Enhanced integrative encoding through active control of learning

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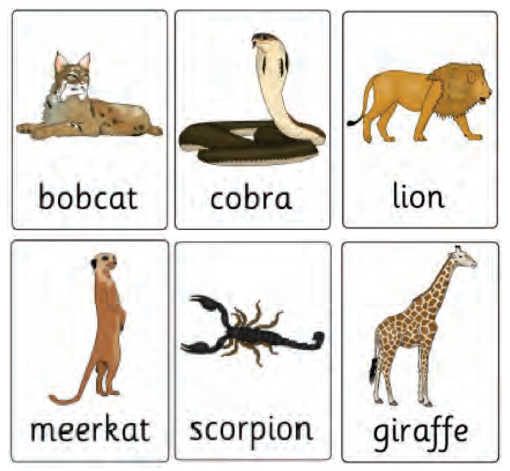
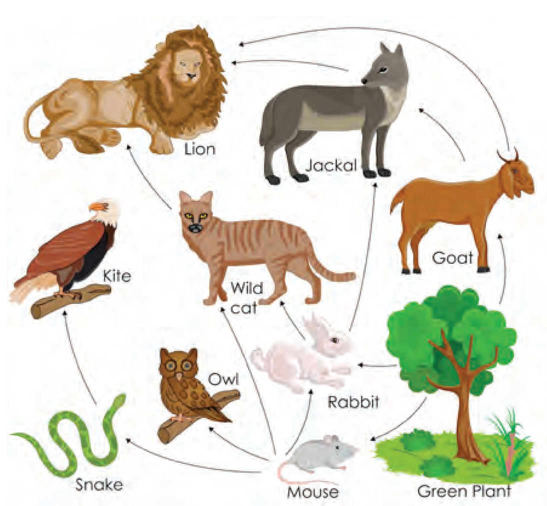
Previous work has shown enhanced *elemental encoding* (Zeithamova, Schlichting & Preson, 2012) when learners control the pacing, sequencing, and content of study (Markant et al., 2016). It is less clear how such control over study impacts the integration of studied material into flexible, relational knowledge.

Elemental encoding
Learning associations for a set of independent pairs

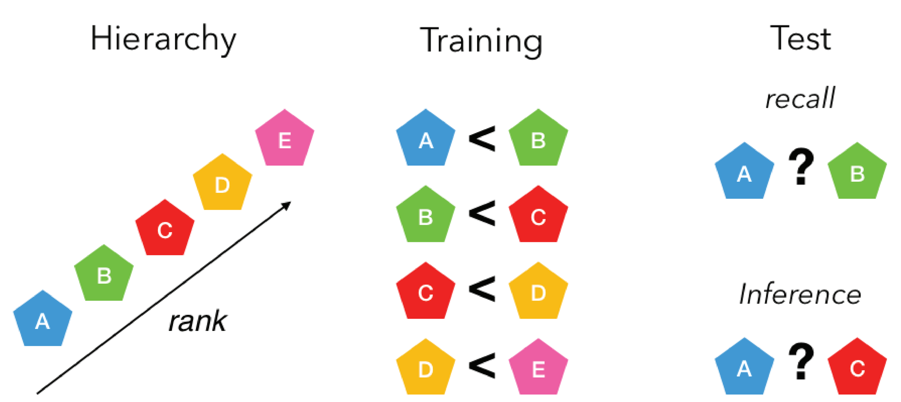


Integrative encoding
Forming integrated, relational knowledge about studied materials



Active transitive inference: Does learner control enhance integrative encoding?

This study examines the effects of active control of learning in *transitive inference* (TI). In TI tasks people learn relations between adjacent items in an ordered hierarchy, followed by a test involving comparisons of the relative rank of any two items. TI is typically studied under passive training conditions in which learners have no control over the sequence of pairs during study.



