Children’s Strategy Use in Playing Strategic Games

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Development of Strategic Play

• What are differences in strategies?
• What cognitive abilities are related to strategy use?
Strategic Game


“A knows that I will play X, so A will play Y”

<table>
<thead>
<tr>
<th>Player I’s Payoffs</th>
<th>Player II’s Payoffs</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 4</td>
<td>1 2</td>
</tr>
<tr>
<td>1 2</td>
<td>3 4</td>
</tr>
</tbody>
</table>

Decision Tree

- Player I switches
- Player II stays
- Player I stays
- Player II switches
Theory of Mind

• Thinking about other peoples and one’s own beliefs or intentions
  – “The other person believes X”
  – False belief test, appearance-reality tasks

• Cognitive abilities
  – Working memory
  – Inhibitory control
  – Control for verbal abilities, intelligence and age!

this is Sally

Sally puts her ball in the basket

Sally goes away

Anne moves the ball to her box

where will Sally look for her ball?
Flobbe et al. 2008, 2nd order

“The other person (A) plays X”

“A knows that I will play X, so A will play Y”
Flobbe et al., 2008

- False belief task
  - Sullivan et al.'s (1994) 'Birthday Puppy' story
- Sentence comprehension task
  - Speakers need to reason about the hearer’s alternatives
- First order reasoning
  - 55% of the 8 to 10 years old children, > 83% corr.
- Second-order reasoning
  - These 55% children show above chance level performance
- No relation between tasks
Development of Playing Strategic Games

• What strategies do children apply?
  – Strategy analysis

• Relation to Cognitive Abilities
  – Theory of Mind
  – Working Memory
  – Correction for age, verbal abilities, general intelligence
Method

Participants

- 129 children in the age range of 5 to 12 years
  - Traveling game
    - Zero order
    - First order
    - Second order
- (Out of the 129) 49 children (4 and 6 years old)
  - IQ: Raven Progressive Matrices A, B, C
  - Verbal ability: TAK – sentence comprehension
  - WM: digit span forward, backward
  - ToM: Two stories (Flobbe, et al., 2008; Tager-Flusberg and Sullivan, 1994)
Traveling Game, zero-order
Test Design

Expected Strategies
- 0-A: optimal strategy
- 0-B: choice for largest sum leaves+marbles
- 0-C: choice for largest relative gain

<table>
<thead>
<tr>
<th>Item types</th>
<th>I</th>
<th>II</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-A</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>0-B</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>0-C</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>
Traveling game, First-Order
Test Design: First Order

Expected Strategies
- 1-A: optimal strategy
- 1-B: choice for largest relative gain
- 0-A: zero-order largest gain
- 0-B: zero-order largest sum
- 0-C: zero-order largest relative gain
- 0-D: go directly to the right

<table>
<thead>
<tr>
<th>Item types</th>
<th>I</th>
<th>II</th>
<th>III</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-A:</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>1-B:</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>0-A:</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>0-B:</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>0-C:</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>0-D:</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>
Traveling game, second-order
Table A6: Expected accuracy patterns for different potential strategies

<table>
<thead>
<tr>
<th>Items</th>
<th>2-A</th>
<th>1-A</th>
<th>1-B</th>
</tr>
</thead>
<tbody>
<tr>
<td>1, 9, 4, 7</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>2, 3</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>5, 6, 8</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

- 2-A: optimal
- 1-A: first-order with second choice child
- 1-B: first-order without second choice child
Procedure

• Zero-order task
  – 2 example items, scaffolding + animations
  – 9 test items, no direct feedback//animations

• First-order task
  – 3 example items, scaffolding + animations
  – 15 test items, no direct feedback/animations

• Second order task (only after first-order criterion)
  – 3 example items, scaffolding + animations
  – 9 test items, no direct feedback/animations
Results traveling game

• Mean scores
  – Above chance level for 0-, 1\textsuperscript{st} order task (t(128) = 40.1, 
    \( p < .001 \); t(128) = 10.6, \( p < .001 \)).
  – Not above chance level 2\textsuperscript{nd} order task (t(54) = 1.6, \( p = .06 \))

• 55 children (43\%) past first-order task
  – Mean age = 9.8 (1.96)

• Strategy Analysis, separately per task
Strategy Analysis: Pattern Matching

- Siegler (1981), most cases in developmental psychology and other behavioral studies

- Pattern Matching
  - Matching observed response patterns with expected patterns with criterion for minimal match
  - Criterion is e.g., minimum of 85% match

- Example:
  Participant x observed scores:
  - Type I items: .90
  - Type II items: .15

  Strategy 0-C (largest relative gain)
  Mismatch = .125
Latent Class Analysis (McCutcheon, 1987)
Statistical Test for Strategies

