A Model of the Reference Frame of the Ventriloquism Aftereffect Considering Auditory Saccade Adaptation

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Abstract

Background: The ventriloquism aftereffect (VAE), observed as a shift in the perceived locations of sounds after audio-visual stimulation, requires reference frame (RF) alignment since hearing and vision encode space in different frames (head-centered, HC vs. eye-centered, EC). Previous experimental studies observed inconsistent results: a mixture of head-centered and eye-centered frames for the VAE induced in the central region vs. a predominantly head-centered frame for the VAE induced in the periphery. A previous model proposed to describe these data required different parameter fits to predict the central vs. peripheral aftereffect data. Here, a new version of the model is introduced to provide a unified prediction of all data sets considering that saccade responses, used to measure VAE, are also adapted.

Methods: VAE was measured using eye-tracked saccades to the perceived locations of sound (i.e., "auditory saccades") presented via loudspeakers. The model has two components: an auditory space representation component and a saccade-representation component. The former is adapted by ventriloquism signals in the head-centered reference frame. The later one characterizes adaptation in auditory saccade responses in eye-centered frame.

Results: The updated version of the model provides a unified prediction of all the data, even if only head-centered RF is considered in the auditory space representation, while proposing that there are a priori biases in the auditory saccades and that the auditory saccades also undergo ventriloquism adaptation.

Conclusion: The results suggest that purely head-centered RF is used for adaptation of auditory spatial representation in the ventriloquism aftereffect, and that the apparently mixed eye-and-head centered RF observed experimentally is most probably due to adaptation in auditory saccades that are eye-centered.

1 Introduction

The neural representations of visual and auditory space use different reference frames. Vision is referenced relative to the direction of eye-gaze (eye-centered), while hearing is referenced relative to the head orientation (head-centered). The current study examines how are these two representations aligned at higher level of spatial processing to allow visually guided adaptation of auditory spatial perception.

Existing models of the audio-visual (AV) RF alignment only consider integration when in the auditory and visual stimuli are presented simultaneously (i.e., the ventriloquism effect; VE) (Razavi et al., 2007; Pouget et al., 2002). We proposed a model of the visually guided adaptation of auditory spatial representation in VAE (Lokša & Kopčo, 2023) to describe behavioral data of Kopčo et al. (2009, 2019). Here extensions of the model are introduced: to characterize the mixed RF of VAE observed in Kopčo et al. (2009); to provide a unified account of conflicting results of Kopčo et al. (2009, 2019)

In addition to auditory space representation in HC RF, the current model and the dHEC model (Lokša and Kopčo, 2023) model consider 3 candidate mechanisms underlying these effects: eye-centered signals influencing auditory space representation, fixation-position-dependent attenuation in auditory space adaptation, adaptation in the saccades used for responding in the experiments.

Finally, Kopco et al. (2019) observed a new adaptive phenomenon induced by aligned audiovisual stimuli presented in the periphery that is also considered.

2 Model

The SA-HC model (Fig. 1) focuses on explaining both central and peripheral data using one mechanism. It assumes that auditory space is adapted by visual signals only in HC RF (like in the basic version of dHEC model), while the saccades, used for responding, are also adapted – in EC RF. Specifically, it assumes that (1) during training, the saccades are adapted to be hypometric or hypermetric, depending on FP, A component, and V component locations, (2) during testing, the adapted saccades either enhance or reduce the bias due to auditory space representation, depending on the A target location vs FP.

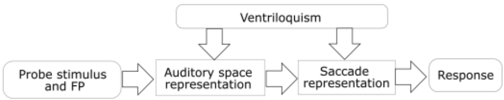

Fig. 1: Diagram of the SA-HC model.

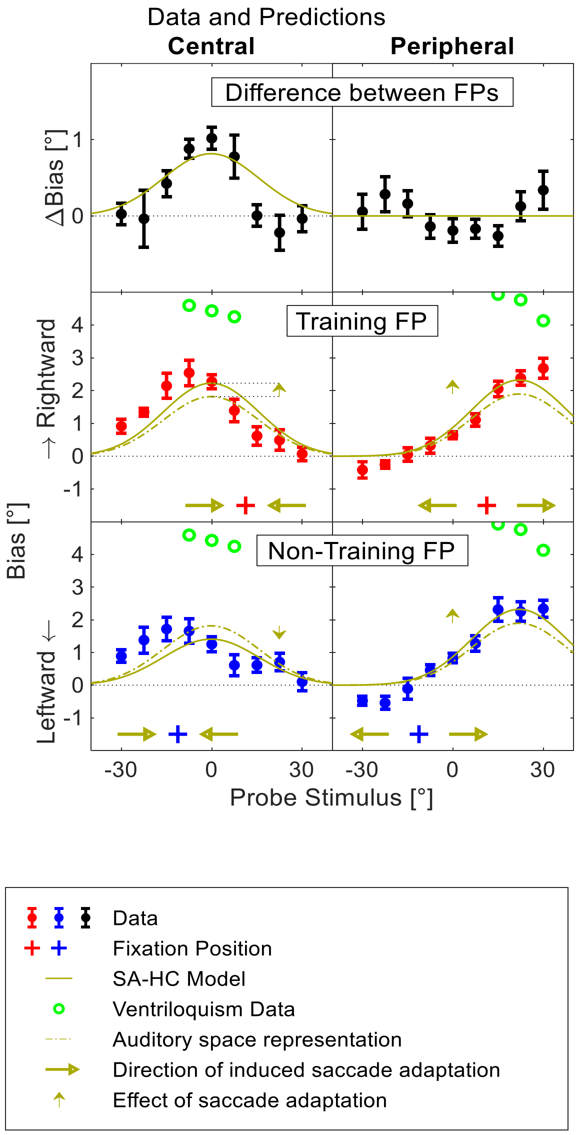

Fig. 2: SA-HC model evaluation on central & peripheral data. Model predictions (solid lines) and experimental data (symbols). Arrows and dash-dotted lines illustrate model operation: Ventriloquism (green circles) determines auditory space adaptation (dashed lines) which is additionally modified by the ventriloquism-adapted hypo/hypermetric saccades (horizontal arrows).

3 Results

SA-HC model fits the central and peripheral data simultaneously (Fig. 2). Since the model only uses HC RF to induce VAE, this result supports the conclusion that reference frame of VAE is purely head-centered, and the previously observed mixed RF was due to saccade adaptation.

4 Conclusion

We introduced an extended model to describe the reference frame of ventriloquism aftereffect data of Kopčo et al. (2009, 2019).

A previous model by Lokša & Kopčo (2023) was able to explain central adaptation and peripheral adaptation results of Kopčo et al. (2009, 2019) when fitted to the data separately, i.e., with different values of model parameters. Thus, the inconsistency between the behavioral results were not reconciled.

The current model, incorporating auditory saccade adaptation, can explain the central and the peripheral data simultaneously which confirms that RF of VAE is most likely not mixed.

Next steps are to (1) explain ventriloquism-like adaptation induced by AV-aligned stimuli in Kopčo et al. (2019), and to (2) experimentally test the model predictions about saccade-related EC bias and saccade representation adaptation, as well as the prediction that the reference frame of the VAE is purely head-centered.

Acknowledgements

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