Do Humans Adapt their Planning Horizon?

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An analysis of sequential decision-making in the videogame *Frogger*

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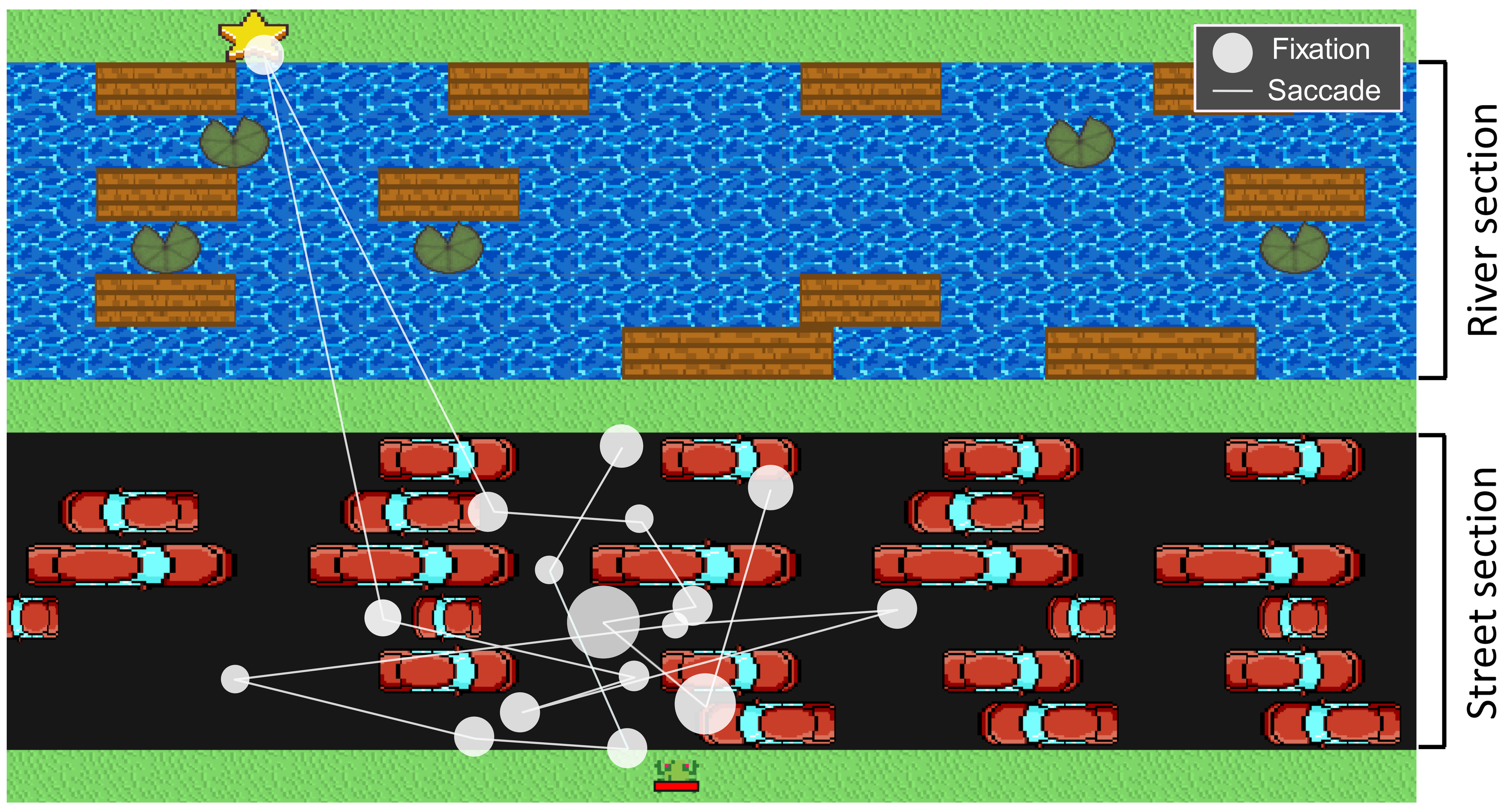
Humans only have limited computational capacity (Callaway et al., 2022) and thus need to adjust how far ahead they plan their actions, in order to not exceed these computational limits. Most studies on planning behavior focus on abstract tasks in non-naturalistic environments (van Opheusden et al., 2019). Video games provide more natural tasks while still maintaining a controlled setup.

