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Dear Editor,

We are submitting the Registered Report, **"How movement variability constrains locomotor use-dependent learning"**, to be considered for publication in *eNeuro*.

Repetition is an essential component of motor skill acquisition. Yet, even after skills are well-learned, repetition continues to impact movement patterns—by reducing movement preparation time, increasing movement speeds, and, most relevant to the current Registered Report, biasing future movements to become similar to repeated ones (Diedrichsen et al., 2010; Hammerbeck et al., 2014; Mawase et al., 2018). This "use-dependent" learning is distinct from well-studied forms of error-based learning, such as sensorimotor adaptation, in that it occurs independent of an error signal and is purely repetition-based. Thus, use-dependent learning is linked to Hebbian learning and considered a basic form of motor memory (Classen et al., 1998; Verstynen and Sabes, 2011).

To date, use-dependent learning has been almost exclusively studied in upper-extremity movements, and rarely looked at in lower-extremity activities. This is surprising given that walking is, by definition, a repetitive, cyclical movement that is repeated until a destination is reached, and thus provides an excellent opportunity to study a repetition-based learning mechanism. Our recently published manuscript (Wood et al., 2020) represents an early attempt to tackle use-dependent learning in walking from a behavioral perspective. In the study, participants increased their stepping asymmetry in response to visual targets on a computer screen, causing them to walk with a limp. Of note, the visual feedback provided to participants was veridical, and therefore participants learned, and practiced, this asymmetry in the absence of sensory prediction error (i.e., difference between expected and actual sensory feedback). After several minutes of practice, when the participants were asked to return to normal walking without any visual feedback, we observed a use-dependent bias in the form of a limp in the practiced direction that persisted for more than 5 minutes.

In the proposed Registered Report, we aim to extend prior work on use-dependent learning by examining constraints on this process during walking and providing a computational framework for understanding this basic form of learning. We will compare two distinct computational accounts of how use-dependent learning may arise and will test their unique predictions regarding the impact of movement consistency on use-dependent learning. In the Adaptive Bayesian model, adopted from a study of reaching (Verstynen and Sabes, 2011), use-dependent learning is framed as a process of combining quickly adapting prior probabilities of target (step) locations with current sensory estimates of where to step. Thus, the magnitude of the use-dependent bias is directly related to the consistency of the environment, or target locations. Our second model, the Strategy plus Use-Dependent model, involves two processes acting in parallel: a strategic learning process that is active when the goal is to match step lengths to visual targets, and in parallel, a slowly updating use-dependent process that biases movements in the direction of immediately preceding movements (Diedrichsen et al., 2010). Due to the slow learning and slow forgetting nature of use-dependent learning in this model, it is robust to changes in movement consistency. Critically, while both computational accounts provide putative explanations for use-dependent biases, they differ markedly in their theoretical underpinnings and, to our knowledge, have not been directly

compared with each other. Thus, we have designed a set of walking experiments that systematically vary environmental consistency and assess the state of use-dependent biases during no-feedback trials in order to discriminate between these two competing theories on the underlying constraints of use-dependent learning.

The results of this Registered Report should have broad implications for the study of locomotor learning and, we hope, will motivate re-investigation of key findings in the literature. For instance, repetition is intrinsic to locomotor studies of sensorimotor adaptation, likely the most well-studied form of locomotor learning, yet use-dependent learning has largely remained ignored until now, despite its likely contributions to behavioral changes in such paradigms (e.g., split-belt treadmill walking). Similarly, repetition is a primary component of rehabilitation practices, but to what extent repetition during walking contributes to altered gait patterns, whether adaptive or maladaptive, remains unknown. Therefore, we expect this study to be of interest to neuroscientists engaged in motor learning, locomotion, and clinical research. In addition, given the fundamental nature of the research question and its anticipated appeal to basic and clinical researchers, we expect others will be interested in replicating the findings from our Registered Report. Thus, our steps towards transparency in all aspects of this research project should facilitate others' efforts in this direction.

We currently have approval from the University of Delaware Institutional Review Board to perform this work. We furthermore have the facilities and funding to complete the work. However, all labs have been shut down due to the COVID-19 pandemic. Data collections are ready to be initiated as soon as human research resumes at the university. Given uncertainty around when labs will be reopened, we offer a proposed resubmission window from January 15th, 2021 to June 15th, 2021. All authors agree to share the raw data, any digital study materials, including experimental and analysis code, and laboratory log for all published results. We will also register the protocol on the Open Science Framework regardless of our acceptance here. Lastly, if we later withdraw this paper, we agree to eNeuro publishing a short summary of the pre-registered study under the Withdrawn Registration section.

We look forward to your assessment.

Sincerely,

Jonathan Wood, Susanne Morton and Hyosub Kim