Adult Age Differences in Dynamics of Model-based Decision-making

Alexa Ruel
Department of Psychology
Concordia University
Montreal, Canada
alexa.ruel@mail.concordia.ca

Florian Bolenz
Faculty of Psychology
Technische Universität Dresden
Dresden, Germany
florian.bolenz@tu-dresden.de

Shu-Chen Li
Faculty of Psychology
Technische Universität Dresden
Dresden, Germany
shu-chen.li@tu-dresden.de

Ben Eppinger
Department of Psychology
Concordia University
Montreal, Canada
ben.eppinger@concordia.ca

Abstract

Younger adults' decision-making behavior is often a combination of model-free (MF) and model-based (MB) decision strategies. In contrast, older adults seem to primarily rely on MF strategies. This age-related shift in decision strategies has been interpreted in terms of a deficit in the representation of transition structures necessary for MB decision-making. The aims of the current study were twofold: first, we aimed to examine if the degree of MB decision-making in older adults is sensitive to changes in demands on representing the transition structure; second, we investigated the neural dynamics underlying age-related shifts in decision strategies. To do so, we used a modified version of a two-stage Markov decision task and manipulated the demands on the representation of the transition structure in two conditions (60%-40% and 80%-20%). Furthermore, we acquired electroencephalography (EEG) data during the task. Behavioral results show evidence for MB decision-making in younger adults in both conditions, with a greater MB contribution in the 80-20 condition. In contrast, the older adults demonstrated MF behavior in the high demand (60%-40%) condition. Yet, with more predictable transitions (80%-20% condition), older adults showed significantly greater MB decision-making. For the EEG results, we focused on the P300 and the FRN components which have been associated with state transition effects and reward processing, respectively. Preliminary analyses suggest that, in younger adults, the P300 was sensitive to the transition probability structure, whereas the effect was strongly reduced in older adults. This is consistent with recent suggestions that the P300 might reflect the processing of state prediction errors. With respect to the FRN, results suggest that younger adults were sensitive to reward feedback, evidenced by a greater FRN following reward feedback. This component was reduced in older adults. Future analyses will combine computational and EEG approaches.

Keywords: aging, decision-making, learning, task demands

Acknowledgements

This work was supported by the Deutsche Forschungsgemeinschaft (SFB 940/2, subproject B7) as well as a Canada Research Chair awarded to B.E.

1 Extended Abstract

The distinction between habitual (model-free) decisions, which rely on the association between actions and rewards, and goal-directed (model-based) decisions, which are guided by the representation of the decision environment, or a cognitive map (Tolman, 1948), has been a topic of discussion for several years. Despite their cost in cognitive resources, the benefit of MB decision strategies is that they provide greater behavioral flexibility, which is particularly relevant in complex and changing environments. In younger adults, decision-making behavior is often a combination of MF and MB strategies (Daw et al., 2011; Eppinger et al., 2017). In contrast, older adults seem to primarily engage in a MF decision strategy, which has been associated with their constraints in cognitive resources necessary for MB decision-making (Eppinger et al., 2013). These empirical findings are consistent with theoretical ideas suggesting that MB learning and decision processes develop gradually into adulthood (Decker et al. 2016) and decline in older age (Eppinger et al., 2013; Eppinger et al., 2015).

The neurobiological mechanisms underlying ageing-related shifts in decision strategies are largely unclear. One leading hypothesis is that age differences in the engagement in MB strategies may result from deficits in prefrontal mechanisms involved in learning and representing the state transition structure of the decision environment (Hämmerer & Eppinger, 2012; Samanez-Larkin et al., 2012).

In the current study, we investigated whether younger adults (20 to 28 years, *n*=26) and older adults (65 to 80 years, *n*=25) differ in their ability to use model-based decision-making strategies in a modified two-stage Markov task (based on Eppinger et al., 2017; see Figure 1). Specifically, we aimed to examine if older adults would demonstrate a greater degree of MB decision-making when the demands on representing the transition structure are reduced due to the greater predictability of choice outcome. To investigate the age differences in the neural dynamics underlying MB and MF decision-making, we acquired encephalography (EEG) data while participants performed the task. All participants completed two 60%-40% transition probability blocks, and two 80%-20% transition probability blocks (116 trials each), corresponding to a high demand and low demand condition, respectively. The task involved two decision stages. In the first stage, participants had to choose one of two options (i.e., an upward or downward facing airplane). In the example below, the left option is associated with a higher probability of transitioning (i.e., common trials, 60% or 80%) to the lower left options at stage two, and a lower probability (i.e., rare trials, 40% or 20%) of transitioning to the lower right options. The reverse is true for the right stimulus at stage one. At the second stage of the task, participants had to learn which of four stimuli is currently associated with the highest reward. Note that rewards are dichotomous (participants either obtained reward or no reward feedback) and the probability of obtaining a reward were determined by Gaussian random walks. In this task, model-free behavior is defined as a first stage choice which is guided solely by the previous reward outcome, regardless if this outcome occurred after a common or rare transition on the previous trial. Contrarily, first stage choices are considered to reflect model-based behavior when they are guided by the interaction of transition probabilities and rewards obtained on the previous trials.