Environment

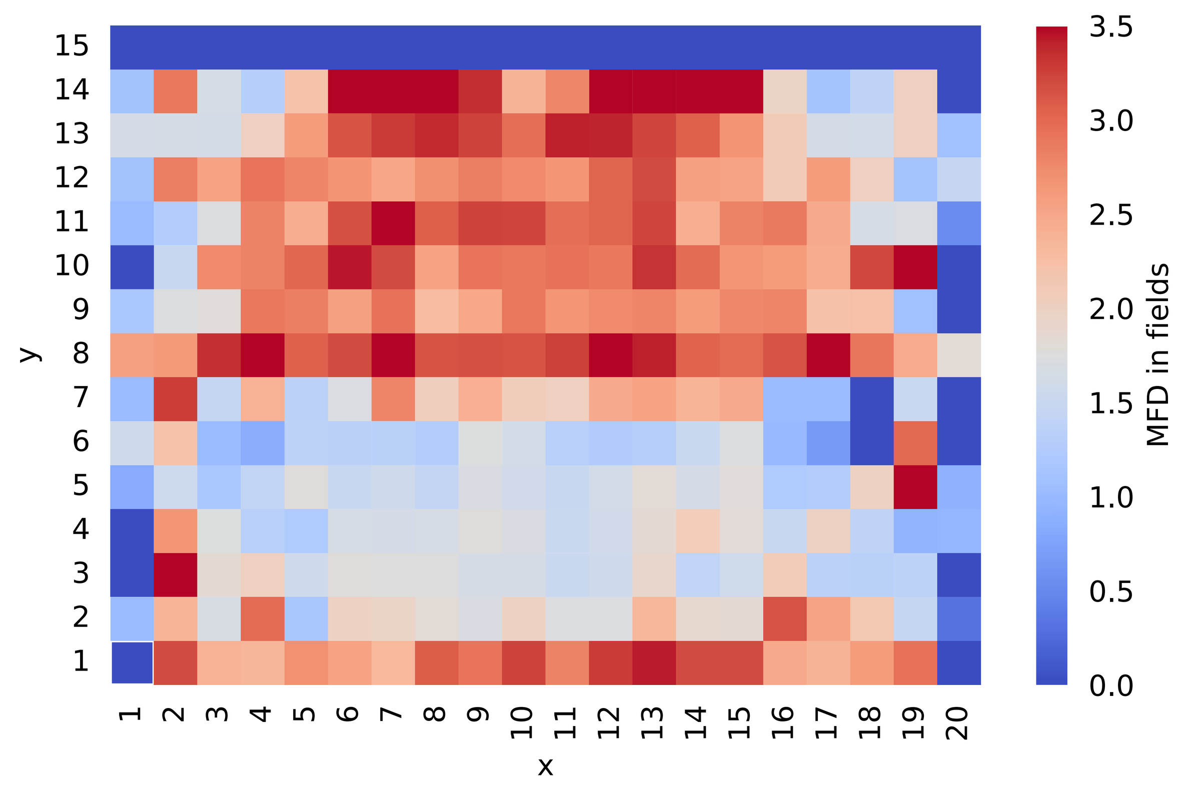


Experiment environment. Saccades are indicated as white lines and fixations as circles of a size proportional to their duration.

- Subjects were presented with an environment inspired by the video game *Frogger*. They needed to avoid cars and water in order to get to a target.
- The environment contains different obstacle avoidance tasks in a path finding setting.
- For measuring the planning horizon, we treated eye movements as externalization of cognitive planning processes (Zhu et al., 2022).
- Introduced Mean Fixation Distance (MFD) as a measure of fixation distance for a set of fixations $\mathbf{F}$ with fixation position (x_i, y_i) and duration δ_i while the player is at position $(x_{\text{player}}, y_{\text{player}})$:

$$\text{MFD}(x_{\text{player}}, y_{\text{player}}, \mathbf{F}) = \frac{1}{\sum \delta_i} \sum_{(x_i, y_i, \delta_i) \in \mathbf{F}} \left(|x_{\text{player}} - x_i| + |y_{\text{player}} - y_i|\right) \cdot \delta_i$$

