner as that witnessed in the whole display, but when comparing manipulated displays, emulative information regarding object manipulations was more useful for success on the KW than information regarding the imitation of hand movements.

As well as reduced success in extraction of the reward from the KW for children who witnessed the hands-and-tools-only display (presenting information about a model's hand movements in relation to tool manipulations, but lacking information about how the objects interacted), there was also a reduction in the copying of hierarchical-sequence information. Such a finding is consistent with the fact that although these children witnessed the spatial sequence of the actions, it was less clear how this sequence of actions related to the KW and successful extraction of the reward. In contrast, the lack of fidelity to the hierarchical sequence and the reduced level of success for children who witnessed displays that contained box-and-tools-only (emulative) information in comparison to the whole displays is surprising, as the effect of the sequence of tool manipulations in relation to the KW in the box-and-tools-only displays was visible, along with information about the previous and subsequent actions. The only element that was lacking from this display was the model's hands and the hand movements. Thus, it appears that displays that present information regarding how objects interact with one another in a complex task (but don't display a model's hands), are not equivalent to a whole display for children as young as those we studied.

A number of possibilities might explain this significant finding. First, it could be that the difference in size of the elements in the video presentations caused the reduction of hierarchical sequence information reproduction. As Figure 2 shows, the display containing the box-and-tools-only information provided a slightly larger version of the KW, while the whole display contained the same information and also the model's hands and so, as a result the KW is slightly smaller on the screen. For both displays the camera tracked to focus on the workings of the pertinent part of interest, as well as aspects within the immediate frame (previously manipulated item, and subsequent action item). It seems unlikely that having a larger view of the point at which specific information is given, in this case hierarchical sequence information, provides less information to an observer, and we do not believe that the different size of the KW in each of the displays is the cause of the disparity in the adoption of hierarchical sequence information or success.

The critical distinction between the two displays was that one contained the model's hands, the tools and the KW, while the other only contained the tools and the KW. Perhaps seeing the model's hands provided children with some reference about where they should put their hands in relation to the tools. Alternatively, having a "social" element, another person (even just their hands), within the display may facilitate greater focus on the display, as recorded for 24 month-olds (Slaughter, Nielsen, & Enchelmaier, 2008). Future work could address the importance of the presence of the model's hands as a social aspect of the scene, perhaps by having hands in the scene that are not active. Hopper *et al.* (2008) used an enhanced ghost control, as described in our introduction, albeit with a much simpler task in which a door was moved left or right using fishing wire, with a non-active child sitting passively waiting for the reward to exit the box present within the scene. She found that children copied the movement of the door in their first response for both a full demonstration and an enhanced control condition; but across all trials a higher level of matching occurred after the full demonstration compared to the enhanced ghost condition, with the level of matching being similar in both the standard ghost control that did not contain an additional social element and the enhanced ghost control. In contrast to the KW task used in the current study, Hopper *et al.* (2008) used a very simple task illustrated by the fact that six out of eight children who were presented with the task in a no information condition were able to successfully extract the reward, a level of success that did not significantly differ to the success of the full demonstration group. Thus it remains unclear whether attempting an enhanced ghost control condition by adding a set of passive hands in the current study's box-and–tools-only condition with our more complex task, thus signalling a social aspect to the demonstration but providing no information about how these hands move the tools, would result in more initial copying but less fidelity over trials (as in Hopper et al. 2008) or whether the greater complexity of the KW would produce different results.

Copying hierarchical structure of actions versus style details

Overall, children showed fidelity to whichever of the two hierarchical action sequences they witnessed. A developmental change was seen in the replication of the hierarchical sequences, as 5-year-olds showed a stronger tendency than did 3-year-olds to adopt the witnessed hierarchical sequence. Such a difference may be explicable by 5-year-olds' more advanced memory and/or cognitive skills.