TI can by achieved by multiple mechanisms: Elemental encoding-based strategies involve reactivating memories of studied pairs at test and reasoning across overlapping pairs (Kumaran & McClelland, 2012). Integrative encoding-based strategies involve the formation of a unified representation of the hierarchy during study, which is then used to compare the position of items at test (Zeithamova & Preston, 2010).

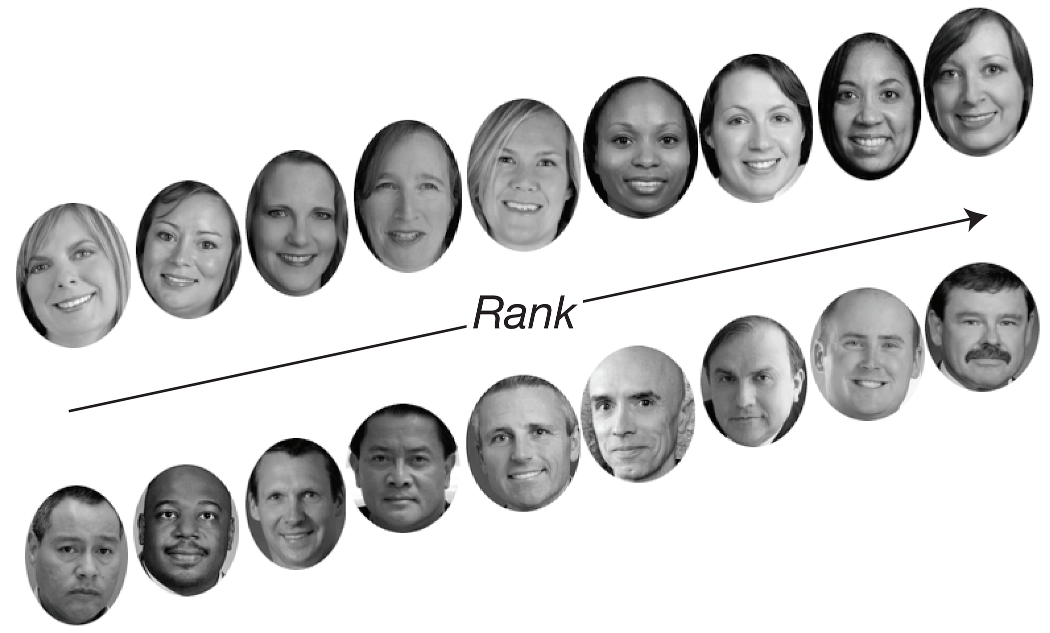
These mechanisms predict different relationships between inferential distance and accuracy: Elemental encoding predicts that accuracy is highest for studied pairs but decreases as the distance between items increases, whereas integrative encoding that distant inferences are more accurate (*symbolic distance effects;* Acuna, Sanes, & Donoghue, 2002). Integrative encoding is more likely when people are aware there is a hierarchy to be learned and entails greater cognitive costs during study (dependence on working memory; Libben & Titone, 2008).

Questions

1. Does active control, through which people choose their own training sequence, lead to more efficient learning in TI?
2. Is any advantage from active control due to enhanced elemental encoding or integrative encoding?
3. Is any advantage from active control dependent on participants' working memory capacity (WMC)?
4. Are the effects of active control accounted for by changes in training sequences generated by participants?