I - Humans Adapt Their Planning Horizon

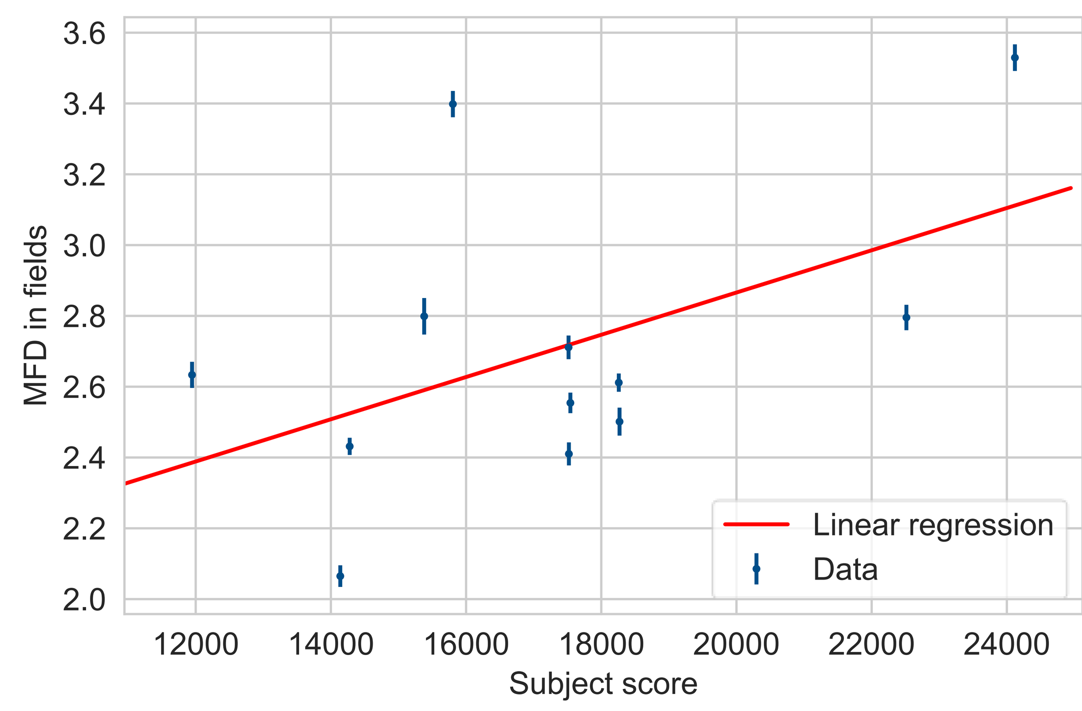


Average fixation distance from the player avatar weighted by fixation duration per position in the environment grid.

- Subjects adapted to bigger planning horizons in the river than in the street section ($t(60382) = 36.13, p < 10^{-283}$).
- Spatial distribution of fixations is more omnidirectional in the river, allowing for more complex trajectories.
- Smaller planning horizon in street section could also stem from higher time pressure caused by the cars.

Subjects employed task-dependent planning horizon adaptation. The planning horizon is increased in the river section and extends into more directions spatially.

II - More Planning Increases Performance



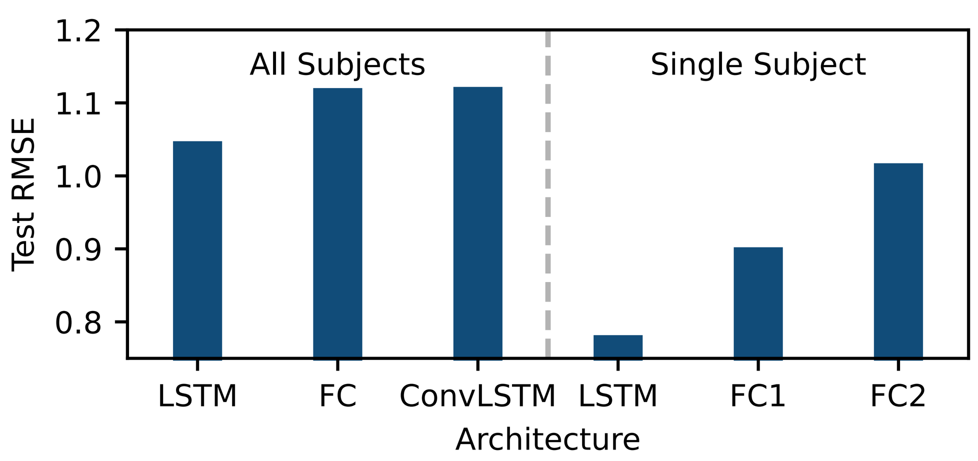
Mean Fixation Distance (MFD) over the subject's scores with linear regression. Error bars show the standard error of the mean.

