Improving Quality Assurance in Digital Cognitive Pre-Screening Through Single-Session Anomaly Detection

Alexander Taptiklis[1], Martina De Lillo[1], Alexander J Kaula[1], Francesca Cormack[1], Nicholas Taptiklis[1]

1. Cambridge Cognition, Cambridge, UK

Introduction

- The Digit Symbol Substitution Test (DSST) has potential value as a brief remote pre-screening tool, with task score significantly predicting cognitively normal versus mild cognitive impairment (MCI) status[1], and the 90-second digital DSST performing comparably to longer cognitive assessments.[2]
- However, interpretation of a single-session score is limited by the possibility that an isolated incidence of low performance may be unrepresentative of a participant's true underlying cognitive ability.
- Beyond total score alone, the digital DSST contains rich trial-level behavioural data that may help identify such anomalous performances.
- This analysis utilises data from the Intuition study (NCT05058950) to develop a model that can detect anomalous performance on the DSST across normative data-defined groups.

Methods

- Data were obtained from 23,004 US adults followed for up to 24 months as part of the Intuition study, yielding 3.5 million DSST sessions (**Figure 1**).
- From low-level within-task signals such as response latency and drawing behaviour, over 1,000 features were extracted per DSST session, capturing variability, timing irregularity, and within-session disruption.
- Anomalous first sessions were labelled retrospectively from each participant's first four sessions: session 1 had to fall: at or below the 5th percentile for age, sit more than 2 median absolute deviations below the typical session-1-to-later-best drop for its 5-year age band, and be followed by a rebound to normative performance in sessions 2–4.
- An XGBoost classifier was trained on labelled sessions from 16,272 participants and evaluated on its ability to detect anomalous first-session performance across norm-defined groups in 4,086 held-out participants.

Corresponding author email address:
Nick.Taptiklis@camcog.com

Presented at the International Society for CNS Clinical Trials and Methodology (ISCTM) Autumn Conference, 16–17 September 2026, Philadelphia, PA, USA

Results

Figure 1. DSST feature extraction from the Intuition cohort

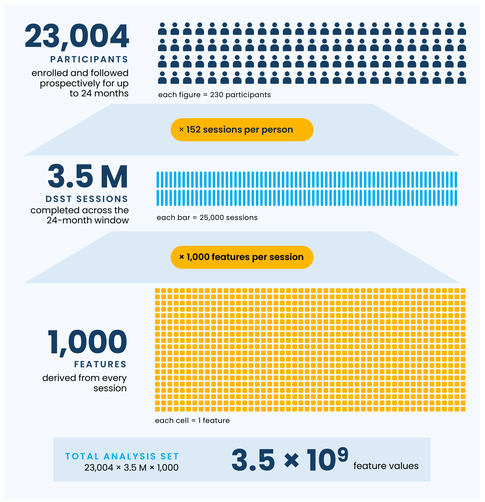
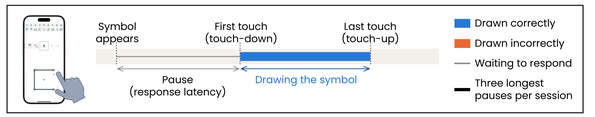


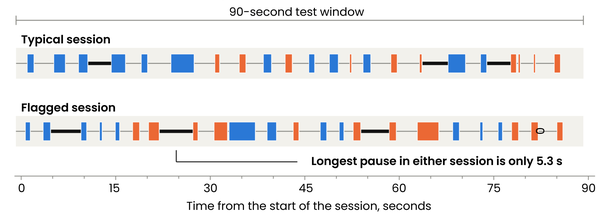
Table 1. Demographics and DSST performance of example matched pair

Characteristic	Typical session	Flagged session
Sex	Female	Female
Age, years	69	64
Education	Master's degree	Bachelor's degree
DSST total correct	12	12
DSST symbols attempted	22	23
Pause time (total), s	57.6	55.9
Drawing time (total), s	26.5	28.5
Mean pause time, s	2.62	2.43
Longest single pause, s	4.0	5.3
Total time on task, s	84.1	84.4
Anomaly score	**0.04**	**0.65**

Figure 2. Two sessions with equal DSST total correct scores are distinguished only by uneven pauses



