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Conditional Discrimination in Young Children: The roles of Associative and Relational Processing

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Abstract

Two experiments examined conditional discrimination in 4- to 6-year-olds. Children learned to choose one of two objects (e.g., circle) when the background was (say) red and to choose the other object (e.g., triangle) when the background was (say) blue. Awareness was assessed and interpreted as a marker of relational processing. In Experiment 1, most 4- and 5-year-olds did not reach the learning criterion. Children in Experiment 2 solved simpler reversal learning problems before the conditional discrimination problems. Most 4- to 6-year-olds reached criterion, but they did not necessarily demonstrate awareness suggesting that reversal learning and conditional discrimination can be acquired through associative or relational processing. Relational processing increased with age and was used more on simpler problems. Fluid intelligence predicted problem 2 performance in children who used relational (not associative) processing on problem 1. Prior experience with simpler problems and awareness of relational structure are influential in children's conditional discrimination.

Conditional Discrimination in Young Children: The roles of Associative and Relational Processing

Conditional discrimination involves learning that a particular response will be rewarded and another response will not be rewarded in one context and that the contingencies will be reversed when the context changes. More generally, C1: A+ B-; C2: A- B+, where C1 and C2 represent two different contexts, A and B represent two different responses, + and - indicate whether the responses lead to positive or negative outcomes. Conditional discrimination is required in many everyday situations. For example, telling jokes is rewarded at parties, but not at funerals, whereas crying is acceptable at funerals, but not at parties. Adult humans appear capable of conditional discrimination in that they modify their responses as a function of context. They can also discuss and evaluate the appropriateness of their own and others' responses in different contexts. This suggests that their mental representations of conditional discrimination are accessible to conscious awareness.

Whereas adults' conditional discrimination competence seems self-evident, young children's capacities for conditional discrimination are less well understood. The experiments reported here examined conditional discrimination in 4- to 6-year-old children. Our aims were to elucidate the conditions under which children are able to learn a conditional discrimination; to determine their level of awareness of what they have learned; to determine the extent to which their performance improves on subsequent problems (inter-problem learning); to examine the potential role of fluid intelligence in inter-problem learning; and ultimately to achieve a better understanding of the cognitive processes that underlie children's conditional discrimination.

Research in young children's conditional discrimination dates back to at least the 1960s. Gollin and Liss (1962) examined conditional discrimination in three age groups of children (3½ to 4 years, 4½ to 5 years, 5½ to 6 years), using a methodology that was adapted from Lashley's (1938) research with rats. The stimuli were geometric objects (circle, triangle) and the two contexts were the black and striped backgrounds on which the objects were presented. In the discrimination training phase, children were rewarded for selecting one of two objects, which were always presented in the same context. Once children had reached the learning criterion they progressed to the reversal phase. The objects were presented in the context that had not been used in discrimination learning. Children were rewarded for selecting the previously unrewarded object. After reaching the reversal criterion they progressed to the conditional discrimination phase. The displays from discrimination and reversal phases were presented on odd-numbered and even-numbered trials, respectively. Children of all ages learned the discrimination, but the youngest group made more reversal errors. In the youngest, middle, and oldest groups, 10%, 17% and 54% of children, respectively reached the conditional discrimination learning criterion. These age differences were attributed to the difficulty of understanding the reversal principle (one object is correct with one background and the other object is correct with the other background) and keeping track of which form is correct with which background.

Rudy, Keith, & Georgen (1993) used a similar three-phase procedure to examine conditional discrimination in 4-year-olds (46 to 52 months) and 5-year-olds (57 to 71 months). All children met criterion in the discrimination and reversal phases, whereas 11% of 4-year-olds and 89% of 5-year-olds did so in the conditional discrimination phase. Rudy et al. interpreted their findings in terms of solutions based on elemental versus configural associations. Elemental associations are sufficient for correct responding during discrimination (e.g., A+, B-) and reversal (e.g., A-, B+) because the significance of the stimulus elements remains consistent across trials. To succeed on conditional discrimination, children must be capable of solutions that involve associations between configurations of context and object (e.g., C1/A) and the reinforcement values (+, -), that is (C1/A)+, (C2/B)+, (C2/A)-, (C1/B)-. Notice that each configuration is unique. For example, C1/A is not the same as C2/A, which is not the same as C2/B. Conditional discrimination is learned when each unique configuration is associated with its reinforcement value (+ or -). Rudy et al. linked their findings to the maturation of the neural systems that underpin elemental versus configural associations.

Gollin (1965) tested children on conditional discrimination without prior training on either simple discrimination or reversal learning. Children were trained on both contexts simultaneously (C1: A+ B-; C2: A- B+) from the outset. The 5½ to 6-year-old children performed above chance level only in the runs-of-5 condition where 47% children reached criterion. The performance of younger children (3½ to 4 years; 4½ to 5 years) did not exceed chance level, and just two children in each age group (13%) reached criterion.

These studies showed that conditional discrimination is difficult for children younger than 4½ years. The majority of 5- to 6-year-olds succeeded when the task was decomposed into separate components (discrimination, reversal, conditional discrimination) that could be learned in sequence (Gollin & Liss, 1962; Rudy et al., 1993) but a minority of 5½ to 6-year-olds succeeded when both contexts were presented simultaneously (Gollin, 1965).

Rudy et al. (1993) interpreted age differences in conditional discrimination in terms of two types of associative processing, elemental versus configural. An alternative explanation that was not considered previously is that conditional discrimination involves relational processing. According to the theory proposed by Halford, Wilson and Phillips (1998b; 2010) relational knowledge has many properties that characterize higher cognition. It is accessible to consciousness, it supports transfer based on structural correspondence, and it is effortful and imposes a working memory demand. These properties will be described further.

Relational systems represent structure explicitly (Halford, et al., 1998b; 2010). Relational representations of conditional discrimination would include three slots corresponding to context, object and outcome. The slots function as variables that can be filled in various ways. For a problem in which two objects (circle, triangle) are presented on red and blue backgrounds, and outcomes are happy or sad faces, the slots would be filled as follows: *red background, circle, happy face*; *red background, triangle, sad face; blue background, circle, sad face*; *blue background, triangle, happy face*. If an explicit relational representation is constructed during acquisition, its components will be accessible and available to conscious awareness (Halford et al., 1998; 2010). This would allow children to retrieve the context, given the object and the outcome, to retrieve the object, given the context and outcome, and to retrieve the outcome, given the context and the object.

Explicit representation of relational structure enables analogical mapping (Gentner, Holyoak & Kokinov, 2001; Gentner 2010; Halford et al., 2010) and transfer to isomorphs. That is, the structure learned in one problem can be mapped to a second problem that has the same form, but different surface features. To the extent that children construct explicit representations of the relational structure their performance on subsequent problems should be facilitated, that is inter-problem learning should occur. Inter-problem learning was not addressed in the studies reviewed above because a single problem was presented. Configural processing would support learning within a single problem (Rudy et al., 1993), but it would not provide a strong basis for inter-problem transfer or for awareness. For example, if children form configurations (e.g., red background/circle, blue background/triangle etc.) and associate each with an outcome (+ or -), the components (e.g., red and circle) will not be accessible. They are like ham and peas in a drop of soup, the combined flavours are recognisable but the individual flavours probably are not. When children receive another problem with different elements they will form new configurations (e.g., green background/rectangle, yellow background/oval etc). It is difficult to see any similarity between configurations red background/circle (problem 1) and green background/rectangle (problem 2). It is easier to recognise the structural correspondence between these problems if they are represented as relations in which the components are identifiable. Theories of analogical mapping (Gentner, 2010; Halford et al., 2010) predict that transfer can be made on this basis and empirical findings (Halford, Bain, Maybery & Andrews, 1998a) support the prediction.

