Complexity Effects on the Children's Gambling Task.

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Abstract

The Children's Gambling Task (CGT, Kerr & Zelazo, 2004) involves integrating information about losses and gains to maximize winnings when selecting cards from two decks. Both Cognitive Complexity and Control (CCC) theory and Relational Complexity (RC) theory attribute younger children's difficulty to task complexity. In CCC theory, identification of the advantageous deck requires formulation of a higher-order rule so that gains and losses can be considered in contradistinction. According to RC theory, it entails processing the ternary relation linking three variables (deck, magnitude of gain, magnitude of loss). We designed two less complex binary-relational versions in which either loss or gain varied across decks, with the other held constant. The three closely matched versions were administered to 3-, 4-, and 5-year-olds. Consistent with complexity explanations, children in all age groups selected cards from the advantageous deck in the binary-relational versions, but only 5-year-olds did so on the ternary-relational CGT.

Complexity Effects on the Children's Gambling Task

Executive functions (EFs) are often described as domain-general, but some researchers now distinguish between 'cool' EFs which are elicited by relatively abstract, decontextualised problems, and 'hot' EFs which are required for problems involving affect and motivation (Zelazo & Muller, 2002). The Iowa Gambling Task (Bechara, Damasio, Damasio & Anderson, 1994) is thought to elicit hot EF. Participants are given an initial stake of play money and instructed to win as much money as possible by choosing cards from four decks, which have different gain-loss profiles. Two decks offer high gains but higher losses, and a net loss. Two decks offer smaller gains but minimal losses, and a net gain. Unimpaired adults quickly identify the advantageous decks and select from them, while avoiding the disadvantageous decks. Patients with brain lesions continue to select cards from the disadvantageous decks, arguably because they fail to develop somatic markers that would bias their decisions toward the advantageous decks (Bechara et al.).

The task has been modified for use with children. Crone and van der Molen (2004) developed a 4-deck/door version for use with children aged 6 years and above. Garon and Moore (2004) used a 4-deck 40-trial version with Smarties as rewards with 3-, 4-, and 6-year-olds. Although awareness of the contingencies increased with age, there was no significant age-related improvement on card selections, and even 6-year-olds performed at chance level. The requirement to track and maintain the gains and losses associated with four decks might be too demanding for children in this age range.

Kerr and Zelazo's (2004) 2-deck version, the Children's Gambling Task (CGT) seems more suitable for young children. The cards displayed happy and sad faces indicating the numbers of candies won and lost respectively. During the last 25 of 50 trials, 3-year-olds made more disadvantageous choices than 4-year-olds, and only 4-year-olds performed above chance. Kerr and Zelazo interpreted their findings in terms of Cognitive Complexity and

Control (CCC) theory (Zelazo & Frye, 1997), in which age-related changes in the complexity of rule systems allow increasing control over thoughts and actions. From around 3 years of age children can use a pair of arbitrary rules. Around 5 years, they can integrate two incompatible pairs of rules into a single rule system via a higher-order rule (Zelazo, Jacques, Burack & Frye, 2002). Considering gains alone results in selections from the disadvantageous deck, considering both gains and losses produces selections from the advantageous deck. Integrating gains and losses requires consideration of two dimensions in contradistinction. Whereas 3-year-olds can learn the initial discrimination (striped deck has high gains, dotted deck has low gains) they have difficulty coordinating this with emerging evidence about losses (striped deck has high losses, dotted deck has low losses). Older children can formulate a higher-order rule and this allows them to appreciate net gains.

