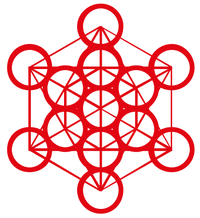
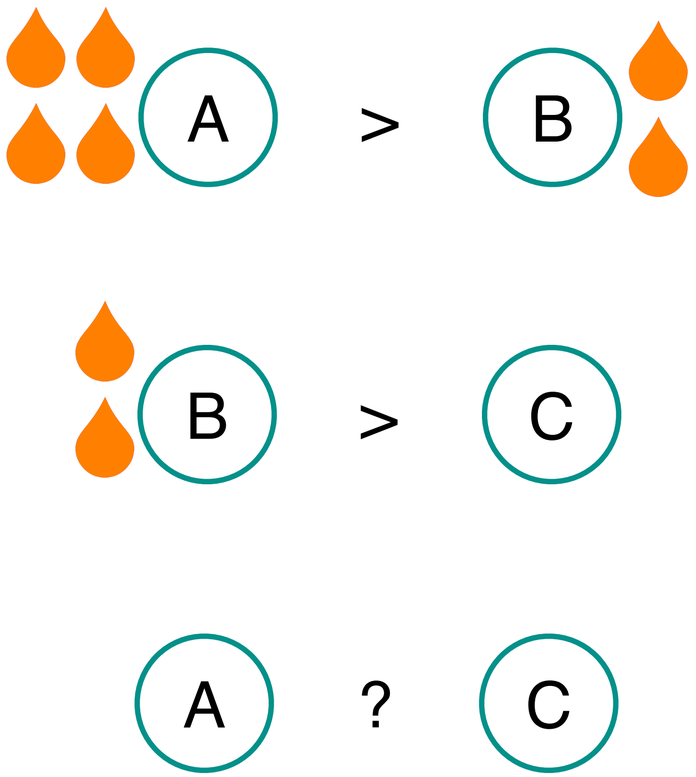


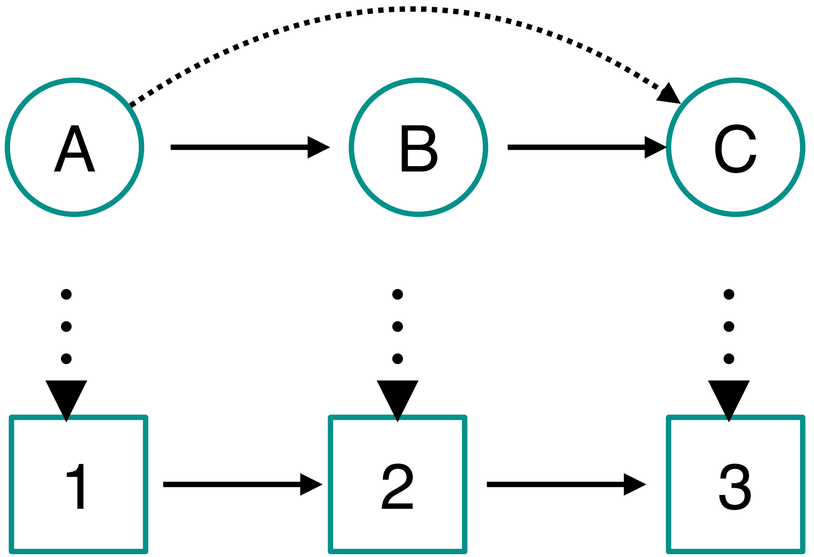
(Aversive) Learning in structured environments

Błażej M. Bączkowski

15.03.2021

Structured relationships allow for inference due to abstraction (according to TEM idea)

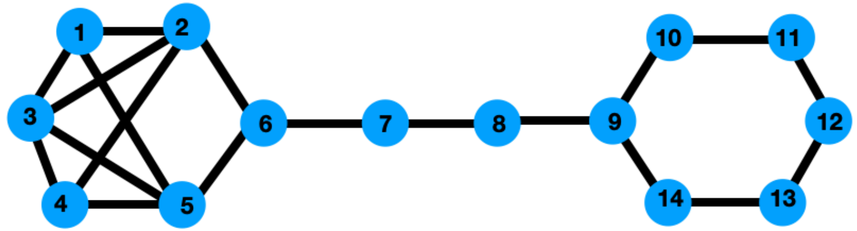




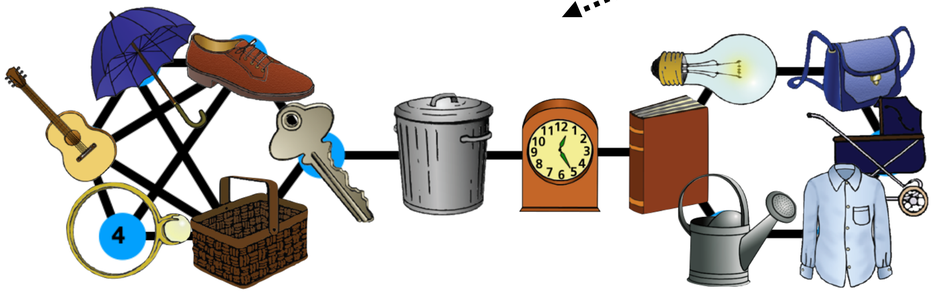
Dusek et al., 1997 (PNAS); Liu et al., 2019 (Cell); Whittington et al., 2020 (Cell)

Concept

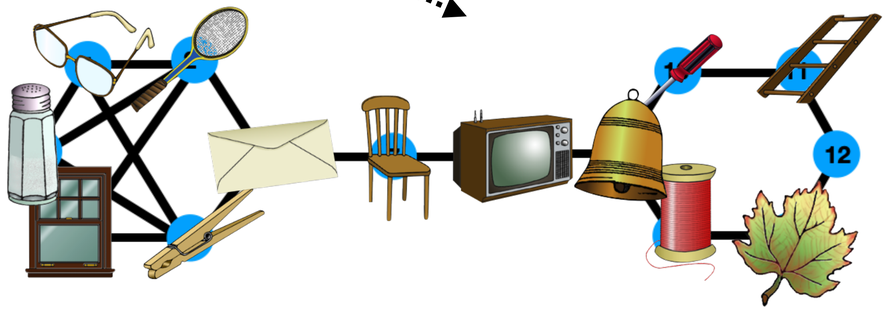
Graph
(context-invariant)

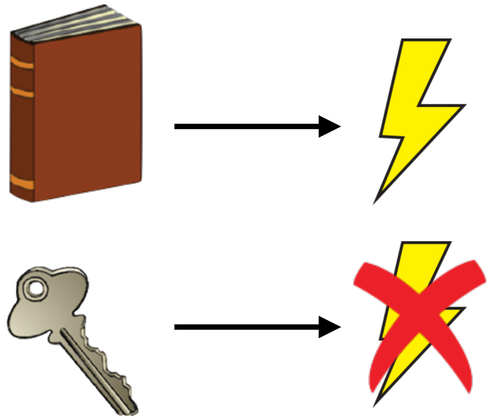


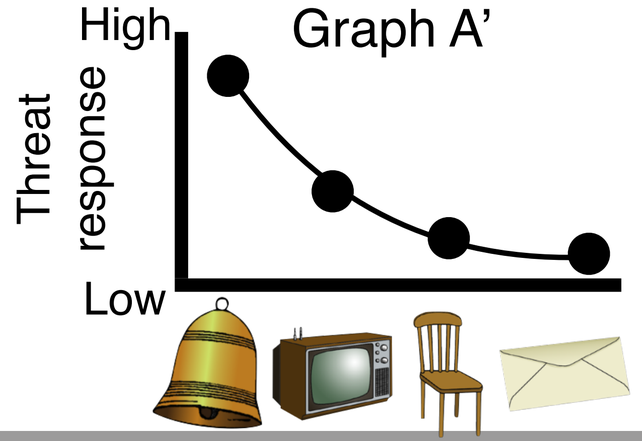
Graph A
(context-dependent)



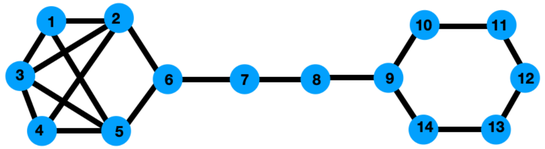
Graph A’
(context-dependent)





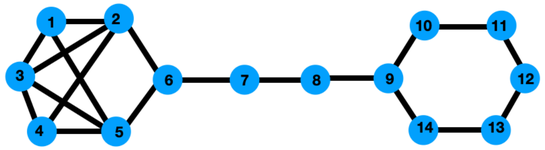


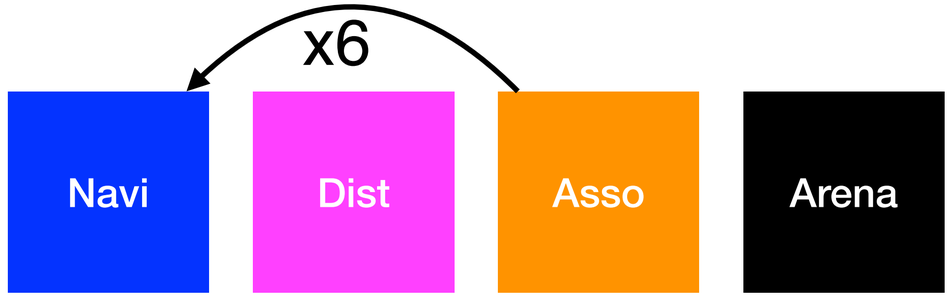
Pilot studies



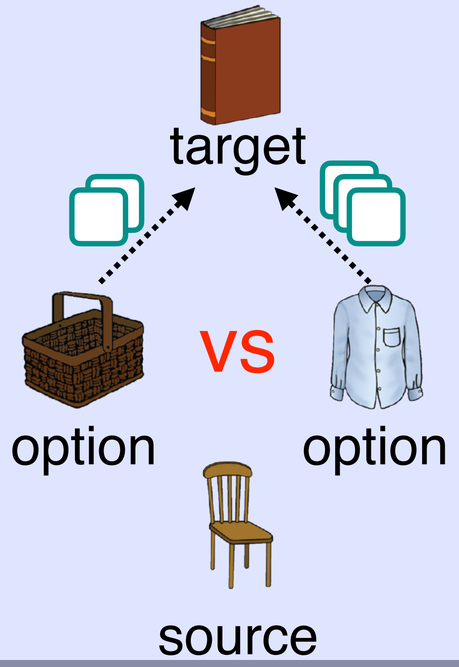
1. Acquisition rate of the graph knowledge (v3.1.1)
2. Effects of memory consolidation (v3.1.3)
3. Effects of inference between two corresponding graphs using a decision-making task (v3.2.0)

1-day experiment (3.1.1) n = 15

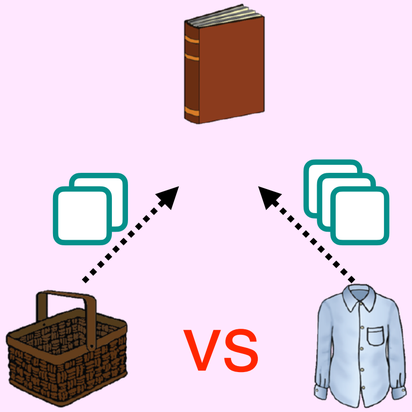




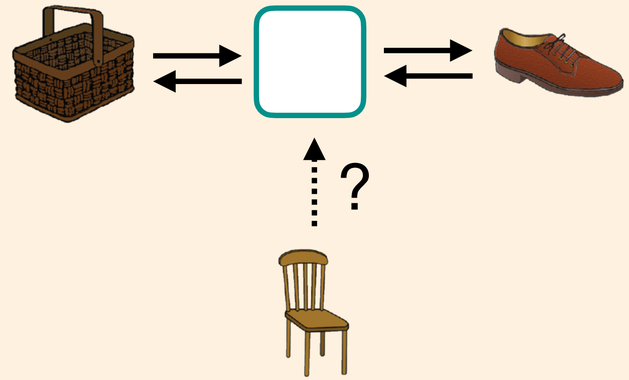
Navigation task (feedback after trial)



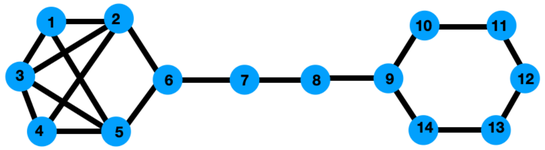
Distance estimation task (feedback after block)

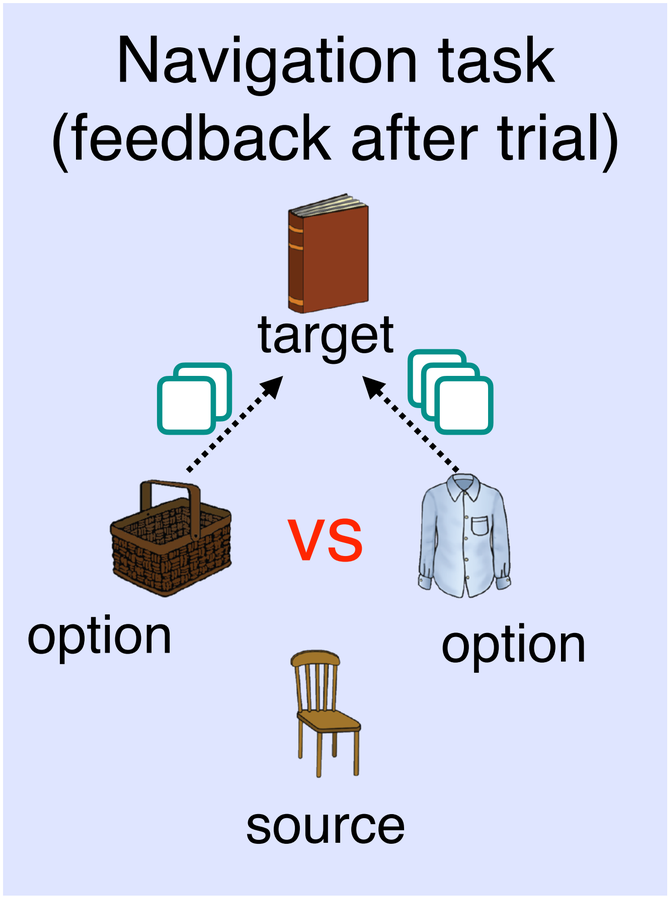


Association task (feedback after block)



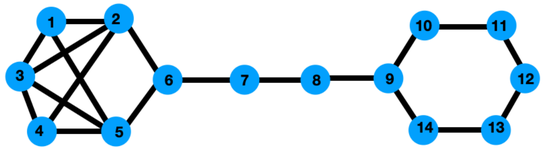
Navigation task (3.1.1)

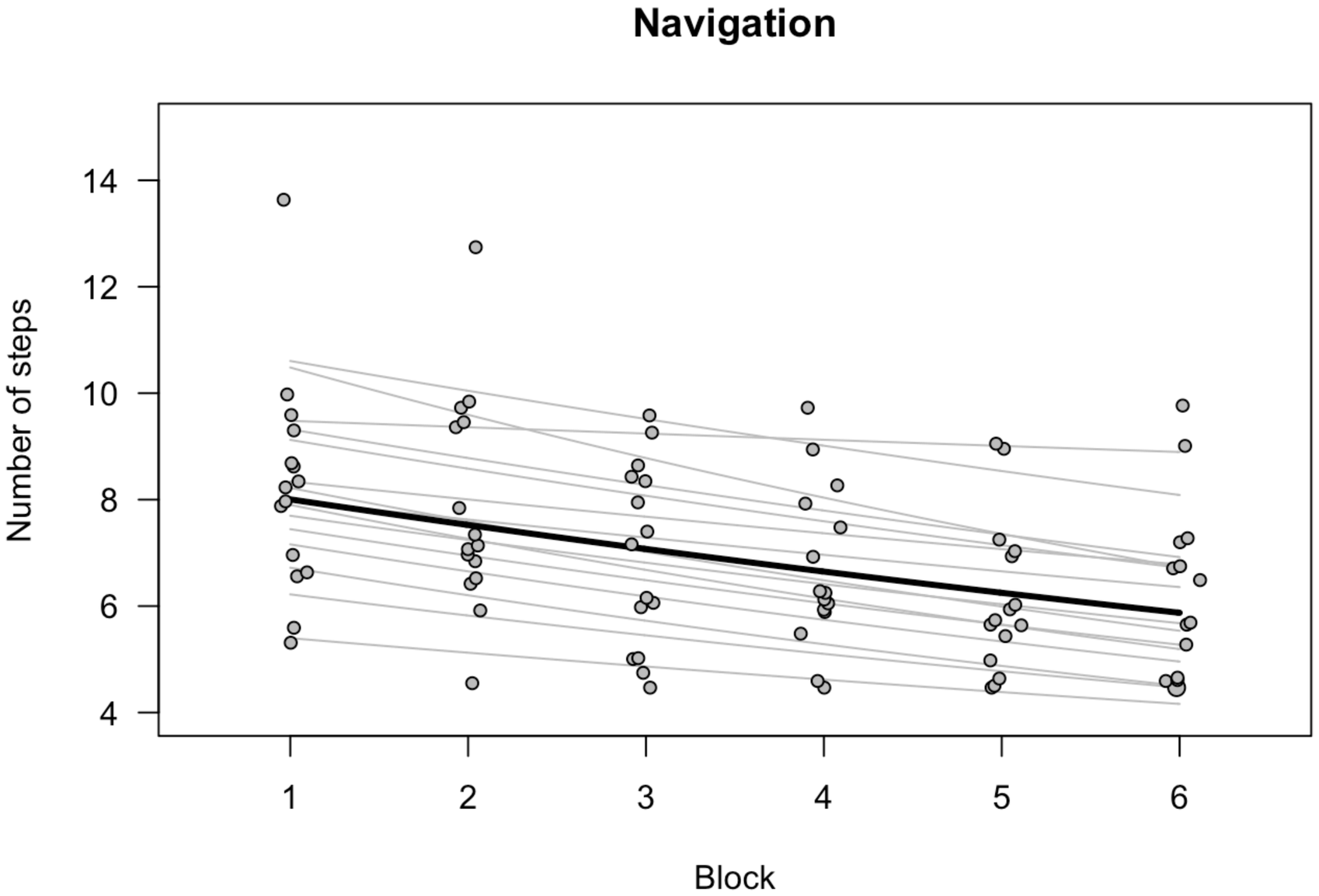




- Any node can be a source node except the nodes that form the ‘bridge’
- Each source node is presented twice (20 trials in total)
- Trials are selected such that minimum distance is between 3 and 6 links to force community exit
- The minimum distance (3-6) has to be sampled minimum 4 times in a block