2 Behavioral results

Behavioral results show a greater degree of MB behavior (interaction between transition type and reward) in the low demand (80-20) compared to the high demand (60-40) condition in younger adults. In older adults, there is evidence for a MB contribution to choice behavior in the low demand condition (80-20), whereas decision behavior is model-free (main effect of reward) in the high demand condition (60-40) (see Figure 3). Thus, our results replicate previous findings in younger adults (Eppinger et al., 2017), suggesting that participants' engagement in an MB decision strategy depends on the demands on the representation of the transition structure. Moreover, our findings show that older adults are able to engage in MB decision-making if the demands on the representation of the transition structure are reduced.

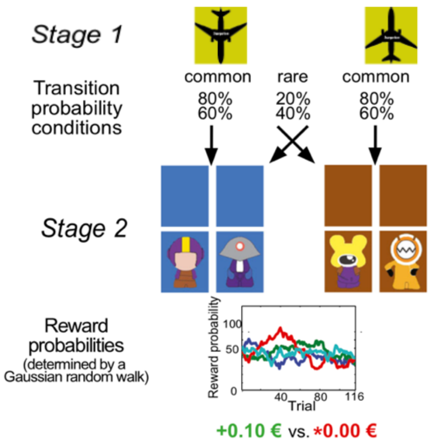

Figure 1. Schematic representation of the modified two-stage Markov decision task. Participants have to constantly update their reward predictions at stage 2 (model-free decision-making) and use these predictions to guide their choice at the first stage of the task (model-based decision-making).

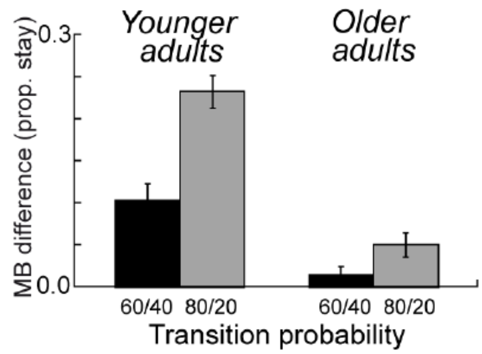

Figure 2. Proportion of trials on which participants repeated the same first stage choice (stay behavior) as a function of the transition probability condition for younger and older adults. Error bars reflect the standard error of the mean (SEM).

3 ERP results

Preliminary analyses of ERPs during the second stage of the task revealed a greater stimulus evoked P300 after common compared to rare transitions in the 80-20 condition in younger adults. This transition effect was reduced in the 60-40 condition. In the older adults, a small P300 transition effect was observed in the 80-20 condition whereas the effect was absent in the 60-40 condition. The results in younger adults are consistent with previous findings suggesting that the P300 may reflect state prediction errors (Nieuwenhuis et al., 2005). The findings in older adults are in line with the behavioral data and indicate deficits in the representation of the task structure.