Kerr and Zelazo's (2004) findings can also be accounted for by Relational Complexity (RC) Theory (Halford, 1993; Halford, Wilson & Phillips, 1998) in which higher cognitive processes (including EFs) involve processing of relations. Complexity refers to the arity of relations, that is, the number of arguments. Each argument corresponds to a dimension, and an *N*-ary relation is a set of points in *N*-dimensional space. Number of dimensions corresponds to the number of interacting variables that constrain responses or decisions. In the RC metric, unary relations have a single argument as in class membership, dog(fido), binary relations have two arguments as in larger-than(elephant, mouse), ternary relations have three arguments as in addition(2, 3, 5), quaternary relations have four interacting components as in 2/3 = 6/9, and so on. Processing load increases with RC. The complexity of relations that children can process increases with age. Andrews and Halford (2002) confirmed that around 50% of 5-year-olds, 10% to 20% of 4-year-olds and a negligible percentage of 3-year-olds processed ternary relations in cool domains.

According to RC theory, the CGT requires integration of the differences between the decks in gains and losses. Thus two binary relations are integrated into a ternary relation involving three variables (deck, magnitude of gain, magnitude of loss). Three-year-olds should be able to process the component binary relations, but they should be unable to integrate these binary relations into a ternary relation. By 5 years children should process the ternary relations required for success on the CGT.

Both CCC (Zelazo & Frye, 1997; Zelazo & Jacques, 1996) and RC theories (Andrews & Halford, 2002; Halford, Andrews, Dalton, Boag, & Zielinski, 2002) can account for functioning in cool domains. The theories have also been applied to theory of mind (ToM), which arguably involves hot EF. Both theories attribute children's difficulty to the complexity of the inferences required. Frye, Zelazo and Palfait (1995) and Carlson and Moses (2001) provided evidence for CCC theory. Performance on Dimensional Change Card Sorting and Physical Causality tasks predicted ToM performance before and after age was controlled. The RC analysis was supported by correlational evidence and by research in which complexity of ToM tasks was manipulated (Andrews, Halford, Bunch, Bowden, & Jones, 2003).

The current study tested the complexity interpretation of the CGT by introducing two less complex binary-relational versions, in which the decks differed in either gains only or losses only, with the other variable held constant. They were closely matched to the ternary-relational CGT in other respects. All three versions were administered to 3-, 4- and 5-year-old children. On the ternary-relational CGT, we expected 5-year-olds to make more, and 3-year-olds to make fewer advantageous choices across trial blocks than would be expected by chance. The 4-year-olds should perform at an intermediate level.

All three age groups should succeed on the binary-relational versions which involve two variables (deck, magnitude of gain) or (deck, magnitude of loss). CCC theory also makes

this prediction, because the binary-relational versions do not require a higher-order rule. Success on the binary-relational versions accompanied by failure on the ternary-relational CGT would indicate that the difficulty was due to complexity rather than the materials, task procedures or a failure to develop somatic markers.

<center>Method</center>

Participants

Seventy-two children from three day-care centers participated. There were 24 children (12 males) in each of three age groups. The ages (months) were: 3-year-olds (males, $M = 44.75$, $SD = 2.45$; females, $M = 44.42$, $SD = 2.28$), 4-year-olds (males, $M = 52.67$, $SD = 2.10$; females, $M = 52.17$, $SD = 2.95$), and 5-year-olds (males, $M = 65.33$, $SD = 3.50$; females, $M = 64.33$, $SD = 4.14$). Recruitment and testing procedures received ethical approval. Written parental consent was obtained.

Materials

There were three sets of laminated cards. Each set contained two decks of 50 cards. All cards in a single deck had the same pattern on the reverse side. The pattern differed across decks (e.g., dots versus stripes). The front sides of all cards had black happy faces on a white background (upper half), and white sad faces on black background (lower half). The happy (sad) faces indicated the rewards gained (lost). The lower sections were covered with Post-It notes, which the experimenter (E) lifted to reveal the sad faces. The order of the cards in the decks was identical to Kerr and Zelazo (2004), for the ternary-relational version, and comparable for the binary-relational versions. Rewards were either mini M&M chocolates or stickers, as indicated by each child's parent.

Ternary-relational version. The gain-loss contingencies were identical to Kerr and Zelazo (2004). Cards in Deck A provided a gain of one reward and a loss of zero or one

reward. Cards in Deck B provided a gain of two rewards and a loss of zero, four, five, or six rewards.

