Section: Miscellaneous

Original Research Article

NEURO-DEXTERITY AS A DIGITAL BIOMARKER: RETHINKING NEUROLOGICAL ASSESSMENT THROUGH COMMODITY SMARTPHONE HARDWARE — EVIDENCE FROM A DEPLOYED CLINICAL APPLICATION

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ABSTRACT

Background: The standard toolkit for neurological assessment — including the Unified Parkinson's Disease Rating Scale (UPDRS) and the Mini-Mental State Examination (MMSE) — is structurally limited by its episodic, clinic-bound nature. For conditions defined by slow, continuous decline, a fifteen-minute assessment every six months is a fundamentally inadequate instrument.

Objective: This paper introduces neuro-dexterity — the quantifiable intersection of cognitive intent and fine motor execution — as a candidate digital biomarker suite measurable through sensors embedded in consumer-grade smartphones. We present NeuroDex, a live Apple App Store Medical application implementing five real-time interactive assessments: Path Tracing, Precision Hold, Peg Transfer, Box and Block, and Pinch Dexterity.

Significance: By relocating neurological assessment from the clinic into the patient's daily environment and transforming episodic snapshots into continuous monitoring, neuro-dexterity profiling can identify prodromal signatures of neurodegeneration years before gross clinical signs emerge. NeuroDex demonstrates this is not theoretical: it is deployed, zero-data-collection software, available today.

Keywords: neuro-dexterity, digital biomarkers, Parkinson's disease, smartphone sensors, NeuroDex, kinematic stability, precision hold, path tracing, box and block, peg transfer.

INTRODUCTION

Every few months, millions of people living with Parkinson's disease, Alzheimer's disease, and related neurodegenerative conditions sit across from a neurologist and complete a standardised set of tasks: tapping fingers, walking a corridor, drawing a spiral, answering orientation questions. The clinician watches, scores, and sends the patient home. This system has produced enormous scientific insight, but it has a structural flaw that the field has been quietly working around for decades: a fifteen-minute observation once every six months is a thin basis for tracking a disease that evolves continuously, hour by hour, across every waking day.

The core difficulty is what researchers call ecological validity — the degree to which a measurement reflects real-world function rather than performance under controlled, artificial conditions. Patients with early neurodegeneration often compensate remarkably well during a clinic visit, drawing on residual cognitive reserve, the anticipatory adrenaline of a long-awaited appointment, and an implicit motivation to appear functional. This is not deception; it is a fundamental property of neurological disease that the clinical encounter was never designed to detect.[1]

The argument here is simple: the smartphone already in a patient's pocket is a precision measurement instrument, and medicine has barely begun to use it as one. Modern smartphones contain micro-electromechanical systems (MEMS) that sample motion at up to 100 Hz, microphones capturing vocal frequency with sub-millisecond resolution, and

capacitive touchscreens recording the exact timing and pressure of every tap. This hardware was not designed for medicine, but it turns out to be exactly what neurologists need.

We use the term neuro-dexterity to describe what these sensors can measure: the real-time coordination between what the brain intends and what the body executes. When a person's dopaminergic system begins to deteriorate — sometimes years before the clinical threshold for a Parkinson's diagnosis is crossed — that deterioration leaves traces in the rhythm of their voice, the micro-tremors in their grip, the latency of their responses, and the accuracy of their sustained fine motor control.[2-11]

This paper is accompanied by working screenshots of NeuroDex [Figure 1], a motor assessment application developed by Aspex Studios, now available on the Apple App Store in the Medical category (© 2026 Aahana Bisoi; iOS 16.6+; 1.6 MB). The app implements five real-time interactive assessments that operationalise the neuro-dexterity framework, collecting no external data whatsoever — every score and session record stays entirely on the patient's device. None of this is a proposal on paper — the software is in production today.

Figure 1: NeuroDex dashboard (Apple App Store, Medical category). Five colour-coded assessment cards — Path Tracing, Precision Hold, Peg Transfer, Box & Block, Pinch Dexterity — are accessible from a personalised home screen. The settings gear sits top-right.

Figure 2. NeuroDex Settings. Patient Profile (preferred name, legal name, date of birth), Clinical Details (dominant hand, primary goal), App Preferences (haptic feedback, daily reminders), and Data Management. Footer: NeuroDex v1.0, Precision Motor Tracking.

The snapshot problem: limitations of episodic clinical assessment: The UPDRS is the dominant instrument for rating Parkinson's disease severity. In expert hands it is reliable and clinically meaningful, but it has properties that systematically limit its sensitivity to the early-stage continuous decay that neuro-dexterity profiling is designed to capture.