Access to information on actions, tool operations and the object affected also influenced the adoption of hierarchical sequence information; children who witnessed the whole display made significantly more moves in line with the hierarchical sequence information that they witnessed than children who witnessed more limited displays. Interestingly, by the children's second attempt, those who had witnessed the tools-and-box-only display (which provided emulative information about how the objects could be moved, but lacked information about the bodily movements necessary to make such movements) reproduced significantly more actions in line with the hierarchical sequence information that they had witnessed than children who had seen the hands-and-tools-only display (which provided imitative information about how the hands could be moved in relation to the tools, but lacked the emulative information about how the tools and box interacted). It appears that with some personal experience with the task during their initial attempt and then a subsequent demonstration, children were able to discern and reproduce more of the hierarchical sequence information, but this was true only when the witnessed display contained functional information about the KW (the box-and-tools-only display), and not when it contained information about bodily movements and tool manipulations (the hands-and-tools-only display).

Comparing the whole display and the hands-and-tools-only display allowed the reproduction of the different action styles, tapping versus twisting the tools, to be investigated. It was predicted that as the hands-and-tools-only displays contained little information beyond how the tools were manipulated, there should be significantly more replication of these action styles in this condition than in the whole display, which contained a much richer and more varied series of information about a number of different goals including a clearer demonstration of the hierarchical sequence information. Carpenter *et al*. (2005) and Bekkering *et al.* (2000) showed that when there are competing goals, action style will not be replicated at the expense of an end-state. In the current study, of those children who did reproduce either tapping or twisting, there was fidelity to the method that they witnessed. However, this replication of action style was not dictated by either age or, more surprisingly, by the type of information that a child had witnessed. That is, children who witnessed the hands-and-tools-only information were not more likely to imitate the action styles than children who witnessed the whole display. It was also not the case that children who copied the action styles did so at the expense of learning more about how to open the KW; there was no relation between copying the action style and the successful retrieval of the reward from the KW.

The lack of a relation between the number of goals witnessed in a display (in this case the whole display contained more goals than the hands-and-tools-only display) and the replication of the action style witnessed is difficult to explain. It may be that the complexity of the task presented to the children in the current study affected their replication of the action style, as previous studies in relation to the organisation of the replication of goals have used simpler tasks (moving a toy mouse along a path and placing it in a house, Carpenter *et al.*. 2005; touching a dot on a table with one's hand, Bekkering *et al.*, 2000). However, such an explanation does not seem logical, insofar as the KW was a more complex task, and thus had more sub-goals for the children who watched the whole display, while those who watched the hands-and-tools-only display will have seen fewer sub-goals, and so could have been expected to replicate the action style more; but this did not happen. Alternatively, it may have been that children understood the affordance of the KW and the tools, such that although children in the hands-and-tools-only condition saw the tools being either tapped or twisted, they appreciated, once presented with the KW, that the tools could be inserted into the holes in the tablets without either tapping or twisting, and that the ultimate goal was to insert the tools into the holes in the tablets. If this is the case, this study suggests that the imitation of action styles is not only flexible in relation to the goals witnessed within a series of actions, but also in terms of the children's understanding of the affordances of elements within the task.

Conclusions

Our aim was to establish the relative importance of different aspects of a display during young children's observational learning of a complex task. We focused on children's acquisition of information with regard to three different aspects of the display: the goal of removing the reward from the KW, the hierarchical structure of the sequence of actions the model applied, and their action style. Children who witnessed a display containing all the information in a scene were significantly more likely to extract the reward from the KW, and to produce hierarchical sequences of actions, than children who witnessed either box-and-tools-only (which provided emulative information about how the objects could be moved, but lacked information about the bodily movements necessary to make such movements) or hands-and-tools-only information (which provided imitative information about how the hands could be moved in relation to the tools, but lacked the emulative information about how the tools and box interacted), or who witnessed only information about the end-state or no information. A similar pattern of results was produced for the acquisition of hierarchical sequence information, with children who witnessed the whole display acquiring hierarchical sequence information more quickly than those who witnessed either box-and-tools-only information or hands-and-tools-only information. Finally, the replication of the action styles witnessed was not predicted by the information a child witnessed, or the child's age. Thus, our overall conclusion is that young children's observational learning draws simultaneously on several different sources of information that they witness within a scene; and even when much functional information is present, as in demonstrations of the objects interacting in our KW task, observers cannot always successfully extract a reward or replicate the hierarchical sequence of a series of actions. Although there was a trend for five-year-olds to cope with partial information better than the three-year-olds (as can be seen in Figure 3) this failed to achieve statistical significance. Whether multiple sources of information gain more redundancy for older children remains to be systematically studied: for another quite different task (making a paper aeroplane that flies well, Caldwell &

Millen, 2009) this has been shown to be the case for young adults. However it appears that in observational learning of children as young as those we studied faced with a complex task, as in many other parts of psychology, “the whole is greater than the sum of its parts”.