Binary-relational (gain) version. Cards in Deck A provided a gain of one reward and a loss of zero or one reward. Cards in Deck B provided a gain of two rewards and a loss of zero or one.

Binary-relational (loss) version. Cards in Deck A provided a gain of one reward and a loss of zero or one reward. Cards in Deck B provided a gain of one reward and a loss of zero or five rewards.

Table 1 shows the total number of rewards gained and lost and the net gains/losses over each 10-card sequence. The standard ternary-relational CGT matched the binary-relational (gain) version in terms of rewards gained (10 for Deck A, 20 for Deck B), and the binary-relational (loss) version in terms of rewards lost (5 for Deck A, 25 for Deck B).

Insert Table 1 about here

Procedure

Procedures and instructions were based on Kerr and Zelazo (2004) and were comparable for three versions, which were presented to all children in counterbalanced order. Children were tested individually. They received one reward to motivate them to play, then an initial stake of 10 M&Ms (stickers). There were 6 demonstration and 50 test trials.

On demonstration trials, E selected three cards consecutively from each deck and explained the correspondence between the number of happy (sad) faces and the number rewards gained (lost). E took the rewards gained from an opaque container positioned in front of E, placed each reward onto a happy face then transferred them to a transparent container positioned in front of the child. Then E lifted the Post-it note to reveal the number of sad faces (rewards lost). E removed the rewards from the transparent container, placed each reward onto a sad face, then transferred them into the opaque container.

The same procedure was used on the test trials. In addition, E explained that children should choose one card at a time, and that they could choose as many cards as they wished from either deck. They were encouraged to win as many rewards as possible and told that they could keep the rewards in their container at the end of the game. Children were not permitted to eat M&Ms (play with stickers) until after Trial 50. They were unaware of the number of trials. The dependent measure was number of advantageous choices in each 10-trial block.

Results

Preliminary analyses revealed no significant effect of presentation order and no significant difference between the two binary-relational versions. Subsequent analyses were conducted on a combined binary-relational score, averaged across the binary-relational (gain) and binary-relational (loss) versions.

A 3(age: 3, 4, 5 years) × 2 (gender: male, female) × 2 (complexity) × 5 (blocks 1-5) mixed analysis of variance (ANOVA) yielded significant main effects of complexity, $F (1, 66) = 41.47$, $p < .001$, $\eta^2 = .386$, block, $F (4, 264) = 17.69$, $p < .001$, $\eta^2 = .211$, and age, $F (2, 66) = 7.99$, $p < .001$ $\eta^2 = .195$, significant 2-way interactions of Complexity × Age, $F (2, 66) = 17.43$, $p < .001$, $\eta^2 = .346$, Block × Age, $F (8, 264) = 5.91$, $p < .001$, $\eta^2 = .152$, and Complexity × Block, $F (4, 264) = 18.75$, $p < .001$, $\eta^2 = .221$, and significant 3-way interactions of Complexity × Blocks × Age, $F (8, 264) = 5.19$, $p < .001$ $\eta^2 = .136$, and Complexity × Age × Gender, $F (2, 66) = 3.24$, $p = .045$, $\eta^2 = .09$. The 4-way interaction was not significant.

The Complexity × Blocks × Age interaction was partitioned by complexity. For the ternary-relational CGT (Figure 1), there were significant effects of block, $F (4, 276) = 5.00$, $p = .001$, $\eta^2 = .068$, and age, $F (2, 69) = 14.70$, $p < .001$, $\eta^2 = .299$, and a significant Blocks × Age interaction, $F (4, 76) = 6.99$, $p < .001$, $\eta^2 = .168$. Advantageous choices decreased across

blocks for 3-year-olds, F (4, 92) = 5.11, p = .001, η^2 = .182, increased across blocks for 5-year-olds, F (4, 92) = 22.24, p < .001, η^2 = .492, and did not change significantly for 4-year-olds. The 3-year-olds' means were significantly above chance (5) for block 1, t (23) = 2.32, p = .029, and significantly below chance for blocks 2, 3 and 4 (all ps < .05). The 4-year-olds' mean for block 1 was significantly above chance, t (23) = 2.70, p = .013, but the means for the remaining blocks did not differ from chance. The 5-year-olds' means were significantly above chance for blocks 1 to 5, smallest t (23) = 2.91, p = .008.

