Knowledge Transfer

An Investigation into the Adaptive Shifting Hypothesis

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Background

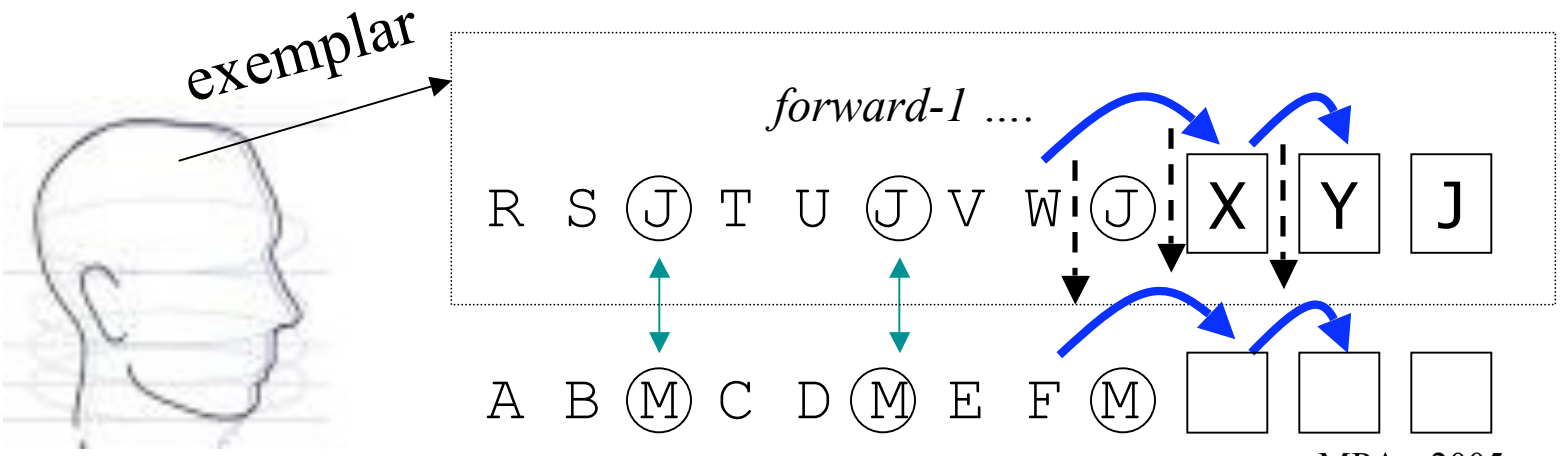
- A central goal of cognitive science is to develop a general theory of knowledge transfer.

- In past work researchers have progressed towards this goal by investigating *separate mechanisms of transfer*:
  - Analogy (Gentner, Holyoak, & Kokinov, 2001)
  - Knowledge Compilation (Anderson, 1983; Anderson & Lebiere, 1998)
  - Constraint Violation (Ohlsson, 1996; Ohlsson & Rees 1991)

- Each mechanism has been hypothesized to use a set of distinct *cognitive processes* and operate on different types of *knowledge structures*.

Analogy (Gentner, Holyoak, & Kokinov, 2001)