a) Younger Adults **b) Older Adults**

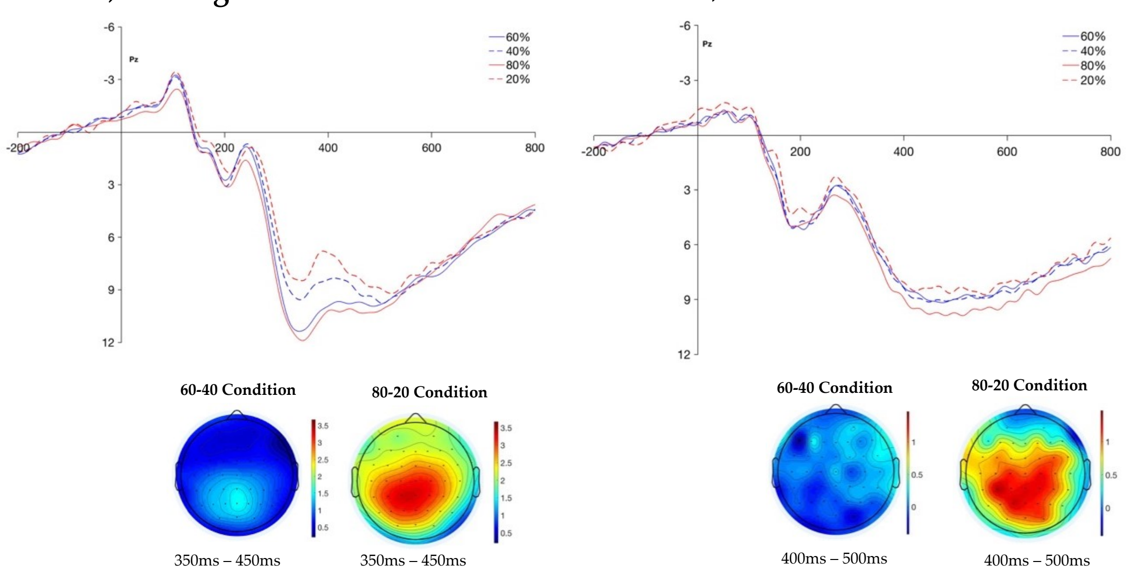

Figure 3. *Top:* ERPs elicited by second-stage stimuli at electrode Pz, displayed separately for the 80-20 condition (red) and the 60-40 condition (blue), as well as the common transitions (solid lines), and rare transitions (dashed lines) for both **a)** younger adults, and **b)** older adults. *Bottom:* The topographical map displays of the difference between common and rare transitions for the 60-40 condition (left) and the 80-20 condition (right) for **a)** young adults and **b)** old adults.

Finally, preliminary analyses at the reward stage of the task revealed an FRN component for no-reward compared to reward outcomes for younger adults, and a reduction in this component for older adults (see Figure 4). This finding is consistent with previous results (Eppinger et al., 2008; Eppinger & Kray, 2011; Hämmerer et al., 2011) and points to a greater sensitivity to reward-related feedback in younger than older adults.

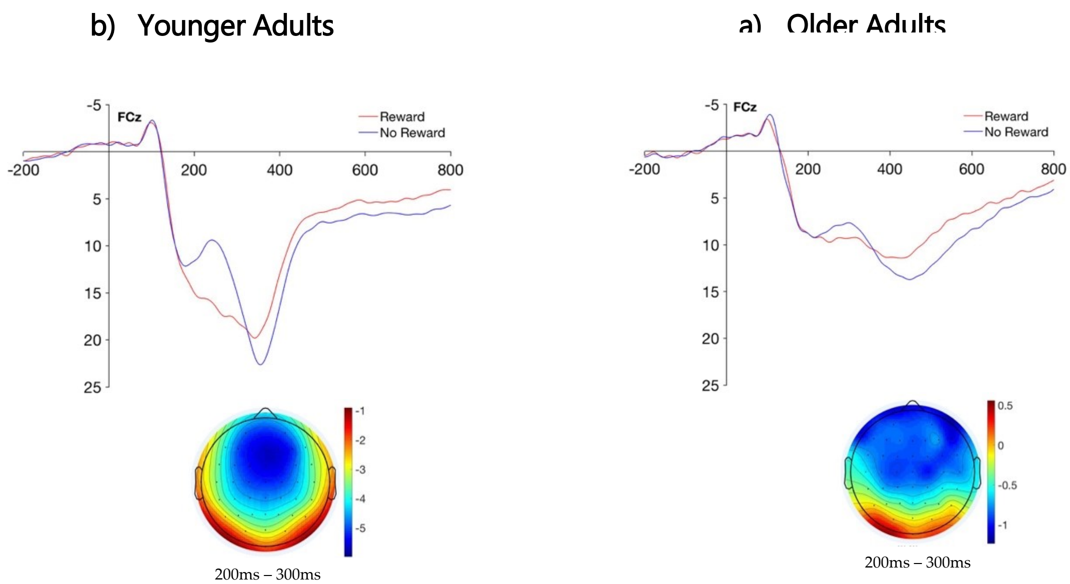

Figure 4. *Top:* Feedback locked ERPs at electrode FCz for rewards (red) and no rewards (blue) for **a)** younger adults, and **b)** older adults. *Bottom:* The topographical map displays of the differences between no reward and reward feedback for **a)** younger adults, and **b)** older adults.

