Bayesian integration of prior knowledge into perception in a virtual reality tennis return situation

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Introduction and Method

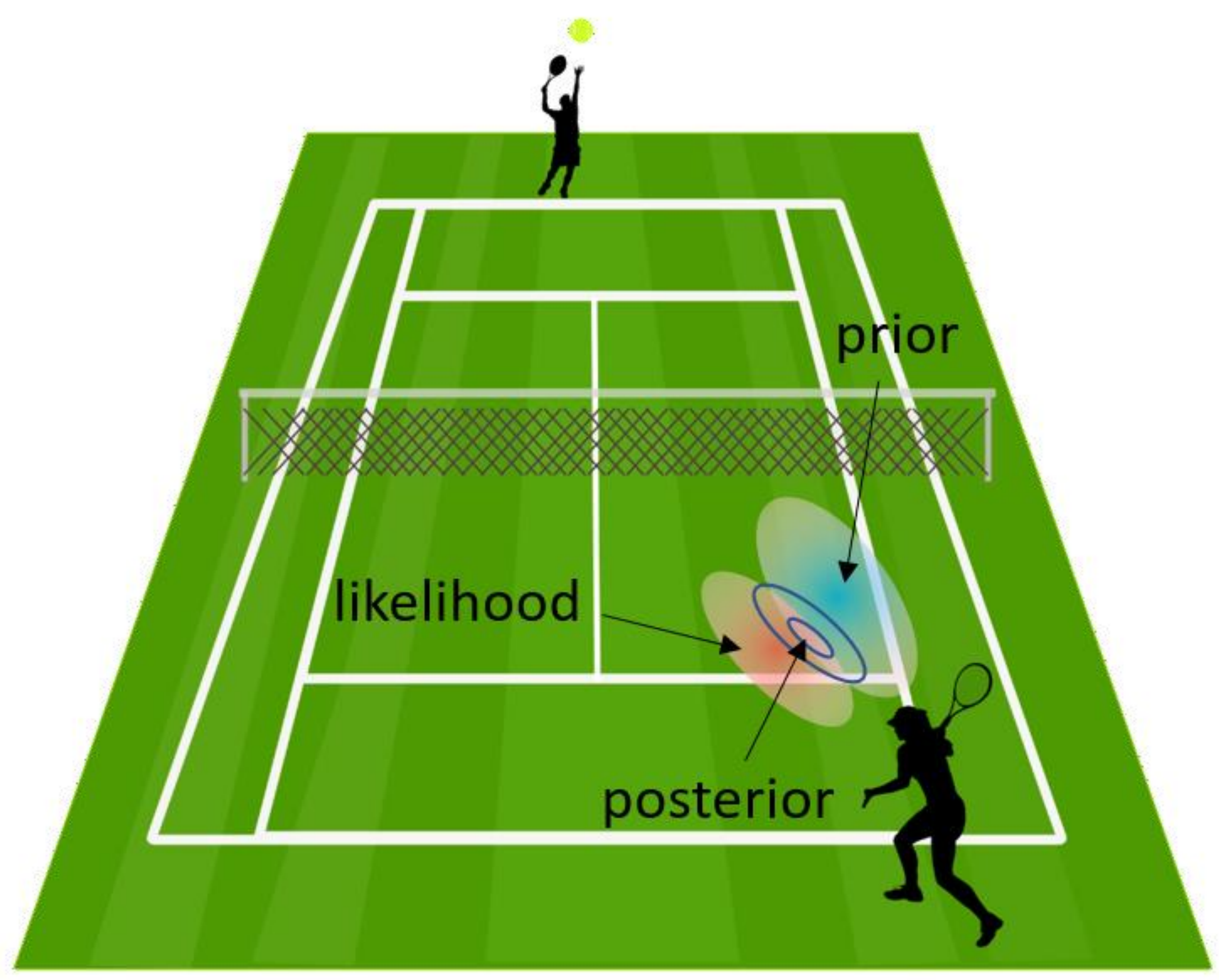
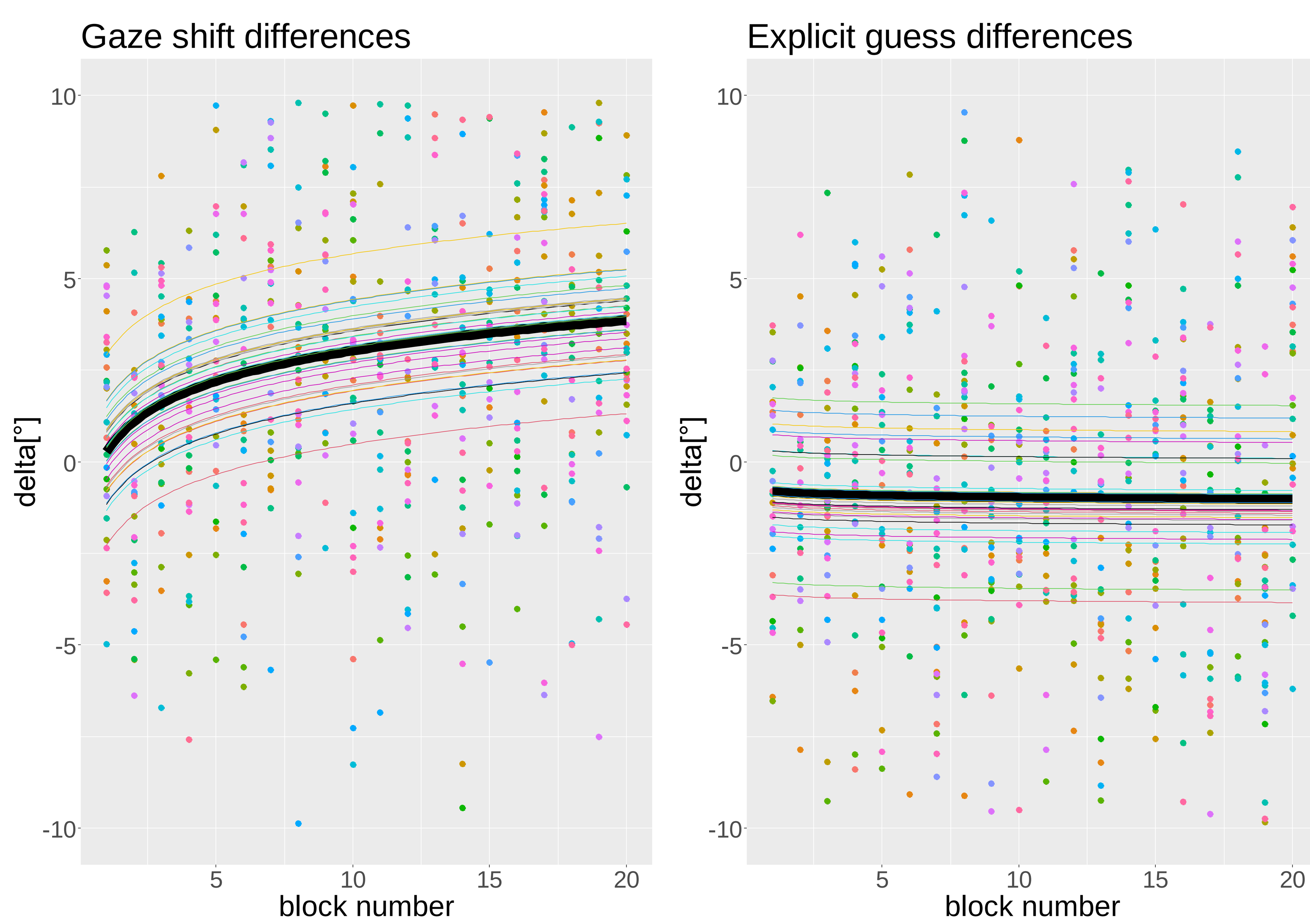


