Decoding the production of durations in size-varying virtual environments

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INTRODUCTION

Environmental constraints can affect subjective duration.

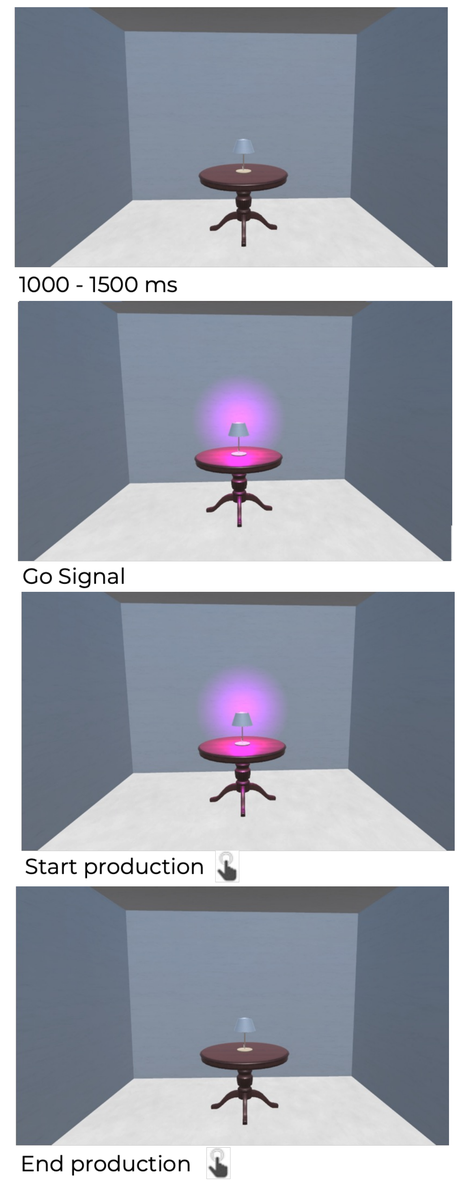
Subjects observing differently sized environments undergo shifts in their experience of time, namely an **overestimation of durations in larger environments compared to smaller ones** [1,2,3].

A proposed explanation for these findings, derived from the action constraint theory [4,5,6], suggests that **larger environments involve longer potential movements** (and consequently, longer travel times). However, this hypothesis has never been tested, and the mechanisms underlying this effect remain speculative.

To test this proposition, **we combined virtual reality** (to manipulate spatial constraints) and **electroencephalography** (EEG), to understand when and how duration is encoded in the brain and to dissect the neural dynamics of the effect of environmental constraints.

METHODS

DURATION PRODUCTION TASK



Participants were asked to produce durations (1.45s or 2.9s, prompted by a cue: the 'go' signal) within virtual environments that varied in **size** (which impacted action constraints) and ceiling **height** (which did not impact action constraints), while their brain activity was recorded using EEG. To capture the spatio-temporal dynamics of planning and production, and investigate the influence of environmental constraints, we trained and tested a logistic regression classifier at each time step within a temporal window around the 'go' signal.