Start with the ceiling effect. The MMSE tops out at 30, and patients with mild cognitive impairment routinely score 29 or 30 — not because nothing is wrong, but because the scale cannot resolve the earliest executive-function deficits. Motor rating has the same blind spot: a tremor obvious on a patient's home video can be scored zero in clinic because the patient had a good morning or timed a dose well.[4]

Then there is wearing-off. Levodopa and the other dopaminergic drugs lose their effect in the hours between doses, so each day swings between relative normalcy and impairment — and the clinic usually catches only the medicated "on" state. A systematic review of longitudinal digital-health-technology studies in early PD found that some tools registered disease changes at time points where the standard rating scales did not, with one study reporting larger effect sizes for the digital measures over the same follow-up window.[3]

Frequency is the third gap. Seen twice a year, a patient supplies twelve data points across five years; a daily smartphone assessment supplies roughly 1,825 over the same span. For catching slow, gradual drift, that gulf in statistical power is not a matter of degree — it changes what is detectable at all, for care and for research alike.

The Three Data Streams of Neuro-Dexterity: Neuro-dexterity as a diagnostic construct is not a single measurement but a multimodal profile. Three data streams, each accessible through commodity smartphone hardware, constitute its core. NeuroDex implements all three across five interactive tests, administered daily without clinical supervision.

Kinematic Stability: The tremor characteristic of Parkinson's disease has a spectral signature. Parkinsonian rest tremor typically oscillates at 4–6 Hz, while benign essential tremor presents at 8–12 Hz. Fourier analysis of accelerometer data can distinguish these frequencies with precision exceeding what the human eye reliably detects.[5]

The WATCH-PD multicentre study, using commercially available smartwatches and smartphones in early, untreated Parkinson's disease, found that tremor, finger tapping, and gait measures differed significantly between patients and age-matched controls at baseline, with significant longitudinal changes detectable over twelve months of follow-up.[4] A multimodal smartphone study across 496 participants found that hand movement data alone achieved a diagnostic AUC of 0.74 for distinguishing PD patients from controls, rising to 0.82 in a combined multimodal model.[2]

NeuroDex operationalises kinematic assessment through Precision Hold and Box and Block. The Precision Hold test [Figure 3–5] requires placing a thumb inside a solid circle and holding it stationary for fifteen seconds without lifting or drifting; every loss of contact is counted as a drift event in real time. The Box and Block test [Figure 7–9] requires dragging blocks across a central dividing line as many times as possible in fifteen seconds, measuring gross manual dexterity and functional reach speed.

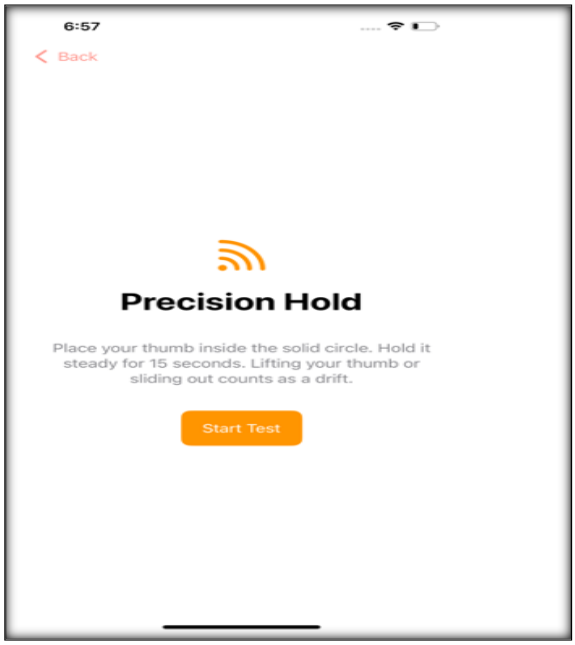

Figure 3: Precision Hold intro screen. Patients are instructed to hold their thumb inside the solid circle for 15 seconds without lifting or sliding, which counts as a drift.

Figure 4: Precision Hold — Holding Steady. Circle turns green; status: "Holding steady…" Drifts: 0, Time: 13.3s. Green = within boundary.

