

Adaptation to environmental statistics in an action control task

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Abstract

Although humans are prone to perceptual illusions and decision biases, they perform very well in every-day tasks with varying difficulties and complexities. It has been shown that humans learn to adopt to the statistical regularities of the environment. However, whether humans have correct physical intuitions about these ordinary processes and reflect related dynamics in an appropriate internal model has been disputed. Recent studies have shown that human behavior in diverse physical judgment tasks can indeed be explained with probabilistic models based on realistic, Newtonian functions while considering sensory uncertainties. Here, we examined whether humans use physical models of their environment in a control task, which involves non-linearities in the involved dynamics. Participants were asked to shoot a puck into a target area affected by realistic friction. By deploying Bayesian models we can show that humans are capable to adopt to these physical relationships and have appropriate internal beliefs about relevant quantities.

Keywords: Intuitive physics, Bayesian modelling, decision making

Experimental Design and Data

We conducted an experiment involving a control task to examine people's understanding of physical events and their dynamics. To this end, we chose the non-linear dynamics of a puck gliding over slippery ground affected by realistic friction such as in curling.

The general objective was to test whether humans are able to grasp the non-linear dynamics of this task and perform accordingly and whether their behavior can be described with a Bayesian model based on Newtonian physics while considering perceptual and internal model uncertainties.

Results

On average, participants hit the target closely with deviations due to perceptual uncertainty and motor variability. Furthermore, we examined their behavior within this control task using a Bayesian model including noisy perception of distance and time while illuminating internal beliefs about relevant quantities. Comparing inferred latent beliefs with values used in the experiment reveal the ability of humans to adjust to statistics in their surroundings by utilizing appropriate models.

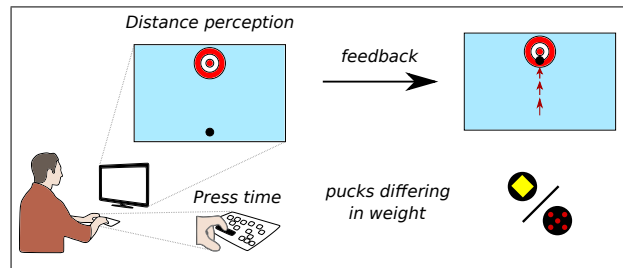


Figure 1: **Single trial illustration.** Target area and puck are presented from bird's-eye perspective. Releasing the pressed button accelerates the puck by instantaneously applying a force (momentum change) proportionally to the press time. Participants were able to adjust by seeing the puck moving, slowing down and stopping.

Descriptive Results

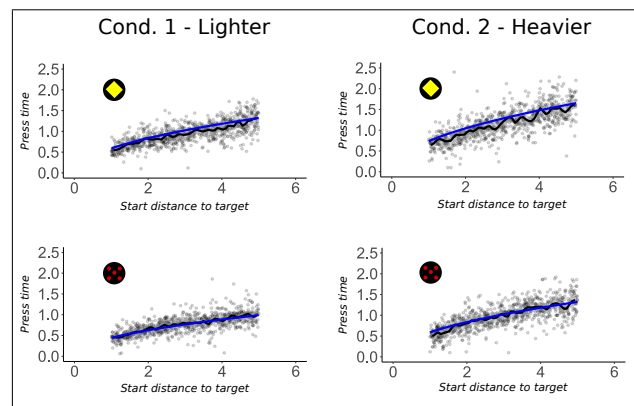


Figure 2: **Press times by distance to target for both conditions.** Press times over distances for all participants by condition and puck with data points in black and correct and perfectly Newtonian relationship in blue. Participants performed close to optimal with regard to perceptual and motor uncertainties. Optimal press time durations given the distance and the environmental properties (e.g. friction coefficient, puck weight) are shown as a blue line.

Participants were capable to hit the target (almost) exactly in average (five dots puck - one-sample Wilcoxon Signed

Rank test, $p = 0.1588$, $\mu = 0$; diamond puck - one-sample Wilcoxon Signed Rank test, $p = 0.7081$, $\mu = -0.3464$, and see fig.2 & fig.3). They were able to take the non-linear nature of gliding with realistic friction into account.

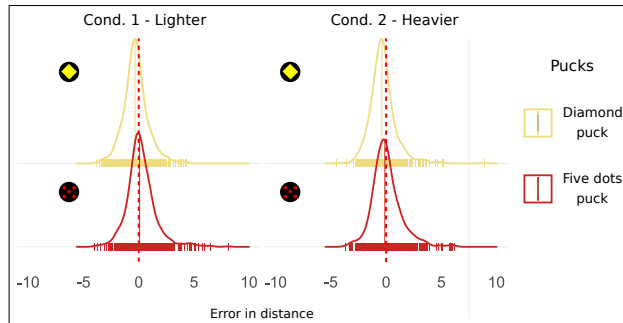


Figure 3: **Average error distribution.** Pooled final discrepancy between target and puck for all participants. Pucks being shot too short are shown with negative values, pucks with a positive deviation were shot too far.