Navigation task: count model



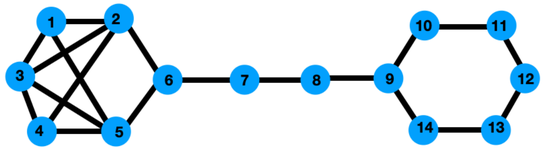


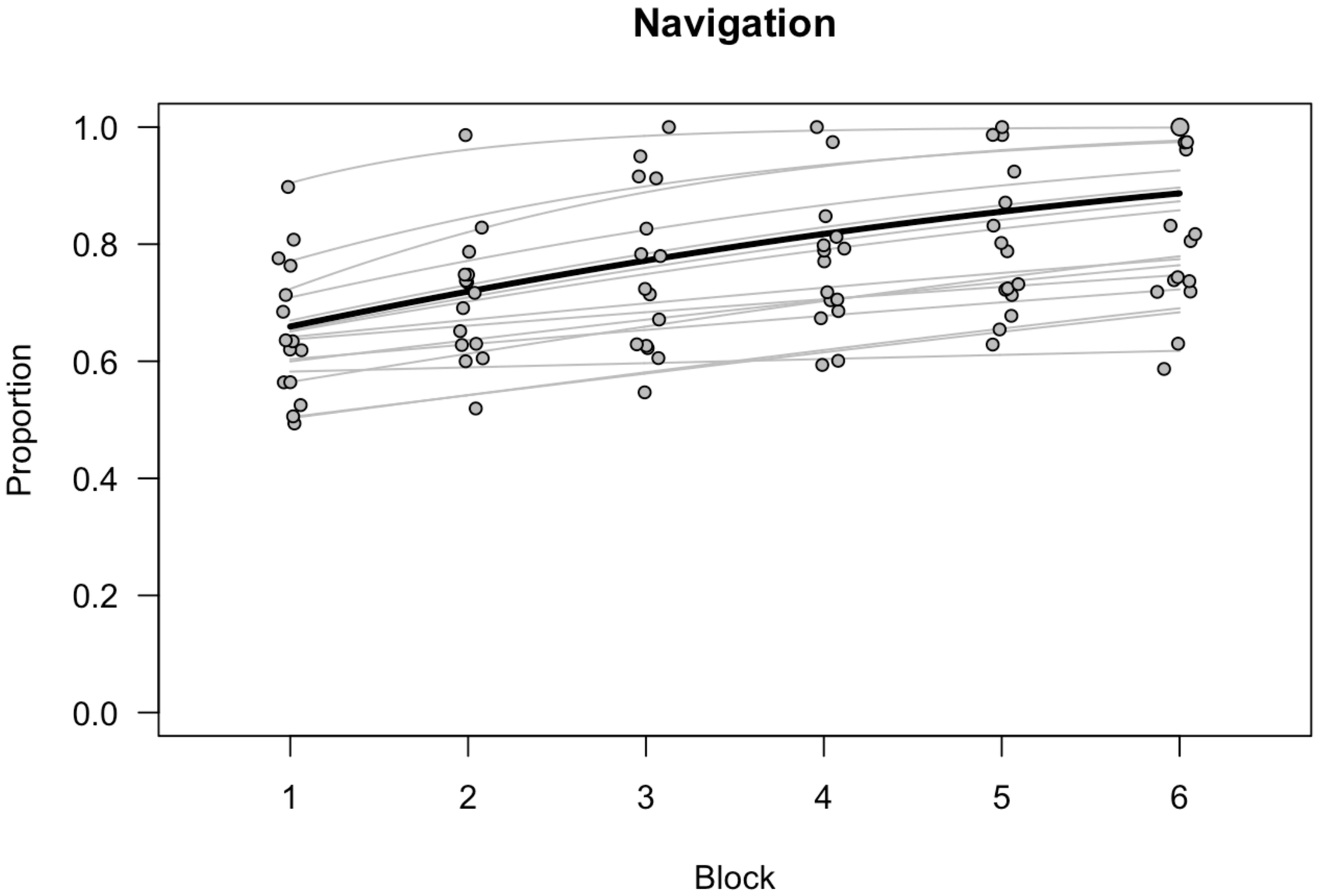
nSteps ~ 1 + block +
(1 + block | subject) +
(1 | sourcenode) +
(1 | targetnode)

$$\chi(1) = 21.034$$

$$p = 4.511e - 06$$

Navigation task: binomial model



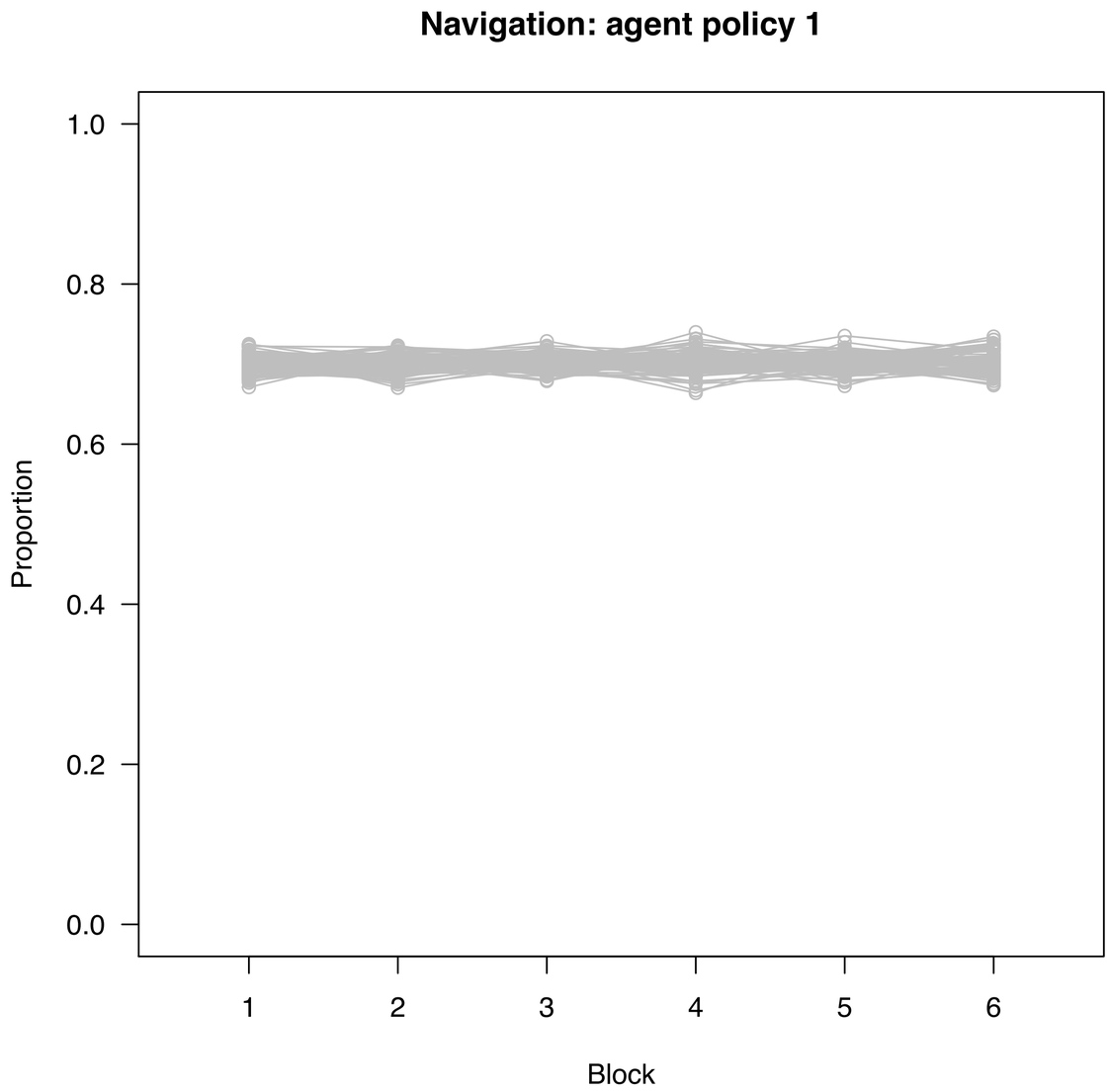


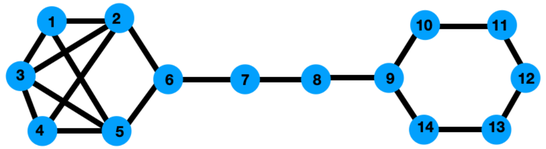
isCorrect ~ 1 + block +
(1 + block | subject) +
(1 + block | sourcenode) +
(1 + block | distance)

$$\chi(1) = 3.45$$

$$p = 0.063$$

Navigation task: binomial model

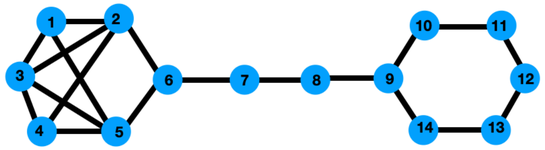




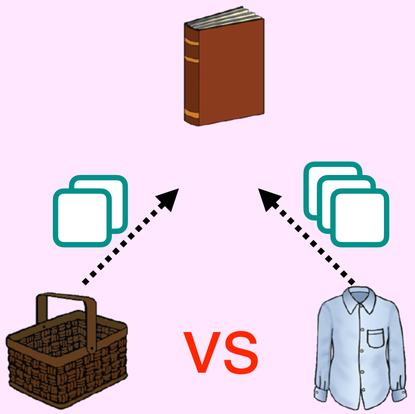
100 models

Policy: avoid previous source node

Distance estimation task (3.1.1)

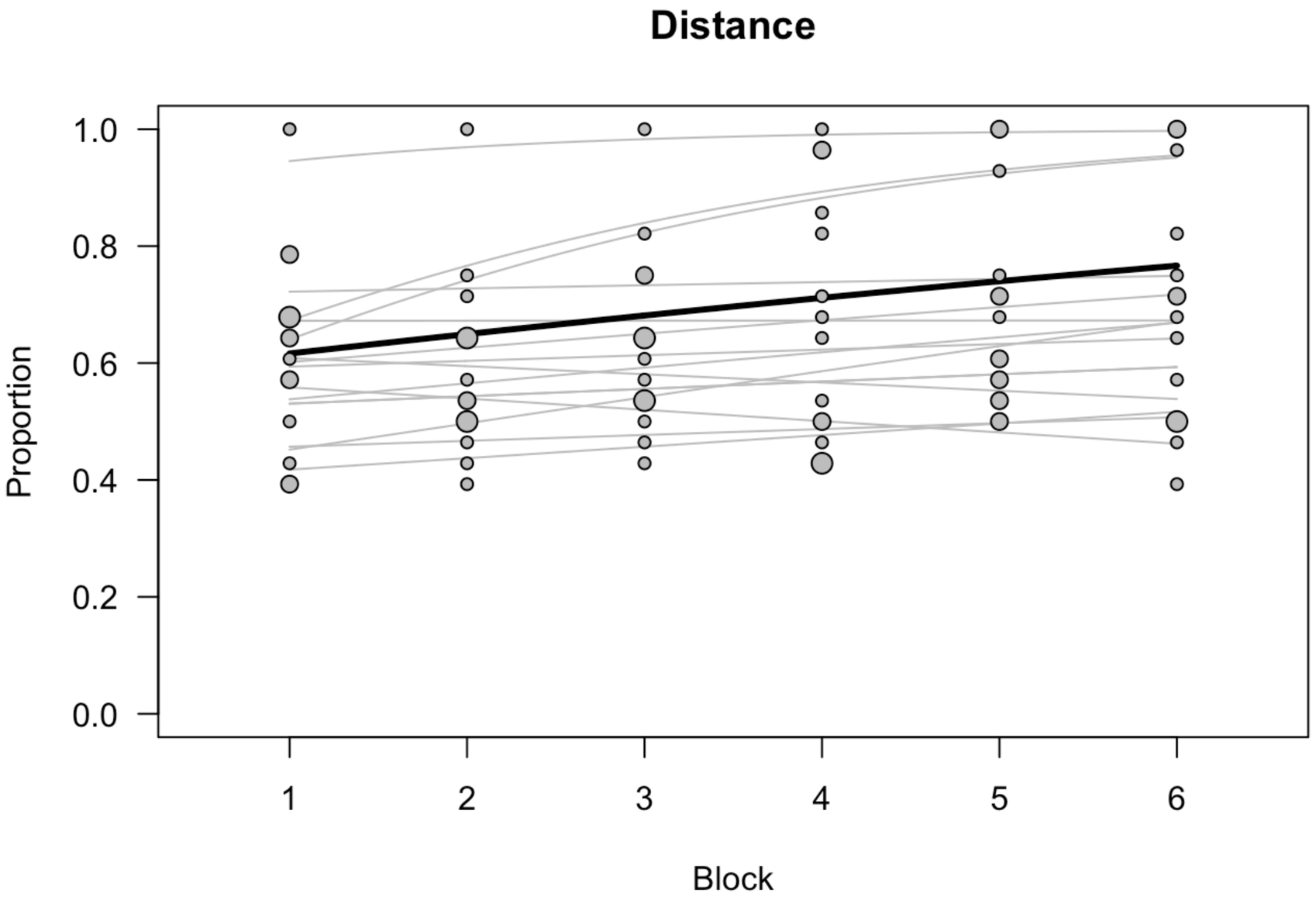


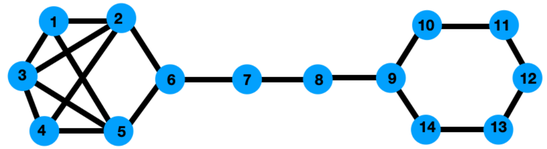
Distance estimation task
(feedback after block)



- Trials are selected such that each node is a source twice
- The minimum distance must be more than 1
- The difference of distances between source to target and source to foil is minimum 2 and maximum 4

Distance estimation task: binomial model (trend)



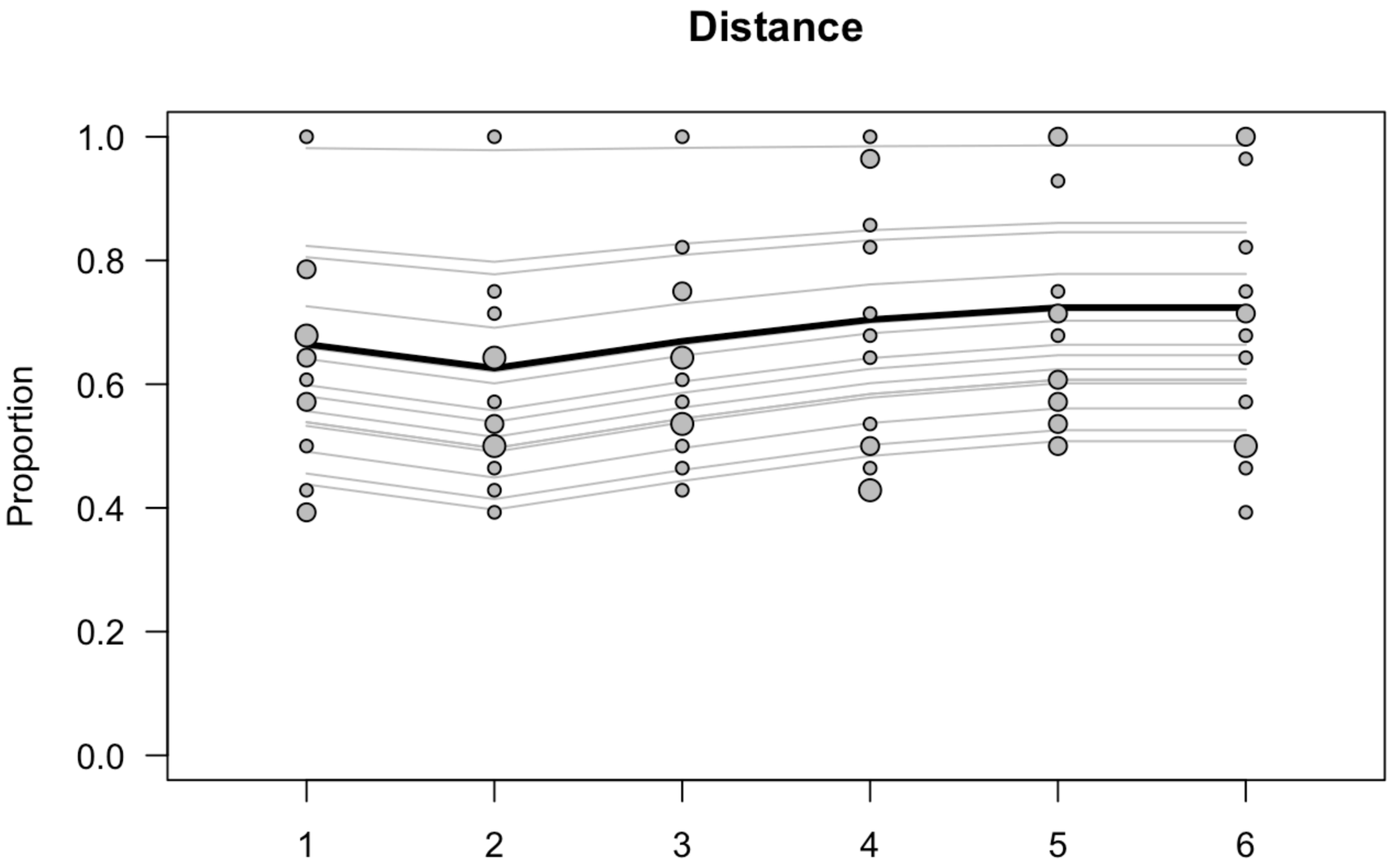


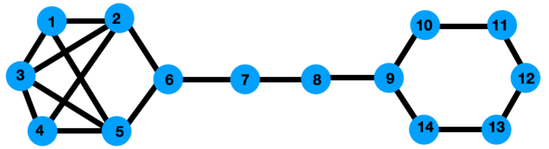
isCorrect ~ 1 + distdiff + block +
(1 + block | subject) +
(1 | sourcenode)

$$\chi(1) = 4.47$$

$$p = 0.034$$

Distance estimation task: binomial model (factorial)



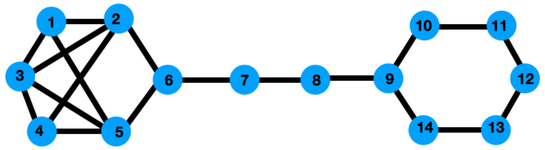


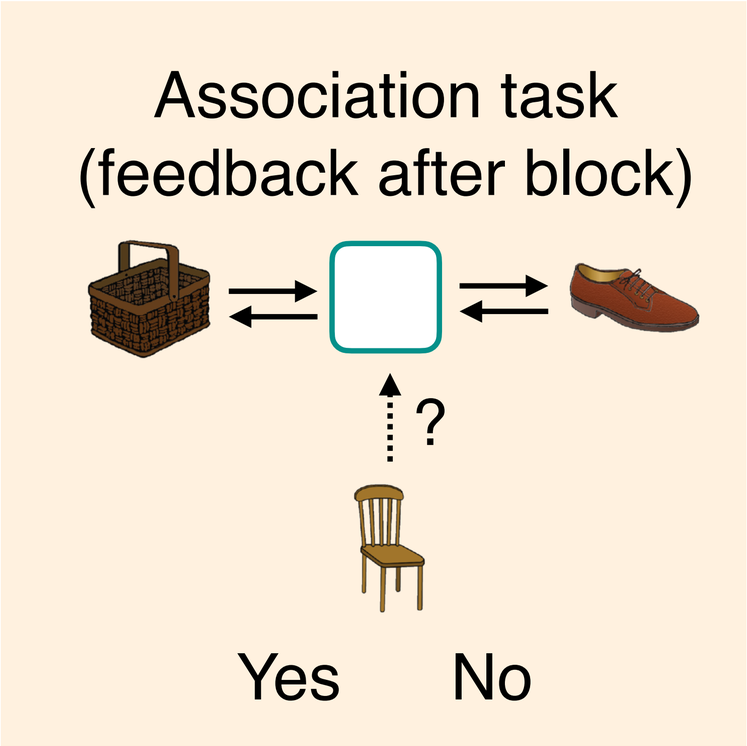
isCorrect ~ 1 + distdiff + block +
(1 | subject) +
(1 | sourcenode)

$$\chi(5) = 14.11$$

$$p = 0.015$$

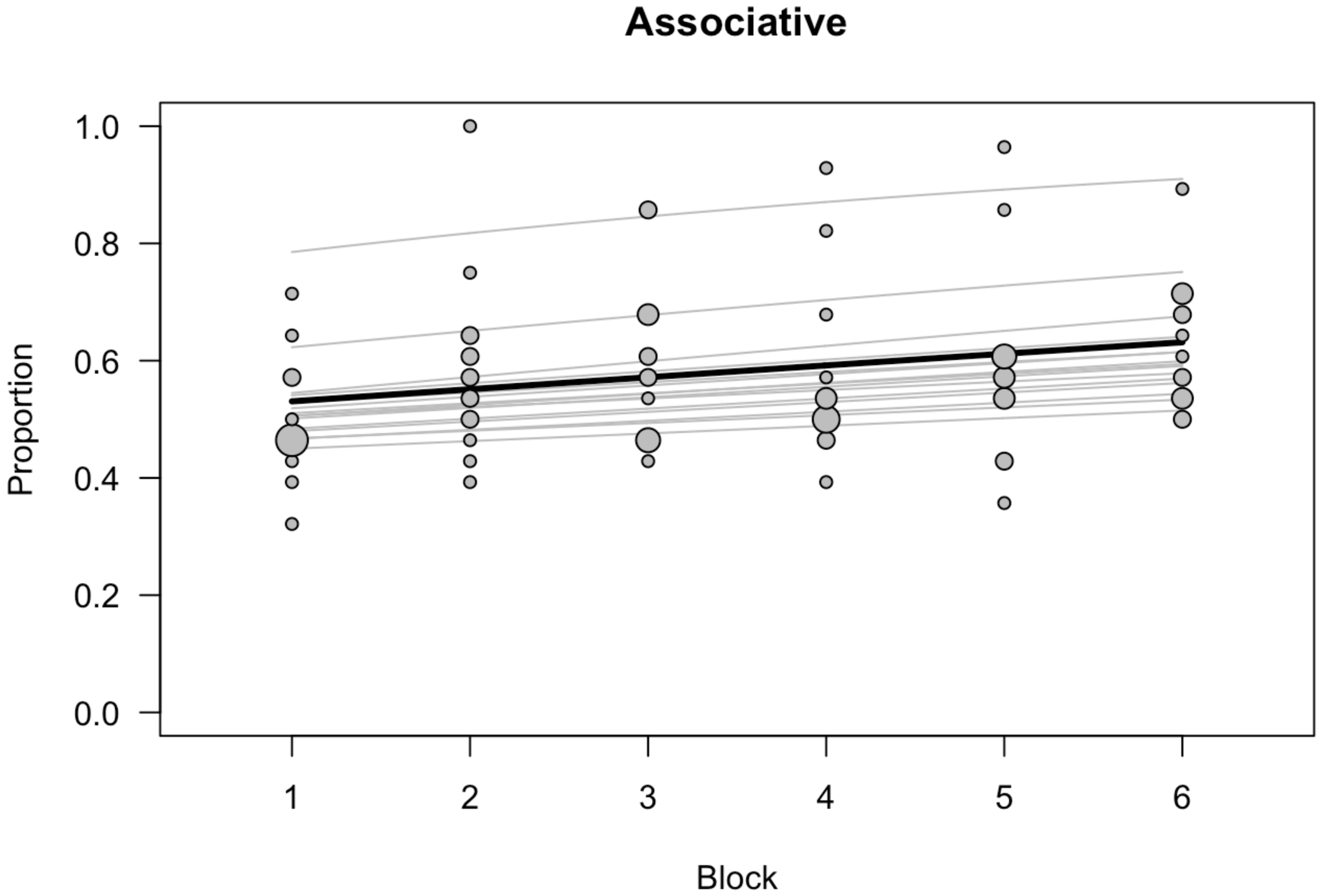
Association task (3.1.1)