Insert Figure 1 about here

For the combined binary-relational versions (Figure 1), there were significant effects of age, F (2, 69) = 4.15, p = .02, η^2 = .107, and block, F (4, 276) = 54.15, p < .0001, η^2 = .440. The Blocks × Age interaction was not significant. The means of 3-, 4- and 5-year-olds for all trial blocks were significantly above chance, smallest t (23) = 2.66, p = .014.

The Complexity × Age × Gender interaction was partitioned by complexity. For the ternary-relational CGT (Figure 2, right) there was a significant age effect, F(2, 66) = 15.44, p < .001, η^2 = .319, and a significant Gender × Age interaction, F (2, 66) = 3.14, p = .05, η^2 = .087. For 3-year-olds (but not 4- or 5-year-olds), females made significantly more advantageous choices than males, F (1, 22) = 5.30, p = .031, η^2 = .194. For the binary-relational version, there was a significant age effect, F (2, 66) = 4.06, p = .022, η^2 = .109. Four-year-olds made fewer advantageous choices than three-year-olds. Neither the main effect of gender nor the Gender × Age interaction was significant.

Insert Figure 2 about here

Individual scores of 32 or more out of 50 are significantly above chance (binomial distribution, chance = 0.5, p < .05). Using this cut-off (Table 2) the median ages of mastery were 5 years for the ternary-relational CGT, and 3 years (or earlier) for the binary-relational versions.

Insert Table 2 about here

Table 3 cross-tabulates the chance and above-chance scores for the binary- and ternary-relational versions. Fifty-seven percent of children (41) demonstrated mastery of both versions or neither version. The 31 children who showed an inconsistent pattern were more likely to perform above chance on the binary-relational and not the ternary-relational CGT (83.87%) than the reverse pattern (16.13%), McNemar test, $\chi^2(N = 72, 1) = 12.90$, $p < .001$. Thus the binary- and ternary-relational versions constitute a valid scale of difficulty.

Insert Table 3 about here

Discussion

The main finding was that young children succeeded when task complexity was reduced. The 3-, 4-, and 5-year-olds selected cards from the advantageous deck and avoided the disadvantageous deck when correct selections depended on information about gains alone or losses alone (binary-relational versions). The ternary-relational CGT involved integrating gains and losses to identify the advantageous deck. The group-based analyses indicated that 3-year-olds made fewer advantageous choices than would be expected by chance. Only 12.5% of 3-year-olds mastered this more complex version. Kerr and Zelazo's (2004) 3-year-olds performed similarly. For 4-year-olds, the group-based analyses suggested that they performed at chance level throughout. However the individual scores showed that 41.66% of 4-year olds mastered the ternary-relational CGT. This heterogeneity might indicate a transition around 4 to 5 years of age. The 5-year-olds clearly demonstrated mastery of the ternary-relational CGT. Their performance was similar to Kerr and Zelazo's 4-year-olds.

The 3- and 4-year-olds' success on both binary-relational versions suggests that they can perform all components of the CGT. They processed differences in gains on the binary-relational (gain) version and differences in losses on the binary-relational (loss) version. What they and most 4-year-olds could not do was to integrate these differences to identify the

advantageous deck in the ternary-relational CGT. These results are consistent with RC theory and also with CCC theory because the binary-relational versions do not require a higher-order rule.