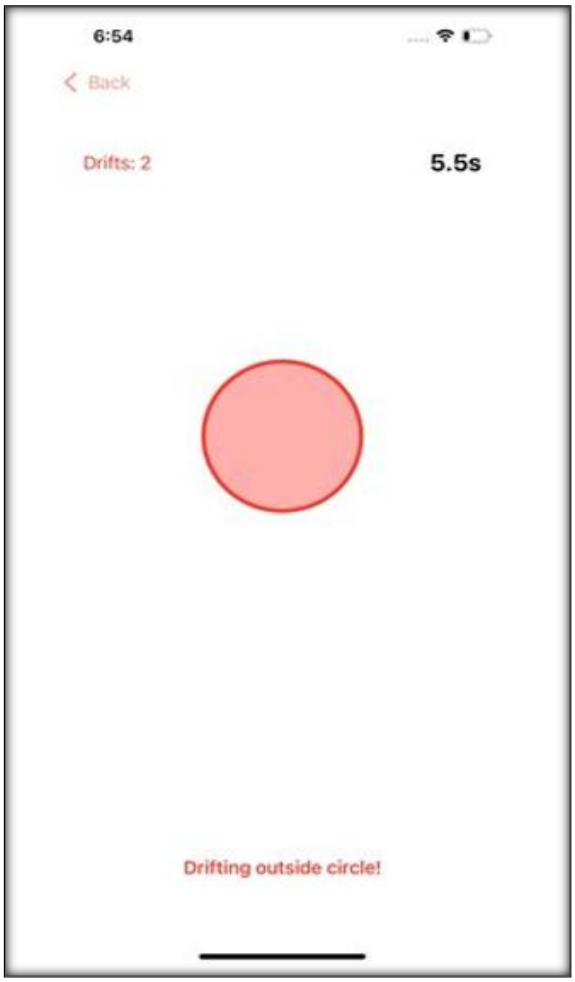

Figure 5: Precision Hold — Drifting Outside. Circle turns red; alert: "Drifting outside circle!" Drifts: 2, Time: 5.5s. Every boundary exit is counted.

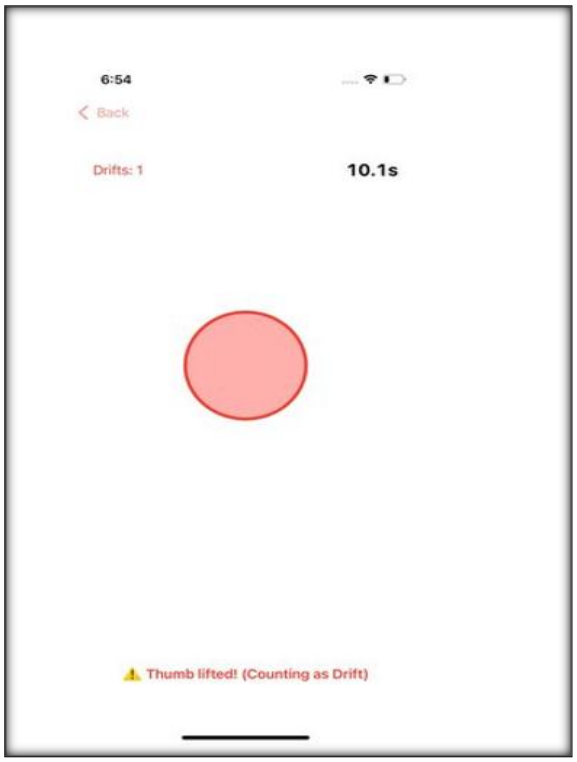

Figure 6: Precision Hold — Thumb Lifted. Warning triangle appears: "Thumb lifted! (Counting as Drift)." Drifts: 1, Time: 10.1s. Lift-offs are tracked separately, providing a fine-grained tremor and stability index.

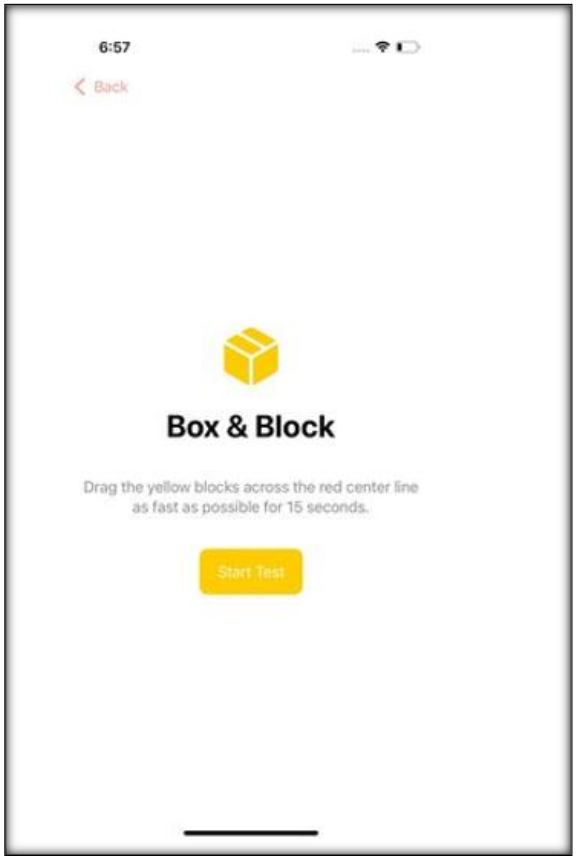

Figure 7: Box & Block intro screen. Patients drag the yellow block across the red centre line as fast as possible for 15 seconds, directly measuring gross manual dexterity and bimanual speed.