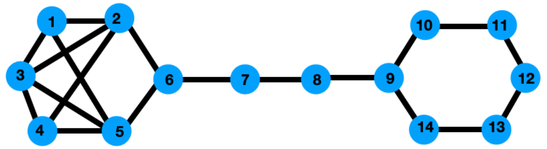




- Trials are selected such that each node is a source twice:
  - once in a correct sequence
  - once in an incorrect sequence

Associative task: binomial model (trend)



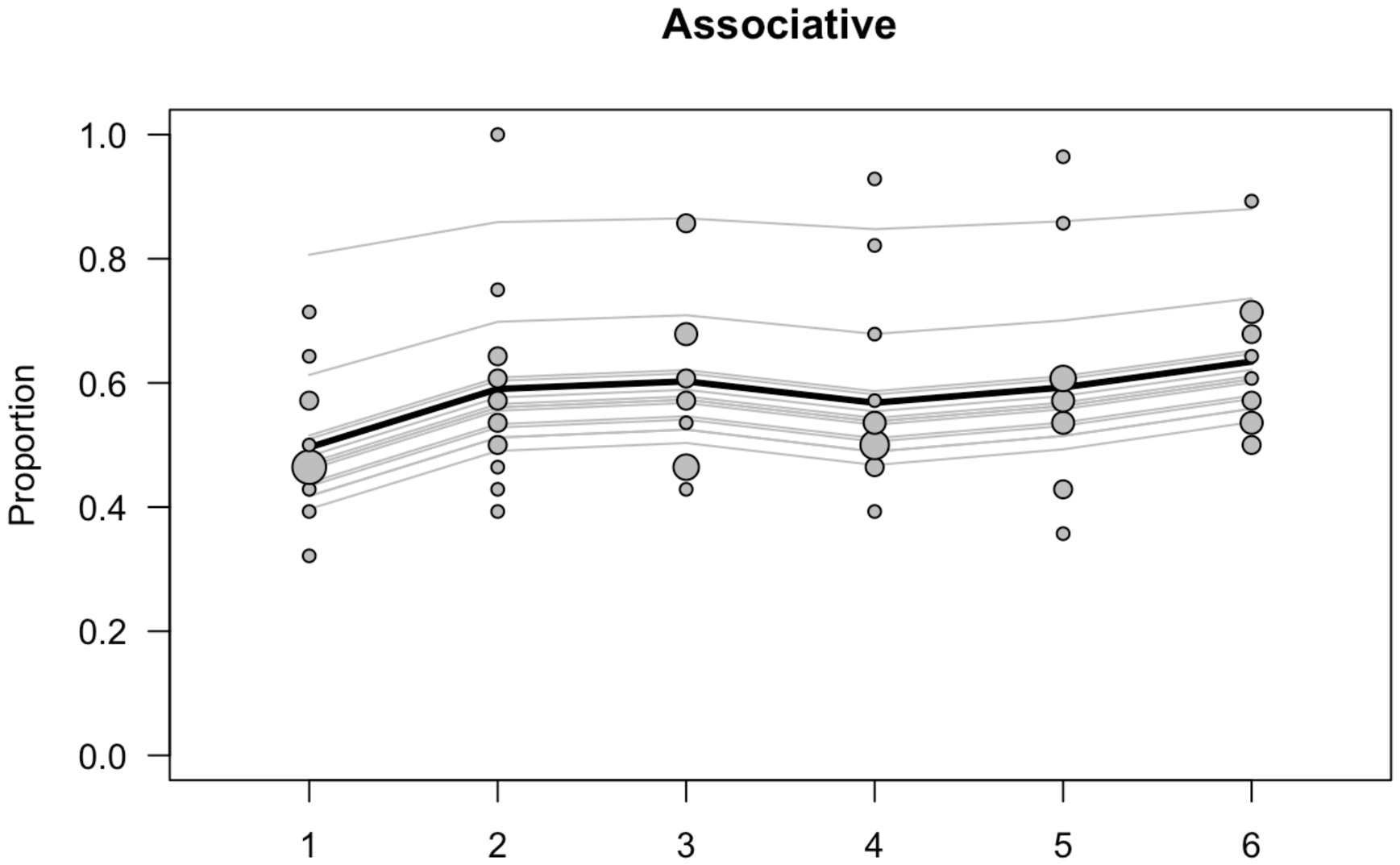


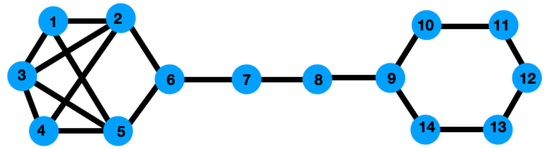
isCorrect ~ 1 + block +
(1 + block | subject)

$$\chi(1) = 7.57$$

$$p = 0.006$$

Associative task: binomial model (factorial)



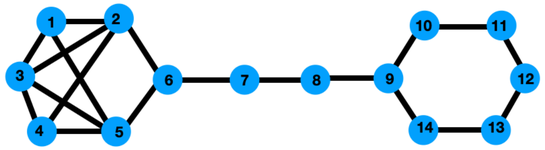


isCorrect ~ 1 + block + (1 | subject)

$$\chi(5) = 18.02$$

$$p = 0.003$$

Arena task


1
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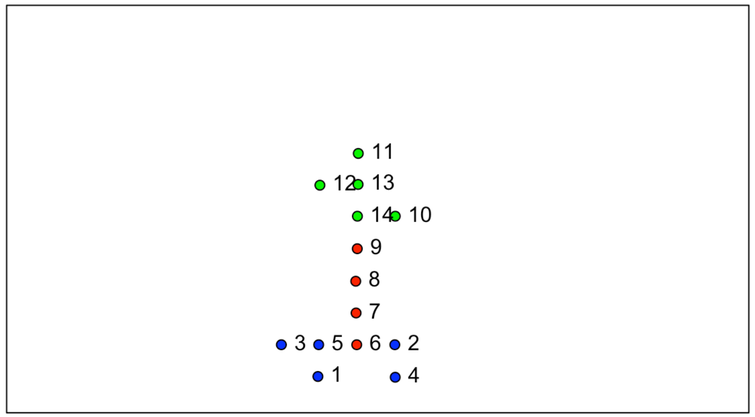
13
14


11
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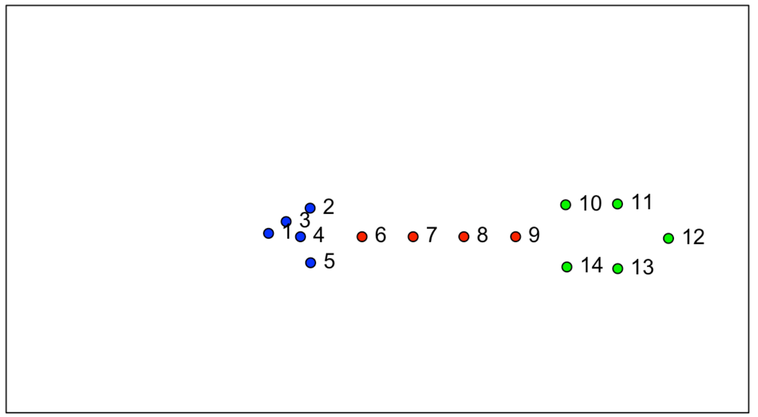
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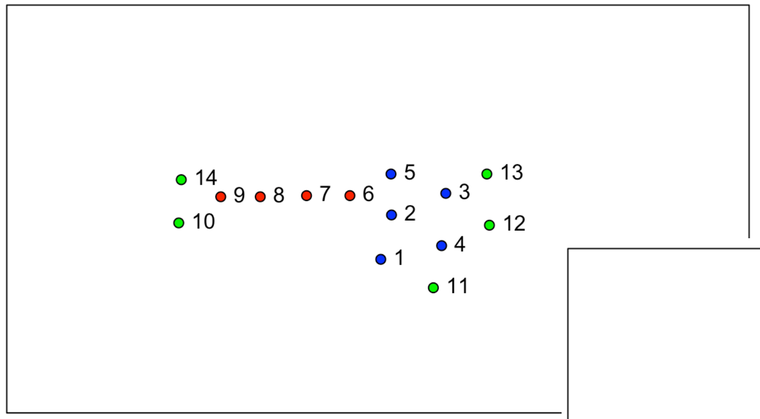
14
9
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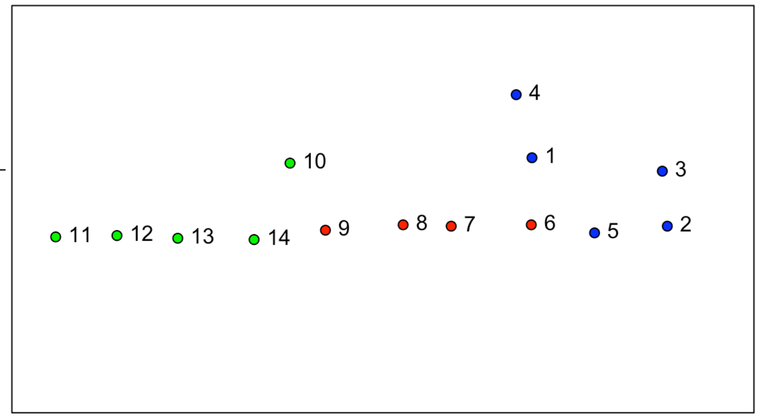
4
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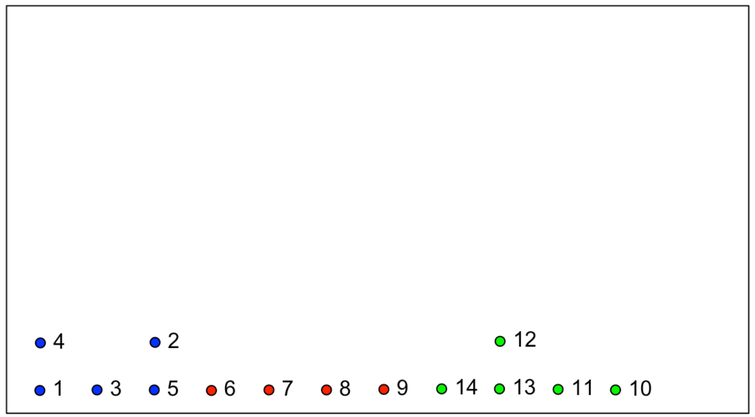
4
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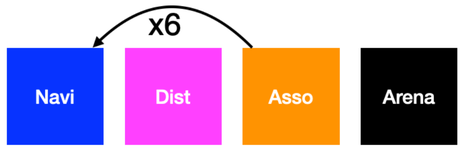
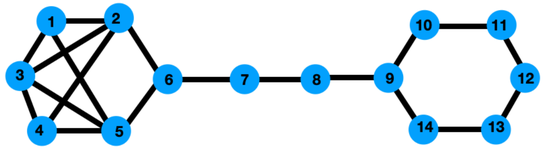
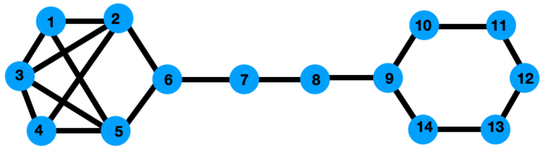
Interim summary

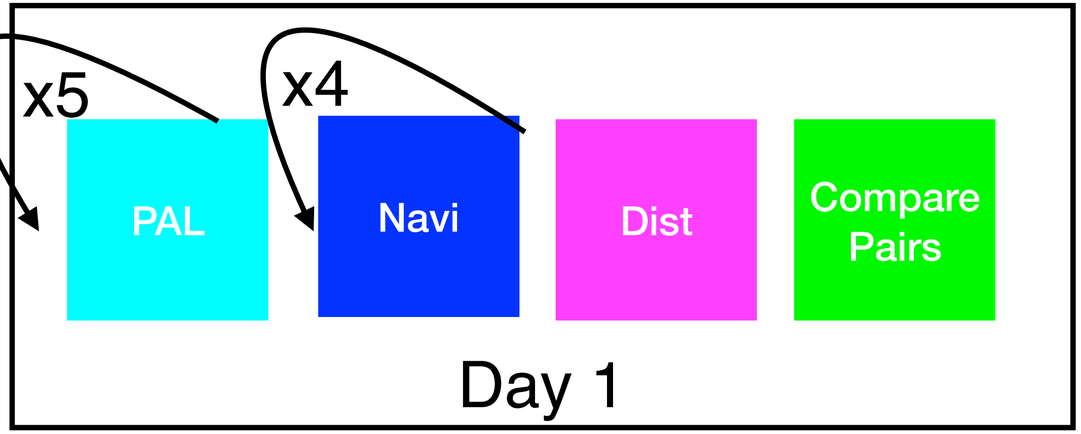


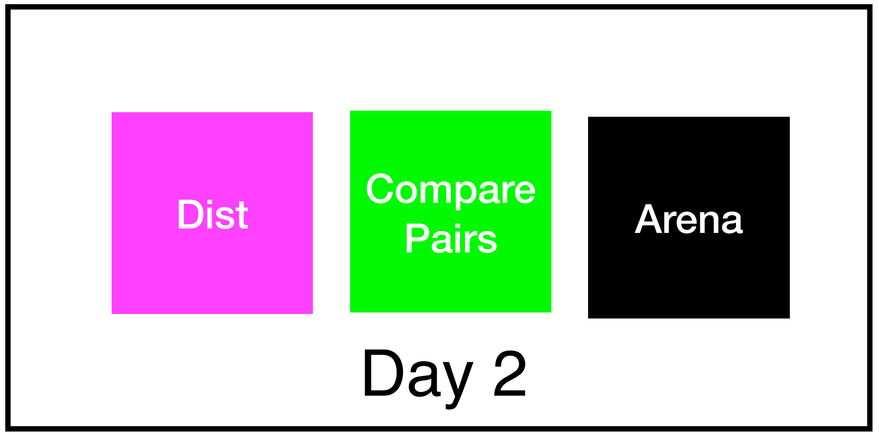


- There is improvement in the navigation task over blocks, but it is not necessarily ceiling
- The improvement in the distance task is rather shallow and max average performance reaches 70%
- Improvement in the associative task seems rather step-wise (rather than exponential).
  - It seems to be difficult — maximum average performance reaches 60%
  - Perhaps showing incorrect sequences interferes with learning

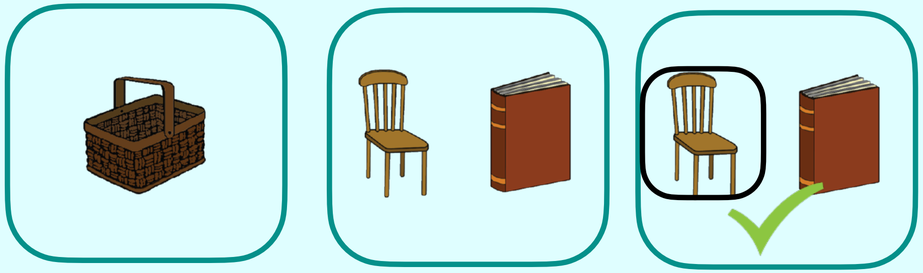
2-day experiment (3.1.3) n = 22



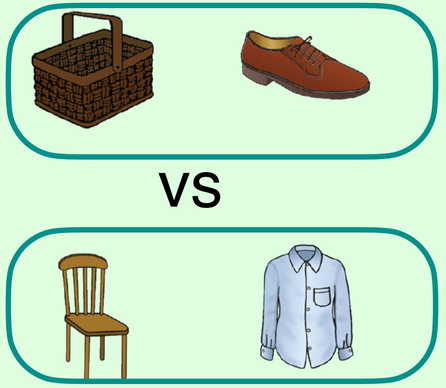




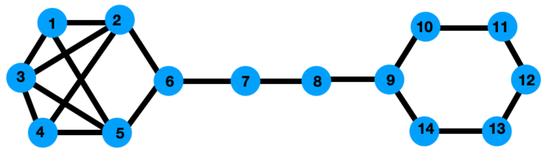
Paired associate learning task (feedback after trial)



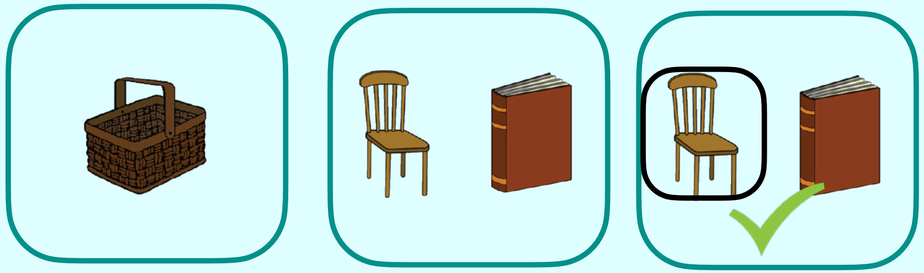
Compare pairs task (feedback after block)



Paired associate learning task (3.1.3)

