The Average Progression of Learning Can Obscure Multiple Learning Trends: A Computational Cautionary Tale

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Neurorehabilitation is often modeled as experience-driven skill acquisition (i.e., a form of learning). While some researchers argue that sensorimotor learning is adaptable and influenced by prior experience (Zeidan, 2024; Shadmehr and Holcomb, 1997; Kitazawa et al., 1997), they often overlook the inherent variability in individual learning trajectories.

This study explores the emergence of multiple learning trends by moving away from averaging the progression of learning across individual trials. An iterative unsupervised clustering approach was guided by Silhouette score analysis that quantifies the degree of separation between clusters and ranges from -1 to 1, where a high positive score indicates that the data point is well-matched to its own cluster and poorly matched to neighboring clusters Rousseeuw (1987). This enables identifying distinct learning trends within and across curricula, revealing differences in the progression of learning and final fitness.

The learning process is structured around Proximal Policy Optimization (PPO), a reinforcement learning algorithm as presented in Ojaghi, Mir et al. (2024). We trained a simulated robotic hand to manipulate a ball across five curricula when the task changes midpoint in learning: (1) lift followed by lift and rotation,(2) rotation followed by lift and rotation, (3) a baseline (i.e., no curriculum) where lift and rotation were trained throughout the learning, (4) lift and rotation followed by rotation and, lastly (5) starting with lift and rotation before transitioning to only lift. This allows us to examine whether and how curricula shape learning progression. After performing 60 trials for each curriculum, we ran a two-level K-means approach to cluster the progressions of learning to have the average height of the final 10 seconds of each trial within 25% of the target height of 25 mm. By applying unsupervised clustering techniques, the research seeks to identify and categorize distinct learning trends, moving beyond traditional performance averaging.

Our findings indicate that multiple learning trends emerge from curriculum learning, challenging the notion of a single learning trend. The study identifies trends such as *'no learner,' 'steady learner,' 'saturate high'* and *'learn and drop,'* each describing different progression paths. The results demonstrate that the average progression of learning can obscure multiple learning trends, and highlights the need for a nuanced evaluation of 'rehabilitative' trends (Valero-Cuevas et al., 2016).

Justification Statement: The study's findings have implications for neurorehabilitation, particularly in the design of rehabilitation protocols that foster a desired learning trend for recovery (Valero-Cuevas et al., 2016). Understanding multiple learning trends can help optimize therapy regimens, ensuring that patients

receive training tailored to their individual needs. By elucidating these learning dynamics, our research offers valuable insights for neurorehabilitation, ultimately enhancing motor recovery and skill acquisition.

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