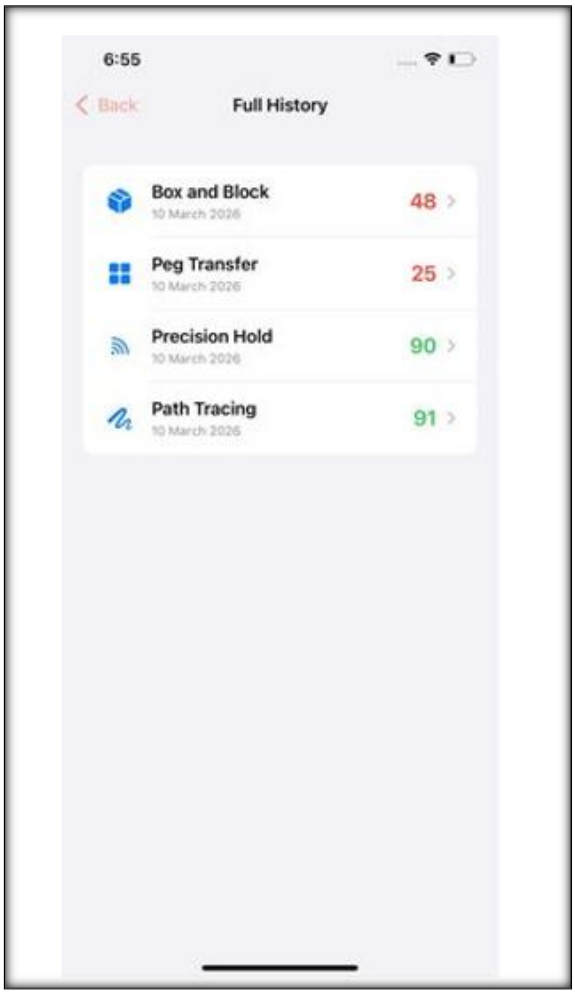

Figure 8: History screen. The app displays completed assessment results in a history log, showing each test name, date, and performance score. This allows users and clinicians to review progress.

Acoustic Phonation

Hypokinetic dysarthria — the voice changes characteristic of Parkinson's disease — is among the earliest and most consistent manifestations of the condition. Speech changes can predate the classic motor symptoms by years and respond sensitively to medication state.[6]

The two primary acoustic biomarkers are jitter (cycle-to-cycle variation in fundamental frequency) and shimmer (cycle-to-cycle amplitude variation). Both increase as fine motor control of the vocal folds deteriorates. Landmark work by Tsanas et al. demonstrated that noninvasive self-administered speech tests could replicate UPDRS assessment with clinically useful accuracy — approximately 7.5 UPDRS points from clinicians' estimates — using only sustained phonation collected remotely from 42 patients across six medical centres [7]. A more recent study in npj Parkinson's Disease found that acute levodopa effects were statistically significant across prosodic, respiratory, and spectral domains, with a hypokinetic compound score correlating strongly with MDS-UPDRS-III changes (r = 0.70).[6] A smartphone microphone, used systematically, can

detect the functional effect of a medication dose more sensitively than standard clinical rating scales.

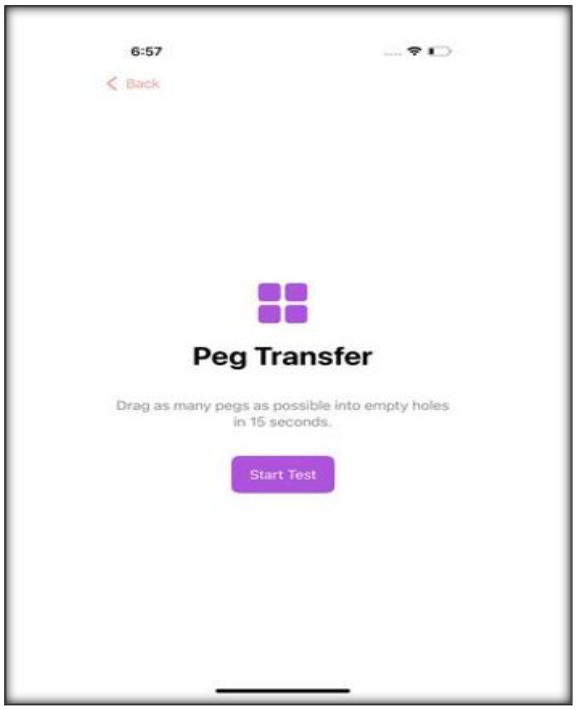

Figure 9: Peg Transfer intro screen. Patients drag as many pegs as possible into empty holes in 15 seconds, measuring fine motor coordination and goal-directed reaching speed.