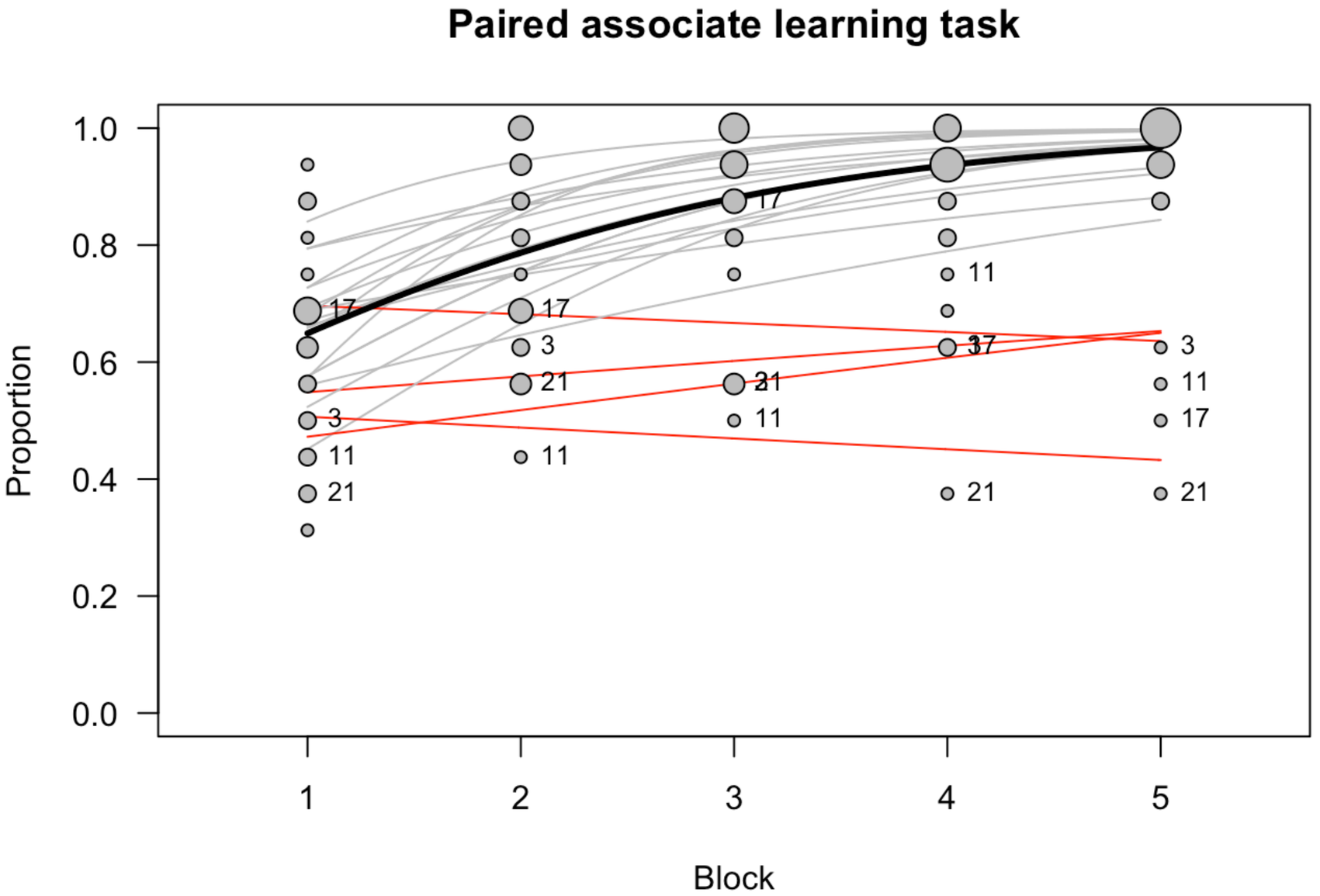


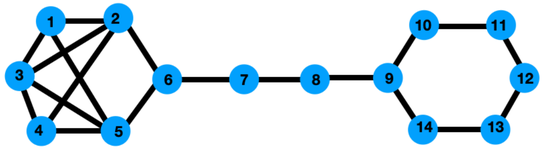
Paired associate learning task
(feedback after trial)



- To learn associations between four nodes (6,7,8,9) that form a ‘bridge’

Paired associate learning task: binomial model



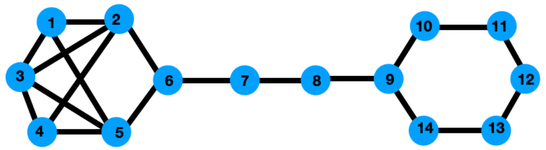


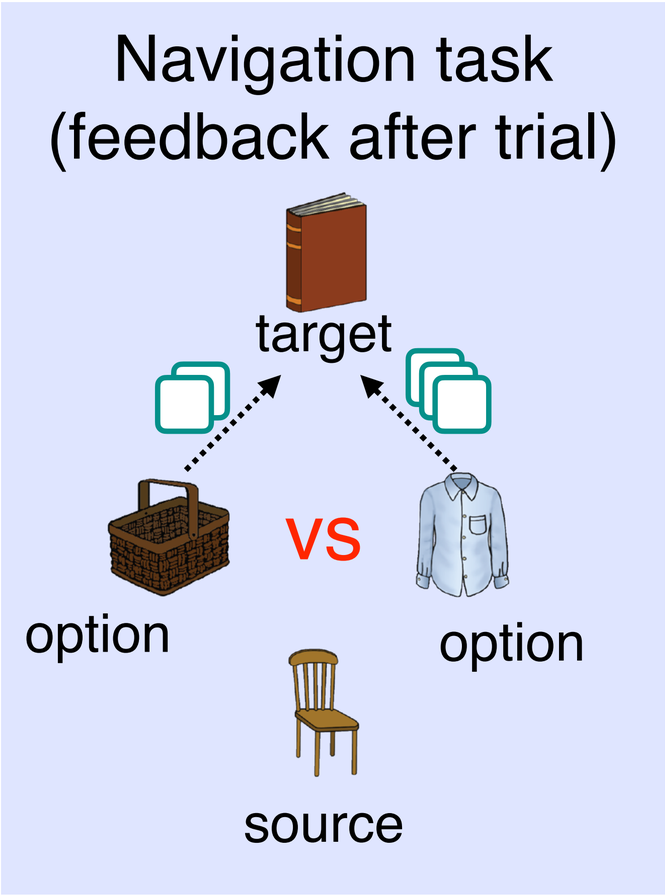
isCorrect ~ 1 + block +
sourcenode +
(1 + block | subject)

$$\chi(1) = 20.97$$

$$p = 4.662e - 06$$

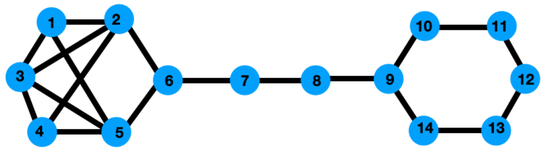
Navigation task (3.1.3)

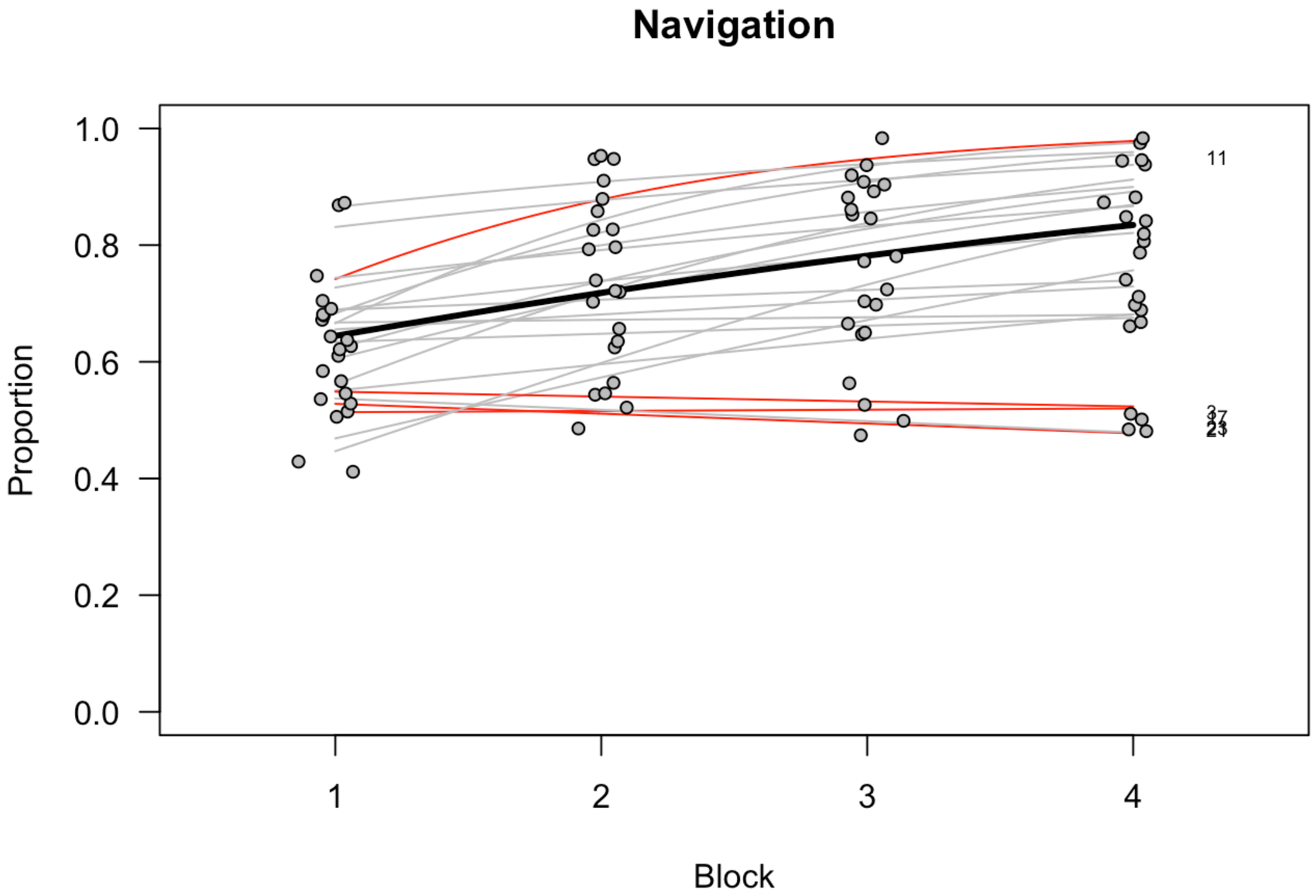




- Any node can be a source node except the nodes that form the ‘bridge’.
- All links of the source nodes are sampled. This means that for the right-hand side community some pairs are repeated to keep the number of source node presentations constant across the two communities.
- The minimum distance between a source and a target node is such that participants have to exit a community, i.e., distance range is 4-8.

Navigation task: binomial model



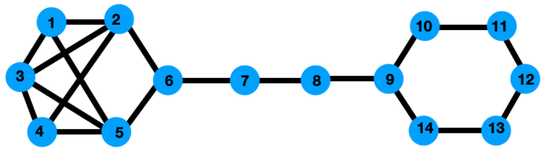


isCorrect ~ 1 + block +
(1 + block | subject) +
(1 + block | sourcenode) +
(1 | distance)

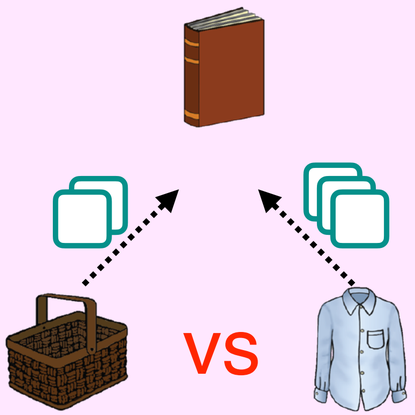
$$\chi(1) = 15.82$$

$$p = 6.777e - 05$$

Distance estimation task (3.1.3)

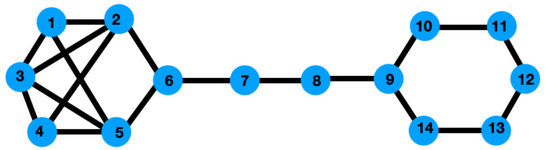


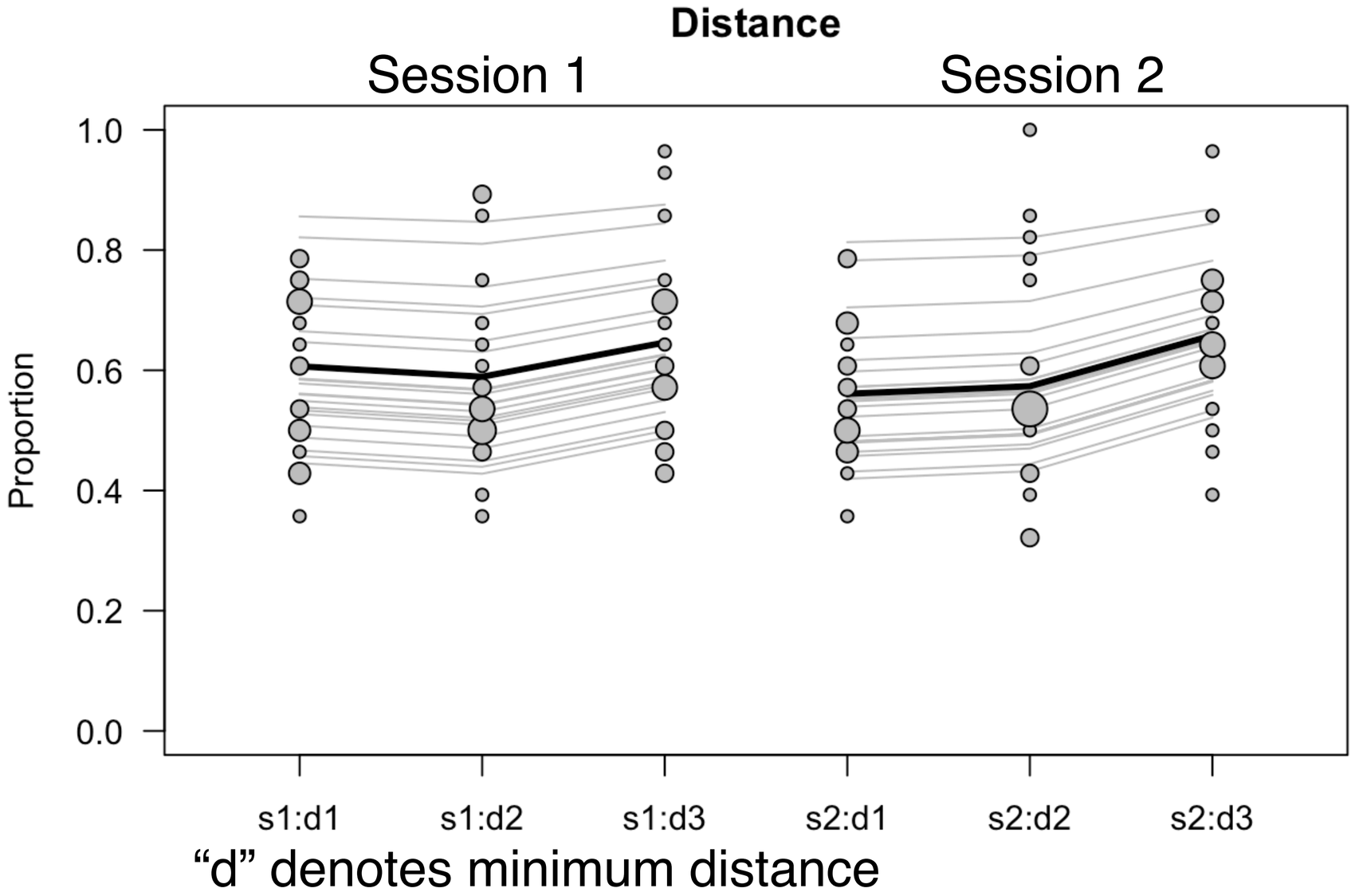
Distance estimation task
(feedback after block)



- Minimum distance to the target is 1, 2, or 3 links.
- Foil node has to be a neighbour of the target, i.e., the target and the foil are on the same path.
- This also means that the difference in distance between a foil and a target is always only 1 link.
- Each node is a source 6 times during the block (twice for each distance length).

Distance task: binomial model





"d" denotes minimum distance

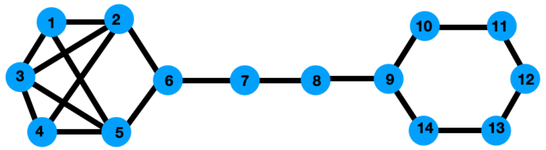
isCorrect ~ 1 + mindist +
session +
mindist:session +
(1 + session| subject) +
(1 | sourcenode)

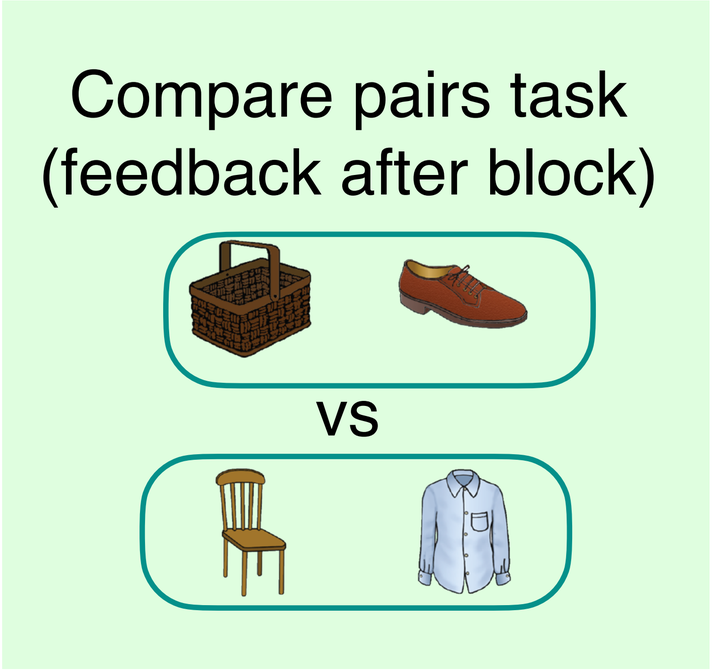
$$\chi(2) = 1.93$$

$$p = 0.38$$

No effect of "session"
but "distance3"