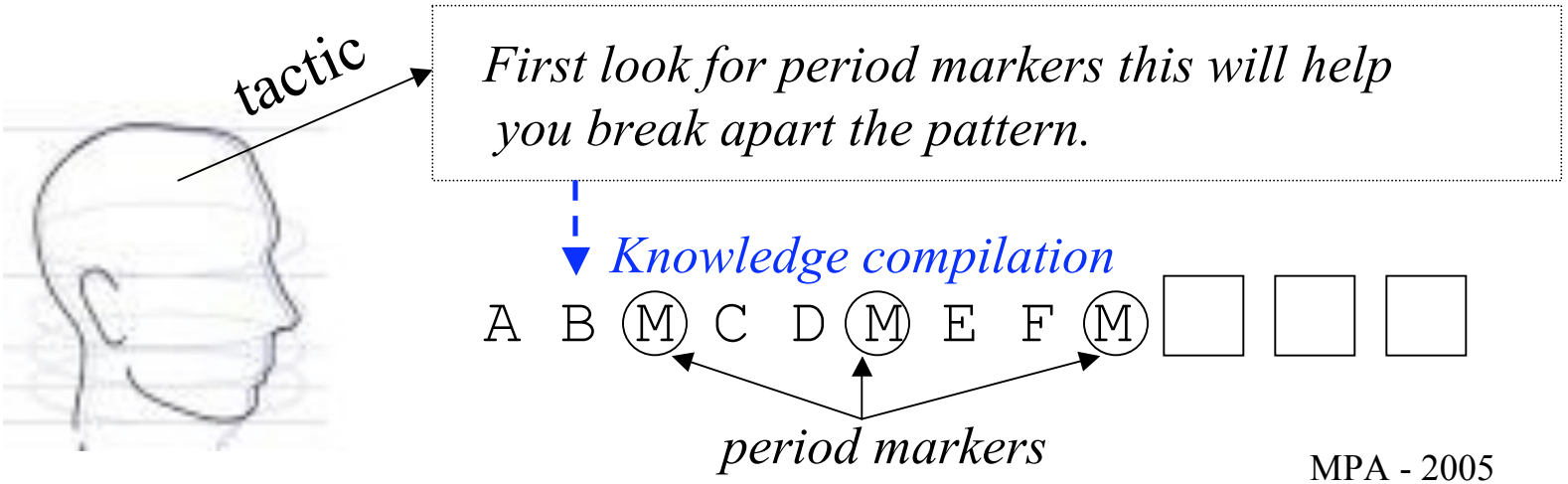
- Transfer of prior examples to solve new problems.
- Process: retrieval, alignment, mapping, inference
  - Memory access driven by surface features match.
  - If procedures transfer solution will be fast (no need to generate procedures).



Knowledge Compilation

(Anderson, 1983; Anderson & Lebiere, 1998)

- Transfer of declarative tactics to solve new problems.
- Process: translation device
  - Uses interpretive rules to translate prior tactics knowledge into procedures and actions to solve a particular problem.
  - Can be used over variety of tasks but costs time because knowledge must be specialized.



Constraint Violation

(Ohlsson, 1996; Ohlsson & Rees 1991)

- Transfer of domain constraints to solve new problems.
- Process: generate and test
  - Attempt solution, evaluate it, if constraints are violated revise procedures and try again.
  - Can be used over a wide variety of tasks but costs both time and errors.

constraint

*Letter relations for a given group **must** be repeated from the immediately preceding group.*

revise

A B M C D M E F M ? ? M

Local Explanations

- Each mechanism constitutes a ‘local explanation’ for transfer performance under particular prior knowledge and problem solving conditions.
- *However*, there has been no program of research designed to test the interaction of these mechanisms.
- Goal of the current work is to test and synthesize across current lines of research.

Adaptive Shifting Hypothesis

- Analysis of each theory suggests a cost-benefit trade off between the mechanisms.
  - Analogy applies only to similar problems, but is fast and efficient if procedures are transferred.
  - KC of tactics applies to a variety of problems but costs time because the knowledge must be proceduralized.
  - Constraint violation applies across many problems in a domain but costs both errors and time.
- hypothesis - an adaptive agent will use the mechanism that is most likely lead to a successful solution with the least amount of cognitive effort.
  - analogy --> knowledge compilation --> constraint violation

Experiment

- *Acquisition phase:*
  - Trained on examples, tactics, and constraints.

- *Application phase*: extrapolation problems (Thurstone & Thurstone, 1941)
  - Solved 3 novel problems with different task characteristics.

Acquisition (3-part training)

- Exemplar section
  - Solved 4 exemplar problem isomorphs
    - Exemplar 1: `ABMCDMEFM . . .`
    - Exemplar 2: `RSQTUQVWQ . . .`
- Tactics section
  - Read tactics tutorials (learned about pattern relations); memorized 5 tactics
    - *First look for period markers, this will help you break the pattern into its parts.*
- Constraints section
  - Constraints tutorial; memorized 4 constraints
    - *All letter completed letter strings **must** be divisible into five groups of letters.*

Application (3-problem test)

- Subjects solved three novel sequence extrapolation problems.
  - Problems were presented one at a time on the computer.
    - Participants were given 8 minutes to solve each one.
    - They were allowed to revise their solutions.
    - Instructed to think aloud.

