Osu! as a Natural Laboratory for Human Sensorimotor and Cognitive Limits: Neurocognitive Analysis and Methodological Framework

osu!science

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Abstract

The rhythm-action game *osu!* has nearly two decades of history and millions of players worldwide, making it a unique natural environment to study human sensorimotor and cognitive limits. Unlike most video games, *osu!* is largely deterministic: performance is determined by visual processing speed, target accuracy, rhythmic synchronization, and motor endurance. This paper presents a theoretical neurocognitive model of involved processes, analyzes limitations of the current ranking system (pp), and proposes a methodological framework for large-scale community-based studies. The work serves as a preprint and invitation for collaboration between the gaming community and scientists.

1 Introduction

Video games have become a rich source of behavioral data: millions of players, repeated tasks, and long-term training history. However, only some games allow studying pure cognitive-motor processes, as many genres involve strategy, teamwork, and randomness, complicating interpretation of behavioral metrics.

Osu! (released in 2007) is a rare digital environment where the primary measurable factor is *mechanical skill* — the precision and speed of performing rapid sensory stimuli. Events are recorded with millisecond precision, maps are reproducible, and intrinsic motivation (ranking, pp score) ensures long-term engagement. This makes *osu!* a natural laboratory to study:

- Limits of psychomotor speed;
- Eye-hand coordination;
- Rhythmic synchronization and prediction;
- Longitudinal learning curves and plateaus.

2 Rationale and Significance

2.1 Why osu! is unique

1. **Determinism:** Beatmaps are fully reproducible; no RNG.
2. **High temporal precision:** Timing measured in milliseconds.

3. **Mechanics purity:** Minimal strategic or random factors.

4. **Large and long-term database:** Players with years of experience.

5. **Intrinsic motivation:** Competition and social incentives make training natural.

2.2 Research questions accessible via osu!

- Which cognitive factors (age, musical training, device) predict skill progression?
- What are typical learning curves and clusters of trajectories?
- How does sensorimotor speed limit evolve with training years and age?
- Can we build a statistically grounded model to improve the pp system?

3 Neurocognitive basis of osu! performance

3.1 Visual-spatial processing

Functions: Object localization, motion tracking, trajectory prediction. **Brain regions:** Occipital cortex (V1–V5), posterior parietal cortex (PPC), MT/V5.

3.2 Motor planning and execution

Functions: Motor program formation, movement initiation, hand-finger coordination. **Brain regions:** Primary motor cortex (M1), supplementary motor area (SMA), premotor cortex, cerebellum, basal ganglia.

3.3 Auditory-motor synchronization

Functions: Beat detection, interval prediction, movement synchronization with rhythm. **Brain regions:** Auditory cortex, auditory-motor pathways, cerebellum.

3.4 Executive functions and working memory

Functions: Error monitoring, attention switching, short-term pattern retention. **Brain regions:** DLPFC, ACC.

3.5 Sensorimotor integration

Integration of visual and auditory stimuli with motor commands occurs via parieto-motor pathways and cerebellum.

4 Cognitive functions measurable in osu!

- Processing Speed: Mean reaction time, variance of hit timing.
- Visuospatial Accuracy: Average spatial offset from target.
- Rhythmic Stability: Standard deviation of temporal errors.
- Motor Rate: Tapping frequency (Hz).
- Endurance: Accuracy change during long maps.
- Predictive Ability: Cursor movement predictability.

5 PP system review: problems and improvement directions

5.1 Current system limitations

- Weights and heuristics are empirically tuned;
- pp depends heavily on map pool and popularity;

- Combines different skills (aim, reading, speed) without separating contributions;
- Lacks validation against independent cognitive measures.

5.2 Directions for scientific validation

1. Identify core metrics;
2. Factor analysis to discover latent components;
3. Regression model predicting expert skill and stability;
4. Cross-validation and external test sets.

6 Large-scale community study design

6.1 Goals

- Study correlation of demographics and cognitive functions with performance;
- Cluster learning trajectories;
- Validate neurocognitive pp model;
- Examine tablet active area effects on performance.

6.2 Data collection

Survey: age, gender, start year, device, tablet size, playstyle, weekly playtime, consent. osu! API / Replays: pp history, ranks, accuracy, hit deviation.

6.3 Analytical plan

- Descriptive analysis: distributions, correlations, spaghetti plots.
- Trajectory clustering: functional data analysis or DTW + clustering.
- Growth models: mixed-effects curves.
- Prediction: ML models (random forest, XGBoost).
- Retention analysis: Kaplan–Meier, Cox proportional hazards.

7 Ethics

Mandatory informed consent, anonymization, withdrawal rights, transparency.

8 Implementation tools

Python (pandas, scikit-learn), R (lme4, survival), visualization matplotlib/ggplot2.

9 Discussion and Future Directions

Develop objective neurocognitive pp metric, longitudinal study of plateaus, age-related sensorimotor curves, training interventions.

10 Conclusion

Deterministic mechanics, high temporal precision, and massive audience make *osu!* a unique natural laboratory for human sensorimotor and cognitive research.

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