The effortful nature of relational processing is captured by the relational complexity metric (Halford et al., 1998b). Complexity corresponds to the number of variables related in a cognitive representation, or the number of slots to be filled. Unary relations have a single slot, as in class membership. The fact that Fido is a dog can be expressed as *dog*(Fido). Binary relations have two slots. An example is *larger-than*(elephant, mouse). Ternary relations have three slots as in *arithmetic addition*(2,3,5). Quaternary relations have four slots, as in *proportion*(2,3,6,9). Relational processing imposes a demand on limited cognitive resources. This is supported by research demonstrating that more complex relations impose higher loads than less complex relations (Andrews, Birney, & Halford, 2006; Andrews & Halford, 2002; Andrews, Halford, Bunch, Bowden & Jones, 2003; Andrews & Todd, 2008; Birney & Halford, 2002; Birney, Halford & Andrews, 2006; Halford, Baker, Mc Credden, & Bain, 2005; Viskontis, Holyoak, & Knowlton, 2005). In contrast, associative learning imposes low demands on processing resources (Litman & Reber, 2005).

Relational complexity (RC) theory (Halford et al., 1998b) incorporates two strategies that can sometimes be used to reduce complexity and processing load. Segmentation involves breaking down complex tasks into less complex components that do not overload capacity. For example, conditional discrimination entails three variables (context, object, outcome) so it is ternary-relational. When the context is held constant, as it is in discrimination and reversal learning, complexity is reduced to binary-relational, because there are only two variables (object, outcome) to consider. Conceptual chunking involves recoding concepts into fewer variables (Halford et al., 1998b). The distinction between relational and configural processing is related to conceptual chunking because forming configurations effectively collapses two variables (context, object) into one. This reduces complexity and processing load, but the components will be less accessible with configural processing.

Conditional discrimination tasks are similar in some respects to task switching procedures and to the Wisconsin Card Sorting Task (WCST, Heaton 1981) and the Dimensional Change Card Sorting task (DCCS, Zelazo, Müller, Frye, & Marcovitch, 2003) which are widely used to assess executive function in adults and children, respectively. In the WCST, cards depicting objects that vary in colour, shape and number are sorted according to one dimension at a time. Participants use feedback about the accuracy of their responses to discover the sorting rule. At various points in the procedure, the researcher changes the sorting rule without informing the participant. Perseverative errors occur if participants continue to sort by the first rule instead of switching to the new rule. Like conditional discrimination, WCST involves rule induction and rule use.

In the DCCS the objects depicted on the cards vary along two dimensions (color, shape). Children are informed of the current sorting criterion, rather than having to discover the rule. Children under 4 to 5 years of age sort correctly using the first rule, but have difficulty shifting to the second rule (Zelazo et al., 2003). For example, in the color game children would be able to sort a red boat with red flower, and a blue flower with blue boat. However they would experience difficulty in the shape game in which the red boat must be sorted with the blue boat and the blue flower must be sorted with the red flower. Cognitive Complexity and Control-Revised (CCC-R) theory (Zelazo et al., 2003) attributes the difficulty of the DCCS to rule complexity. Use of more complex rules requires reflection on (and awareness of) less complex rules. The DCCS requires a higher-order rule that integrates pairs of less complex rules into a rule hierarchy. The higher-order rule is necessary to distinguish between the rule pair that is relevant in the color game and the rule pair that is relevant in the shape game. A similar analysis could be applied to conditional discrimination whereby a higher-order rule would be used to distinguish between the object-outcome rules that apply in the two contexts.

The DCCS has been also analysed using RC theory. The analysis showed that the standard task is ternary-relational and it is resistant to segmentation. Halford, Bunch and McCredden, (2007) demonstrated that 3- and 4-year-olds who failed the standard DCCS succeeded on a modified version of the task. The modifications facilitated segmentation and reduced effective complexity from ternary- to binary-relational. Thus the standard DCCS and conditional discrimination are comparable in complexity, but DCCS involves rule use whereas conditional discrimination also involves rule acquisition.

Research in other content domains has also shown that ternary-relational processing (Andrews & Halford, 1998; 2002; 2011; Bunch, Andrews & Halford, 2007; Halford & Andrews, 2011; Halford, Andrews, Dalton, Boag & Zielinski, 2002; Halford, Andrews & Jensen, 2002) and the capacity to deal with higher order rules (Frye, Zelazo, & Palfait, 1995; Kerr & Zelazo, 2004; Zelazo, Jacques, Burack & Frye, 2002) emerge by a median age of 4½ to 5 years. Younger children succeed on comparable tasks at lower levels of complexity. Therefore complexity theories predict that relational processing in conditional discrimination will be more evident in children aged 5 years and above than in younger children who might rely more on configural processing.

Experiment 1

The aims of Experiment 1 were to examine whether 4- and 5-year-olds can solve conditional discrimination problems without prior training on discrimination and reversal learning, and to assess children’s awareness of their learning. Intra-problem learning would be evidenced by a systematic increase in response accuracy across trial blocks within the problems. Intra-problem learning would be consistent with both configural associative and relational processing. Awareness of relational structure was assessed using questions posed after the problems. Examples are shown in Table 1. If children construct explicit representations of the relational rule structure, then they should demonstrate awareness of what they have learned. This prediction is based on the accessibility property of relations in RC theory (Halford et al., 1998b) and on CCC-R theory (Zelazo et al., 2003) in which construction of higher-order rules depends on reflection. To the extent that children use relational processing (as indicated by their awareness), there should also be evidence of inter-problem learning (higher accuracy on problem 2 than problem 1). If children use configural processing, they would be expected to learn the conditional discrimination, but they would not be expected to demonstrate awareness of what they have learned. Configural learning would not provide the basis for inter-problem learning based on structural correspondence.

Method

Participants.

Participants were 24 children. The twelve 4-year-olds (7 boys, 5 girls) had a mean age of 4 years 5 months (*SD* = 3.68 months). The twelve 5-year-olds (7 boys, 5 girls) had a mean age of 5 years 4 months (*SD* = 3.55 months). The children were recruited from a privately run child care centre and a state run preschool in the Gold Coast region of Queensland, Australia.

Materials and procedures

Conditional Discrimination problems. The two problems were presented on a Dell latitude laptop computer (30 cm × 25 cm screen). The stimulus displays consisted of two objects on a colored background. In one problem, the objects were a circle and a triangle, which were presented on either a red or blue background. In the other problem, the objects were a rectangle and an oval, which were presented on either a green or yellow background.

The objects were approximately 4cm in width or diameter. They were presented side by side on the screen. There were also two feedback displays. The positive feedback display consisted of a black line drawing of a single happy face. The negative feedback display consisted of black line drawing of a single sad face. The faces were displayed in the centre of the screen on a white background.

Each problem consisted of two practice trials and four or six blocks of 12 test trials (i.e., maximum of 72 test trials per problem). On each trial, two objects were presented on a colored background. Children pressed the left shift key to select the object on the left side of the screen and the right shift key to select the object on the right side. Positive feedback (happy face) was presented following correct responses. Negative feedback (sad face) was presented following incorrect responses. The experimenter explained the feedback after each practice trial of the first problem. For example, if the child chose correctly, the experimenter would say, “That’s right, the background was red and you chose the triangle, so the happy face came onto the screen. Try to get another happy face next time.” If the child chose incorrectly, the experimenter would say “That’s not right, the background was red and you chose the circle, so the sad face came onto the screen. Which one should you have chosen to get a happy face? Try to get a happy face next time.” On subsequent trials, non-specific encouragement was provided (e.g., Keep going, you’re working well).

The objects were displayed until the child responded, or for a maximum of 60 seconds. Each object-background combination and its left-to-right reversal appeared once in the first, second and third sets of four trials within each 12-trial block. Children were instructed to obtain as many happy faces as possible. The computer program incorporated a learning criterion which was applied after each trial block. Four or more correct responses out of six were required for each background color. The probability of success on any single trial was .5 because there were two response options. According to the binomial distribution, the probability of responding correctly to four or more trials for each background by chance alone is $p = .11$. This is the probability level for each 12-trial block. All children completed the first four trial blocks (48 trials). Two additional trial blocks were presented to children who had not reached the learning criterion after block 4. Children were credited with criterion-level performance if they reached the criterion and maintained that level of performance on subsequent trial blocks. The joint probability of reaching and maintaining criterion level performance depends on the trial block on which the criterion was first met. For example, the probability of reaching criterion on block 2 and maintaining it on blocks 3 and 4 is $p = .001$. The probability of reaching criterion on block 3 and maintaining it on block 4 is $p = .012$.