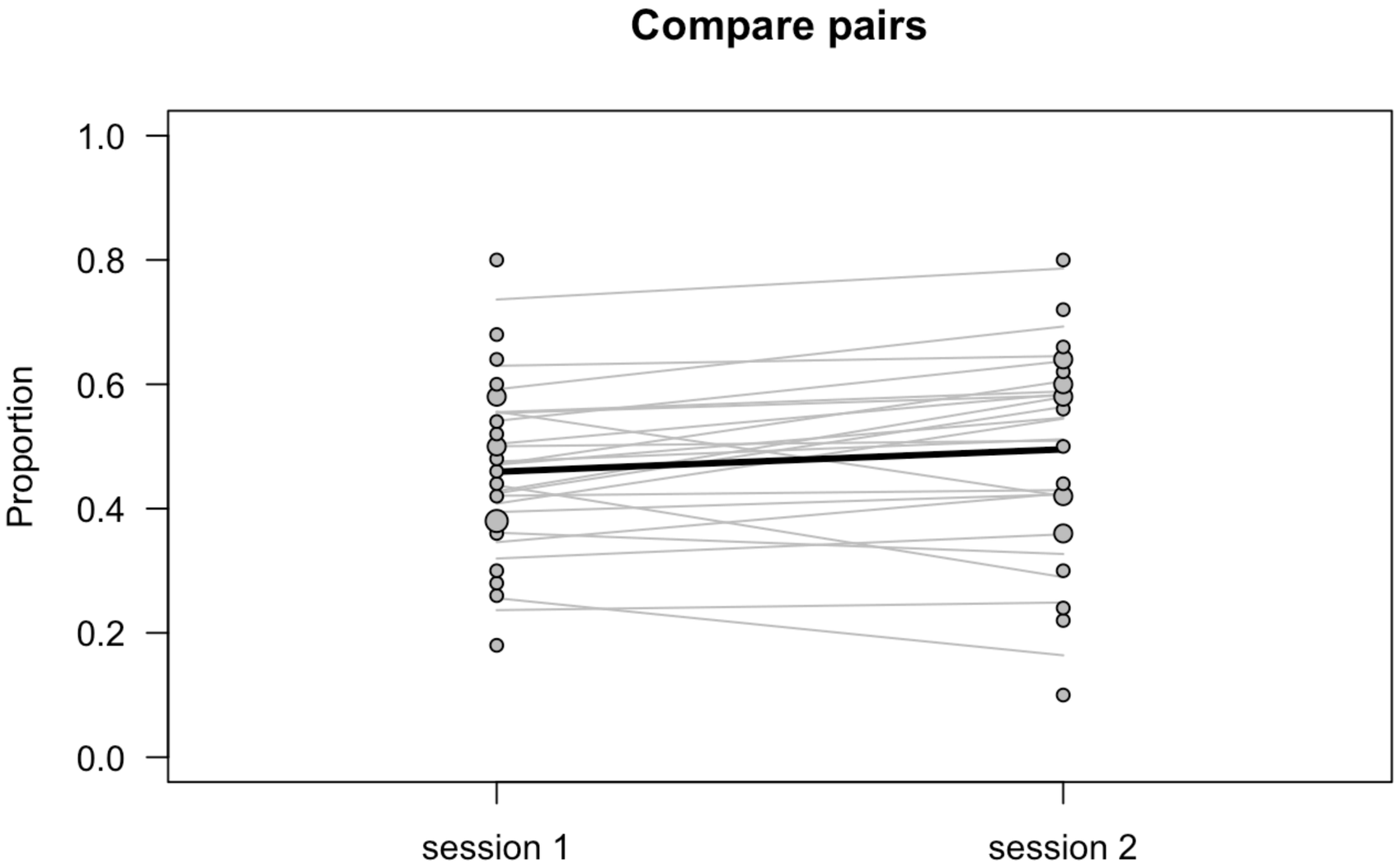
Compare pairs task (3.1.3)

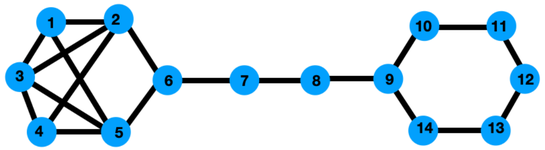




- Participants compare pairs that involve nodes from a ‘bridge’ and a community for each pair. This means that the pairs that involve nodes from the left-hand side represent ‘shorter’ distance than the pairs that involve nodes from the right-hand side.
- Trials come from a basis set that is repeated 5 times in a session.
- The order of trials is pseudo-randomized such that there are max 3 trials in a row with the same node of the family [6 7 8 9].

Compare pairs task: binomial model



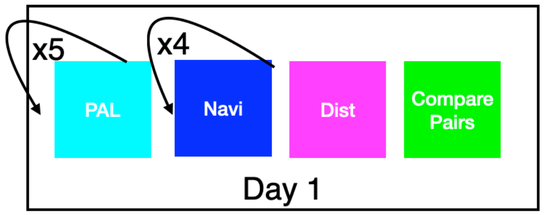


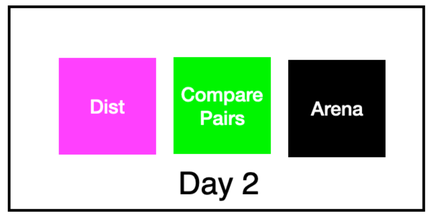
isCorrect ~ 1 + session +
(1 + session| subject)

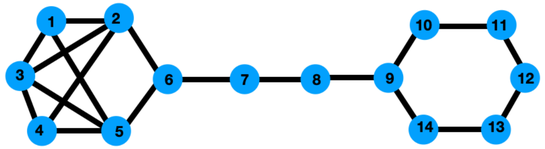
$$\chi(1) = 1.02$$

$$p = 0.31$$

Interim summary





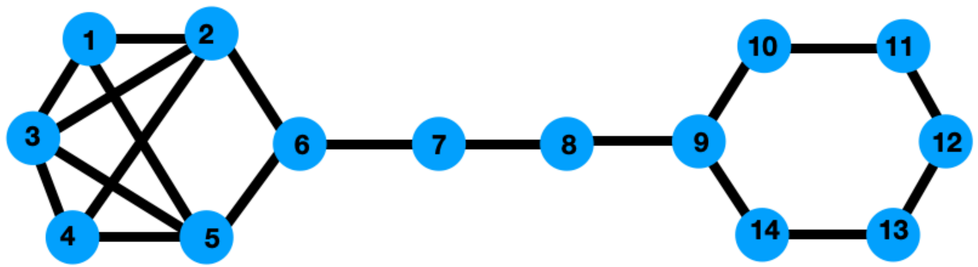


- There is no improvement on the 2nd day, but also no loss.
- PAL task does not seem to benefit learning the graph
- Distance task: the task seems to be easier if it involves nodes that are farther away from the source node suggesting a coarse representation of the graph (?)
- Compare pairs task seems to be too difficult (random performance) as it potentially involves to simulate two instance of a trajectory (to compare two pairs of items)
  - Or simply that they could not differentiate the two communities in their structure

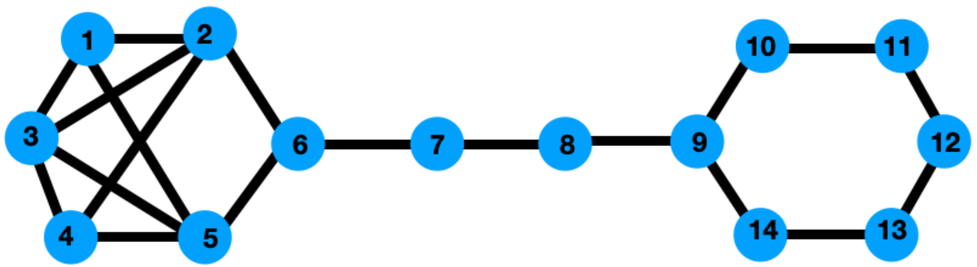
3-day experiment (3.2.0) n=21

Graph A

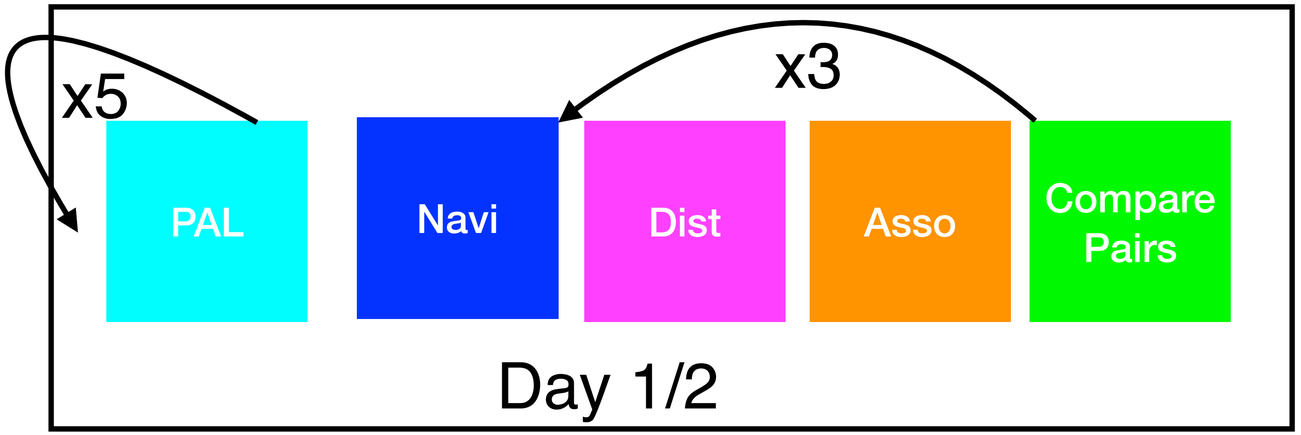
stimuli

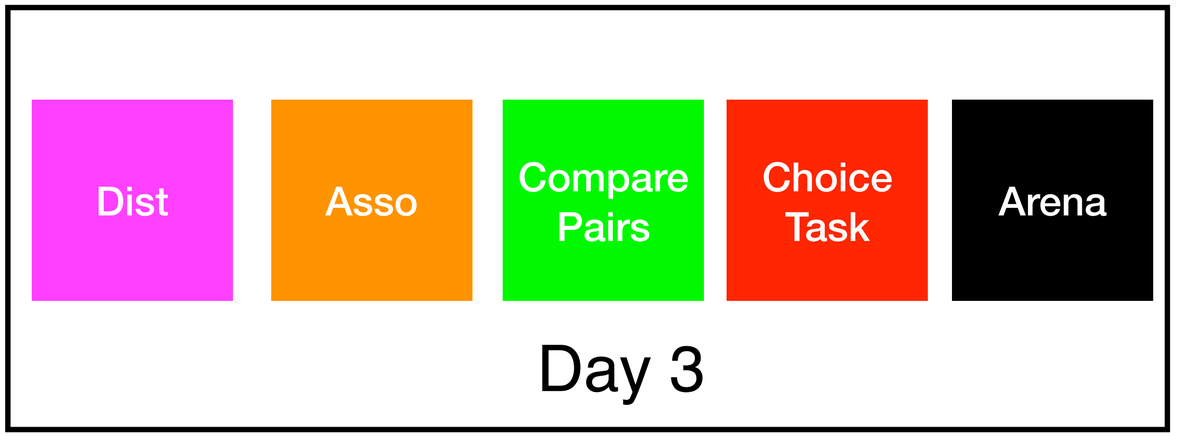


Graph A’

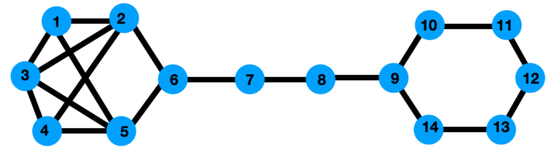


stimuli

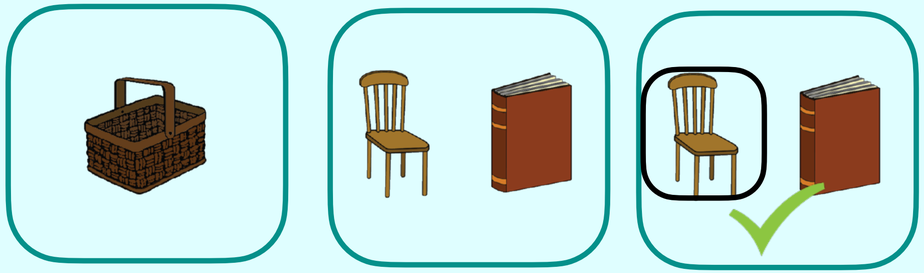




Paired associate learning task (3.2.0)

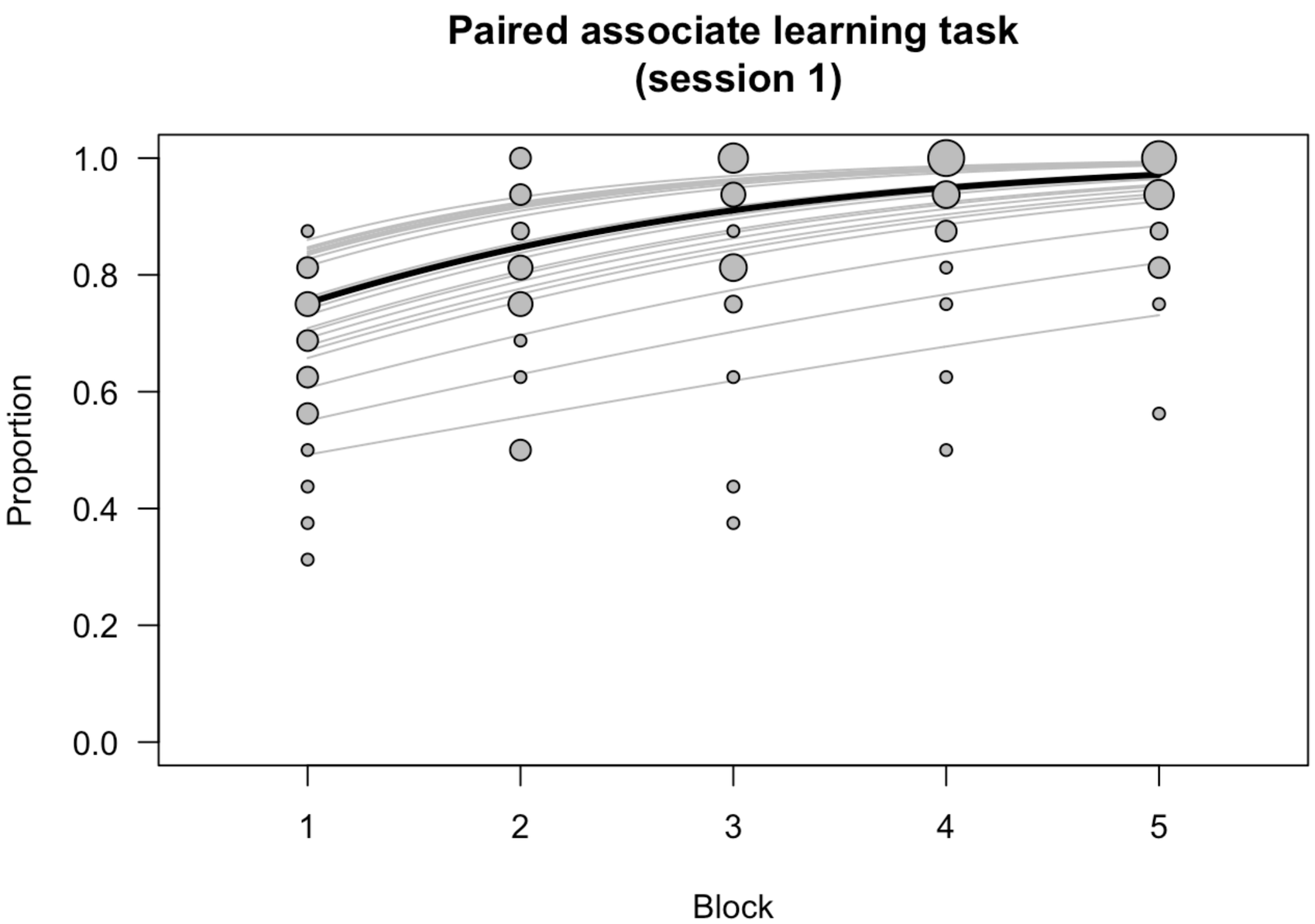


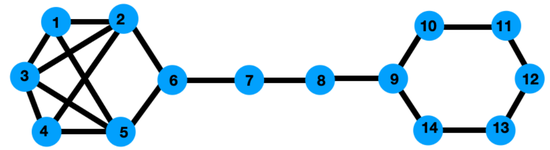
Paired associate learning task
(feedback after trial)



- To learn associations between four nodes (6,7,8,9) that form a ‘bridge’

Paired associate learning task: binomial model



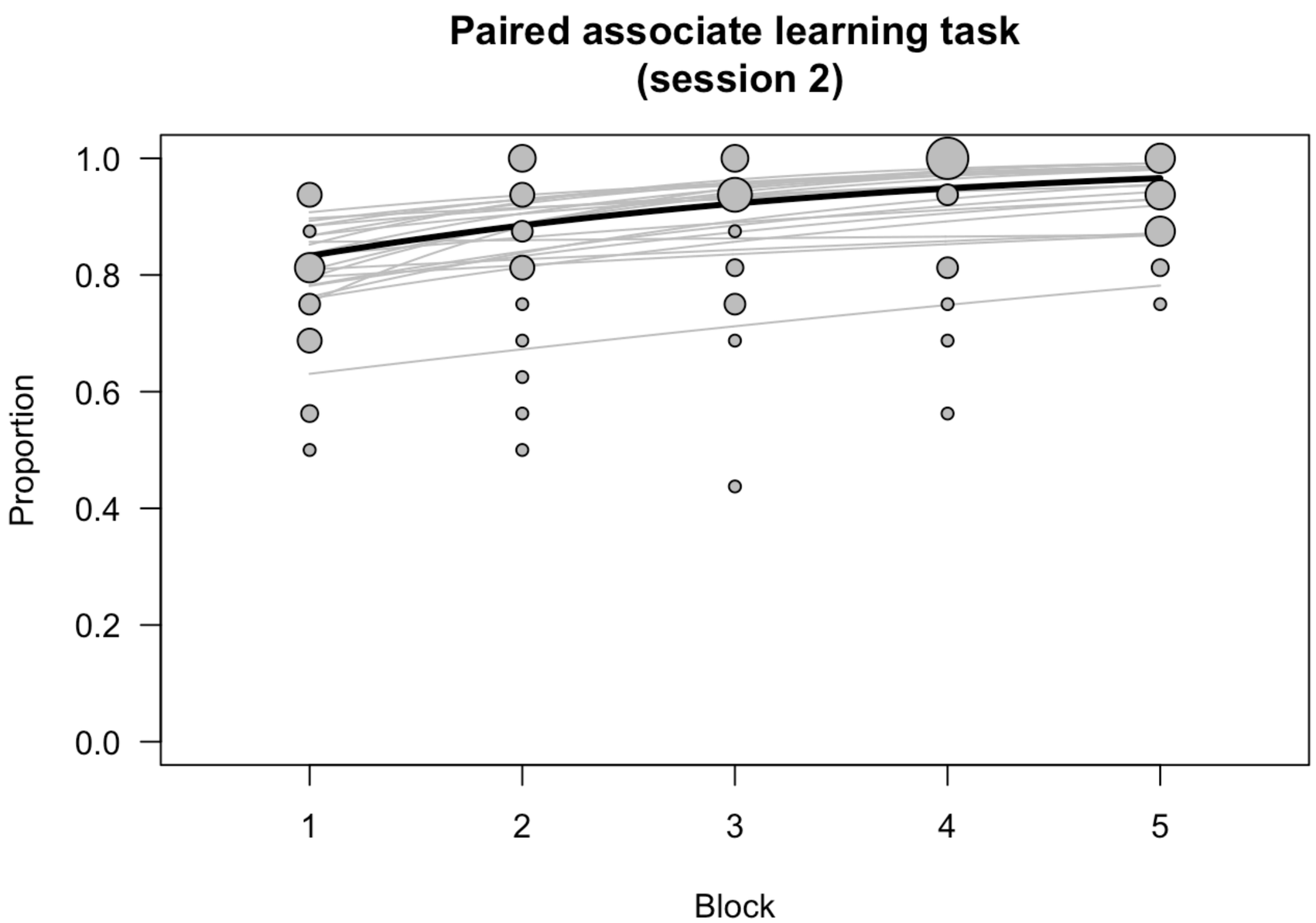


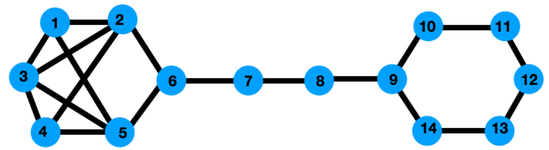
isCorrect ~ 1 + block +
sourcenode +
(1 + block | subject)

$$\chi(1) = 34.88$$

$$p = 3.501e - 09$$

Paired associate learning task: binomial model



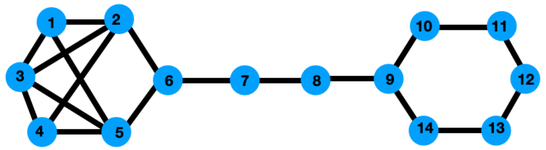


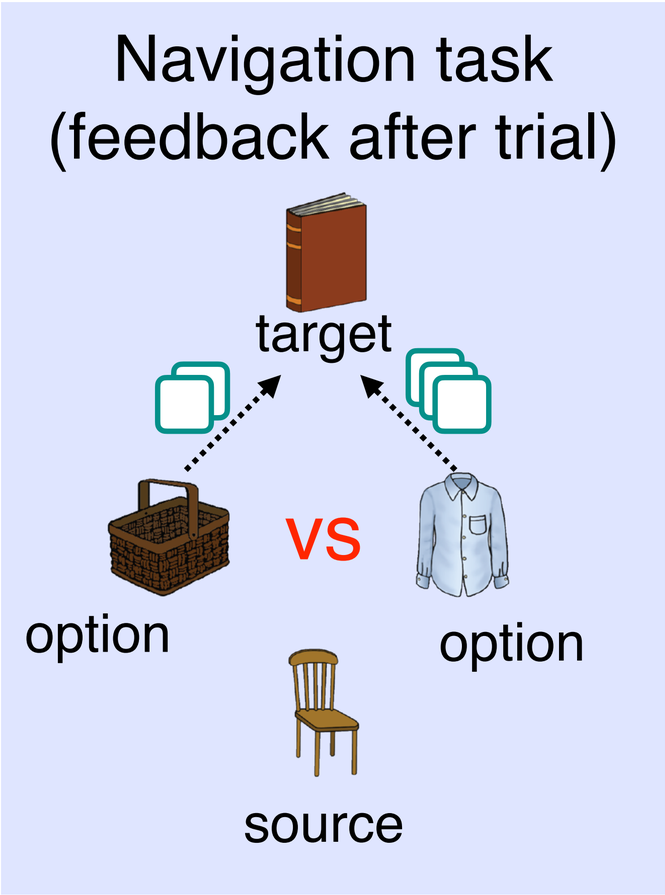
isCorrect ~ 1 + block +
sourcenode +
(1 + block | subject)

$$\chi(1) = 16.60$$

$$p = 4.606e - 05$$

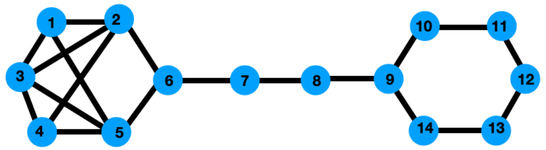
Navigation task (3.2.0)