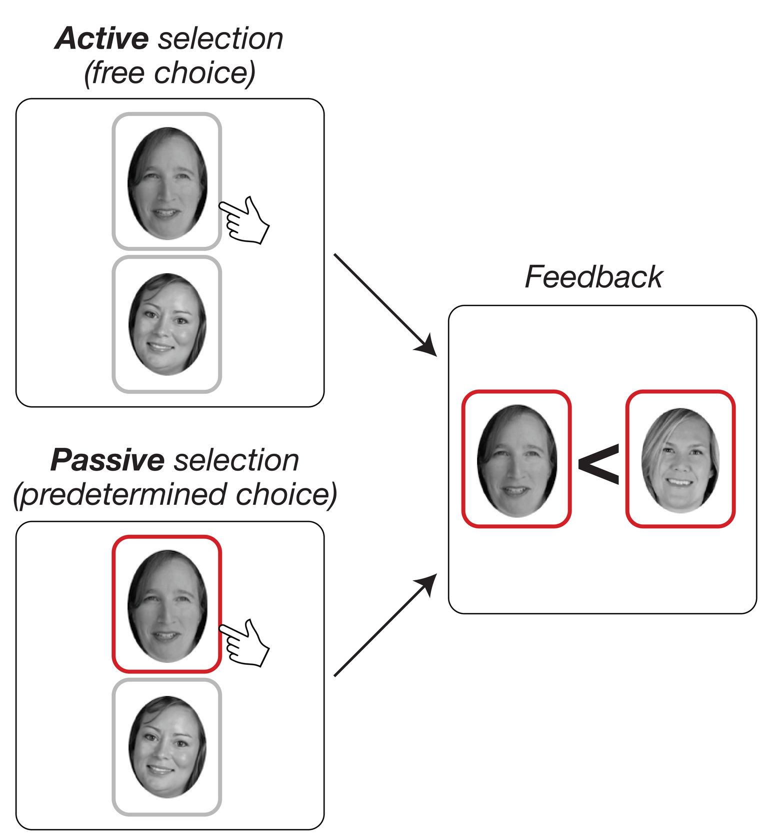
Experiment: Learning the "Chain of Command"

Goal: Learn about the "chain of command" at two companies. On each learning trial one face is selected from the hierarchy, followed by that person's direct supervisor (the next-highest item).

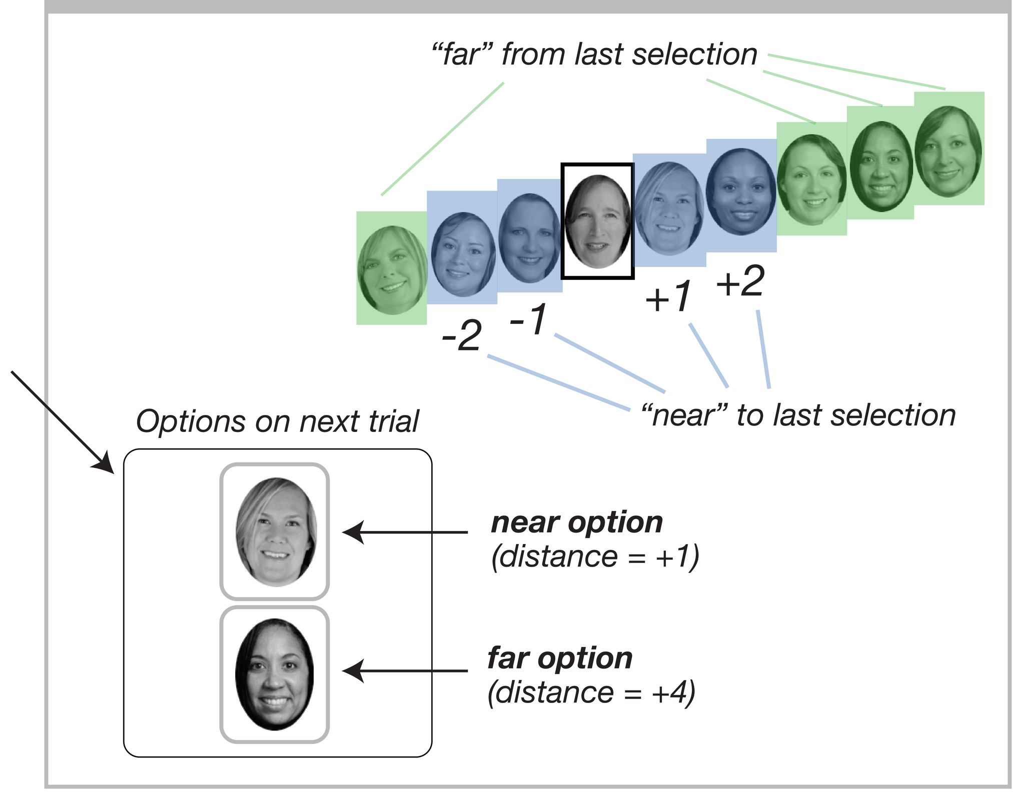


Each participant learns one hierarchy through **active selection** (on each trial choosing a person to learn their direct supervisor) and the other hierarchy through **passive selection** (learning the direct supervisor of a predetermined person). Participants are then tested on their ability to identify the higher-ranked person for every possible pairing.