Awareness questions. Table 1 shows examples of the three question types (outcome, object, background) for one of the problems. Children responded to twelve questions after each problem. One third of the children within each age group received the outcome questions first, one third the object questions first, and one third the background questions first. The order within each subtype was random. For each problem, there were six laminated cards (8 cm square). Each card depicted an object (circle, triangle, rectangle, or oval), a background color (red, blue, green, or yellow) or an outcome (happy or sad face). The four cards relevant to the question were presented. For example, during the object questions, cards depicting one color and one outcome were displayed as they were mentioned in the question. Then the cards depicting the two objects were added. One point was awarded for each correct verbal response or for pointing to the appropriate card (max score = 12 per problem).

Results and Discussion

Criterion. Of the 24 children, ten (three 4-year-olds; seven 5-year-olds) reached the criterion on problem 1 and eleven (four 4-year-olds; seven 5-year-olds) did so on problem 2.

This represents 42% (problem 1) and 46% (problem 2) of the sample. On average, children reached criterion in 3.5 trial blocks (range 1 to 6) in problem 1 and 2.55 trial blocks (range 1 to 6) in problem 2. Nine of the ten children who reached criterion on problem 1 also reached criterion on problem 2. This supports the validity of the learning criterion. Twelve children (50%) did not reach criterion on either problem.

Response accuracy. A 2 (Age group) × 2 (Problem) × 4 (Block) mixed ANOVA was conducted. Descriptive statistics are shown in Figure 1. Within-subject contrasts examining block revealed a marginally significant linear component, F (1, 22) = 3.83, p = .063, partial η^2 = .148, which interacted with problem, F (1, 22) = 5.13, p = .034, partial η^2 = .189. The interaction reflected a significant increase in accuracy from trial block 1 to block 4 on problem 1, F (1, 23) = 8.01, p = .009, partial η^2 = .258, but no significant increase on problem 2. The main effect of problem approached significance, F (1, 22) = 3.38, p = .08, partial η^2 = .113. Accuracy tended to increase from problem 1 to problem 2.

Single sample t-tests showed that response accuracy on trial block 4 of problem 1 was significantly above chance level (6 correct out of 12) for 5-year-olds, t(11) = 2.48, p = .031, and marginally above chance for the 4-year-olds, t(11) = 2.12, p = .057. On problem 2, 5-year-olds' response accuracy was significantly above chance on trial blocks 2, 3 and 4, smallest t(11) = 2.46, p = .032. The 4-year-olds performed significantly above chance only on trial block 2, t(11) = 2.25, p = .046.

In summary, intra-problem learning occurred on problem 1. Accuracy increased across blocks and was above chance level on block 4 of problem 1 for 5-year-olds and marginally so for 4-year-olds. The 5-year-olds maintained their above-chance performance on blocks 2 to 4 of problem 2. The 4-year-olds' performance on problem 2 fluctuated around chance level, being significantly above chance only on trial block 2. The findings are consistent with inter-problem learning by 5-year-olds, but not 4-year-olds. The percentages reaching criterion were comparable to Gollin (1965) who used a similar procedure.

Awareness questions. A 2 (Age) × 2 (Problem) mixed ANOVA yielded a significant main effect of age, F (1, 22) = 6.29, p = .02, partial η^2 = .078. The 4-year-olds (M = 11.42; SE = 1.08) gave fewer correct responses than 5-year-olds (M = 16.33; SE = 1.64). The 4-year-olds' mean did not differ from chance (12 correct out of 24), whereas the 5-year-olds' mean exceeded chance, t (11) = 2.65, p = .023.

The probability of obtaining an awareness score of 9 or more correct (out of 12) by chance is p = .07, according to the binomial distribution. Using this cut-off, just 5 children (one 4-year-olds; four 5-year-olds) and 6 children (one 4-year-olds; five 5-year-olds) demonstrated awareness following problems 1 and 2, respectively.

Awareness and criterion-level performance. Table 2 (upper section) relates conditional discrimination performance (reaching criterion or not) to awareness. On problems 1 and 2 respectively, 17 and 19 children performed consistently in that they either (i) did not meet criterion nor demonstrate awareness, or (ii) they met criterion and demonstrated awareness. Of the seven children who performed inconsistently on problem 1, six met criterion but did not demonstrate awareness. One child showed the reverse pattern. Of the five children who performed inconsistently on problem 2, all met criterion but did not demonstrate awareness. McNemar tests showed that this pattern approached significance on problem 2 (p = .063). Thus there was a trend for children who performed inconsistently to reach the learning criterion but not demonstrate awareness, rather than the reverse.

Awareness and inter-problem learning. A 2 (Awareness) × 2 (Problem) mixed ANOVA examined inter-problem learning in children who did and did not demonstrate awareness following problem 1. The dependent variable was response accuracy summed across trial blocks 1 to 4 (max = 48). Awareness was a between groups variable with two levels (aware, unaware) based on the cut-off described previously. Problem was a within-subject variable. As in the earlier analysis, the main effect of problem approached significance, *F* (1, 22) = 4.27, *p* = .051, partial η^2 = .163, indicating a trend toward higher accuracy on problem 2 (*M* = 33.87, *SE* = 2.47) than problem 1 (*M* = 30.02, *SE* = 1.90). There was a significant main effect of awareness, *F* (1, 22) = 6.41, *p* = .019, partial η^2 = .226. The aware group (*M* = 37.00; *SE* = 3.55) responded more accurately than the unaware group (*M* = 26.90; *SE* = 1.82). The Awareness × Problem interaction (*F* < 1) was not significant. Paired samples *t*-tests showed that the increase in accuracy from problem 1 to problem 2 did not reach significance in the unaware group (problem 1: *M* = 25.84; *SE* = 1.53: problem 2: *M* = 27.95; *SE* = 2.15) *t*(18) = 1.21, *p* = .24, nor in the aware group, (Problem 1: *M* = 34.20; *SE* = 4.78; Problem 2: *M* = 39.80; *SE* = 5.22), *t*(4) = 1.87, *p* = .14. Although the increase in mean accuracy was numerically larger in the aware group, the inferential analyses provide no evidence of stronger inter-problem learning in the aware group, perhaps because of the small sample size of the aware group (*n* = 5). Independent samples *t*-tests showed that the aware group responded significantly more accurately than the unaware group on problem 2, *t*(22) = 2.40, *p* = .025, but not on problem 1, *t*(4.85) = 1.67, *p* = .158 (equal variances not assumed).

In summary, 4-year-olds demonstrated little or no awareness of their learning. The 5-year-olds demonstrated greater awareness than the 4-year-olds. Meeting the conditional discrimination learning criterion did not guarantee that awareness would be demonstrated. Awareness was associated with higher accuracy on problem 2. Many children learned the conditional discrimination without demonstrating awareness suggesting that they relied on configural processing (Rudy et al., 1993) rather than relational processing.

Experiment 2

In Experiment 1, conditional discrimination was difficult for 4- and 5-year-old children to learn. While this is consistent with Gollin (1965), the findings are less consistent with complexity theories. CCC-R theory (Zelazo et al., 2003) and RC theory (Halford et al., 1998b) predict that the majority of 5-year-olds will succeed on tasks that involve higher-order rules and ternary relations, and empirical research (e.g., Andrews & Halford, 2002; Frye et al., 1995) has supported this prediction. One possible reason why fewer 5-year-olds than expected reached criterion and demonstrated awareness is that they did not receive sufficient experience with the components of the task. This would mean that some children who were capable of ternary-relational processing did not demonstrate that capacity. One aim of Experiment 2 was to determine whether conditional discrimination learning and awareness could be facilitated by prior presentation of reversal learning problems.