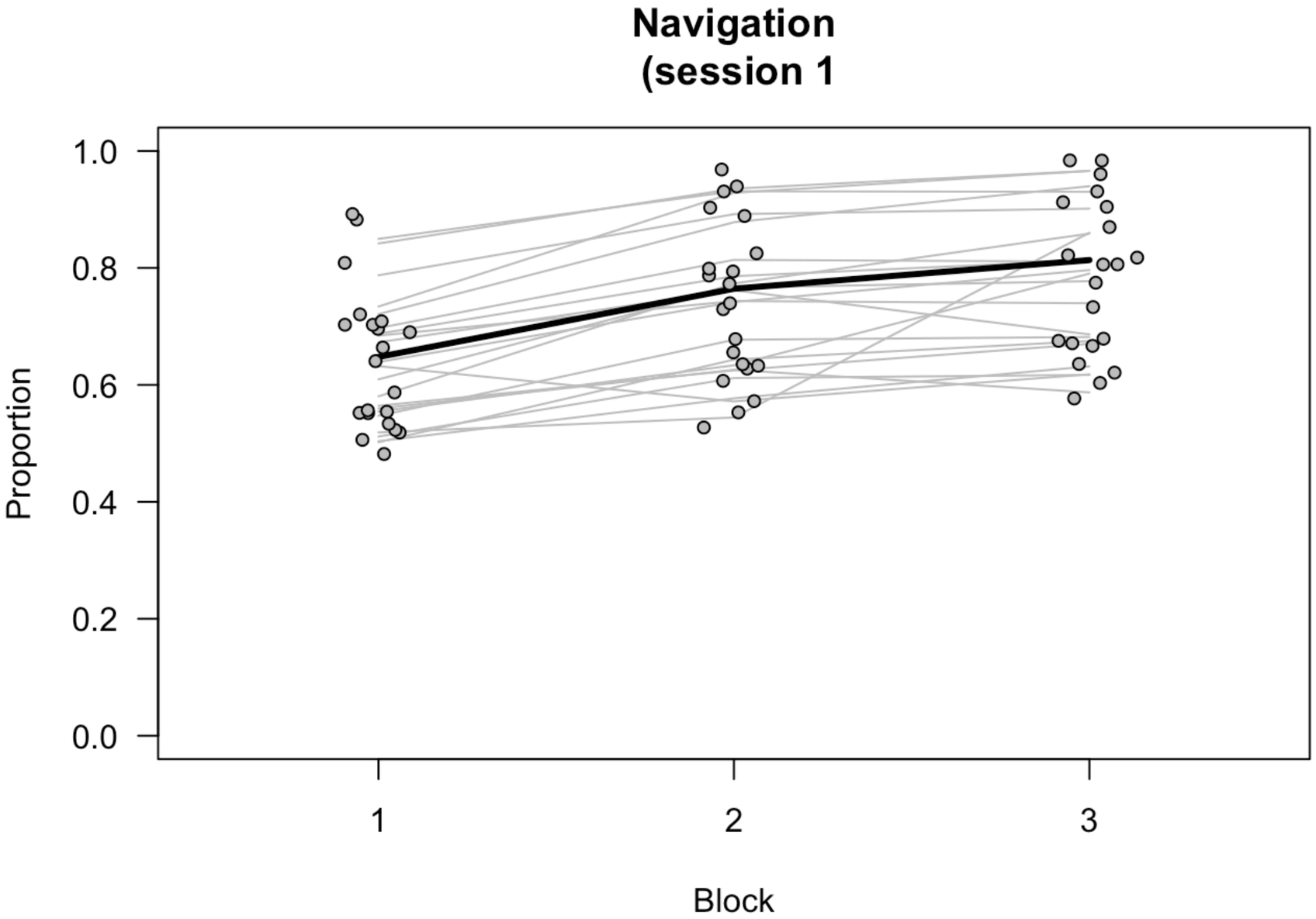




- Any node can be a source node except the nodes that form the ‘bridge’.
- All links of the source nodes are sampled. This means that for the right-hand side community some pairs are repeated to keep the number of source node presentations constant across the two communities.
- The minimum distance between a source and a target node is such that participants have to exit a community, i.e., distance range is 4-8.

Navigation task: binomial model



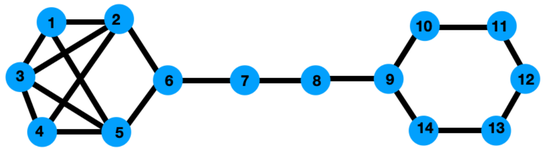


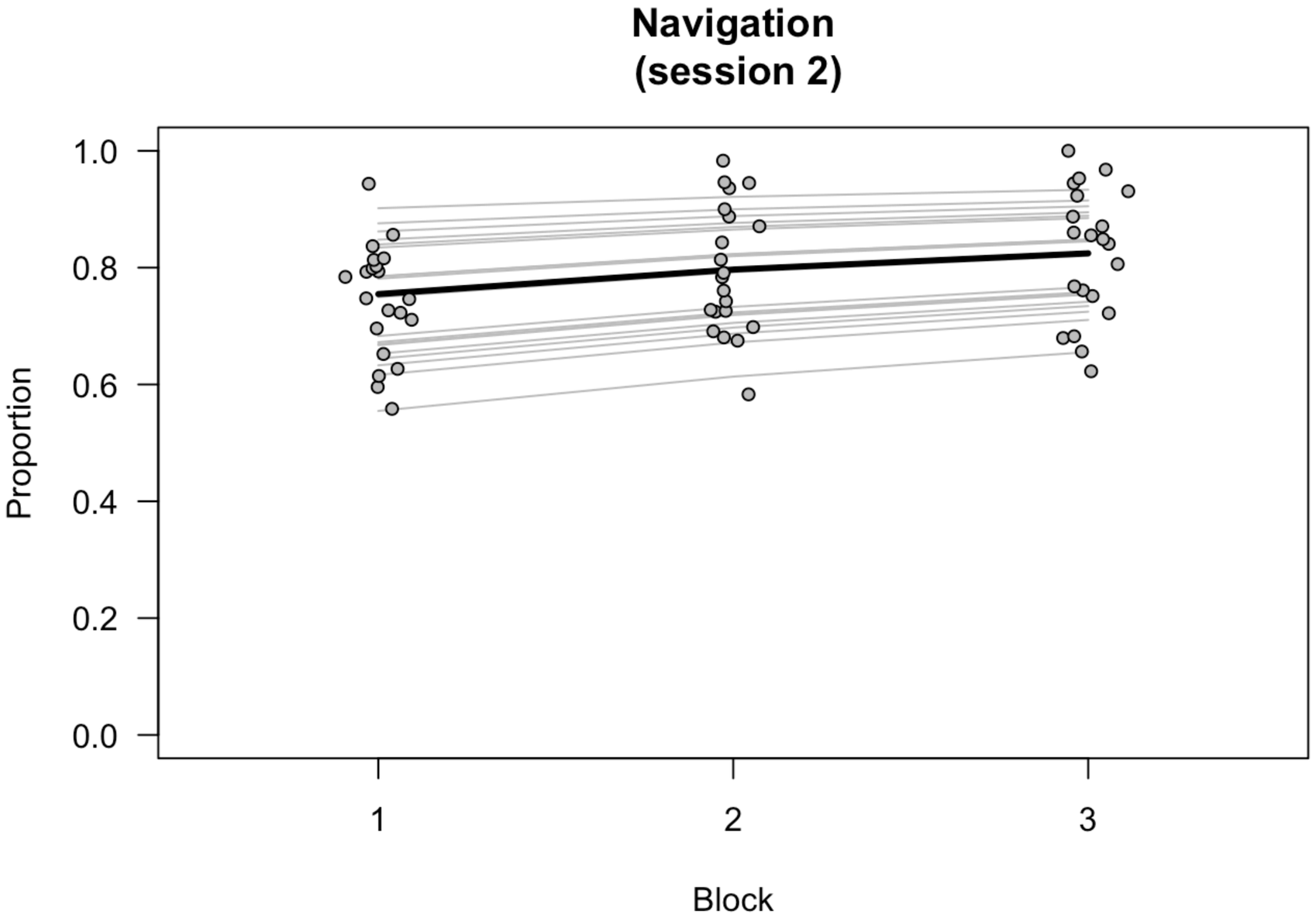
isCorrect ~ 1 + block +
(1 + block | subject) +
(1 | sourcenode) +
(1 | distance)

$$\chi(2) = 21$$

$$p = 2.722e - 05$$

Navigation task: binomial model



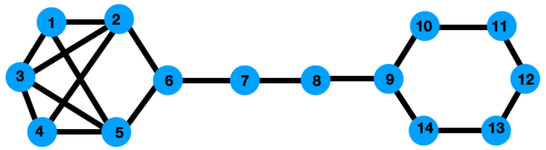


isCorrect ~ 1 + block +
(1 | subject) +
(1 | sourcenode) +
(1 | distance)

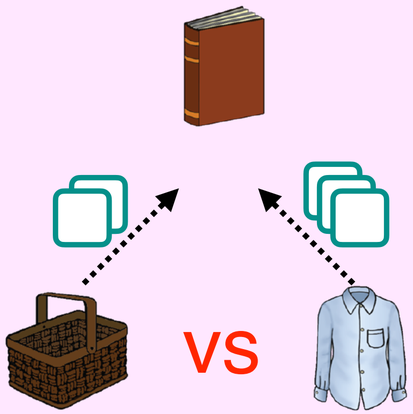
$$\chi(2) = 56$$

$$p = 5.673e - 13$$

Distance estimation task (3.2.0)

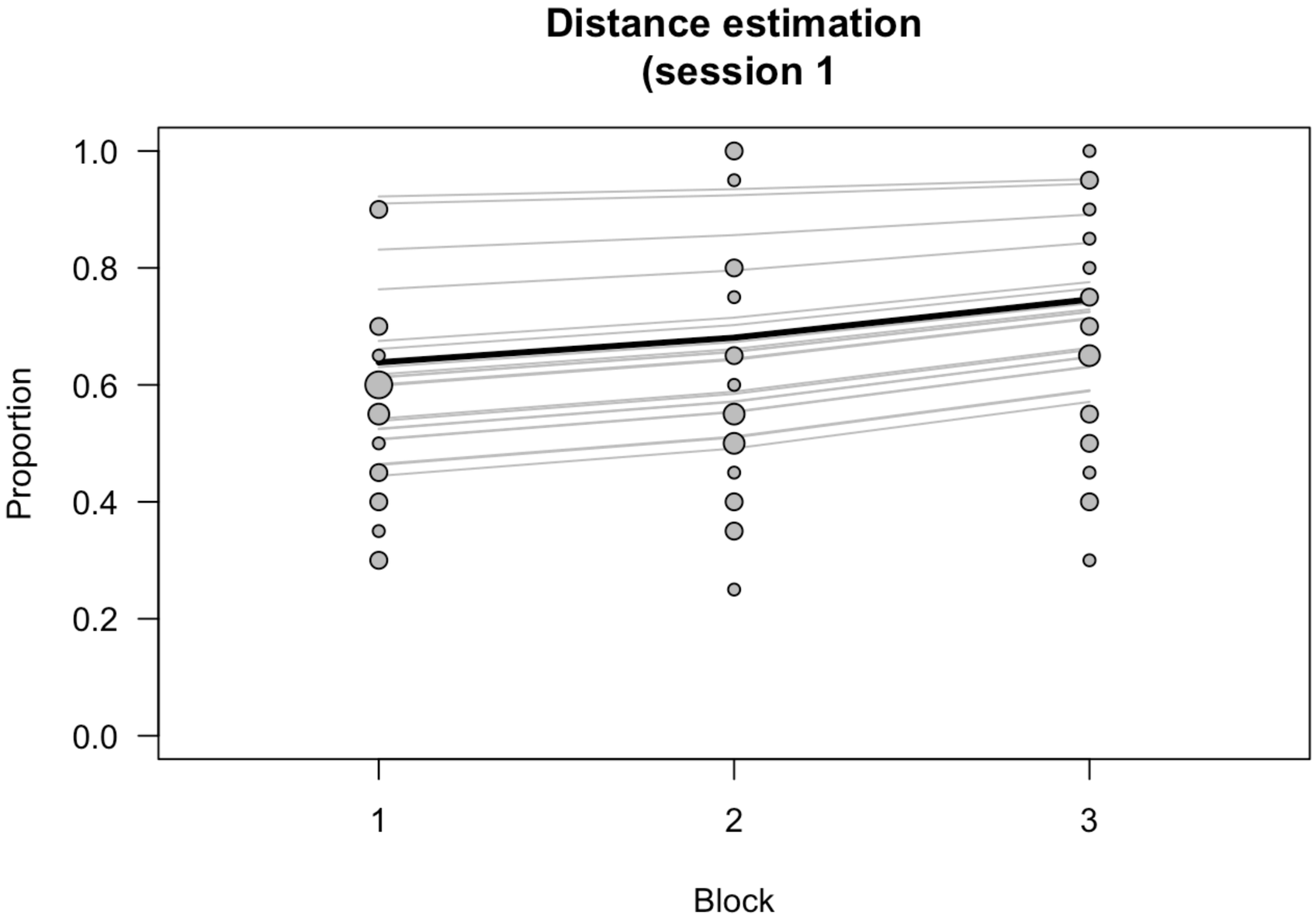


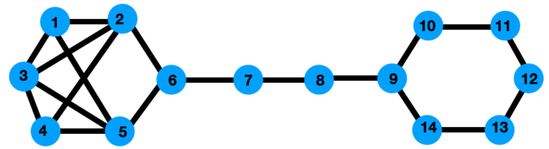
Distance estimation task
(feedback after trial)



- Distance task was modified such that only nodes which belong to a community can be a sourcenode while only nodes that belong to a bridge can be a target node. This way participants are supposed to discriminate the order structure of the bridge nodes.
- The options are always neighbours, for example, option 1 is node 6 while option 2 is node 7.
- The task samples each community node as a source node twice leading to 20 trials in total.

Distance estimation task: binomial model



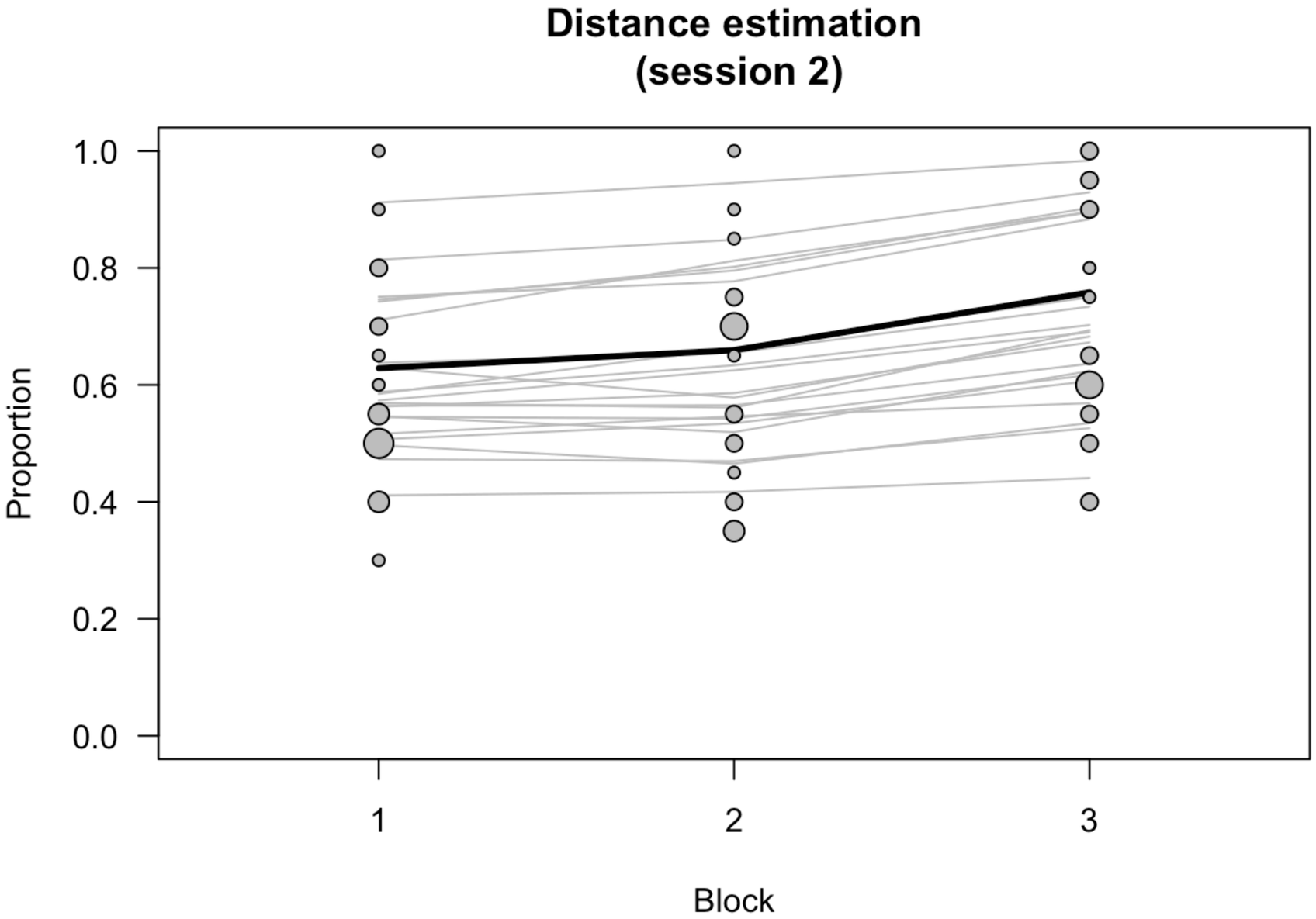


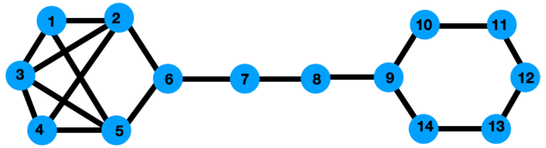
isCorrect ~ 1 + mindist + block +
(1 | subject) +
(1 | sourcenode)

$$\chi(2) = 11.87$$

$$p = 0.0026$$

Distance estimation task: binomial model



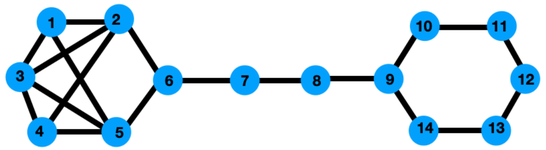


isCorrect ~ 1 + mindist + block +
(1 + block | subject)