4 Discussion

Overall, our results suggest that both younger and older adults show enhanced model-based decision-making when the demands on the representation of the state transition structure are low (in the 80-20 condition) compared to when they are high (in the 60-40 condition). However, this effect is much more pronounced in younger, compared to older adults. The P300 results at the second stage of the task support the behavioral effects by showing an enhanced P300 component for common as compared to rare transitions in the low (80-20) as compared to the high demand condition (60-40) across both age groups. Again, this effect is much more pronounced in younger than older adults. Finally, at the reward stage of the task, we found a diminished FRN component for reward compared to no reward outcomes in older adults, which appears to be consistent with previous findings showing diminished reward prediction error signaling in the elderly (Chowdhury et al., 2013; Eppinger et al., 2013). Future analyses will combine computational and electrophysiological analyses to provide more mechanistic interpretations of ageing-related changes in decision strategies.

References

Chowdhury, R., Guitart-Masip, M., Lambert, C., Dayan, P., Huys, Q., Düzel, E., & Dolan, R. J. (2013). *Dopamine restores reward prediction errors in old age. Nature Neuroscience, 16(5), 648–653.* doi:10.1038/nn.3364

Daw, N. D., Gershman, S. J., Seymour, B., Dayan, P., & Dolan, R. J. (2011). Model-based influences on humans' choices and striatal prediction errors. *Neuron*, *69*(6), 1204-1215. doi: 10.1016/j.enuron.2011.02.027

Eppinger, B., Heekeren, H. R., & Li, S.-C. (2015). Age-related prefrontal impairments implicate deficient prediction of future reward in older adults. *Neurobiology of Aging, 36(8), 2380–2390.*doi:10.1016/j.neurobiolaging.2015.04.010

Eppinger, B., & Kray, J. (2011). *To Choose or to Avoid: Age Differences in Learning from Positive and Negative Feedback. Journal of Cognitive Neuroscience, 23(1), 41–52.* doi:10.1162/jocn.2009.21364

Eppinger, B., Kray, J., Mock, B., & Mecklinger, A. (2008). *Better or worse than expected? Aging, learning, and the ERN. Neuropsychologia, 46(2), 521–539.* doi:10.1016/j.neuropsychologia.2007.09.001

Eppinger, B., Walter, M., & Li, S. C. (2017). Electrophysiological correlates reflect the integration of model-based and model-free decision information. *Cognitive, Affective, & Behavioral Neuroscience*, *17*(2), 406-421. doi:10.3758/s13415-016-0487-3.

Eppinger, B., Walter, M., Heekeren, H. R., & Li, S.-C. (2013). *Of goals and habits: age-related and individual differences in goal-directed decision-making. Frontiers in Neuroscience, 7.* doi:10.3389/fnins.2013.00253

Hämmerer, D., & Eppinger, B. (2012). Dopaminergic and prefrontal contributions to reward-based learning and outcome monitoring during child development and aging. *Developmental Psychology, 48*(3), 862-874. doi: 10.1037/a0027342

Hämmerer, D., Li, S.-C., Müller, V., & Lindenberger, U. (2011). *Life Span Differences in Electrophysiological Correlates of Monitoring Gains and Losses during Probabilistic Reinforcement Learning. Journal of Cognitive Neuroscience, 23(3), 579–592.* doi:10.1162/jocn.2010.21475

Nieuwenhuis, S., Aston-Jones, G., & Cohen, J. D. (2005). Decision making, the P3, and the locus coeruleus--norepinephrine system. *Psychological Bulletin, 131*(4), 510-532. doi: 10.1037/0033-2909.131.4.510

Samanez-Larkin, G. R., Levens, S. M., Perry, L. M., Dougherty, R. F., & Knutson, B. (2012). *Frontostriatal White Matter Integrity Mediates Adult Age Differences in Probabilistic Reward Learning. Journal of Neuroscience, 32(15), 5333–5337.* doi:10.1523/jneurosci.5756-11.2012

Somerville, L. H., & Casey, B. (2010). *Developmental neurobiology of cognitive control and motivational systems. Current Opinion in Neurobiology, 20(2), 236–241.* doi:10.1016/j.conb.2010.01.006

Tolman, E. C. (1948). Cognitive maps in rats and men. *Psychological Review, 55*(4), 189-208. doi: 10.1037/h0061626