Problems of Pattern Matching
- Many factors effect optimal criterion
  - # Items
  - Set of Expected Rules
  - # Guessers
  - Accuracy of rule-application
- No criterion for optimal model
  - Most parsimonious model that fits the data well

Advantages of Latent Class Analysis
- Unexpected rules are detectable
- Minimizing False Positives
- Statistical tools for fitting models and model selection

Strategies zero-order task

<table>
<thead>
<tr>
<th>zero-order items</th>
<th>prior</th>
<th>conditional probabilities</th>
</tr>
</thead>
<tbody>
<tr>
<td>bias to sum</td>
<td>.17</td>
<td>.62</td>
</tr>
<tr>
<td></td>
<td></td>
<td>.75</td>
</tr>
<tr>
<td>optimal</td>
<td>.83</td>
<td>.98</td>
</tr>
<tr>
<td></td>
<td></td>
<td>.99</td>
</tr>
</tbody>
</table>
Relation to Age

- Strategies for the zero-order task were related to age (Wald test, $p = .002$)
Strategies first order task

<table>
<thead>
<tr>
<th>first-order items</th>
<th>type 1</th>
<th>type 2</th>
<th>type 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>guess</td>
<td>.39</td>
<td>.62</td>
<td>.47</td>
</tr>
<tr>
<td>0-order</td>
<td>.19</td>
<td>.96</td>
<td>.04</td>
</tr>
<tr>
<td>go right</td>
<td>.04</td>
<td>.03</td>
<td>.97</td>
</tr>
<tr>
<td>optimal</td>
<td>.38</td>
<td>.94</td>
<td>.94</td>
</tr>
</tbody>
</table>
Relation to Age

- Strategies for the first-order task were related to age (Wald test, $p = .001$).

![Bar chart showing distribution of strategies by age group for 1st-order task.](chart.png)
Strategies second order task

- Type 2 items: only correct for first-order without second choice for the child.
Relation to age

- Strategies for the second-order task were related to age (Wald test, p = .005).
Mean Scores

Scores above chance level depends on
• Items in the task
• Strategies used

<table>
<thead>
<tr>
<th>Task</th>
<th>S1</th>
<th>S2</th>
<th>S3</th>
<th>S4</th>
<th>All</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-order</td>
<td>0.66 (0.12)</td>
<td>0.98 (0.05)</td>
<td></td>
<td></td>
<td>0.94 (0.12)</td>
</tr>
<tr>
<td>1st-order</td>
<td>0.58 (0.16)</td>
<td>0.54 (0.05)</td>
<td>0.51 (0.08)</td>
<td>0.94 (0.06)</td>
<td>0.70 (0.22)</td>
</tr>
<tr>
<td>2nd-order</td>
<td>0.42 (0.16)</td>
<td>0.60 (0.17)</td>
<td></td>
<td></td>
<td>0.54 (0.19)</td>
</tr>
</tbody>
</table>
Cognitive tests

- Correlations after correcting for age and verbal ability
- ToM and WM: $r = .32$, $p = .02$
- IQ: $r = .16$, $p = .005$

Table 3: Summary data cognitive tests

<table>
<thead>
<tr>
<th>Task</th>
<th>5 years</th>
<th>6 years</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mean</td>
<td>sd</td>
</tr>
<tr>
<td>ToM</td>
<td>4.80</td>
<td>1.96</td>
</tr>
<tr>
<td>ToM1</td>
<td>2.65</td>
<td>1.18</td>
</tr>
<tr>
<td>ToM2</td>
<td>2.15</td>
<td>1.14</td>
</tr>
<tr>
<td>DS</td>
<td>5.90</td>
<td>2.05</td>
</tr>
<tr>
<td>RPM</td>
<td>13.30</td>
<td>4.50</td>
</tr>
<tr>
<td>Tak</td>
<td>21.85</td>
<td>3.69</td>
</tr>
</tbody>
</table>
Strategies and Cognitive Abilities
(5 and 6 years old, N = 49)

- Zero-order strategies
  - Only age has a unique contribution
    Logistic regression: coeff. = .1, p = .047

- First-order strategies
  - Only WM has a unique contribution
    Logistic regression: coeff. = .59, p = .017
Conclusion

• Optimal and suboptimal strategies in strategic games are related to age.

• Strategies first-order reasoning
  – Not directly related to ToM
  – Related to WM
Discussion

• How to increase children’s abilities in complex reasoning task?
  – Above chance level performance is not conclusive about quality of reasoning (0, 1st, 2nd order).
  – Scaffolding worse performance than short training?
    • Note developmental differences in feedback learning
    • Training in Rekentuin (Mathsgarden)

• Same kind of abilities underlying false belief ToM and playing strategic games?
  – ToM not directly related
    • Static versus dynamic opponent
  – WM important
    • Inhibitory control not measured (pitty!)