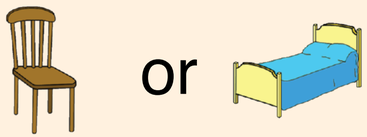
$$\chi(2) = 9.55$$

$$p = 0.008$$

Association task (3.2.0)



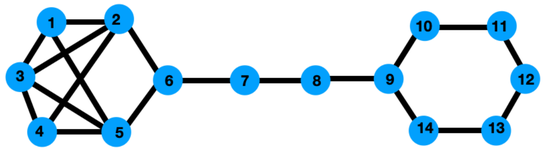
Association task
(feedback after trial)

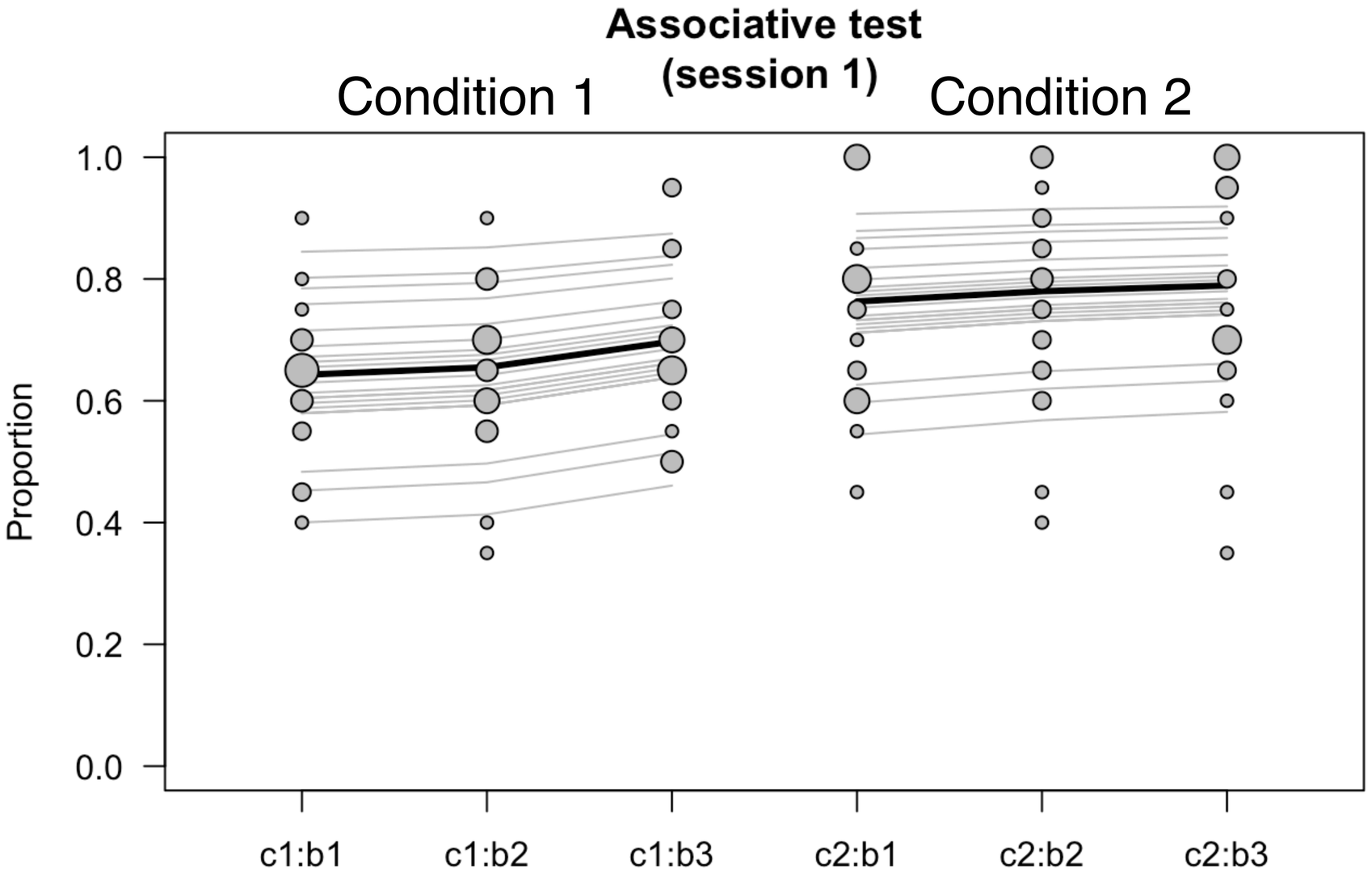


or

- There are two conditions:
  - (1) the options belong to the same community (more difficult) or
  - (2) the options belong to both communities such that participants can solve the task just by knowing which nodes belong to which community (less difficult).
- There are 40 trials in total.
- It is not possible to include node 6 in condition 1 so to keep it constant node 6 and 9 are excluded from the trials as target nodes, i.e., nodes that are the correct choice.

Associative task: binomial model





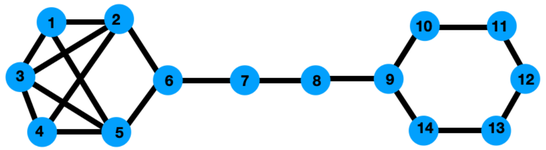
isCorrect ~ 1 + condition +
block + condition:block +
(1 | subject)

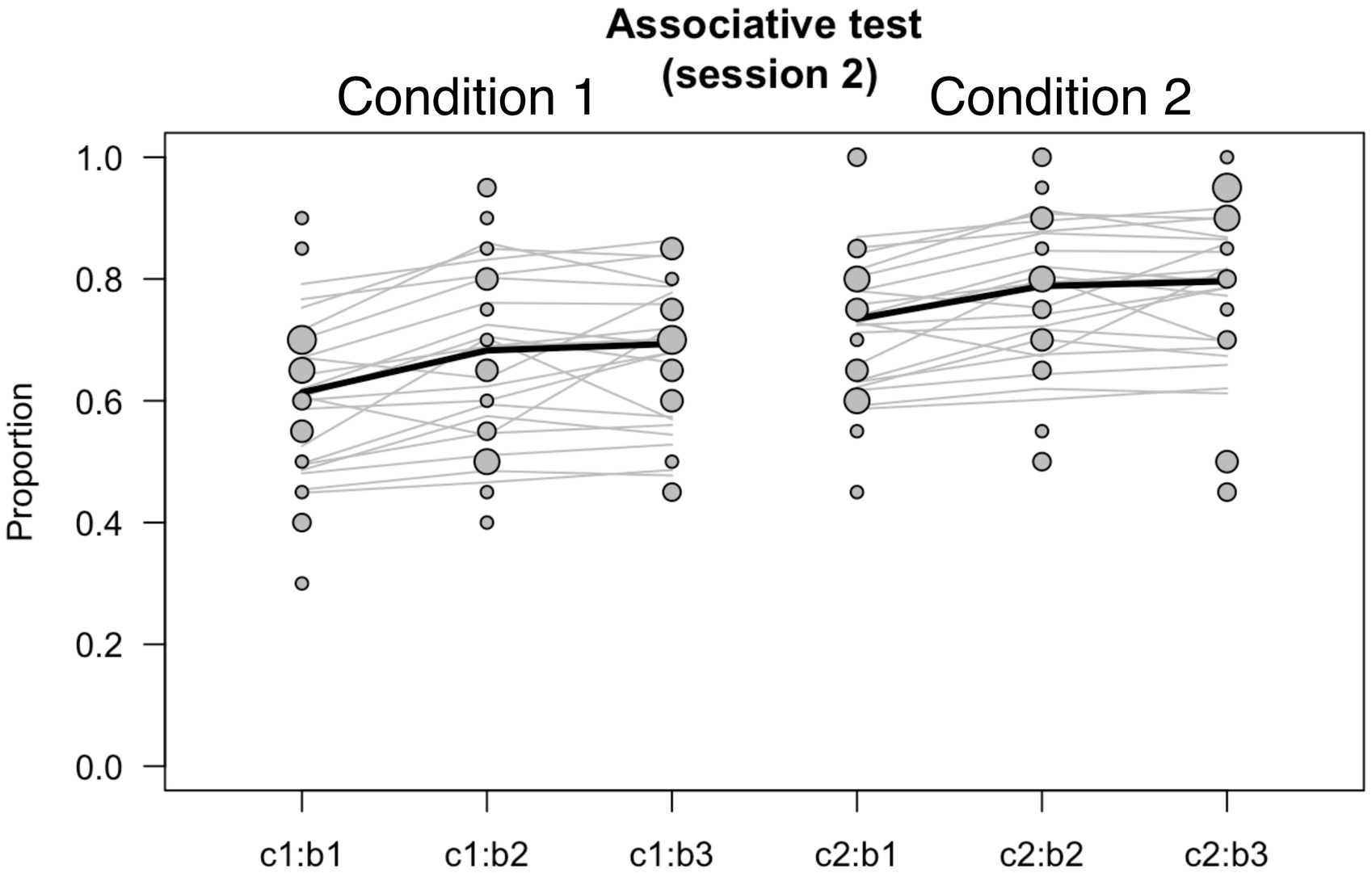
$$\chi(4) = 3.84$$

$$p = 0.42$$

Main effect of condition

Associative task: binomial model





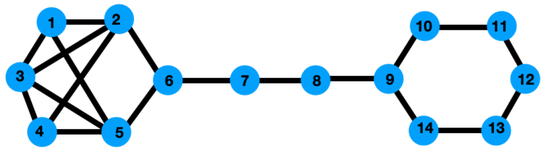
isCorrect ~ 1 + condition +
block + condition:block +
(1 + block | subject)

$$\chi(4) = 7.71$$

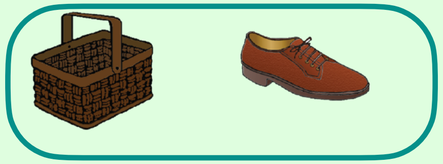
$$p = 0.10$$

Main effect of condition and block

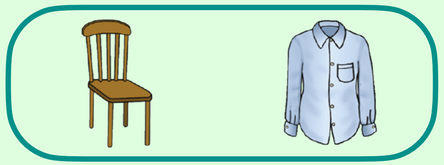
Compare pairs task (3.2.0)



Compare pairs task
(feedback after trial)

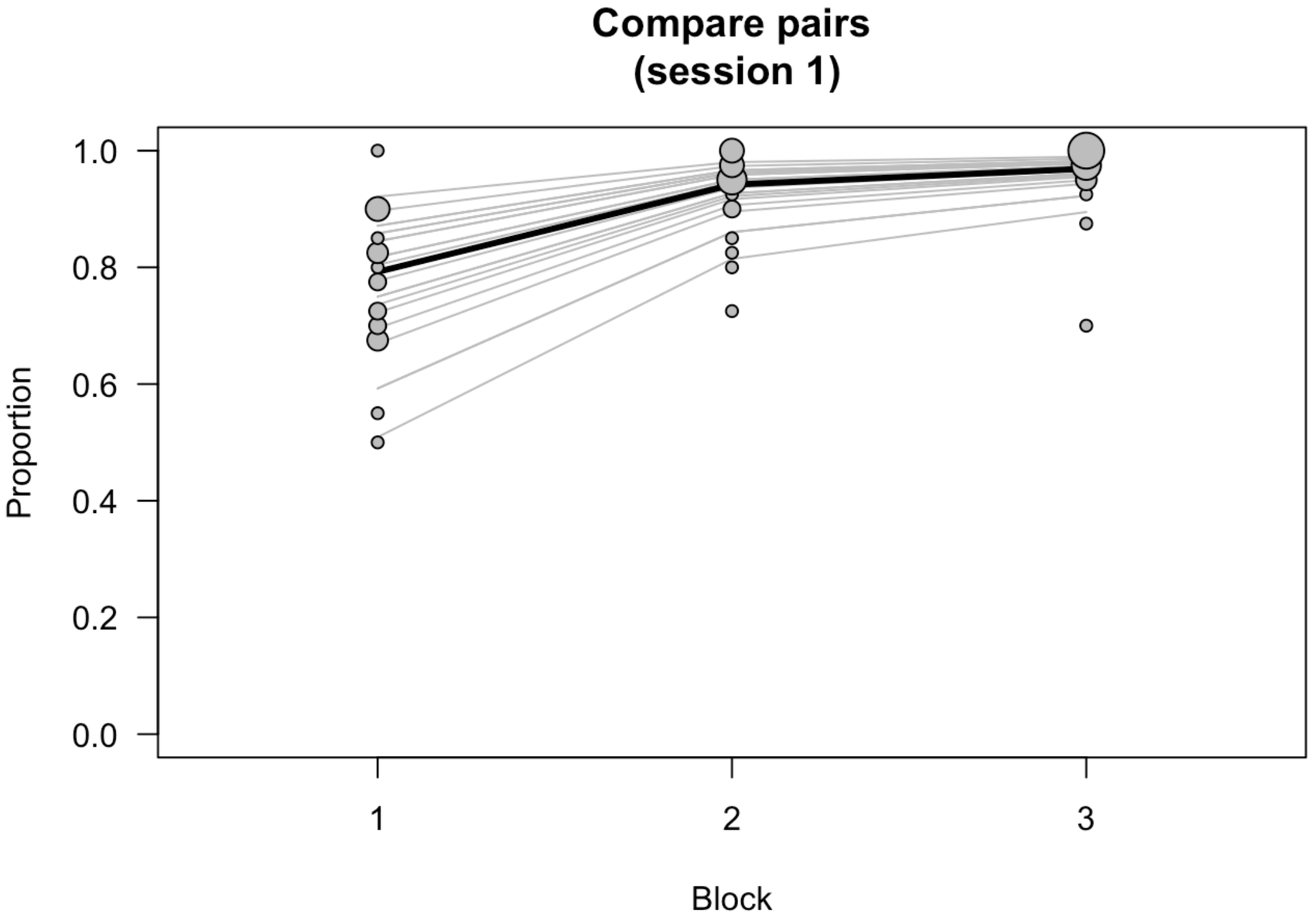


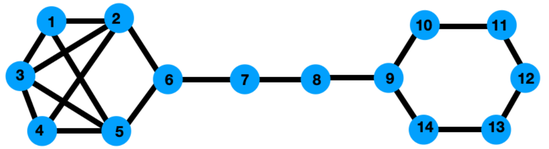
vs



- Participants compare pairs that involve nodes from a ‘bridge’ and a community for each pair. This means that the pairs that involve nodes from the left-hand side represent ‘shorter’ distance than the pairs that involve nodes from the right-hand side.
- Trials come from a basis set that is repeated 4 times in a session.
- The order of trials is pseudo-randomized such that there are max 3 trials in a row with the same node of the family [6 7 8 9].
- There are 40 trials in total.

Day 1: Compare pairs task: binomial model



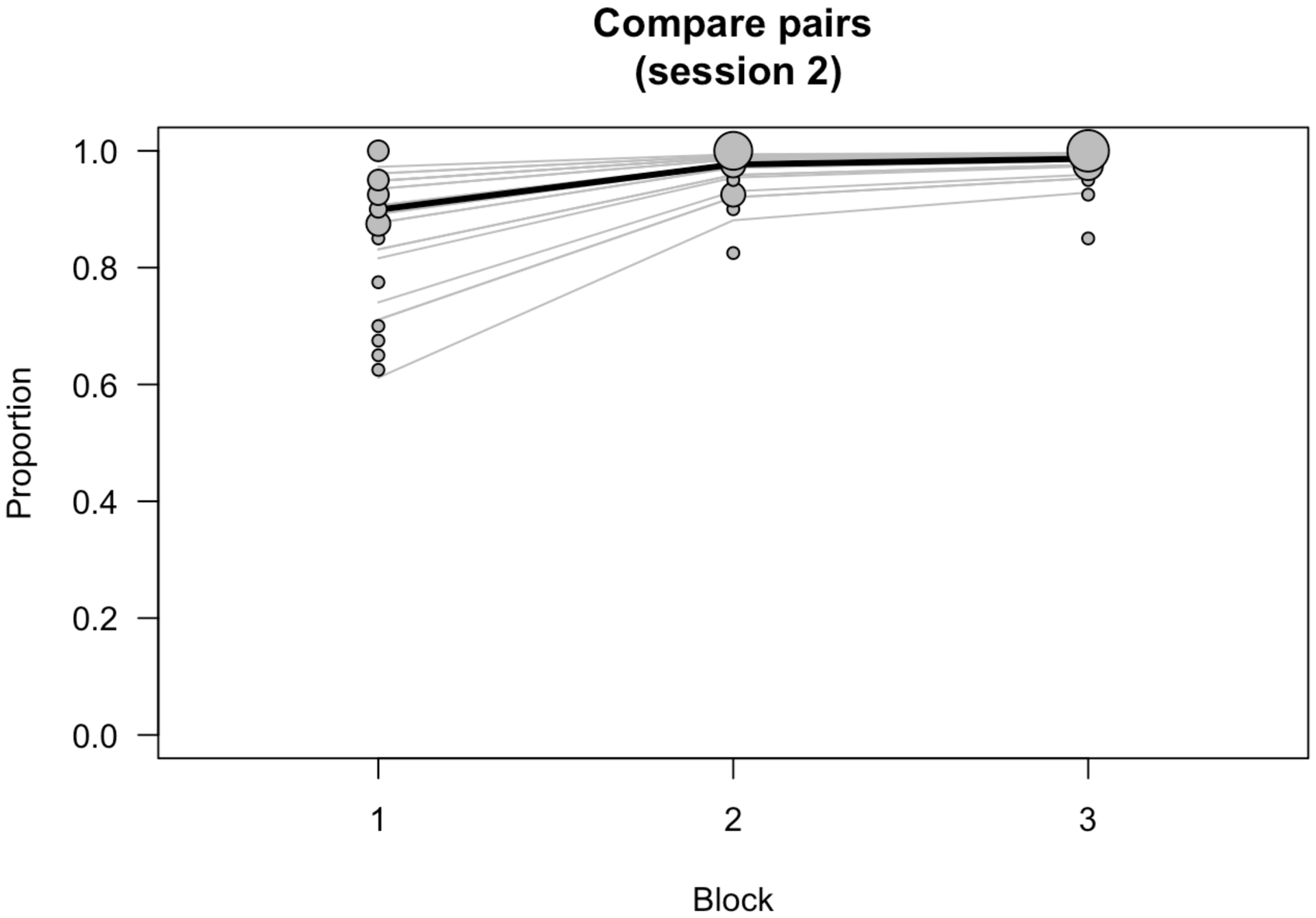


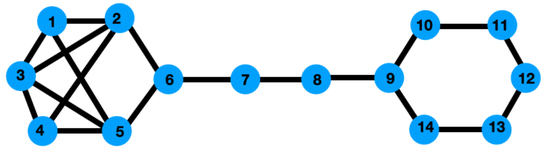
isCorrect ~ 1 + block + (1 | subject)