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Table 1. Descriptive statistics for the participants in the different conditions.

	Whole-display				Box-and-tools-only				Hands-and-tools-only				End-State	No Info
	Row		Column		Row		Column		Row		Column			
	Tap	Twist	Tap	Twist	Tap	Twist	Tap	Twist	Tap	Twist	Tap	Twist		
	n=10	n=10	n=10	n=10	n=10	n=10	n=10	n=10	n=10	n=10	n=10	n=10	n=10	n=10
3-year-olds														
Mean Age	44	42	42	43	41	43	43	42	42	42	41	43	42	41
SD	*3.39*	*2.55*	*3.13*	*2.71*	*2.91*	*3.03*	*2.75*	*3.38*	*3.27*	*3.10*	*3.61*	*3.02*	*3.37*	*2.16*
Female:Male	6:4	6:4	4:6	3:7	3:7	7:3	4:6	7:3	6:4	4:6	5:5	3:7	4:6	5:5
Mean VMA	38	38	38	38	38	38	38	39	38	39	38	39	38	38
SD	*4.64*	*4.99*	*6.04*	*5.53*	*4.55*	5.49	*4.66*	*5.14*	*4.84*	*5.04*	*5.76*	*5.36*	*5.21*	*4.63*
5-year-olds														
Mean Age	66	65	65	64	64	64	64	66	65	64	66	65	64	65
SD	*3.34*	*3.96*	*3.82*	*3.31*	*3.28*	*3.17*	*2.88*	*3.33*	*3.84*	*3.59*	*4.22*	*3.18*	*3.31*	*3.08*
Female:Male	5:5	3:7	3:7	3:7	5:5	8:2	8:2	4:6	5:5	2:8	6:4	7:3	7:3	5:5
Mean VMA	63	64	64	64	64	64	63	64	64	64	64	64	64	64
SD	*12.25*	*13.40*	*12.20*	*12.64*	*13.12*	*12.85*	*12.37*	*12.78*	*12.41*	*12.54*	*13.01*	*12.04*	*12.09*	*12.94*

Note. Chronological age and verbal mental age are presented in months, SD standard deviation, VMA Verbal Mental Age

Figure Captions:

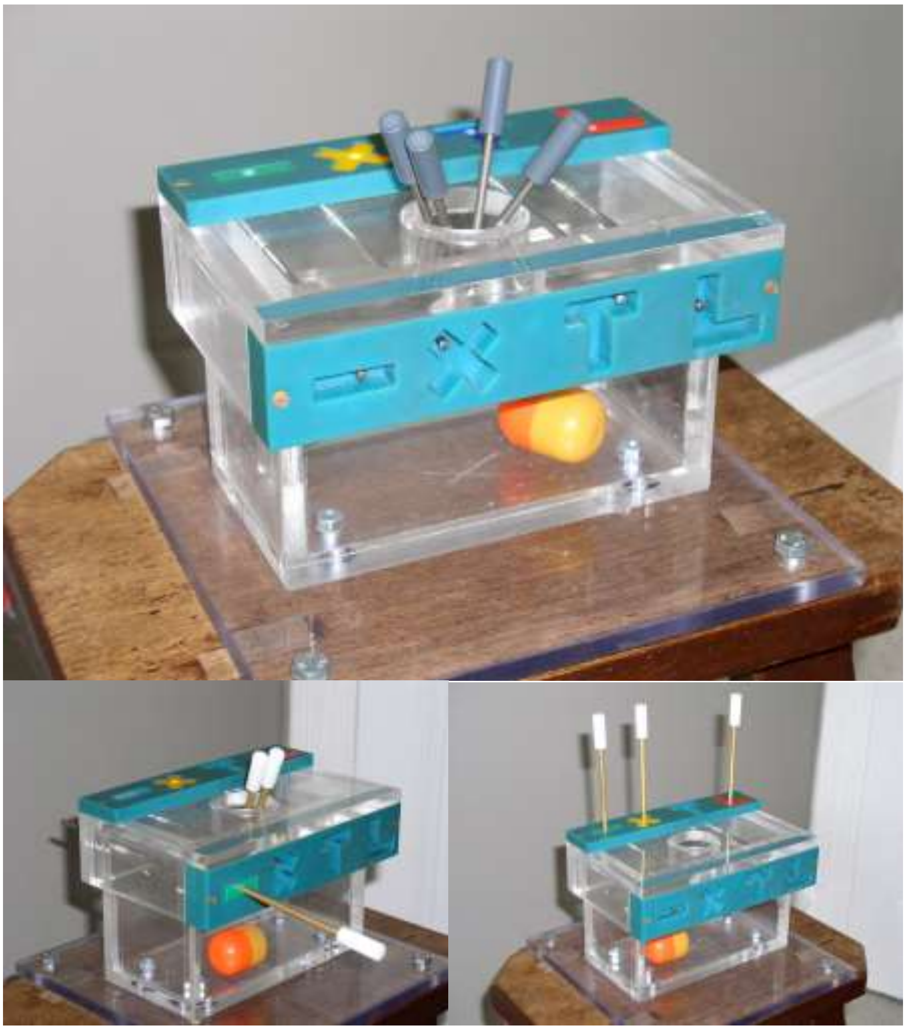
Figure 1. Keyway fruit (a) as presented at the beginning of testing, with the lid held in place by four skewers running through the lid and box (one of the skewers can be seen most clearly in c). In order to open the KW, tools need to be inserted into holes in a series of plastic shapes on the upper face of the KW (as can be seen in b). These "keys" can then be inserted into a series of similarly-shaped hollows at the front-face of the lid (seen most clearly in c). As a result of inserting the keys into the front hollows the skewers, which are holding the lid in place, move through the back of the lid allowing them to be pulled out with one's hands. The "keys" can then be removed. Once this sequence of actions has been completed with all the KW shapes the lid can be taken off, allowing the reward to be retrieved. This series of actions could be undertaken in a Column-wise sequence, in which all the actions were performed on one Perspex shape, as partly shown in (b), in which the tool is inserted into a hole in a shape, that shape is placed in the hollow, the corresponding skewer is removed, and the key removed from the hollow or in a Row-wise sequence, in which all of the same type of action were performed together, e.g., all the tools are inserted into the holes as shown in (c) and then all shapes inserted into hollows.

Figure 2. Stills from the video displays, (a) whole display, (b) box-and-tools-only display, (c) hands-and-tools-only display, and (d) the end-state display.

Figure 3. Rate of successful extraction of the reward from the KW across age and experimental condition, whole display (WD), box-and-tools-only (B&T), hands-and-tools-only (H&T), end-state (ES), no information (No Info). Note, Children in the no information condition did not have a second attempt.

Figure 4. Number of children manipulating the missing tablet at different positions in their sequence of actions.

Figure 1



(a)

(b) (c)