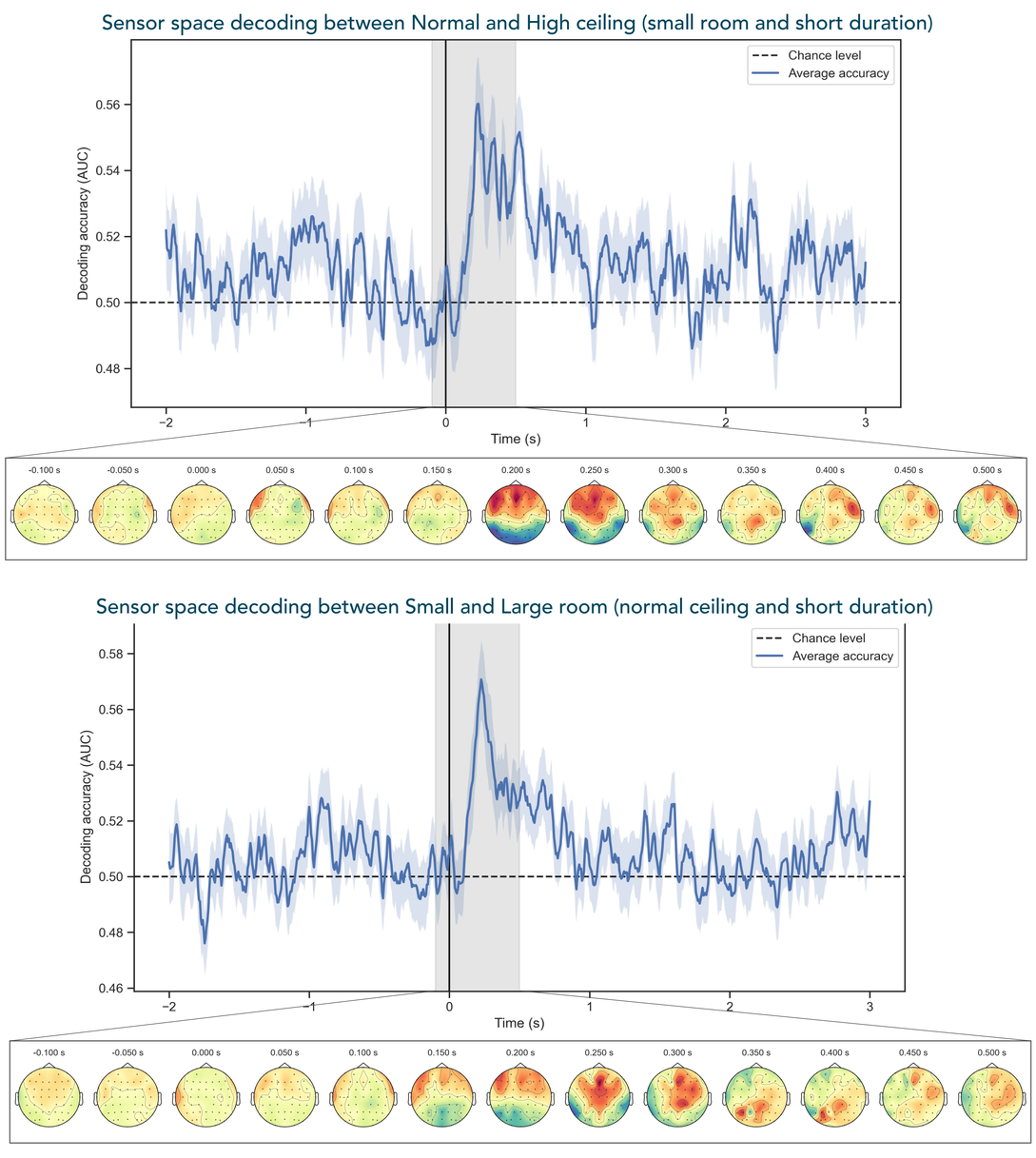
OBJECTIVES

Can we replicate the effect of environment size on duration production in virtual environments?
Testing (more directly) the hypothesis that individuals overestimate durations in larger environments because they involve greater travel times.

When and how is duration encoded in the brain?
Using multivariate pattern analyses (MVPA) to decode the size/height of the room from the EEG signals.

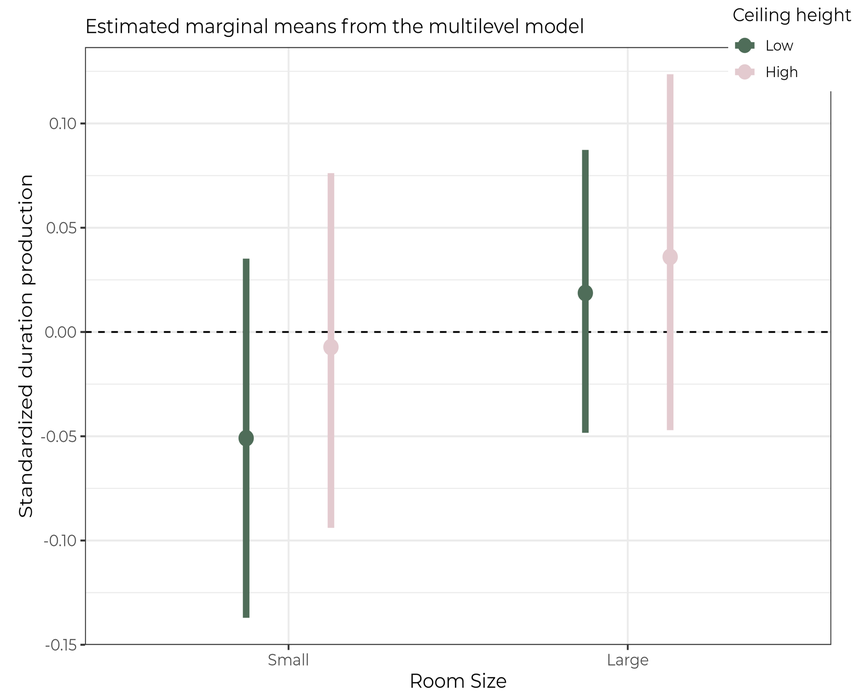
DECODING (MVPA)