That the ternary-relational CGT was more difficult than the binary-relational versions is consistent with RC theory (Halford et al., 1998) in which processing load increases with task complexity. The median ages of attainment for ternary-relational (5 years) and binary-relational (by 3 years) versions are consistent with previous findings. The percentages of 3- (12.5%), 4- (41.67%), and 5-year-olds (83.33%) demonstrating mastery of the ternary-relational CGT were somewhat higher than previously observed for ternary-relational tasks in cool domains (Andrews & Halford, 2002), but comparable to the corresponding percentages (3.57%, 35.7%, 75%) for ToM (Andrews et al., 2003). This suggests that hot EF tasks are mastered earlier than cool EF tasks of the same complexity.

Kerr and Zelazo (2004) suggested that 3-year-olds' difficulty might stem from a failure to develop somatic markers (Bechara et al., 1994) associated with the disadvantageous deck. However our 3-year-olds avoided disadvantageous decks in the binary-relational versions. The Somatic Marker theory would need to explain why somatic markers were developed for binary-relational versions but not the ternary-relational version. Further research could determine whether brain-impaired patients succeed when complexity is reduced.

Paradoxically, 3-year-olds outperformed 4-year-olds on the binary-relational versions. On the ternary-relational CGT, the 3-year-olds appeared to systematically consider gains and ignore losses, arguably because they cannot yet integrate two variables. Focusing exclusively on one variable yields correct selections on the binary-relational versions. The 4-year-olds' performance on the ternary-relational CGT suggests an emerging but still fragile ability to

integrate two variables, which might (in some cases) disrupt performance on the binary-relational versions, where a single variable is relevant.

There is mixed evidence regarding gender effects on the CGT. Garon and Moore (2004) reported a female advantage whereas Kerr and Zelazo (2004) reported a trend favoring males among 3-year-olds. Our results showed female superiority among 3-year-olds on the ternary-relational CGT. Clearly, further research with larger sample sizes is needed.

In summary, the two binary-relational versions were closely matched to the ternary-relational CGT except for the number of variables. The 3-, 4-, and 5-year-olds made advantageous card selections on these versions, where they could process gains and losses separately. Only 5-year-olds did so on the ternary-relational CGT. Thus children's difficulty appears to be due to the complex relations that must be processed. Age-related changes in the complexity of relations that can be processed constitute an important constraint on EF development during childhood.

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Table 1.

Gains and Losses for 10-card blocks in Decks A and B for the Ternary-relational, Binary-relational (Gain) and Binary-relational (Loss) Versions of the Children's Gambling Task.

Version	Deck A			Deck B		
	Per 10-card block			Per 10-card block		
	Gain	Loss	Net [a]	Gain	Loss	Net [a]
Ternary-relational [b]	10	5	+5	20	25	-5
Binary-relational (gain) [c]	10	5	+5	20	5	+15
Binary-relational (loss) [b]	10	5	+5	10	25	-15

[a] + indicates gain; - indicates loss. [b] Deck A is advantageous in the ternary-relational and binary-relational (loss) versions. [c] Deck B is advantageous in the binary-relational (gain) version.

Table 2.

Frequencies of Children in Each Age-Group who Performed Significantly above Chance (≥ 32) and not Significantly Above Chance (< 32) on the Combined Binary-Relational and Ternary Relational Versions

	Binary-relational		Ternary-relational	
Age	< 32	≥ 32	< 32	≥ 32
3 years	4	20	21	3
4 years	10	14	14	10
5 years	5	19	4	20

Table 3.