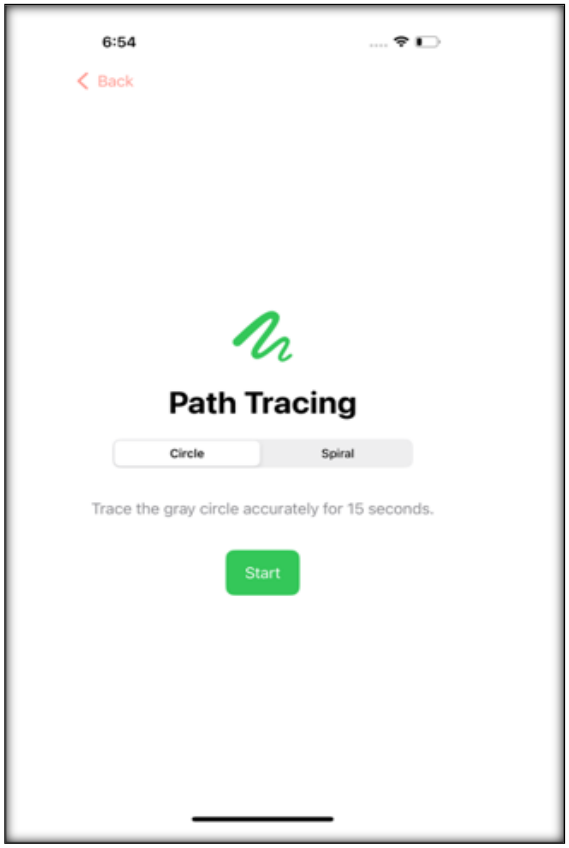

Figure 10: Path Tracing intro screen. Patients select Circle or Spiral mode and trace the target shape accurately for 15 seconds. Accuracy is scored in real time against the target geometry.

Cognitive-Motor Precision and Response Latency: The third stream measures the time elapsed between a motor-cognitive stimulus and the correct execution of a response — integrating executive processing speed, inhibitory control, and fine motor coordination into a single measurable index. Changes of 20–50 milliseconds, invisible to a clinician scoring binary correct/incorrect responses, may accumulate over months of daily monitoring into a reliable trajectory of frontotemporal decline.[4]

NeuroDex operationalises this through Path Tracing and Peg Transfer. Path Tracing [Figure 10} requires tracing a circle or spiral accurately for fifteen seconds, scored as the proportion of time within the target boundary. Peg Transfer [Figure 11] requires dragging tiles across a grid as rapidly as possible in fifteen seconds. Both generate precision and speed metrics simultaneously, capturing cognitive-motor integration at a temporal scale unavailable to standard clinical assessments.

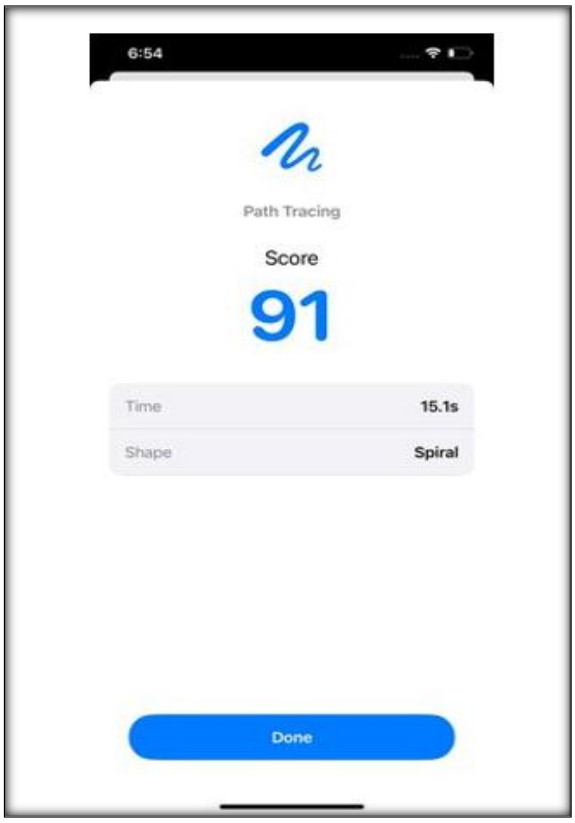

Figure 11: Path Tracing result: Score 91/100, Time 15.1s, Shape Spiral. Results are immediately stored in the on-device Full History log.