Figure 2

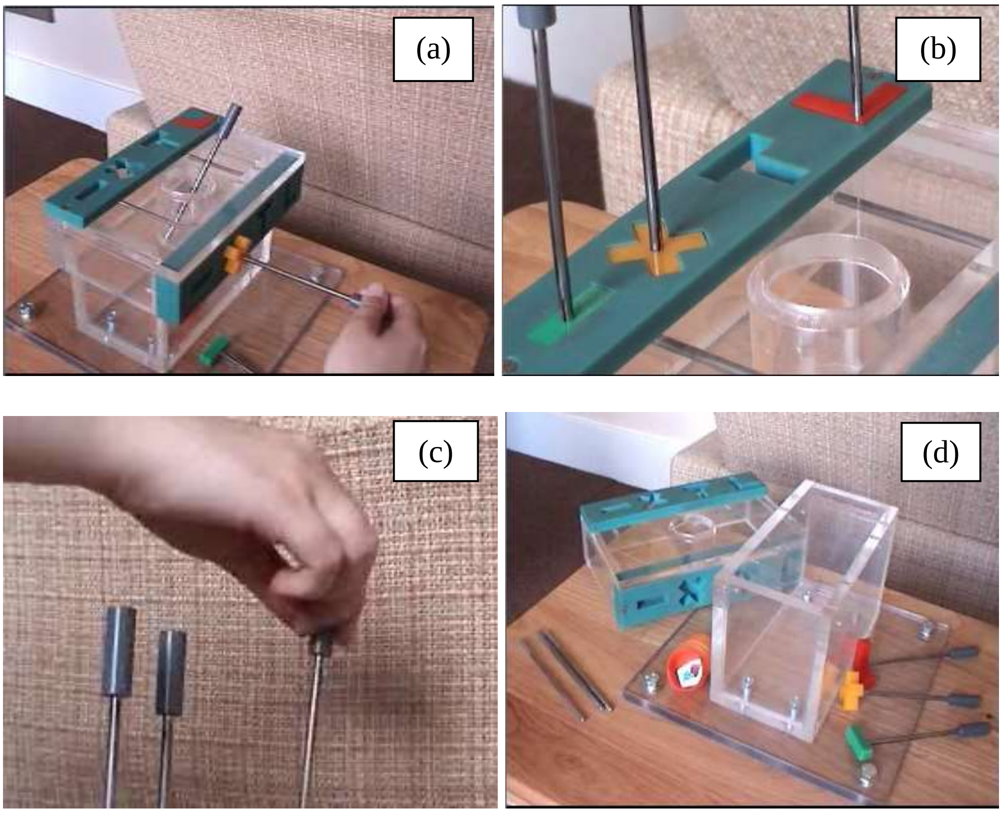
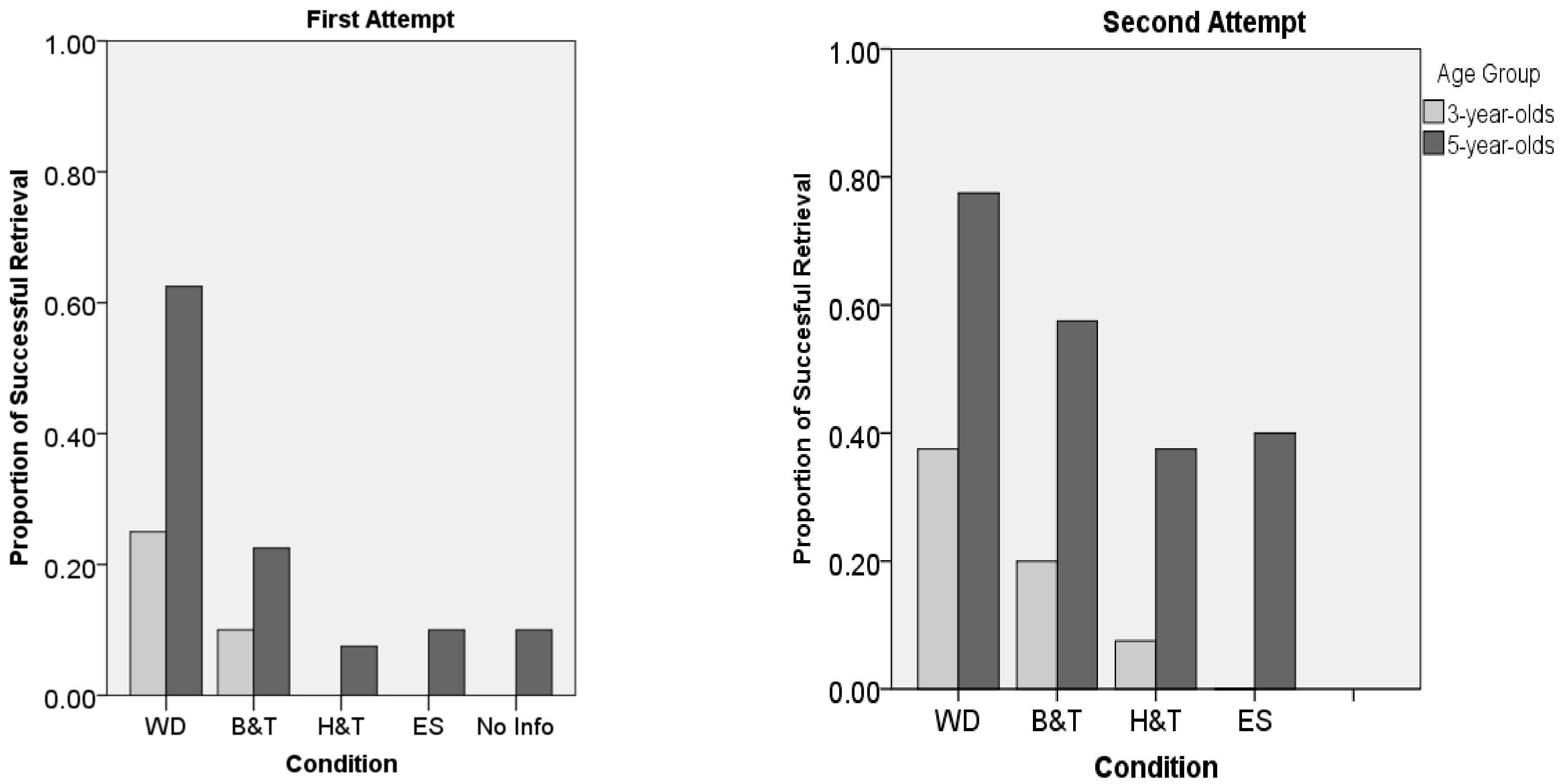
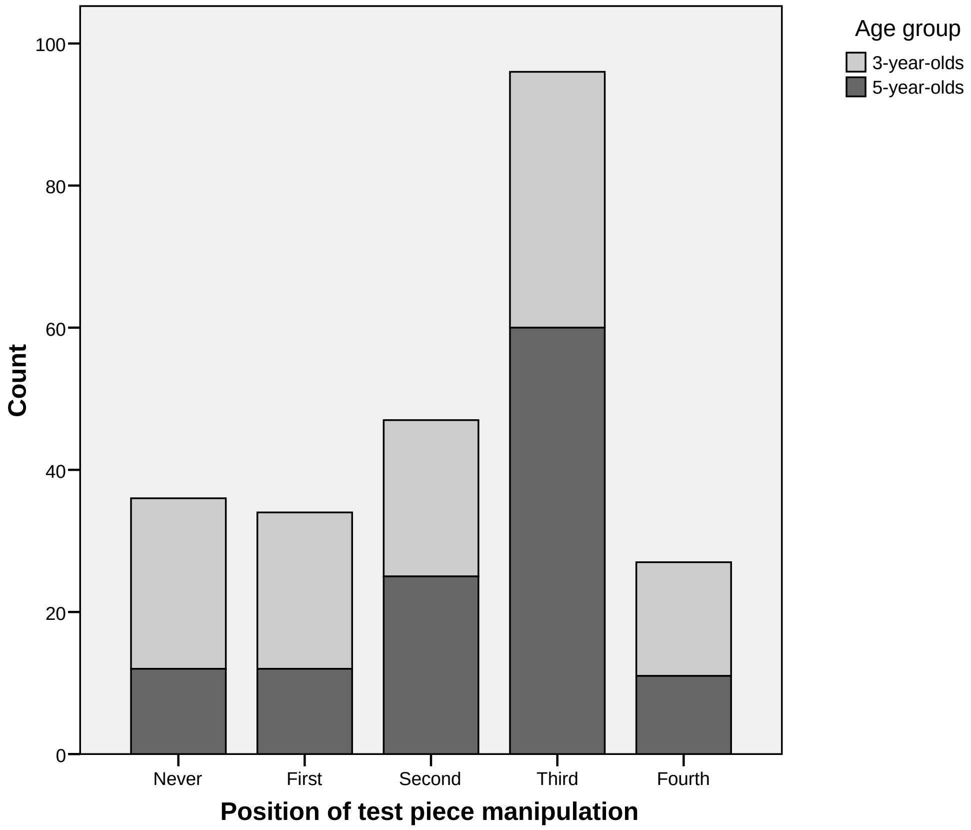


Figure 3



First Attempt
Proportion of Successful Retrieval
1.00
0.80
0.60
0.40
0.20
0.00
WD
B&T
H&T
ES
No Info
Condition
Second Attempt
Proportion of Succesful Retrieval
1.00
0.80
0.60
0.40
0.20
0.00
WD
B&T
H&T
ES
Condition
Age Group
3-year-olds
5-year-olds

Figure 4


Age group
3-year-olds
5-year-olds
100
80
60
40
20
0
Count
Never
First
Second
Third
Fourth
Position of test piece manipulation