In reversal learning, two objects (e.g., triangle, circle) are presented and children learn to select one of the objects (e.g., triangle) and not the other. Once the discrimination is learned the contingencies are reversed. Selection of the previously rewarded object (triangle) receives negative feedback, and selection of the previously unrewarded object receives positive feedback. Reversal learning and conditional discrimination are similar in that each involves using feedback to learn discriminations between objects. Both also require reversal of the learned contingencies. However, reversal learning should be easier because the reversals are made sequentially. Conditional discrimination is more complex because the two sets of contingencies must be acquired simultaneously. Children must use the context cue (background color) to distinguish them. Reversal learning is less complex because there is no context variable to consider. It requires children to learn two binary-relational tasks in succession, whereas conditional discrimination requires them to learn a single ternary-relational task. However, given the commonalities, it seemed plausible that completing the reversal learning problems first would assist children with some components of conditional discrimination. For example, the reversal learning problems should alert children to the possibility that contingencies can be reversed. This might facilitate subsequent performance on conditional discrimination problems.

The reversal learning procedure in the current research differs from that of Gollin and Liss (1962) and Rudy et al. (1993). In the current research the same context (gray background) was used in the original learning and reversal phases whereas in the previous research different contexts were employed. In the current research, reversal learning and conditional discrimination were assessed in separate tasks, whereas in previous research they were assessed in different phases of the same procedure. Thus in the current study, the specific discriminations learned during reversal learning were of no relevance to the conditional discrimination problems. In Gollin and Liss' and Rudy et al.'s procedures, children who reached criterion in the discrimination and reversal phases needed only to reproduce their earlier responses to succeed in the conditional discrimination phase.

Experiment 1 showed that children who reached criterion on the conditional discrimination problems did not always demonstrate awareness of their learning. The second aim of Experiment 2 was test the robustness of this finding and to further examine the links between children's awareness and their reversal learning and conditional discrimination performance. If relational processing is employed, children should demonstrate awareness at least in the less complex binary-relational reversal learning problems. Related to this, we also examined whether children's awareness following the reversal learning facilitates their subsequent conditional discrimination performance. This would be consistent with CCC-R theory (Zelazo et al., 2003) in which transition to more complex rules requires reflection on less complex rules.

The third aim of Experiment 2 was to examine a potential correlate of inter-problem learning. Fluid intelligence is an essentially nonverbal ability involved in solving novel problems (Cattell, 1987). Previous research (Andrews & Halford, 2002) showed that relational processing and fluid intelligence are closely related constructs. Correlations with fluid intelligence should be observed if children use relational processing, but not if they rely on associative processing, whether this be elemental or configural. Above-chance performance on the awareness questions was interpreted as a marker of relational processing. Fluid intelligence should predict inter-problem transfer in children who use relational processing, but not in children who use associative processing. In view of the numbers of 4- and 5-year-old children who did not reach criterion in Experiment 1, the age range was extended to include 6-year-olds.

Method

Participants

Participants were 63 children in three age groups. The twenty-two 4-year-olds (10 boys, 12 girls) had a mean age of 4 years 7 months (*SD* = 3.42 months). The twenty-one 5-year-olds (6 boys, 15 girls) had a mean age of 5 years 6 months (*SD* = 4.20 months). The twenty 6-year-olds (8 boys, 12 girls) had a mean age of 6 years 4 months (*SD* = 3.33 months). The children were recruited from privately run child care centres, preschools and schools in the Gold Coast region of Queensland, Australia.

Materials and Procedures

Reversal learning problems. Each display consisted of two objects: a circle and a triangle in one problem, and a rectangle and an oval in the other problem. The objects were always presented on the same gray colored background. The positive (happy face) and negative (sad face) feedback displays were identical to those used in the conditional discrimination problems. All children completed two reversal learning problems, which were presented in counterbalanced order.

Each problem was preceded by two practice trials. The problems included a learning phase and a reversal phase, each with one or two blocks of twelve trials (maximum of 48 trials per problem). On each trial, a two-object display was presented. Children selected one object, then they received feedback. Once the discrimination had been learned to criterion, the contingencies were reversed. A criterion of 9 correct responses out of 12 (p = .07) was applied in the learning phase and in the reversal phase. Children who did not reach the criterion in the first trial block received a second trial block. The joint probability of reaching the learning and reversal criteria is p = .005.

Reversal learning awareness questions. Eight questions (four outcome, four object) were developed for each problem. There were no background questions because background color did not vary. Two questions of each type were presented after the learning phase and again after the reversal phase of each problem. Cards depicting the objects and outcomes relevant to each question were displayed, as in the conditional discrimination problems.

Conditional discrimination problems and awareness questions. These were the same as in Experiment 1. The criteria employed in Experiment 1 were also applied in Experiment 2.

Fluid intelligence. Four subtests (Substitution, Mazes, Classification, Similarities) of the Cattell Culture Fair Test, Scale 1 (Cattell, 1950) were administered using standard procedures. The dependent measure was the sum of scores for the four subtests (max = 48).

Results and Discussion

Reversal Learning.

Criterion. Of the 63 children, 59 (eighteen 4-year-olds, twenty-one 5-year-olds, twenty 6-year-olds) reached criterion on problem 1 and all children did so on problem 2, representing 94% and 100% of the sample, respectively.

Response accuracy. Children who met criterion on the first trial block within the learning and reversal phases did not receive the second trial block in that phase. These children were credited with perfect performance (12 correct) on the second trial block. This meant that accuracy of the older children was at or close to ceiling on trial block 2. To avoid zero variance in these cells, blocks 1 and 2 were combined. A 3 (Age group) × 2 (Phase: learning, reversal) × 2 (Problem) mixed ANOVA yielded a significant main effect of problem, $F(1, 60) = 19.99$, $p < .001$, partial $\eta^2 = .25$. Accuracy was higher on problem 2 (*M* = 23.06; *SE* = 0.20) than problem 1 (*M* = 21.64; *SE* = 0.33). There was a significant main effect of age, $F(2, 60) = 10.95$, $p < .001$, partial $\eta^2 = .267$. Scheffe tests showed that accuracy was significantly lower for 4-year-olds (*M* = 20.96; *SE* = 0.37) than for 5-year-olds (*M* = 22.80; *SE* = 0.38) ($p = .002$) and 6-year-olds (*M* = 23.30; *SE* = 0.39) ($p < .001$). The 5- and 6-year-olds did not differ significantly. Thus the 4-, 5-, and 6-year-olds performed at a high level on the reversal learning problems. All children reached criterion on problem 2.

Awareness. A 3 (Age group) × 2 (Phase: learning, reversal) × 2 (Problem) mixed ANOVA yielded only a main effect of age, $F(2, 60) = 9.21$, $p < .001$, partial $\eta^2 = .235$. Scheffe tests showed that the 4-year-olds (*M* = 6.20; *SE* = .26) gave significantly fewer correct responses than 5- (*M* = 7.26; *SE* = .264) ($p = .029$) and 6-year-olds (*M* = 7.83; *SE* = .27) ($p < .001$). The latter two groups did not differ significantly. All group means were significantly above chance level.

Individual scores of 7 and 8 correct (out of 8) are significantly above chance level ($p = .035$) according to binomial tables. Using this cut-off, 44 children (nine 4-year-olds; sixteen 5-year-olds; nineteen 6-year-olds) and 51 children (thirteen 4-year-olds; nineteen 5-year-olds; nineteen 6-year-olds) demonstrated awareness on problems 1 and 2, respectively.

Awareness and reversal learning performance. Table 2 (middle section) relates reversal learning performance (reaching criterion or not) to passing or failing the awareness questions. On problem 1, 48 children performed consistently in that they (i) neither met criterion nor demonstrated awareness, or (ii) both met criterion and demonstrated awareness. Of the 15 children who performed inconsistently, all met the reversal learning criterion, but did not demonstrate awareness. No children showed the reverse pattern. McNemar tests confirmed the significance of this pattern on problems 1 and 2 (*ps* < .001).