Learning phase (56 trials)
Pick one person to learn who is their direct supervisor:

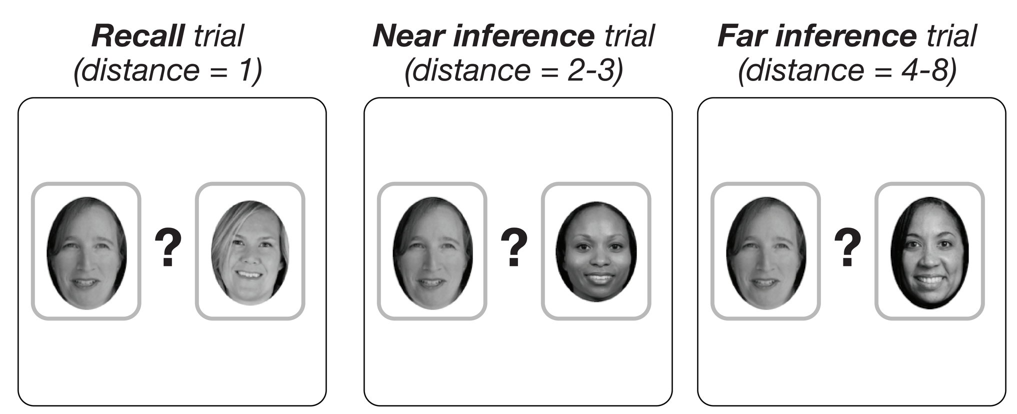


Manipulating option sets to explore search preferences during active study
Each option set included a "near option" and "far option" based on distance from person selected on previous trial (randomly sampled):



Test phase (72 trials)
For each possible pairing of individuals from the hierarchy, choose the person who is ranked higher.

Test test trials vary in inferential distance between individuals, from **recall** of studied pairs (distance = 1), **near inference** (distance = 2-3), to **far inference** (distance = 4+).



Who is ranked higher in the company?

Design and Procedure

- Within subjects manipulation of study condition (active vs. passive selection)
- Following TI task, participants completed operation span task to measure working memory capacity (WMC)
- N=100 participants completed first session (with immediate tests after each study phase); N=62 participants returned a week later for the second session (retest)