Design Summary

Acquisition Scenario

Application Scenario

Training
(n = 36)
•exemplar
•tactics
•constraints

Control
(n = 10)
No-training

Transfer Problem 1
•high exemplar similarity
•tactics relevant
•constraints relevant

Transfer Problem 2
•*low exemplar similarity*
•tactics relevant
•constraints relevant

Transfer Problem 3
•*no exemplar similarity*
•*tactics irrelevant*
•constraints relevant

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Transfer Problem 3
•*no exemplar similarity*
•*tactics irrelevant*
•constraints relevant

General Prediction

Subjects will use the mechanism that leads to a correct solution but requires the least amount of cognitive work.

Transfer Problem 1

Acquisition Scenario

Application Scenario

Training
(n = 36)
•exemplar
•tactics
•constraints

Control
(n = 10)
No-training

Transfer Problem 1
•high exemplar similarity
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•constraints relevant

Transfer Problem 3
•*no exemplar similarity*
•*tactics irrelevant*
•constraints relevant

Transfer 1 Predictions
Mechanism: Analogy of exemplars
Behaviors: +transfer; fast solution time; statements of analogies

Transfer Problem 2

Acquisition Scenario

Application Scenario

Training
(n = 36)
•exemplar
•tactics
•constraints

Control
(n = 10)
No-training

Transfer Problem 1
•high exemplar similarity
•tactics relevant
•constraints relevant

Transfer Problem 2
•*low exemplar similarity*
•tactics relevant
•constraints relevant

Transfer Problem 3
•*no exemplar similarity*
•*tactics irrelevant*
•constraints relevant

Transfer 2 Predictions
Mechanism: Knowledge compilation of tactics
Behaviors: +transfer; long solution times; statements of tactics

Transfer Problem 3

Acquisition Scenario

Application Scenario

Training
(n = 36)
•exemplar
•tactics
•constraints

Control
(n = 10)
No-training

Transfer Problem 1
•high exemplar similarity
•tactics relevant
•constraints relevant

Transfer Problem 2
•*low exemplar similarity*
•tactics relevant
•constraints relevant

Transfer Problem 3
•*no exemplar similarity*
•*tactics irrelevant*
•constraints relevant

Transfer 3 Predictions
Mechanism: Constraint violation
Behaviors: +transfer; long solution times; statements of constraints violation

Training to criterion

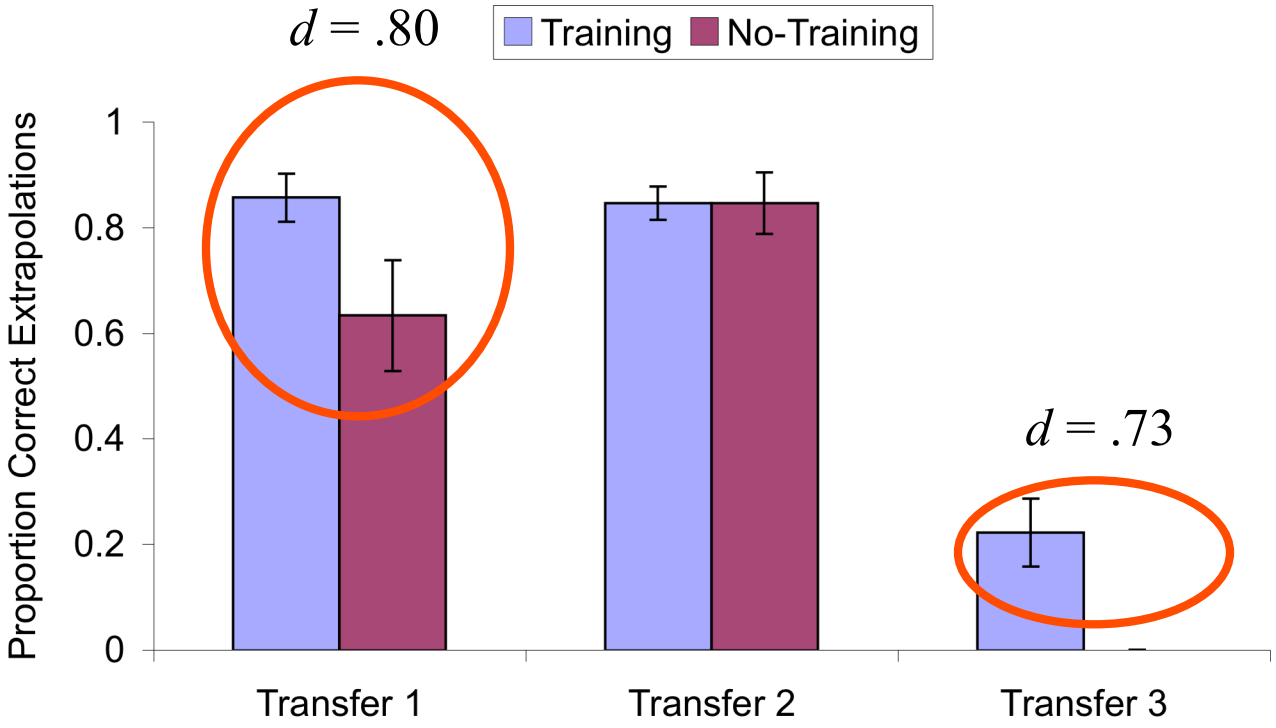
- Subjects were trained to a learning criterion
  - Solved at least two of the exemplar problems correctly.
  - Gave complete recall and correct explanation of tactics and constraints.