Awareness and inter-problem reversal learning. Children were classified into three groups based on whether they demonstrated awareness on neither problem (unaware group: n = 8), problem 2 only (mixed awareness group: n = 11), or both problems (aware group: n = 40). Four children who demonstrated awareness on problem 1 only were excluded from this analysis. A 3 (Awareness) × 2 (Problem) mixed ANOVA examined inter-problem learning in these awareness groups. The dependent variable was response accuracy in the learning and reversal phases (max = 48). There was a significant main effect of problem, F (1, 56) = 17.14, $p < .001$, partial $\eta^2 = .234$ (as reported previously). The effect of awareness approached significance F (1, 56) = 3.05, $p = .056$, partial $\eta^2 = .098$. The trend appears to reflect the higher accuracy of the aware group (unaware: M = 42.69, SE = 1.36; mixed awareness: M = 42.82, SE = 1.19; aware: M = 45.48, SE = 0.61). The Awareness × Problem interaction did not approach significance ($F < 1$). Thus inter-problem learning did not differ as a function of awareness, perhaps because accuracy on problem 1 was already high.

In summary, reaching the reversal learning criterion did not guarantee awareness because 19% of children performed at chance level on the awareness questions following problem 2. Even in these less complex reversal learning problems, some children did not use relational processing. These children might have relied on elemental associative processing, which is sufficient for reversal learning or configural processing (Rudy et al., 1993).

Conditional Discrimination.

Criterion. Of the 63 children, 57 (nineteen 4-year-olds; eighteen 5-year-olds; twenty 6-year-olds) reached the criterion on problem 1, and 60 children (20 in each age group) did so on problem 2. This represents 90% (problem 1) and 95% (problem 2) of the sample. On average children reached criterion in 2.75 trial blocks (range 1 to 6) in problem 1 and 1.50 trial blocks (range 1 to 5) in problem 2. Of the 57 children who reached criterion on problem 1, 56 also reached criterion on problem 2. Two children (one 4-year-old, one 5-year-old) did not reach criterion on either problem.

Response accuracy. Descriptive statistics are shown in Figure 2. A 3 (Age group) × 2 (Problem) × 4 (Block) mixed ANOVA yielded a significant main effect of age, $F(2, 60) = 4.54$, $p = .015$, partial $\eta^2 = .132$. Scheffe tests indicated significantly lower accuracy for the 4-year-olds compared to 5-year-olds ($p = .039$) and 6-year-olds ($p = .043$). The 5- and 6-year-olds did not differ significantly. There was a significant main effect of problem, $F(1, 60) = 74.78$, $p < .001$, partial $\eta^2 = .56$. Accuracy was higher on problem 2 than problem 1. There was a significant main effect of block, $F(3, 180) = 15.17$, $p < .001$, partial $\eta^2 = .202$, which was due mainly to the significant linear component, $F(1, 60) = 38.31$, $p < .001$, partial $\eta^2 = .39$. This linear component interacted significantly with problem, $F(1, 60) = 8.03$, $p = .006$, partial $\eta^2 = .118$. The linear component was stronger on problem 1, $F(1, 60) = 31.48$ $p < .001$, partial $\eta^2 = .344$, than on problem 2, $F(1, 60) = 8.63$, $p = .005$, partial $\eta^2 = .126$. Single sample *t*-tests showed that accuracy was significantly above chance level in all trial blocks of problems 1 and 2 for all age groups, smallest t (21) = 3.53, $p = .002$, except for block 1 of problem 1 where 4-year-olds performed at chance level.

In summary, the majority of children in all age groups reached criterion on both conditional discrimination problems. The percentages reaching criterion far exceeded those observed in Experiment 1 and by Gollin (1965). There was clear evidence for intra-problem learning, which was stronger on problem 1 than problem 2. Inter-problem learning was evidenced by the higher percentage of children reaching criterion and the higher accuracy on problem 2 than problem 1.

Awareness. A 3 (Age group) × 2 (Problem) × 3 (Question type) mixed ANOVA yielded a significant main effect of age group, $F(2, 60) = 15.88$, $p < .001$, partial $\eta^2 = .346$. Scheffe tests showed that the 4-year-olds ($M = 7.00$; $SE = .443$) gave fewer correct responses than 5-year-olds ($M = 9.52$; $SE = .453$) ($p = .001$) and 6-year-olds ($M = 10.48$; $SE = .465$) ($p < .001$). The latter two groups did not differ significantly. There was a significant main effect of question type, $F(2, 60) = 7.55$, $p = .001$, partial $\eta^2 = .112$. Background questions ($M = 2.73$; $SE = .13$) were more difficult than object questions ($M = 3.16$; $SE = .11$) and outcome questions ($M = 3.11$; $SE = .10$). There were no background questions following reversal learning problems, so the poorer performance might stem from the greater novelty of this question type. There was also a significant main effect of problem, $F(1, 60) = 5.74$, $p = .02$, partial $\eta^2 = .087$, indicating greater awareness following problem 2 ($M = 9.36$; $SE = .32$) than problem 1 ($M = 8.64$; $SE = .281$). The age group means were all significantly above chance (6 correct out of 12) (all *p*s < .05).

Using the cut-off of 9 or more correct out of 12 ($p = .07$), 28 children (one 4-year-olds; eleven 5-year-olds; sixteen 6-year-olds) and 42 children (eight 4-year-olds; sixteen 5-year-olds; eighteen 6-year-olds) demonstrated awareness after problems 1 and 2, respectively.

Awareness and conditional discrimination performance. Table 2 (lower section) relates conditional discrimination performance (reaching criterion or not) to passing or failing the awareness questions. On problem 1, 34 children performed consistently. Of the 29 children who performed inconsistently, all met criterion but performed at chance level on the awareness questions. No children showed the reverse pattern. McNemar tests confirmed the significance of this pattern on both problems (*ps* < .001).

Awareness and inter-problem conditional discrimination learning. Children were classified into three groups based on whether they demonstrated awareness on neither problem (unaware group: $n = 19$), problem 2 only (mixed awareness group: $n = 16$), or both problems (aware group: $n = 26$). Two children who demonstrated awareness on problem 1 but not problem 2 were excluded from these analyses.

A 3 (Awareness) × 2 (Problem) mixed ANOVA examined inter-problem learning in these awareness groups. The dependent variable was accuracy on blocks 1 to 4 (max = 48). There were significant main effects of awareness, $F\ (2, 58) = 15.82$, $p < .001$, partial $\eta^2 = .35$

and problem, F (1, 58) = 93.07, $p < .001$, partial $\eta^2 = .616$, which were modified by a significant Awareness × Problem interaction, F (2, 58) = 6.25, $p = .003$, partial $\eta^2 = .177$. The simple effect of problem was significant in the unaware group, F (1, 18) = 29.52, $p <$ .001, partial $\eta^2 = .621$, where accuracy increased from problem 1 (*M* = 30.53; *SE* = 1.67) to problem 2 (*M* = 38.37; *SE* = 1.65). The simple effect of problem was significant in the mixed awareness group, F (1, 15) = 64.33, $p < .001$, partial $\eta^2 = .811$, where accuracy increased from problem 1 (*M* = 34.13; *SE* = 1.60) to problem 2 (*M* = 45.44; *SE* = 0.64). The simple effect of problem was also significant in the aware group, F (1, 25) = 11.81, $p = .002$, partial $\eta^2 = .321$, where accuracy increased from problem 1 (*M* = 40.50; *SE* = 1.27) to problem 2 (*M* = 44.89; *SE* = 0.61). The effect sizes suggest that inter-problem learning was strongest in the mixed awareness group and weakest in the aware group. The aware group's high level of accuracy on problem 1 limited the extent of improvement possible on problem 2. Accuracy on problem 2 approached ceiling in the mixed awareness and aware groups.