References

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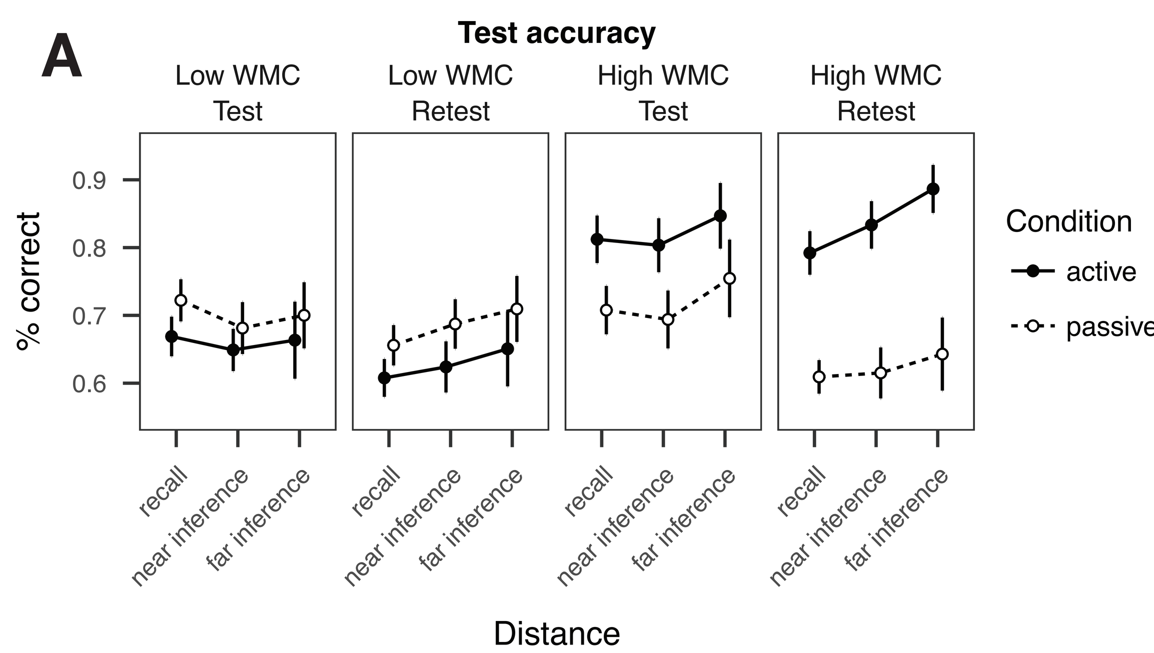
Results

Test accuracy: How does active control impact transitive inference performance?

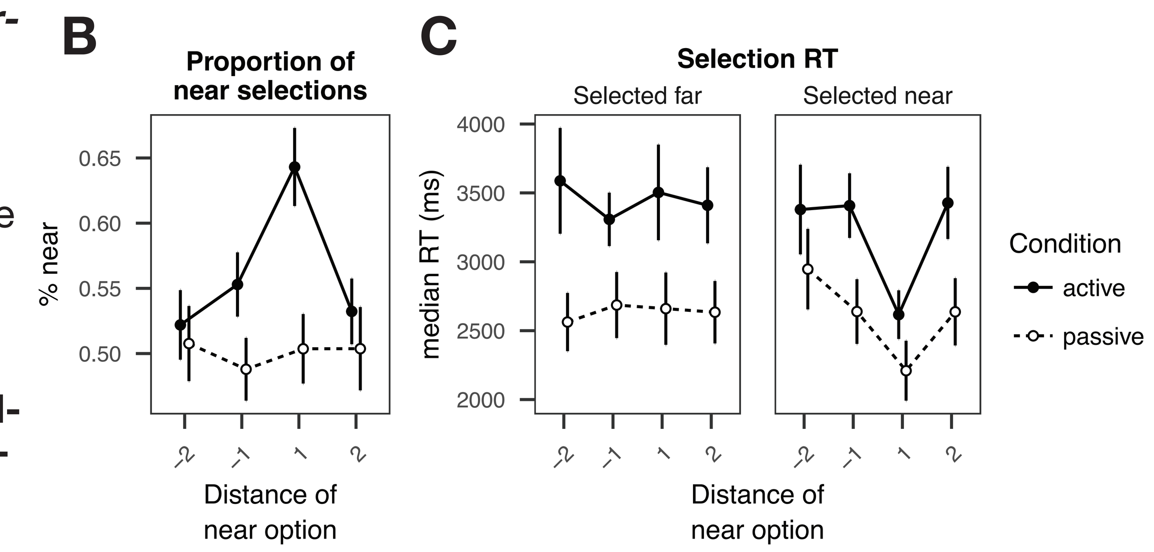
Mixed effects logistic regression was used to model test accuracy with condition (active/yoked), inferential distance (recall/near inference/far inference), session (test/retest), operation span, and pairwise interactions as predictors.