Model Results

Various studies have shown before that allegedly sub-optimal human behavior in certain tasks can be very well described with models which refer to real Newtonian physics but, at the same time, take uncertainties into account (Sanborn, Mansinghka, & Griffiths, 2013; Hamrick, Battaglia, Griffiths, & Tenenbaum, 2016). Here, we elucidate the behavior and performance within this control task using a Bayesian model including noisy perception and motor execution while illuminating an internal belief about mass as relevant quantity for the dynamics of the pucks.

Starting from an unbiased but noisy perception of distances (to target), participants have to decide on suitable press times to move it as closely as possible. This decision is based on their assumption about the functional interaction of the puck with the environment or more precisely the relationship of distance and press time given the magnitude of the initial force, mass of the puck and friction.

The graphical model for this noisy Newtonian model is shown in fig.4. In order to include Weber-Fechner phenomena - uncertainty in perceiving a stimulus increases with magnitude of the stimulus itself - distance and time perception are implemented as log-Gaussian distributions (as done in similar models (Battaglia, Kersten, & Schrater, 2011)).

Discussion

It has already been shown that humans adapt to their environmental statistics (Schwartz, Sejnowski, & Dayan, 2009), reflect prior knowledge in their behavior (Körding & Wolpert, 2004) and are able to judge certain physical scenes very well (Todd & Warren Jr, 1982; Gilden & Proffitt, 1989), while it has been argued whether they reflect realistic Newtonian

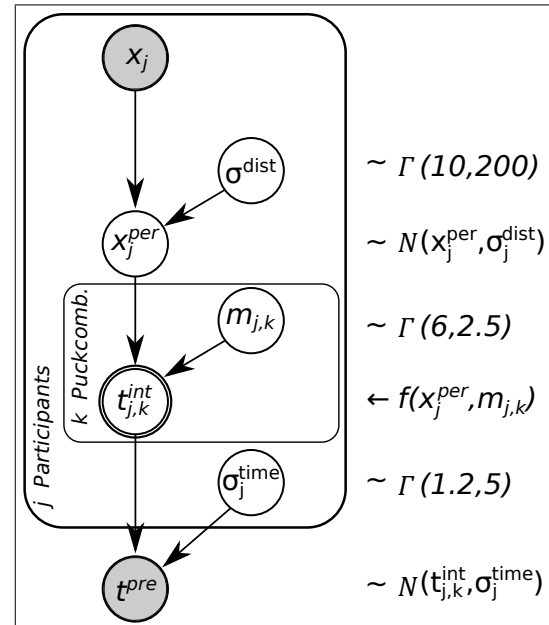


Figure 4: **Graphical noisy Newtonian model (sqrt relationship).** Graphical model for the logarithm of the measured press times t^{pre} given the logarithm of the presented initial distance to target x_j in the SQRT model, assuming that participants do have the correct physical model for gliding under friction. Observed nodes, press time t^{pre} and initial distance x_j , are shown in grey. Unobserved ones in white. Both, the observation of the initial distance x_j just as the action of pressing the key button underlie uncertainties σ^{dist} and σ_j^{time} , respectively. The logarithm is used to scale the standard deviation linearly with the magnitude of the corresponding stimulus. Thus Weber-Fechner phenomena in the perception of distance and time are taken into account (see (Battaglia et al., 2011) for similar usage).

physics in their internal model (Sanborn et al., 2013; Kubricht, Holyoak, & Lu, 2017).

Here, we conducted an experiment involving a control task instead of a judgement task and modeled it within the Bayesian framework as realistic Newtonian noisy model. Participants were able to accomplish this task and by deploying Bayesian models we gathered further evidence that people indeed seem to utilize more than simple heuristics.

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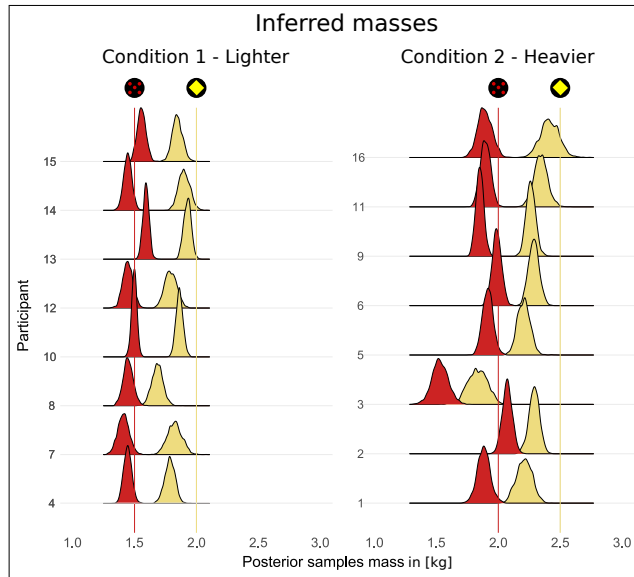


Figure 5: **Inferred mass beliefs.** Inferred mass beliefs for both pucks for each participant by condition (with pucks differing in their weight). Actual masses used in the experiment are shown as colored lines. Participants' beliefs match these actual values quantitatively extremely well and reflect participants' uncertainties and slight biases.

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