The Effects of Different Temporally Structured Cues on Gait Variability in ACL-Injured Athletes

Mafalda P. Hilário[1], Ana Pinto[1], João S. Gomes[1], João R. Vaz[1]
[1] Egas Moniz School of Health & Science, Monte da Caparica, Portugal

INTEGRATIVE MOVEMENT IN NETWORKING SYSTEMS LABORATORY

INTRODUCTION

Anterior cruciate ligament (ACL) injuries are common in sports and may lead to long-term neuromuscular deficits and impaired motor adaptability (Decker et al., 2011; Hollman et al., 2021; Moraiti et al., 2007). Beyond functional limitations, they carry high economic costs and, in elite athletes, can prematurely end sporting careers (Gans et al., 2018). ACL rupture is also associated with a higher risk of secondary injuries, such as medial meniscal tears and early-onset knee osteoarthritis (Domnick et al., 2016). A key concern in ACL rehabilitation is the loss of physiological complexity in motor control, often reflected in altered gait variability. Healthy gait shows fractal patterns—structured variability that supports adaptability—yet these are frequently disrupted post-injury (Moraiti et al., 2007; Stergiou et al., 2004). Traditional rehabilitation tends to overlook such nonlinear aspects of movement.

AIMS

Investigate how different temporally structured cues - rigid (isochronous) versus complex (fractal) - affect gait patterns of acute ACL-injured athletes.

MATERIALS & METHODS

Figure 1 – Representation of the CUED trial setup.

Table 1 – Study methodology.

Participants	17 adult athletes (12 male, 5 female; age 18–35) with MRI-confirmed unilateral ACL rupture, pre-surgical stage.
Protocol	After providing consent and completing the Tampa Scale (TSK-13) (Cordeiro et al., 2013) for Kinesiophobia, each participant performed two 12-minute walking trials on a split-belt treadmill: - one uncued (baseline) and one cued (randomized to ISO or FRC).
Cued Condition	Visual cues were projected in front of the treadmill, and participants synchronized their right heel-strike with each cue peak.
Walking Speed	Each participant's optimal walking speed (OWS) was individually determined using leg length to match a Froude number of 0.25, reflecting efficient and economical walking.
Outcome Measures	Gait variability was analysed using inter-stride intervals (ISIs) and DFA to calculate the fractal scaling exponent (α), where values ≈1.0 reflect healthy variability and lower α indicates reduced complexity. ISIs were extracted using custom MATLAB code.
Statistical Analysis	To investigate differences between groups across conditions, a mixed-model repeated measures ANOVA was used (Group [ISO vs FRC] x Condition [UNC vs CUED]) for α-ISIs.

RESULTS & CONCLUSIONS

Gait variability in ACL-injured athletes is sensitive to the temporal structure of external cues. Isochronous cueing reduced fractal organization, promoting a more random and less adaptable pattern (Jordão et al., 2022; Vaz et al., 2020, 2024). In contrast, fractal cueing preserved baseline α-values, which may help maintain neuromuscular adaptability in early rehab (Vaz et al., 2020). Low α-ISIs at baseline suggest disrupted control, likely due to proprioceptive deficits (Moraiti et al., 2007) and moderate kinesiophobia (Tampa Score: 29.9/52). Although fractal cueing did not improve variability, preventing deterioration is clinically relevant. Given that isochronous cues are widely used but reduced complexity, fractal strategies may offer a better-aligned alternative. Future research should explore long-term outcomes and whether altered variability predicts injury or osteoarthritis (Stergiou et al., 2006).

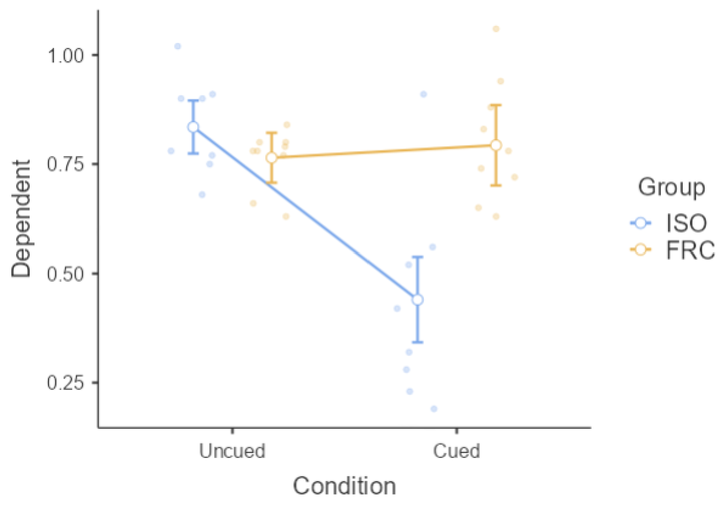

Figure 2 – Marginal means plot of Condition x Group results comparisons. ISO – Isochronous; FRC – Fractal. Data are presented as Mean ± SD.

- For α-ISIs, we have found **an interaction effect** Condition x Group ($F(1,14) = 22.8$, $p < 0.001$, $\eta^2_p = 0.620$).
- FRCcued (0.803 ± 0.140) **was higher** than ISOcued (0.429 ± 0.235, $p = < 0.001$).
- ISOuncued (0.839 ± 0.111) **was higher** than ISOcued (0.429 ± 0.235, $p = < 0.001$).

The ACL-injured athletes in the FRC group showed no significant improvements in the temporal structure of their gait patterns with these cues, while their gait became more random with isochronous cues.

REFERENCES