Neurodex in Practice: A Deployed Clinical Tool on The Apple App Store: NeuroDex already ships as a product — a live application in the Apple App Store's Medical category, built by Aspex Studios (© 2026 Aahana Bisoi). At 1.6 MB, it runs on iPhone (iOS 16.6+), iPad (iPadOS 16.6+), and Mac (macOS 13.5+ with Apple M1 or later), is rated 4+, and ships in English. Apple's own App Privacy review states it plainly: "Data Not Collected — The developer does not collect any data from this app" [Figure 13]. Every

score, session record, and profile detail stays entirely on the user's device.

This privacy architecture is clinically significant. One of the primary barriers to adoption of digital health monitoring tools has been patient concern about data sovereignty: who owns the health information generated by continuous smartphone monitoring? NeuroDex resolves this structurally. There is no server, no cloud upload, no analytics pipeline. Data exists only on the patient's device, erasable at any time through the settings panel [Figure 2].

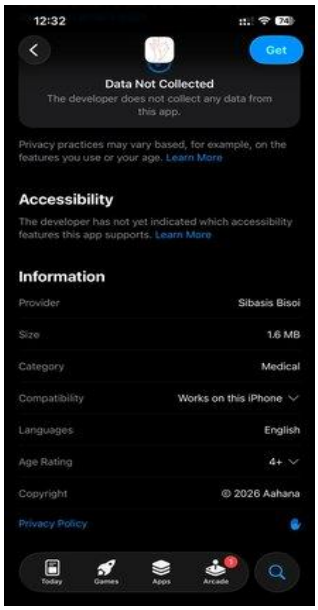

Figure 12: NeuroDex on the Apple App Store — Information panel; Size: 1.6 MB; Category: Medical; Compatible with iPhone, iPad, and Mac; Language: English; Age Rating: 4+; Copyright: © 2026 Aahana.

Figure 13: NeuroDex App Store privacy label: "Data Not Collected — The developer does not collect any data from this app." This on-device-only architecture directly addresses data sovereignty concerns in digital health monitoring.

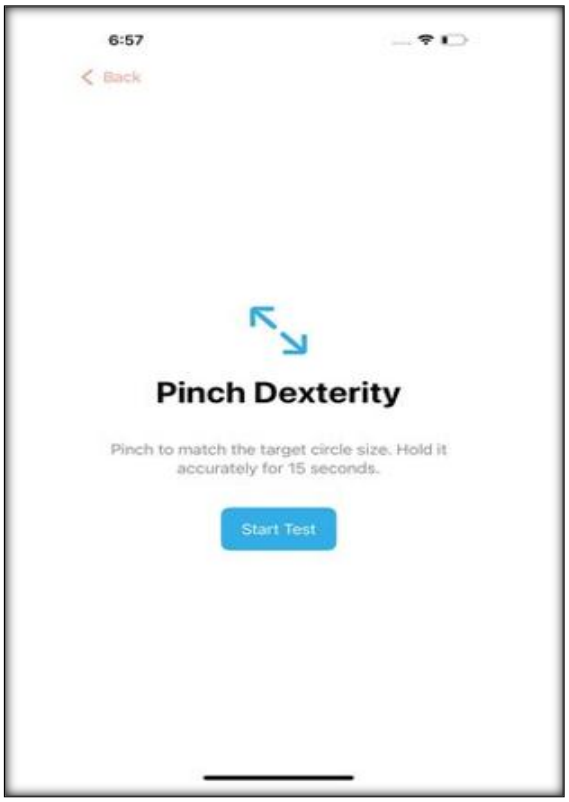

Figure 14: Pinch Dexterity intro. Patients pinch to match a target circle size and hold it accurately for 15 seconds.