- Subjects leveraging bigger planning horizons scored higher, showing a positive linear correlation ($R^2 = 0.2522, p = 0.0481$).
- The observed results are in line with the results by Ma et al. (2021).

We observed a positive linear correlation between the size of the planning horizon and the subjects' performances. Subjects that predict their actions' consequences more extensively perform better.

III - Prediction of the Planning Horizon

- We tested fully-connected, recurrent and convolutional neural networks to exploit spatiotemporal data properties.
- Recurrent layers achieved best results on all subjects and a single subject.

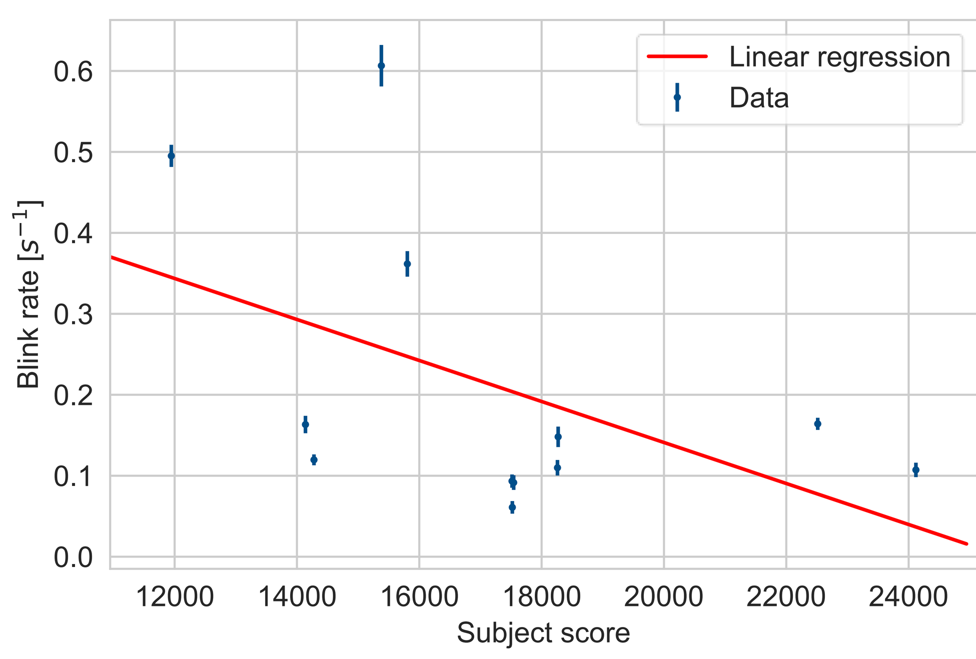


Neural network accuracies. FC = Fully-Connected, LSTM=Recurrent, Conv=Convolutional architecture

Our best **neural networks predict the planning horizon** given the environment state with **1.05 fields accuracy over all subjects.** This increases to **0.8 fields accuracy when only trained on one subject.**

IV - Physiological Findings

- Physiological indicators of cognitive engagement are increased pupil dilation and reduced blink rate (Siegle et al., 2008).
- Negative correlation of score with blink rate and thus positive correlation with cognitive load
- No correlation with pupil dilation ($R^2 = 0.0042$, $p = 0.8407$).



Blink rate over subject score, suggesting negative correlation ($R^2 = 0.2383, p = 0.0537$). Error bars show the standard error of the mean.

We could partially observe a positive correlation between cognitive load and planning horizon size, suggesting that better-performing subjects can employ higher planning horizons with more ease.