$$\chi(2) = 176$$

$$p = 2.2e - 16$$

Day 2: Compare pairs task: binomial model



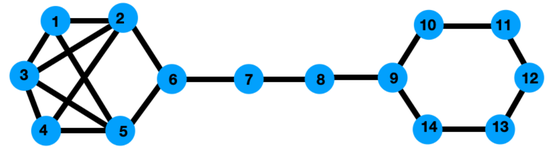


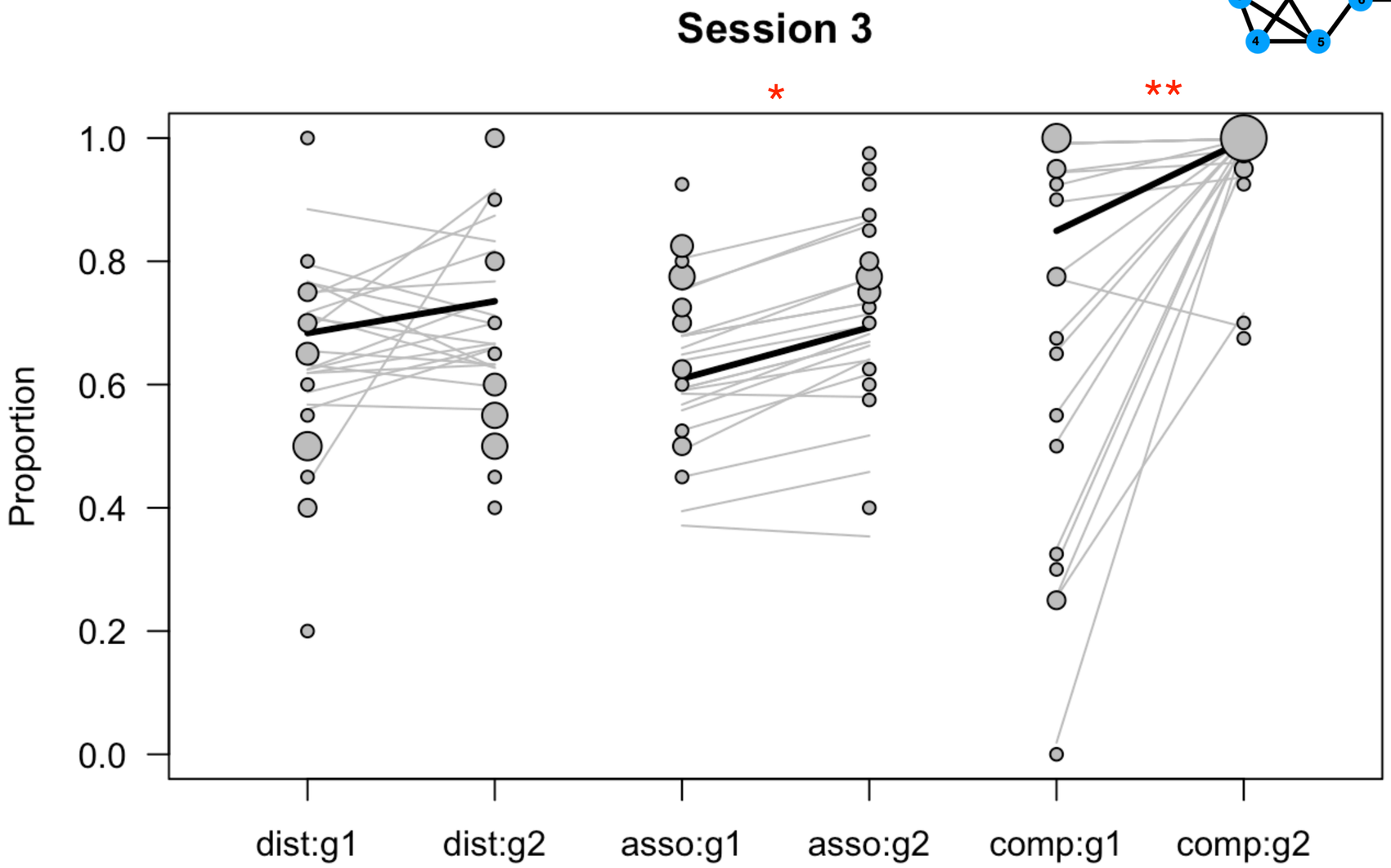
isCorrect ~ 1 + block +
(1 | subject)

$$\chi(2) = 108.25$$

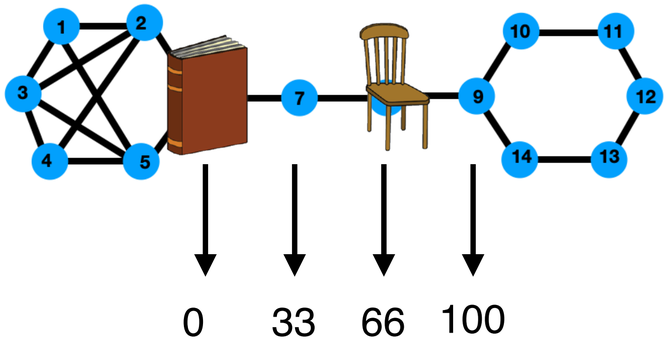
$$p = 2.2e - 16$$

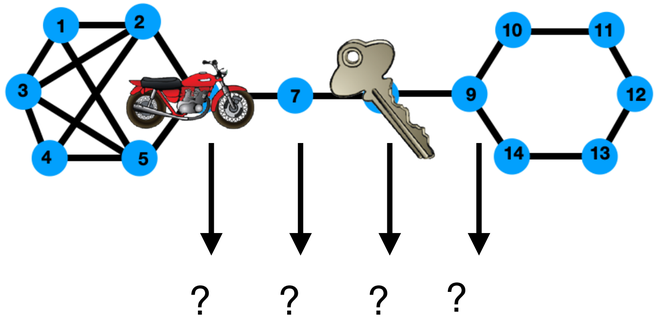
Day 3: distance, associations, compare-pairs



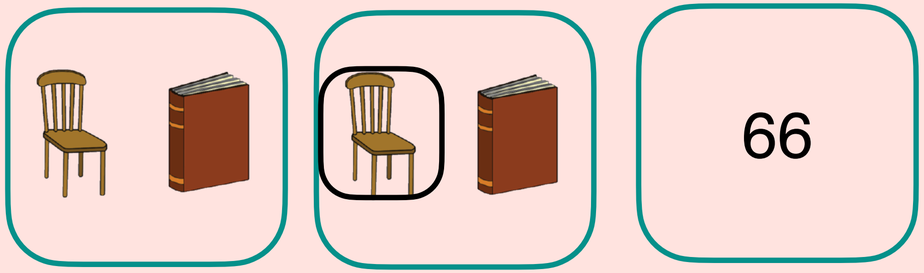


Day 3: Choice task

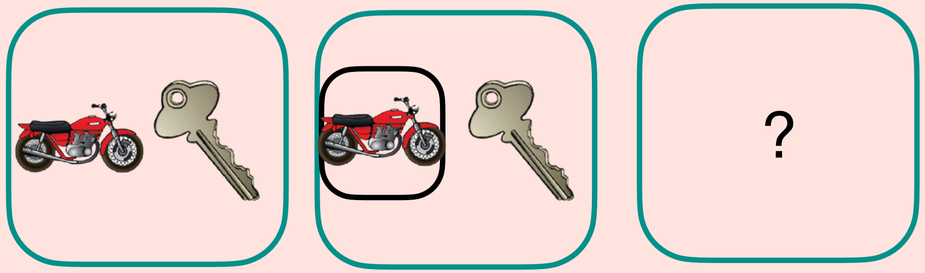




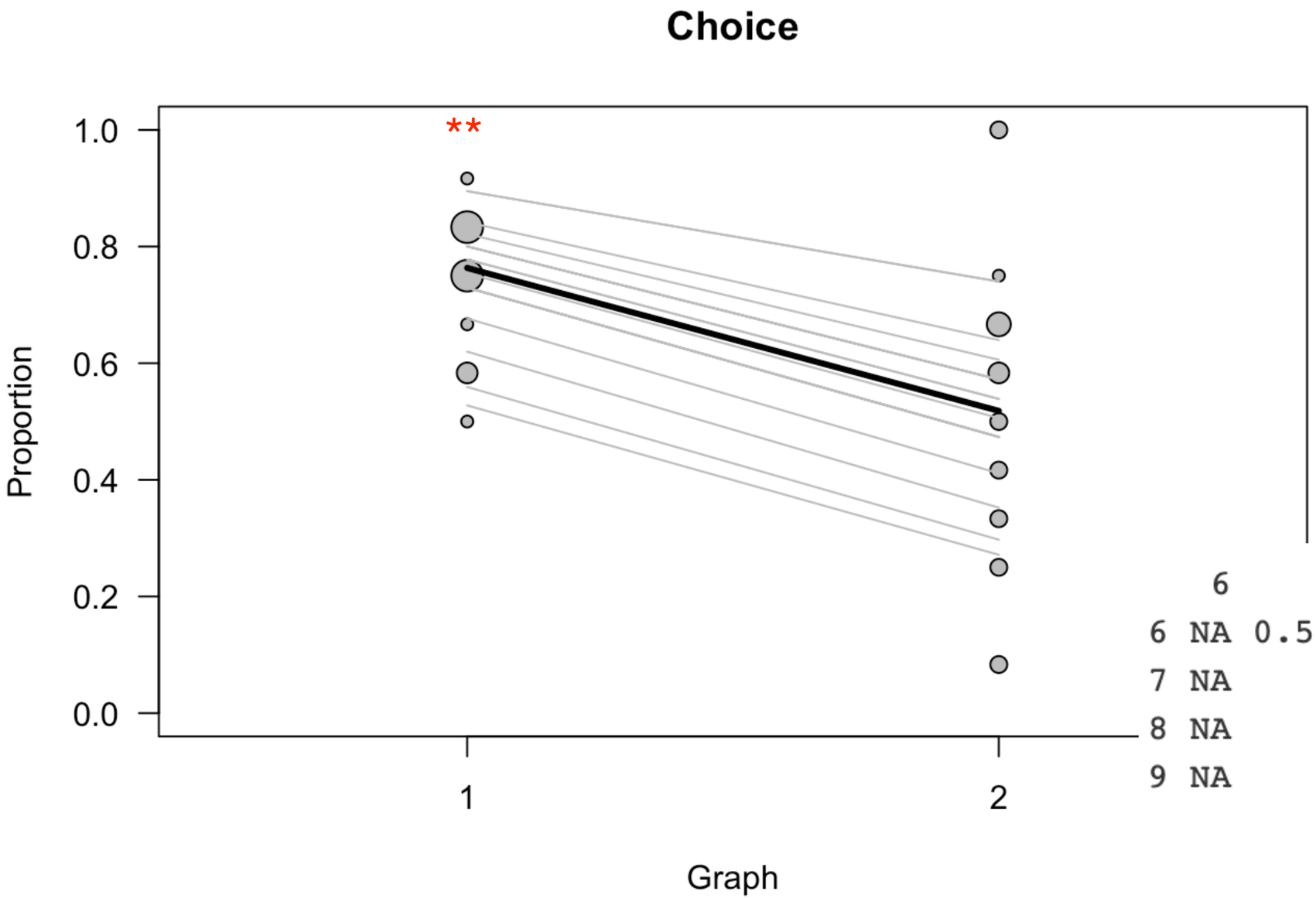
1st half
Graph A



2nd half
Graph A’



Day 3: choice task

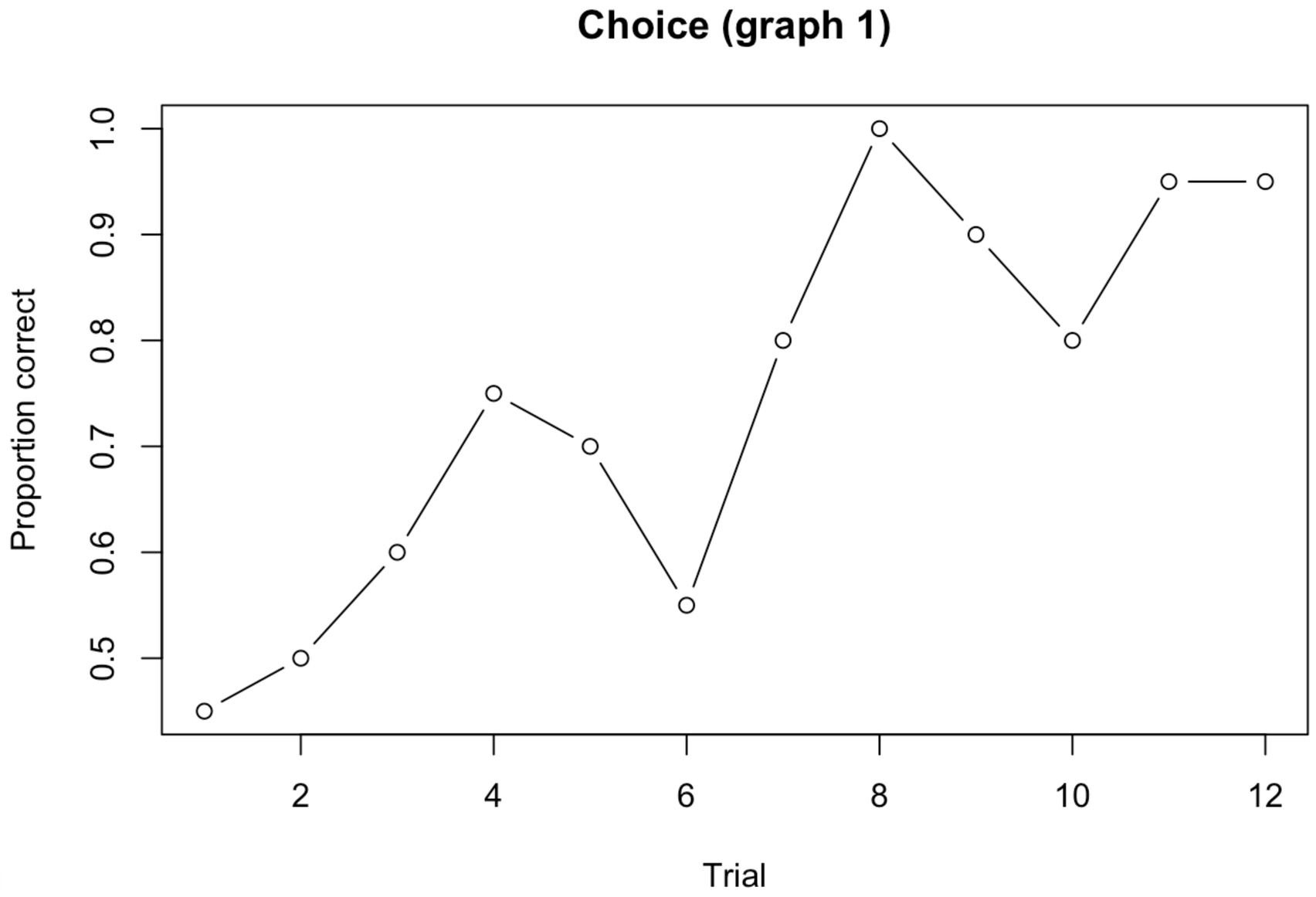


No improvement when subjects are selected based on graph 1 performance

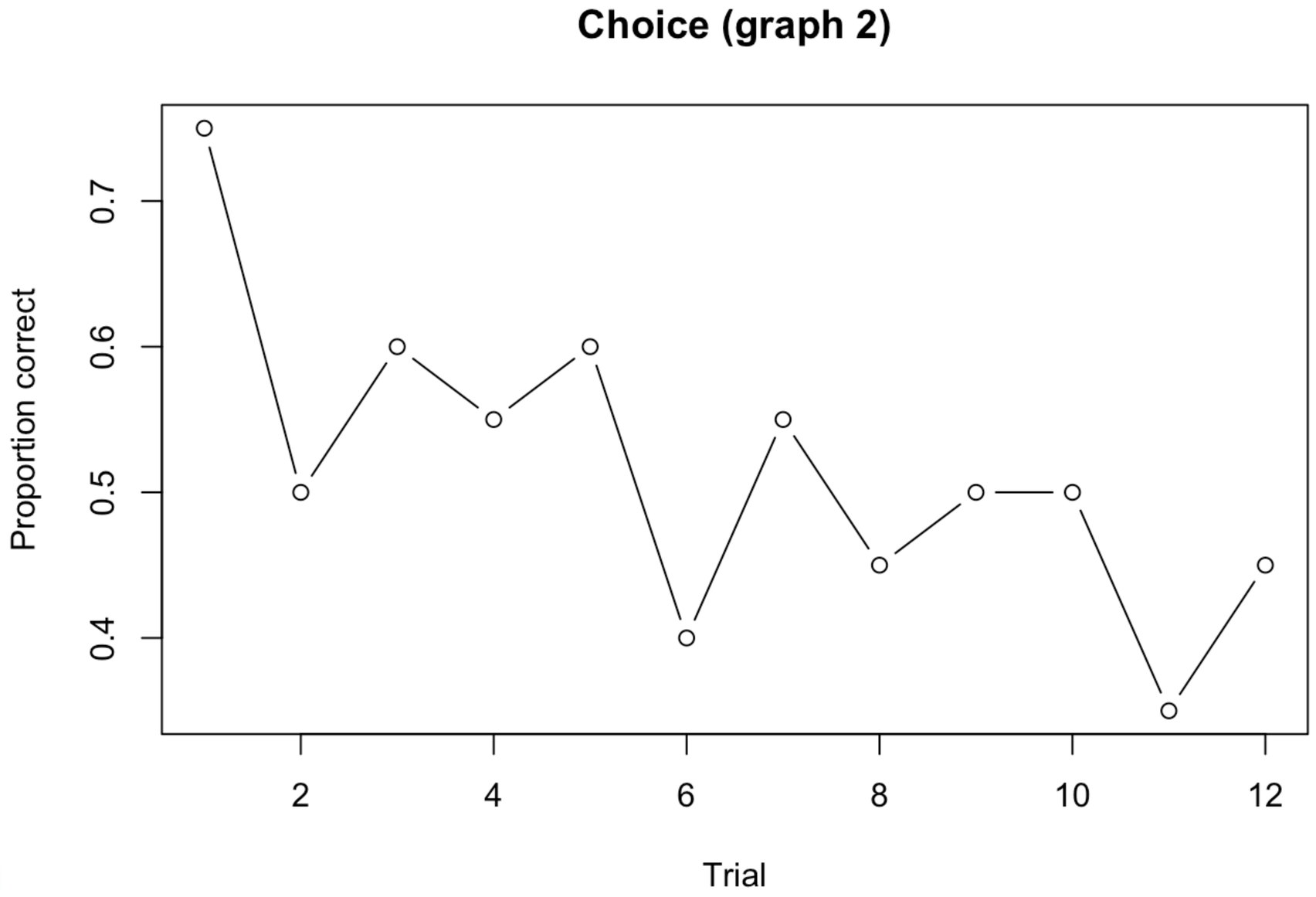
No relationships with arena arrangement

	6	7	8	9
6	NA	0.5666667	0.6333333	0.5666667
7	NA	NA	0.5333333	0.5333333
8	NA	NA	NA	0.6666667
9	NA	NA	NA	NA

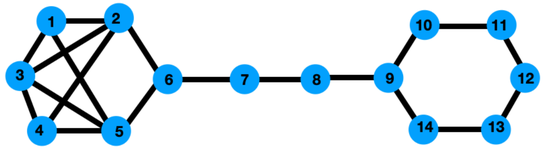
Day 3: choice task



Day 3: choice task



Summary



- The choice task does not indicate that the transfer has occurred as the group level performance is around chance.
- Performance in distance task is perhaps lower than one would wish.
- Performance in the “compare pairs” task looks as if participants learned stimulus-response associations rather than considering the graph structure (rule: choose options including pictures of node 6 or 7). In session 3, in graph 1 their performance is reversed as if they forgot the rule.

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