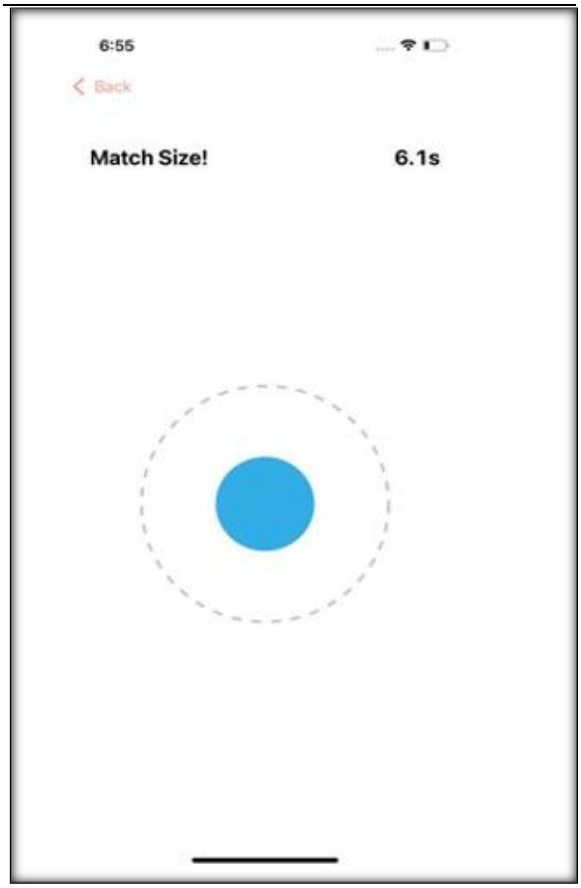

Figure 15: Pinch Dexterity — active session. Blue circle is smaller than the dashed target ring. Status: "Match Size!", Time: 6.1s. The proportion of time accurately matched is scored.

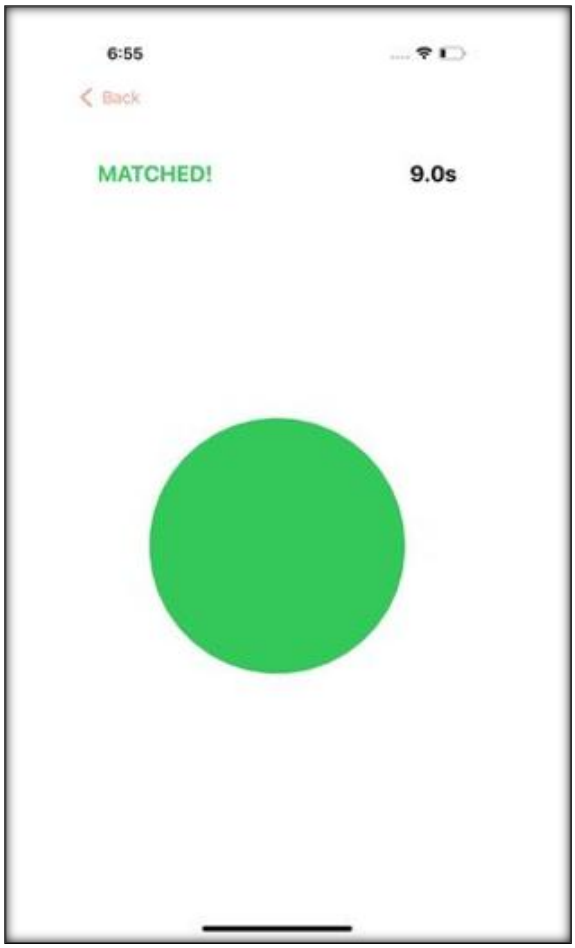

Figure 16: Pinch Dexterity — Matched. Circle fills green; status: "MATCHED!", Time: 9.0s. Sustained matched time constitutes the dexterity precision score.

The five NeuroDex assessments mirror and extend established clinical motor assessment paradigms. Box and Block digitally implements the Mathiowetz Box and Block Test, a validated occupational therapy instrument for gross manual dexterity. Peg Transfer mirrors the Nine-Hole Peg Test and Grooved Pegboard Test, both sensitive to upper limb dysfunction in Parkinson's disease. Precision Hold extends these into sustained positional stability, and Path Tracing into drawing accuracy. Pinch Dexterity — using a pinch gesture to match a target circle size and hold it for fifteen seconds — introduces bimanual fine motor coordination not typically assessed in standard clinical batteries.

Validation Context and Prior Work: The framework advanced in this paper rests on an empirical foundation the authors have directly contributed to. Bisoi, Sundaravadhanan, and Krishna previously published a focused validation study of smartphone-based quantitative assessment of parkinsonian motor and vocal biomarkers, examining the development and initial validation of a remote monitoring application.[8] That study established the feasibility of the core measurement paradigms now implemented in NeuroDex — kinematic precision, acoustic phonation analysis, and timed fine motor tasks — in an ecologically valid home monitoring context. It serves as the primary empirical anchor for the claims made here about the clinical utility of continuous on-device biomarker collection.