Figure adapted from Wolpert and Ghahramani (2005, p. 3)

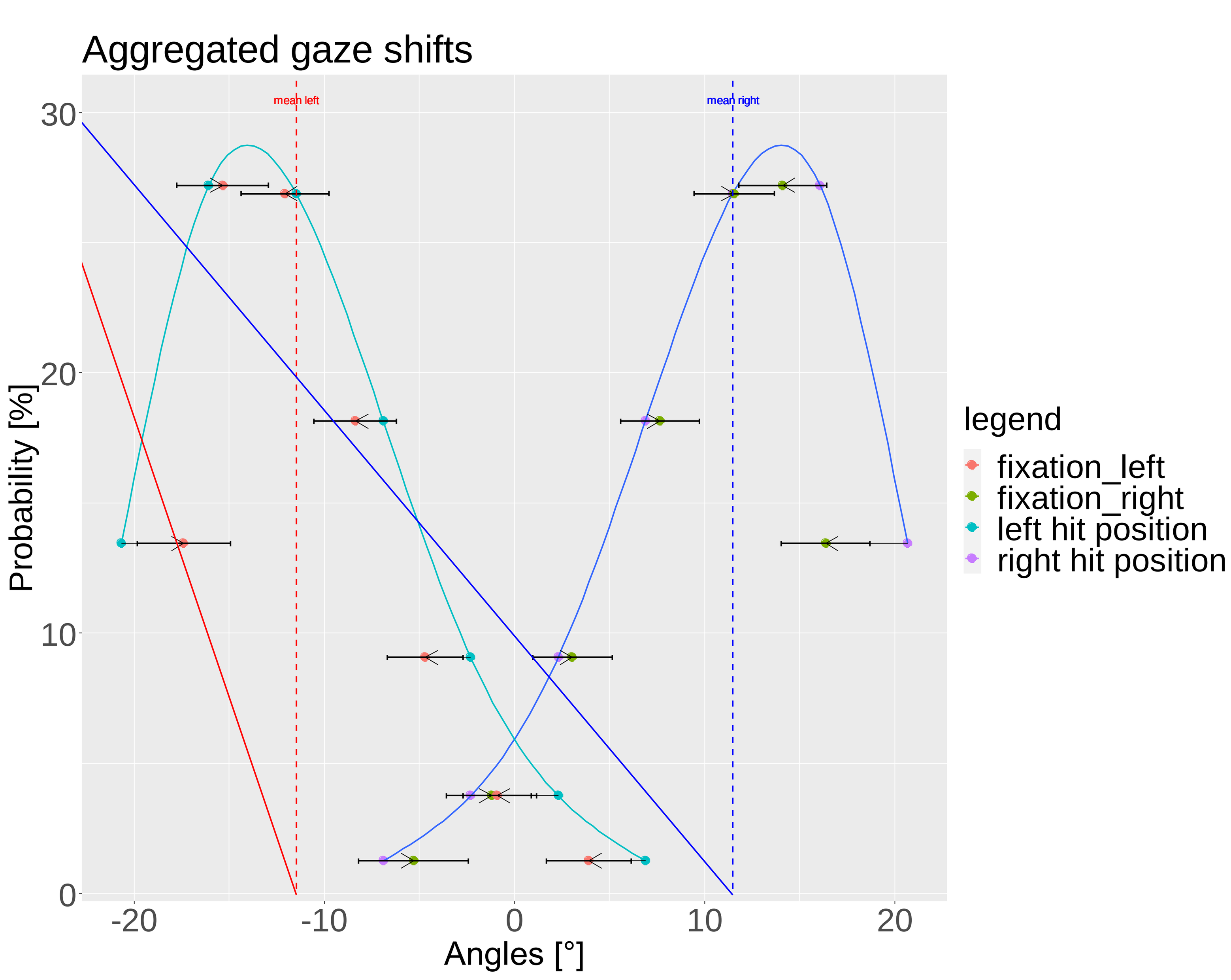
Due to noisy signals in the sensorimotor system, our perception is constantly subject to uncertainty. This is particularly evident in dynamic situations, such as returning a tennis serve. In fundamental research taking on a Bayesian approach to decision-making, it is argued that the weighted integration of prior knowledge and current sensory information according to their reliability reduces uncertainty (Körding & Wolpert, 2006). Therefore, we investigated this mechanism in a virtual tennis return situation. To this end, 32 young adults learned distributions of serve's impact locations in a within-subject design on two days, thereby exactly mirroring the distribution of the first day (either closer to the left or the right of the service field) on the second day. The kinematic information in the serving motion remained identical over all trials due to the very same avatar simulation. The perceptual demands in tracking the ball was high because of a speed similar to a serve in professional tennis. However, ball return was simplified due to a virtually oversized racket. Eye-tracking data was analyzed with an idt-algorithm to calculate the fixation after the predictive saccade before the ball's bounce as a measurement for the expected ball location. Furthermore, participants had to explicitly guess the ball location after the return.

Results

As predicted by a Bayesian framework, a shift of the fixation in relation to the actual ball location towards the current distribution's central tendency was detected that, on top of this, increased over the acquisition period. When analyzing the intraindividual differences of these shifts from both conditions with mirrored distributions in a hierarchical logarithmic regression, a middle significant fixed effect for increasing differences over time was found ($N_{subjects}$ = 32, $N_{measurements}$ = 604, b = 1.20 [0.78 - 1.62], $p < .001$, $R^2_{marginal}$ = 0.047). In contrast, no shift differences in the explicit guesses of the ball's location after the return were revealed ($N_{subjects}$ = 32, $N_{measurements}$ = 631, b = -0.06 [-0.54 - 0.42], p = .807, $R^2_{marginal} < .001$). This result perfectly fits a Bayesian explanatory framework because the reliability of the prior knowledge on the most probable impact location is constantly growing over acquisition.



However, prior knowledge only affects behavior early in the ball's flight trajectory, where the kinematic information on the actual ball flight is still unreliable whilst after the actual impact, prior expectations are overwritten by considerably more reliable kinematic information.



Discussion

Our results not only empirically confirm the claim made by (Körding & Wolpert, 2006) for illustrative purposes that prior knowledge is integrated in tennis returns according to Bayesian principles; moreover, our findings show that this integration must be understood as a dynamic process in which eye movements are affected by prior knowledge in the early phase of the return movement, whereas prior knowledge becomes increasingly useless when more reliable sensory information becomes available.

References

Körding, K. P. & Wolpert, D. M. (2006). Bayesian decision theory in sensorimotor control. *Trends in Cognitive Sciences*, *10*(7), 319–326.

Wolpert, D.M., & Ghahramani, Z. (in press). Bayes rule in perception, action and cognition. In R.L. Gregory (Ed.), *Oxford companion to consciousness*. New York: Oxford University Press.

Experiment task