One way ANOVAs showed that the awareness effect was significant on problem 1, $F(2, 58) = 12.75$, $p < .001$, and problem 2, $F(2, 58) = 13.64$, $p < .001$. Scheffe tests showed that the pattern of group differences differed for problems 1 and 2. On problem 1, the unaware and mixed awareness groups did not differ significantly ($p = .294$), but the unaware group ($p < .001$) and the mixed awareness group ($p = .016$) performed more poorly than that aware group. On problem 2, the unaware group performed more poorly than the mixed awareness and aware groups (*p*s < .001) but there was no significant difference between the mixed awareness and aware groups ($p = .933$). These findings suggest that the unaware group used configural processing throughout, the aware group used relational processing throughout and the mixed awareness group shifted from configural processing on problem 1 to relational processing on problem 2.

In summary, awareness increased with age. Meeting the conditional discrimination learning criterion did not guarantee that awareness would be demonstrated. Although mean levels of awareness in all age groups exceeded chance, the majority of 4-year-olds did not demonstrate awareness of relational structure, suggesting that many of these younger children relied on configural processing rather than relational processing. Inter-problem learning was stronger in children whose awareness increased across problems.

Awareness and task complexity.

Table 2 shows that fewer children demonstrated awareness following conditional discrimination problems than following reversal learning problems. A McNemar test examined awareness following reversal learning problem 1 and conditional discrimination problem 1. Thirty-nine children performed consistently. Of the 24 children with inconsistent awareness, 20 children showed awareness following reversal learning but not conditional discrimination, and 4 showed the reverse pattern, p = .002. A similar analysis was applied to reversal learning problem 2 and conditional discrimination problem 2. Forty-eight children performed consistently. Of the 15 children with inconsistent awareness, 12 showed awareness following reversal learning but not conditional discrimination, and 3 children showed the reverse pattern, p = .035. This suggests that some children who used relational processing on reversal learning resorted to non-relational (configural) processing on the conditional discrimination problems. This is reminiscent of findings that adults sometimes resort to non-relational processing when task complexity increases (Andrews, 2010).

Predicting conditional discrimination from reversal learning and awareness.

The extent to which children's reversal learning performance and awareness predicted performance on the more complex conditional discrimination problems was examined using multiple regression. The criterion was response accuracy on conditional discrimination problems 1 and 2. The predictors were response accuracy on reversal learning problems 1 and 2, awareness of reversal learning, and age. After exclusion of one child with a large standardised residual, the predictors accounted for 30.2% variance in conditional discrimination accuracy, F (3, 58) = 8.37, $p < .001$. Reversal learning accuracy (11.97%, p = .003) and awareness (9.10%, p = .008) each accounted for unique variance in conditional discrimination accuracy and subsumed the age-related variance. This analysis is summarised in Table 3. Awareness of the components of the less complex task (reversal learning) facilitated performance on a more complex tasks (conditional discrimination), independently of performance on the less complex task and age.

Fluid intelligence in inter-problem learning.

As noted above, conscious access to components is a characteristic of relational processing. Relational processing supports inter-problem transfer but it is also more effortful than associative processing. Therefore we expected that fluid intelligence (an index of cognitive capacity) would be more likely to predict inter-problem transfer in children who employed relational processing than in children who relied more on associative processing. To examine this hypothesis in relation to reversal learning, children were assigned to relational (n = 44) and associative (n = 19) groups based on their awareness following reversal learning problem 1. Separate regression analyses were conducted for these groups (see Table 4). The criterion was reversal learning accuracy on problem 2. The predictors were reversal learning accuracy on problem 1, age, and fluid intelligence. For the associative group, the predictors accounted for 41.1% variance in problem 2 accuracy, Multiple R = .64, F(3, 15) = 3.49, p = .042. Problem 1 accuracy accounted for 31% variance (p = .013) independent of age and fluid intelligence. The unique contributions of age and fluid intelligence were not significant. For the relational group, the predictors accounted for 25.9% variance in problem 2 accuracy, Multiple R = .51, F(3, 40) = 4.67, p = .007. Fluid intelligence accounted for 14.52% variance (p = .008) independent of age and problem 1 accuracy. The unique contributions of age and problem 1 accuracy were not significant.

Similar analyses were applied to the conditional discrimination problems (see Table 5). Children were assigned to the relational ($n = 28$) and associative ($n = 35$) groups based on their awareness following problem 1. The criterion was conditional discrimination accuracy on problem 2. The predictors were conditional discrimination accuracy on problem 1, age, and fluid intelligence. For the associative group, the predictors accounted for 40% variance in problem 2 accuracy, Multiple $R = .63$, $F(3, 31) = 6.89$, $p = .001$. Problem 1 accuracy accounted for 25% variance ($p = .001$) independent of age and fluid intelligence. The unique contributions of age and fluid intelligence were not significant. When the associative group was restricted to children ($N = 19$) who demonstrated awareness on neither problem 1 nor 2, the total variance accounted for was comparable at 41.6% ($p = .04$), but the unique contribution of problem 1 accuracy increased to 33.64% ($p = .01$). Neither age nor fluid intelligence was a significant predictor.

For the relational group, the predictors accounted for 31.6% variance in problem 2 accuracy, Multiple $R = .57$, $F(3, 24) = 3.84$, $p = .022$. Fluid intelligence accounted for 22% variance ($p = .01$) independent of the age and problem 1 accuracy. The unique contributions of age and problem 1 accuracy were not significant. When children who demonstrated awareness on problem 2 (but not problem 1) were also included in the relational group ($N = 44$), the total variance accounted for declined to 17.7% ($p = .048$) and the unique contribution of fluid intelligence declined to 10.37% ($p = .031$). Neither age nor problem 1 accuracy was a significant predictor.

Thus fluid intelligence predicted inter-problem learning in children who showed evidence of relational processing. The prediction was stronger in children who used relational processing from the outset, than in children who used relational processing only on problem 2. For children who relied on associative processing, problem 1 performance was the best predictor of problem 2 performance. This was the case for both reversal learning and conditional discrimination. Fluid intelligence was not a significant predictor for children who relied on associative processing.

General Discussion

Our aims were to elucidate the conditions under which 4- to 6-year-old children solve conditional discrimination problems and to achieve a better understanding of the cognitive processes that underlie children's conditional discrimination. We extended existing research by assessing children's inter-problem learning, their level of awareness of the relational structure of the problems and the links between awareness and performance. We also examined the role of fluid intelligence in inter-problem learning and whether this differed as a function of children's reliance on relational versus associative processing.

Experiment 1 confirmed earlier findings using a similar paradigm (Gollin, 1965) that conditional discrimination is difficult for 4- and 5-year-old children to acquire. Less than 50% of children reached criterion in Experiment 1. In Experiment 2, performance was greatly improved and almost all children reached criterion. The main difference was that children in Experiment 2 completed reversal learning problems and the associated awareness questions before the conditional discrimination problems.

The differences observed across the current experiments might appear to parallel the different ages of attainment of conditional discrimination observed by Gollin and Liss (1962) and Rudy et al. (1993) on the one hand and by Gollin (1965) on the other. However, the parallel is more apparent than real because of the differences between the three phase procedure used by Gollin and Liss and Rudy et al. and that used in Experiment 2 of the current research. Nevertheless, reversal learning as assessed in Experiment 2 is similar to conditional discrimination in some respects. For example, the task procedures were very similar, both involved using feedback to inform subsequent responding, and both involved reversal of the contingencies between objects and outcomes. In reversal learning, the original learning and the reversal occur in sequence, whereas in conditional discrimination the contingencies must be acquired simultaneously, with background color serving as the distinguishing cue. This means that reversal learning is less complex than conditional discrimination. The different findings in the two experiments suggest that prior experience solving similar but less complex problems facilitated solution of the more complex conditional discrimination problems.

While most children in Experiment 2 reached criterion on the reversal learning and conditional discrimination problems, they did not necessarily show awareness of what they had learned. Approximately one fifth of children failed to demonstrate awareness following reversal learning problem 2, and about one third failed to do so following conditional discrimination problem 2. If awareness of relational structure is a marker of relational processing, these findings suggest that reversal learning and conditional discrimination can be acquired either through associative processing as proposed by Rudy et al. (1993) or through relational or rule-based processing as defined in RC and CCC-R theories (Halford et al., 1998b; Zelazo et al., 2003).