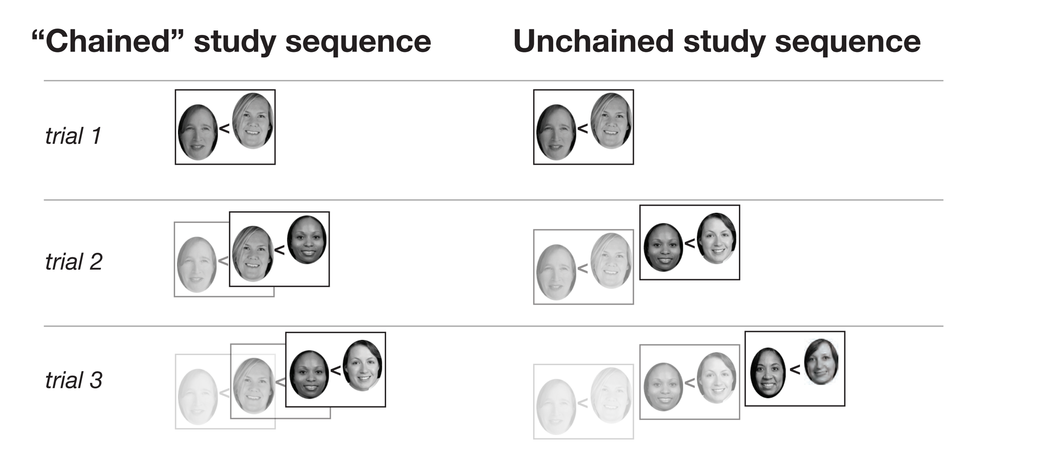
- **Active selection led to higher performance than passive selection** in both the immediate test (OR = 1.31, 95% CI = [1.13, 1.53]) and delayed retest (OR = 1.62 [1.34, 1.94]).
- **Accuracy increased with inferential distance in the active condition** (OR = 1.08 [0.99, 1.19]) but not the passive condition (OR = 1.04 [0.95, 1.13]), replicating symbolic distance effect that is characteristic of integrative encoding.
- **WMC (operation span) was positively related to test accuracy in the active condition** (OR = 1.97 [1.44, 2.68]) **but not the passive condition** (OR = 1.08 [0.79, 1.47]).
- Based on median split on WMC (Figure A), **active selection led to better performance among high WMC participants** (test: OR = 1.97 [1.58, 2.44]; retest: OR = 3.48 [2.65, 4.56]) **but *worse* performance among low WMC participants** (test: OR = 0.80 [0.66, 0.97]; retest: OR = 0.76 [0.60, 0.96]).



Selections during active study: Can participants' choices account for the advantage from active selection?

- Distribution of item selection frequency did not differ between active and passive conditions ($\chi2(1,7) = 7.20$, $p = 0.41$).
- During active study, **participants preferred to choose (and were faster to select) the near option when it was adjacent to the item selected on the previous trial**, particularly when it had appeared as feedback on the last trial; see Figures B and C.
- **Selection of the distance = +1 near option leads to "chains" of overlapping pairs** during training that may facilitate integrative encoding, and which were less frequent in passive condition.
- However, **tendency to select near option was not related to test performance or WMC**, indicating a general preference that can't account for advantage from active study.





Summary

- Test performance in the active (but not passive) condition increased with inferential distance (*symbolic distance effect*), consistent with enhanced integrative encoding from active selection.
- Performance in the active (but not passive) condition increased with higher WMC, replicating link between WMC and TI (Fales et al., 2003; Libben & Titone, 2008). Among higher WMC participants, active selection led to sustained improvement over passive selection after a 1-week delay.
- During active study, people naturally select "chained" sequences of overlapping pairs, generating training sequences previously shown to improve TI (Halford, 1984; Waltz et al., 2004); but this selection preference on its own doesn't account for advantage from active study.
- Active selection only benefited higher WMC participants, who may have capitalized on chained sequences that facilitate integrative encoding (e.g., because they were more likely to maintain information from previous trials). Advantages from active control for relational learning may thus hinge on cognitive resources needed to maintain and integrate information across study episodes.

See preprint at **psyarxiv.com/h2e5f**