- Passing criterion provides support that subjects acquired all three types of target knowledge.

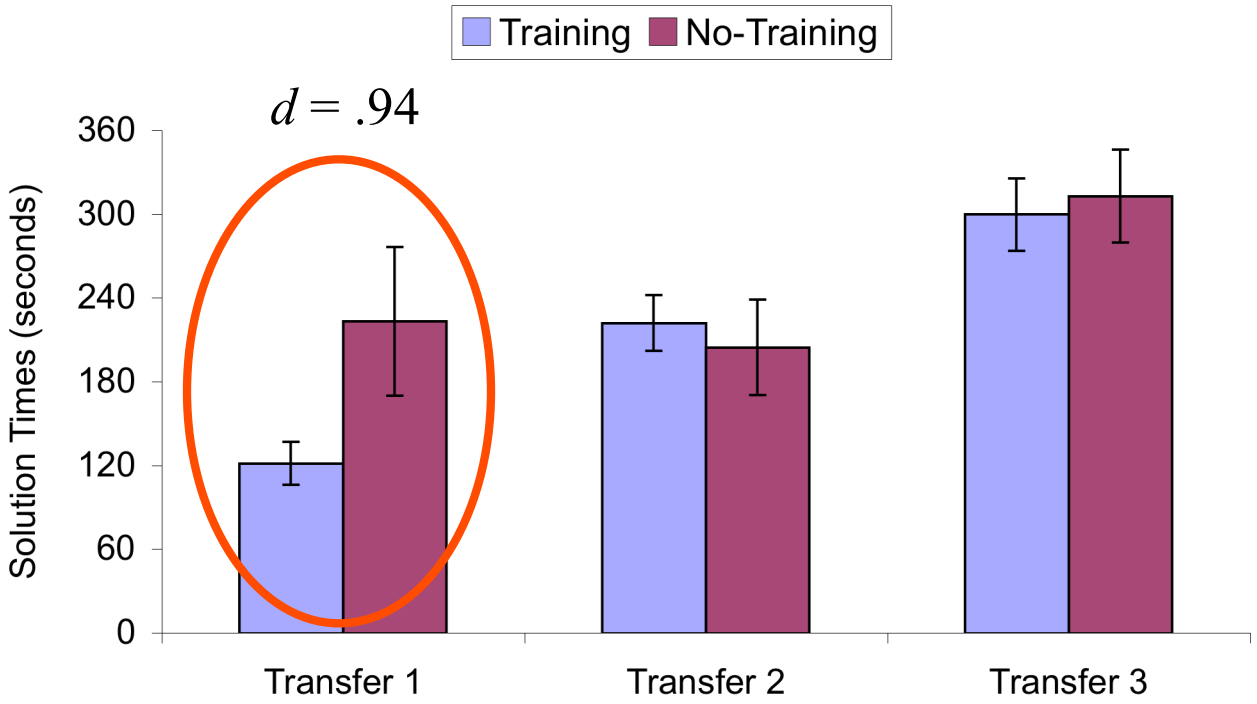
Transfer Measures

- Was there knowledge transfer?
  - Accuracy (proportion of correct extrapolations)
  - Solution times
- How was the knowledge transferred - what mechanisms?
  - Verbal protocols

Transfer: Accuracy



Solution Time



Transfer Results Summary

- Was there transfer of training? -- Yes
  - Training improved performance on problems 1 & 3.
  - Fast solution times on problem 1 suggest transfer of procedures from the exemplar.