The extent to which children relied on associative and relational processing varied with age and problem complexity. On reversal learning (problem 2) 59% of the 4-year-olds, 90% of 5-year-olds, and 95% of 6-year-olds relied on relational processing. Of the children who reached criterion on conditional discrimination (problem 2), 40% of 4-year-olds, 80% of 5-year-olds, and 90% of 6-year-olds relied on relational processing. The percentages in Experiment 1 were comparable, although fewer children reached criterion. Of the children who met criterion, 25% of 4-year-olds and 71% of 5-year-olds relied on relational processing. In both experiments, reliance on relational processing increased with age while reliance on associative processing decreased with age. These age-related changes were more pronounced on conditional discrimination than reversal learning. The higher rate of relational processing on reversal learning than conditional discrimination is consistent with our complexity analyses because reversal learning is binary-relational whereas conditional discrimination is ternary-relational. The majority of 5- and 6-year-old children used relational processing on both reversal learning and conditional discrimination. The majority of 4-year-olds used relational processing on reversal learning but not on conditional discrimination problems. While these findings are consistent with the age of acquisition of ternary relations in other content domains (e.g., Andrews & Halford, 2002), we cannot exclude the possibility that more of the 4-year-olds would show evidence of ternary-relational processing if additional conditional discrimination problems were presented. This could be explored further.

The involvement of associative and relational processes was supported by the analyses relating awareness (a marker of relational processing) to intra- and inter-problem learning and to fluid intelligence. In Experiment 1, children who demonstrated awareness on problem 1 performed more accurately on problem 2 than children in the unaware group. In Experiment 2, the aware group performed significantly better on problem 1 than unaware and mixed awareness groups. On problem 2, the mixed awareness group performed as well as the aware group and better than the unaware group. Thus use of relational processing was associated with better intra-problem learning.

On the conditional discrimination problems in Experiment 2, significant inter-problem learning was observed in aware, unaware and mixed awareness groups. The extent of inter-problem learning in the aware group should be interpreted in the light of their high level of accuracy on problem 1 and their near-ceiling performance on problem 2. Inter-problem learning in this group is consistent with their use of relational processing on both problems. During problem 1, these children would have constructed a relational representation with slots for three variables, context, object, and outcome. Their accurate responding to the awareness questions indicates that the components of the relational structure were accessible.

This would provide the basis for analogical mapping, and their performance on problem 2 would benefit, provided they were able to make the correct mapping between the problems. Constructing relational representations and analogical mapping are effortful processes, which we predicted would depend on cognitive capacity. The regression analyses for the relational group supported this. The only unique predictor of problem 2 performance was fluid intelligence. This pattern of findings, which was observed for both reversal learning and conditional discrimination (see Tables 4 and 5), is consistent with the claim that relational processing is an effortful process (Halford et al., 1998b, 2010) and with earlier research that demonstrated strong links between relational processing and fluid intelligence (Andrews & Halford, 2002).

Inter-problem learning in the unaware group would have a basis other than structural correspondence, because children’s responses to the awareness questions indicated that the components of problem 1 were not sufficiently accessible to allow analogical mapping. These children might have formed configural representations in which the context and object were combined. Given that they did not demonstrate awareness following problem 2, their improved performance from problem 1 to problem 2 might best be interpreted in terms of continued reliance on configural processing, albeit with increased efficiency on problem 2. The regression analyses for the associative groups support this interpretation. The strongest predictor of problem 2 performance was problem 1 performance. That neither age nor fluid intelligence contributed to the prediction suggests that these children relied on associative processing which does not impose a high cognitive load (Litman & Reber, 2005). The finding that fluid intelligence was significant predictor of performance when relational but not associative processing was employed is reminiscent of findings that intelligence is more strongly related to analytic than non-analytic thinking in adults (Stanovich & West, 2000).

Inter-problem learning was strongest in the mixed awareness group. These children demonstrated awareness after problem 2. They did not meet the awareness cut-off score of 9 correct out of 12 after problem 1. Their mean awareness score (*M* = 7.06; *SE* = .31) was significantly higher than the unaware group, (*M* = 6.00; *SE* = .30), $t(33) = 2.47$, $p = .019$, but they did not differ from the unaware group in terms of accuracy on problem 1. Further inspection showed that nine of the sixteen children in this group just failed to meet the awareness cut-off with scores of 8 correct. After problem 1, their access to the components of the relational structure might have been sufficient to facilitate performance on problem 2, even though they did not quite reach the awareness cut-off. This group's relatively low level of accuracy on problem 1 left room for improvement on problem 2, where their accuracy and awareness increased to a level that did not differ from the aware group. Children in this group appear to have transitioned from configural processing to relational processing during the conditional discrimination procedure. The regression analyses examining the role of fluid intelligence suggest further that children in the mixed awareness group employed both associative and relational processing. In the supplementary analyses predicting problem 2 accuracy, problem 1 accuracy was a stronger predictor when these children were not included in the associative group, and fluid intelligence was a weaker predictor when these children were included in the relational group. Thus inclusion of the children with mixed awareness in the associative group reduced the predictive power of problem 1 accuracy. Their inclusion in the relational group reduced the predictive power of fluid intelligence.

Awareness of the relational structure of reversal learning appears to play a role in acquisition of conditional discrimination over and above reversal learning performance. This suggests that awareness of task structure is advantageous to, and might even be a prerequisite for acquisition of more complex structures. The awareness questions were designed to tap the accessibility property of relational knowledge (Halford et al., 1998b; 2010). They might have prompted children to reflect on the relational or rule structure they had learned and this might have facilitated subsequent performance. This would be consistent with theories that incorporate a role for reflection in the transition from lower to higher levels of complexity (Zelazo et al., 2003). The finding raises the possibility of interventions aimed at increasing children's awareness and reflection. To the extent that these are successful, children thinking in a broad range of relational and rule-based tasks could be facilitated.

We have shown that relational processing, which has not been investigated in the conditional discrimination before, plays a role that is distinct from previously recognised associative processes (Rudy et al., 1993). This is consistent with what has been found with relational schema induction (Halford et al., 1998a) and with analogy theory. Thus conditional discrimination has a more cognitive component than previously recognised. This cognitive component appears to be well captured by RC theory (Andrews & Halford, 2002; Halford et al., 1998b) and CCC-R theory (Zelazo et al., 2003) both of which emphasise the importance of cognitive complexity and awareness in cognitive development. The findings broaden the scope of these theories to tasks that involve acquisition of relational or rule structure as well as their use. Our findings also show that awareness of the relations learned moderates the influence of fluid intelligence on acquisition of structured knowledge as exemplified in conditional discrimination.

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Figure Captions

Figure 1. Response accuracy in trial blocks 1 to 4 (max. = 12) of conditional discrimination problems 1 and 2 for 4-year-olds and 5-year-olds in Experiment 1. Error bars represent standard errors.

Figure 2. Response accuracy in trial blocks 1 to 4 (max. = 12) of conditional discrimination problems 1 and 2 for 4-year-olds, 5-year-olds and 6-year-olds in Experiment 2. Error bars represent standard errors.

Table 1

Example Awareness Questions for Conditional Discrimination Problems used in Experiments 1 and 2.

Question type	Example
Outcome	When the background was red and you chose circle, did you get a happy or a sad face?
Object	When the background was red, and you got a happy face, which shape did you choose, triangle or circle?
Background	When you chose circle and you got a happy face, what colour was the background, red or blue?

Table 2.

Numbers of Children who Reached or did not Reach Criterion as a Function of Awareness for Conditional Discrimination Problems 1 and 2 in Experiment 1 (Upper), Reversal Learning Problems 1 and 2 in Experiment 2 (Middle) and Conditional Discrimination Problems 1 and 2 in Experiment 2 (Lower).