Timing of first-session drawing and pauses



The three longest pauses as a proportion of total pause time

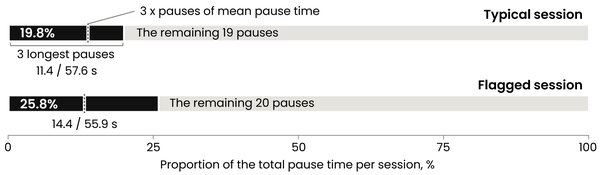


Figure 3. The timing of session 1 can predict the within-person reference frame

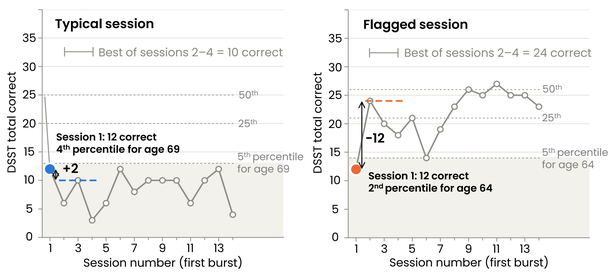
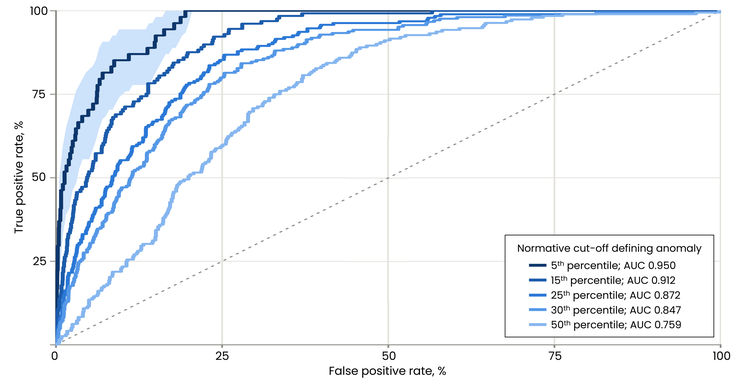
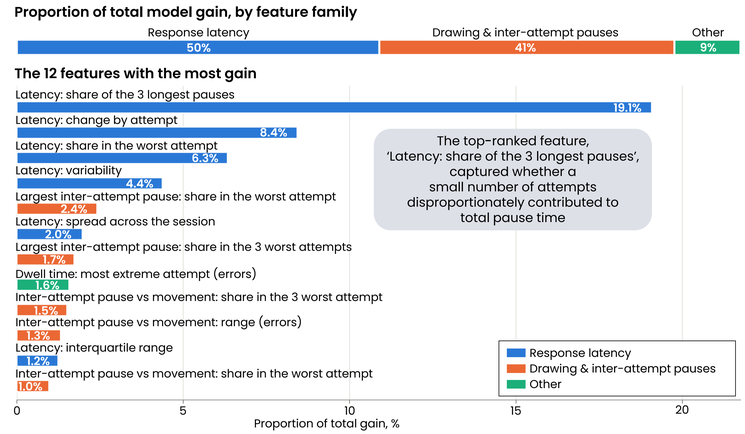


Figure 4. Anomalous first sessions are detectable from one 90-second DSST, with discrimination strongest for the most impaired normative groups



One XGBoost classifier (trained on longitudinally-defined anomalies at the 15th percentile). Evaluated against first-session anomaly labels at five normative cut-offs.

Figure 5. Informative features were dominated by response-latency and drawing-related features



Conclusions

Anomalous first-session performance was detected with ROC AUC up to 0.958 for the most impaired normative groups

Timing irregularity was the dominant signal of anomalous performance, led by response-latency and drawing-related features

Flagging anomalous sessions may improve confidence that low pre-screening scores reflect true impairment rather than transient disruption

The model is now being validated in a healthcare setting to flag patients for repeat assessment, ensuring participants with an underlying cognitive impairment are not excluded

References

1. Scott BM *et al. Arch. Clin. Neuropsychol.* 2022;37:1263. **2.** Dyer JF *et al. J Med Internet Res.* 2025;27:e55469.

Abbreviations

AUC, area under the ROC curve; **DSST**, Digit Symbol Substitution Test; **MCI**, mild cognitive impairment; **ROC**, receiver operating characteristic.

Funding

The Intuition study was funded by Biogen, Inc. with support from Apple, Inc.

Disclosures

All authors are employees of Cambridge Cognition and may own stock or stock options in Cambridge Cognition.

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