- Did the verbal protocols show converging evidence for shifting between knowledge types?

Verbal Protocol Measure

- Subjects were classified as to whether or not they showed protocol evidence for using each mechanism across the three problems.
  - A subject was classified as using a particular mechanism **if she or he made more statements than the average of no-training**.
  - This measure assesses those statements generated due to training; not just normal problem solving.

- For each problem how many subjects made statements using predicted mechanism.
  - Was there a shift across problems?

Transfer: Protocol Results

Transfer Problem	**Transfer Strategy** Number of Subjects Classified (n = 36)		
	Analogy	Tactics Application	Constraint Violation
Transfer 1	4	15	7
Transfer 2	1	21	13
Transfer 3	0	14	17

Transfer Problem 1

Transfer Problem	**Transfer Strategy** Number of Subjects Classified (n = 36)		
	Analogy	Tactics Application	Constraint Violation
Transfer 1	4	**15***	7
Transfer 2	1	21	13
Transfer 3	0	14	17

$Q\,(3, N = 36) = 11.41, p < .05$

Transfer Problem 2

Transfer Problem	**Transfer Strategy** Number of Subjects Classified (n = 36)		
	Analogy	**Tactics Application**	Constraint Violation
Transfer 1	4	15	7
Transfer 2	1	**21***	13
Transfer 3	0	14	17

Q (3, N = 36) = 26.44, p < .05

Transfer Problem 3

Transfer Problem	**Transfer Strategy** Number of Subjects Classified (n = 36)		
	Analogy	Tactics Application	**Constraint Violation**
Transfer 1	4	15	7
Transfer 2	1	21	13
Transfer 3	0	14	**17***

$Q\ (3, N = 36) = 22.46, p < .05$

Relative Shift to Analogy

Transfer Problem	**Transfer Strategy** Number of Subjects Classified (n = 36)		
	Analogy	Tactics Application	Constraint Violation
Transfer 1	**4***	15	7
Transfer 2	1	21	13
Transfer 3	0	14	17

$Q\ (2, N = 36) = 6.50, p < .05$

Relative Shift to Tactics

Transfer Problem	**Transfer Strategy** Number of Subjects Classified (n = 36)		
	Analogy	Tactics Application	Constraint Violation
Transfer 1	4	15	7
Transfer 2	1	**21**$^{+}$	13
Transfer 3	0	14	17

$Q\ (2, N = 36) = 4.30, p = .10$

Relative Shift to Constraints

Transfer Problem	**Transfer Strategy** Number of Subjects Classified (n = 36)		
	Analogy	Tactics Application	Constraint Violation
Transfer 1	4	15	7
Transfer 2	1	21^{+}	13
Transfer 3	0	14	**17***

Q (2, N = 36) = 10.13, p < .05

Results Summary

- Converging evidence for relative shifts between transfer mechanisms across problems.
  - Transfer problem 1 --> Analogy of procedural knowledge
    - accuracy advantage; although few explicit analogy statements fast solution times suggests *procedural transfer* -- tactics relations may have been incorporated into exemplar representation
  - Transfer problem 2 --> Knowledge compilation of tactics knowledge
    - high accuracy; long solution times; statements of tactics
  - Transfer problem 3 --> Application of constraints via error-correction
    - accuracy advantage; long solution times; statements of constraints application and error-correction

Conclusion

- Evidence that people shift between transfer mechanisms based on prior knowledge and the characteristics of transfer tasks.
  - However: individual differences, shifting was not all or none, but more complex some participants used multiple mechanisms.
- Results provide first step towards developing a *general theory of transfer* that incorporates local mechanisms in principled ways.
- In current empirical work I am further investigating these interactions:
  - Different domains (elementary probability theory); Individual differences; Expertise

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