	Demonstrated Awareness?			
	Problem 1		Problem 2	
Conditional discrimination (Experiment1)	No	Yes	No	Yes
Did not reach criterion	13	1	13	0
Reached criterion	6	4	5	6
	Problem 1		Problem 2	
Reversal learning (Experiment 2)	No	Yes	No	Yes
Did not reach criterion	4	0	0	0
Reached criterion	15	44	12	51
	Problem 1		Problem 2	
Conditional discrimination (Experiment 2)	No	Yes	No	Yes
Did not reach criterion	6	0	3	0
Reached criterion	29	28	18	42

Table 3

Standard Multiple Regression of Reversal Learning (RL) Accuracy, RL Awareness, and Age on Conditional Discrimination (CD) Accuracy

	1	2	3	*B*	β	sr^2 unique
1. CD accuracy						
2. RL accuracy	.46***			.54	.40	.12**
3. RL awareness	.42***	.29**		.11	.35	.09**
4. Age	.27*	.46***	.48***	.05	.09	.00

* $p < .05$;** $p < .01$; *** $p < .001$

Table 4

Standard Multiple Regression of Reversal Learning (RL) Problem 1 Accuracy, Age and Fluid Intelligence on RL Problem 2 Accuracy for the Associative Group (N = 19; Upper) and Relational Group (N = 44; Lower).

	1	2	3	*B*	β	sr^2 (unique)
1. RL problem 2 accuracy						
2. RL problem 1 accuracy	.59**			.50	.81	.31*
3. Age	.22	.21		.34	.46	.06
4. Fluid intelligence	.32	.60**	.77***	-.41	-.53	.06
1. RL problem 2 accuracy						
2. RL problem 1 accuracy	.15			-.08	-.15	.01
3. Age	.33*	.60***		.00	-.002	.00
4. Fluid intelligence	.49***	.53***	.74***	.20	.573	.15**

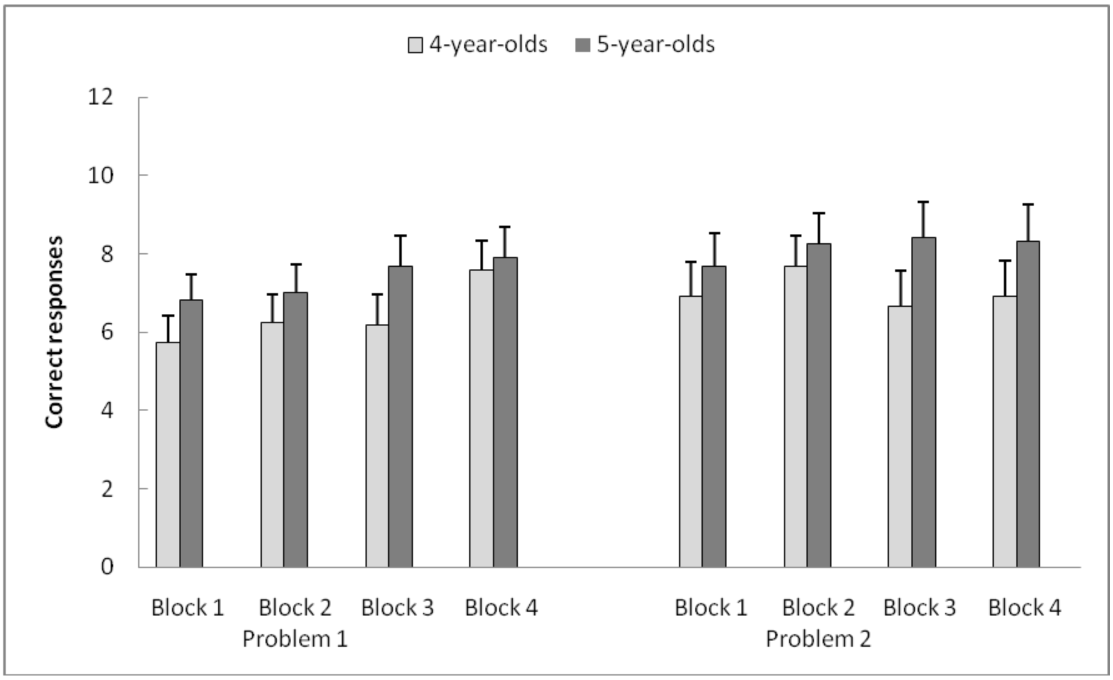
* $p < .05$;** $p < .01$; *** $p < .001$

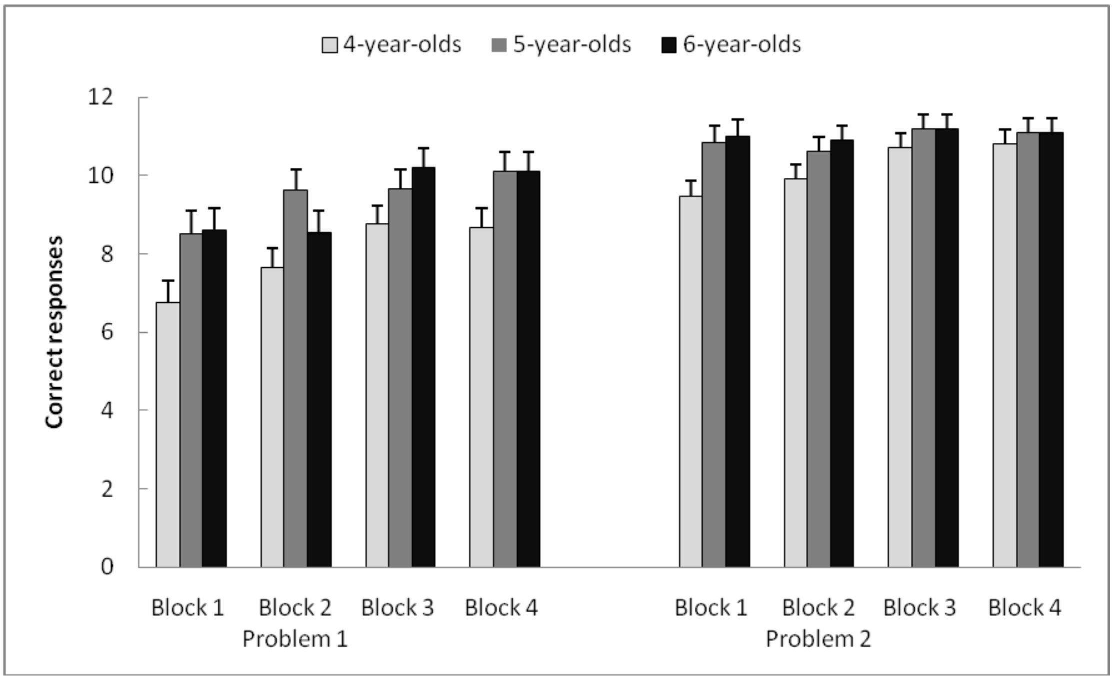
Table 5

Standard Multiple Regression of Conditional Discrimination (CD) Problem 1 Accuracy, Age and Fluid Intelligence on CD Problem 2 Accuracy for the Associative Group (N = 35; Upper) and the Relational Group (N =28; Lower).

	1	2	3	*B*	β	*sr*² (unique)
1. CD problem 2 accuracy						
2.CD problem 1 accuracy	.59***			.49	.53	.25***
3. Age	.25	.08		.04	.05	.00
4. Fluid intelligence	.38*	.28	.78***	.20	.20	.01
1. CD problem 2 accuracy						
2. CD problem 1 accuracy	.32*			.12	.25	.06
3. Age	-.02	-.23		-.13	-.29	.05
4. Fluid intelligence	.42*	.01	.56***	.33	.58	.22**

* $p < .05$;** $p < .01$; *** $p < .001$


4-year-olds
5-year-olds
Correct responses
12
10
8
6
4
2
0
Block 1
Block 2
Block 3
Block 4
Problem 1
Block 1
Block 2
Block 3
Block 4
Problem 2


4-year-olds
5-year-olds
6-year-olds
Correct responses
0
2
4
6
8
10
12
Block 1
Block 2
Block 3
Block 4
Problem 1
Block 1
Block 2
Block 3
Block 4
Problem 2