Decoding accuracy for ceiling height (top) and room size (bottom), in fixed conditions, calculated based on all 61 EEG channels over time, with decoding trained and tested at each time point relative to the 'go' signal. Decoding performance was assessed using ROC AUC as a metric and 4-fold cross-validation. Topographic maps illustrate the spatial distribution of the electrodes' contributions to the decoding accuracy, that is, the relative weight of each electrode across the scalp at different time intervals (from -0.1s to 0.5s). Color gradient reflects the degree of contribution, with warmer colors indicating stronger contributions to the decoding process.



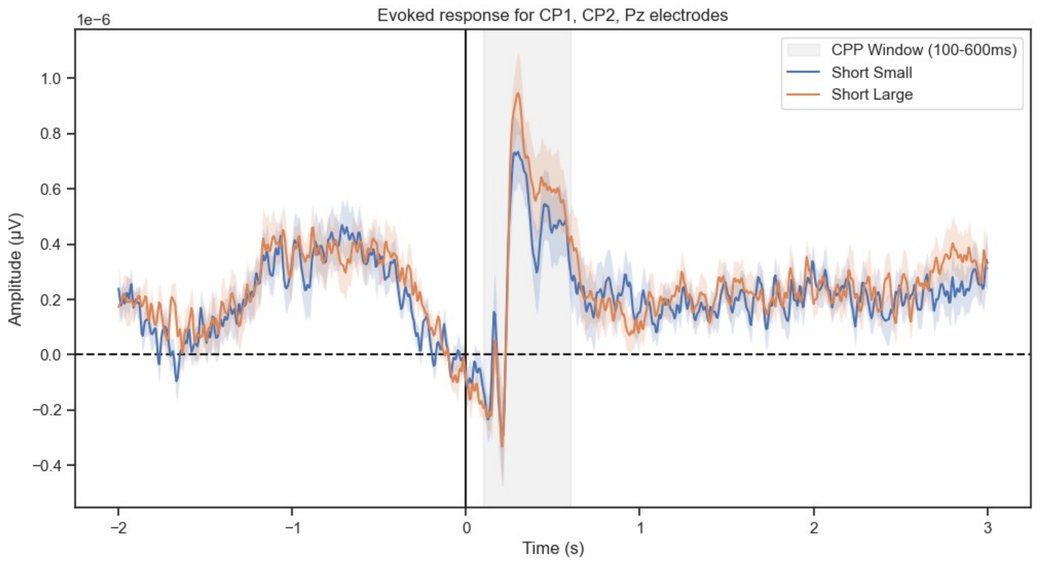
BEHAVIOR

Multilevel linear regression models on duration production revealed that participants overestimated durations in larger environment compared to smaller ones, and in environments with higher ceilings compared to lower ones, with the ceileing effect being more pronounced in small environments.



EVENT-RELATED POTENTIALS (ERPs)

Event-related potentials (ERPs) differences for centro-parietal electrodes between small and large environments conditions, for short duration production (descriptive results). ERPs exhibit greater amplitude in large environment condition compared to smaller environment. A similar pattern was observed for room height.



CONCLUSIONS

Our results replicate the effect of envionment size on duration production [1,2,3]. Larger environment, as well as environments with higher ceilings, lead to an overestimation of durations. This effects were associated with higher centro-parietal positivity (CPP) amplitude, which is thought to reflect evidence accumulation processes[7]. Decoding analyses further revealed that both the height and the size of the environment can be decoded as early as 150-200ms after the cue indicating which duration to produce, suggesting that the effect impact the planification and production stages of the duration production process. While these results are consistent with the magnitude theory, which suggests that larger stimuli are overestimated[8], they are inconsistent with the environmental constraints perspective[4,5,6]. However, further studies are needed to explore these relationships in greater depth.

PERSPECTIVES. Duration production is thought to rely on multiple mechanisms, including evidence accumulation from sensorimotor brain regions (as indexed by the CPP)[9] and population-level neural trajectories[10]. If subjective duration is underpinned by both evidence accumulation and population level trajectories, then we should observe hallmarks of such activity. Ongoing analyses are currently investigating how the size of virtual environment can impact population-level activity (e.g., speed at which neural activity unfolds).

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