Cross-tabulation of Children who Performed Significantly above Chance (≥ 32) and not Significantly Above Chance (< 32) on the Combined Binary-Relational and Ternary-Relational Versions [a]

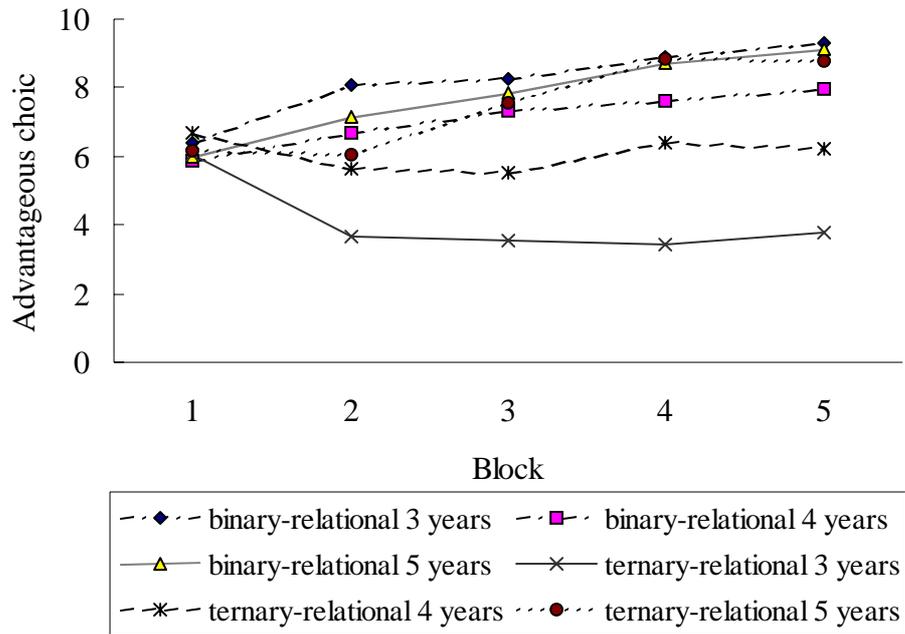| Binary-relational	Ternary-relational	
	< 32	≥ 32
< 32	13	5
≥ 32	26	28

[a] Cell entries are frequencies

Figure 1. Mean number of advantageous choices (with standard errors) on the combined

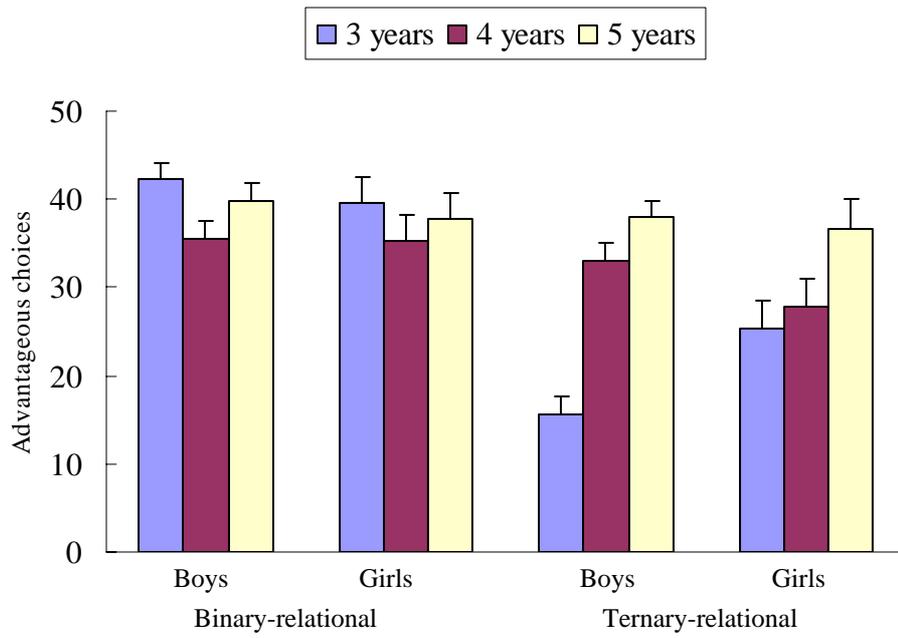binary-relational and ternary-relational versions by trial block and age group.

Figure 2. Mean number of advantageous choices (with standard errors) on the combined

binary-relational and ternary-relational versions by gender and age group.