The present paper extends that foundational work in two directions. First, it situates the approach within the broader peer-reviewed literature on digital neuro-phenotyping in Parkinson's disease, drawing on landmark studies that have validated smartphone and wearable sensor data as clinically meaningful outcome measures.[1-7,10] Second, it documents the transition from validated research framework to deployed consumer application: NeuroDex is publicly available, free of charge, with zero data collection, demonstrating that the implementation gap between research concept and accessible clinical tool can be closed without institutional infrastructure or specialised hardware.

The convergence of these two lines of work — the validation literature and the deployed application — is what makes the neuro-dexterity framework practically significant rather than merely theoretically appealing. The question is no longer whether smartphone sensors detect meaningful neurological signals. The peer-reviewed literature has answered that affirmatively.[2,5,7] The question now is how to deploy that capability responsibly, at scale, in a form that patients can use without technical support and clinicians can interpret without retraining.

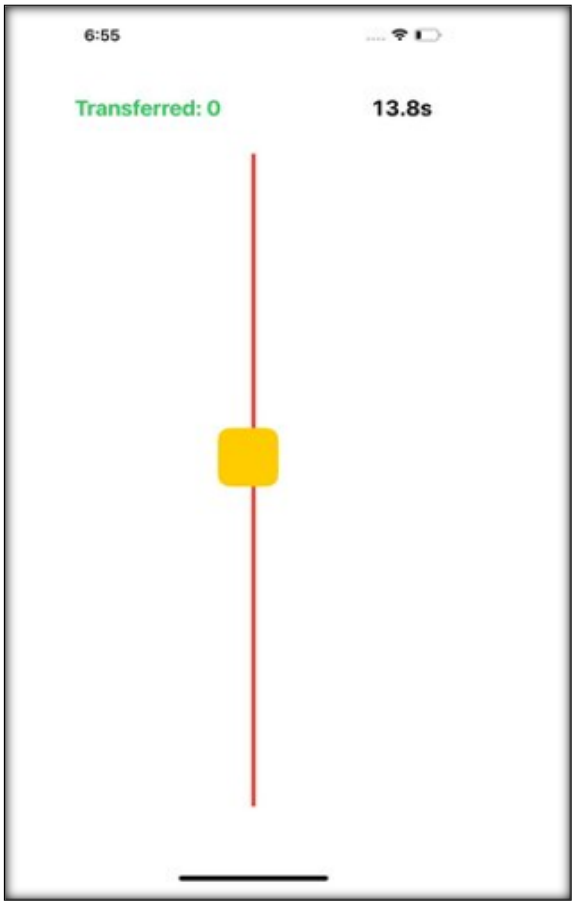

Figure 17: Box & Block session start. Transferred: 0, Time: 13.8s.

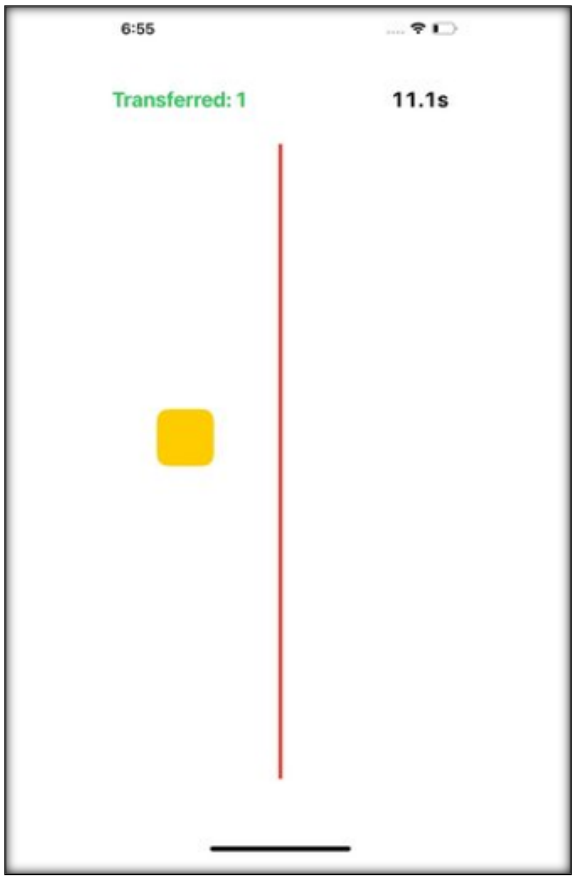

Figure 18: Box & Block — first crossing. Transferred: 1, Time: 11.1s.

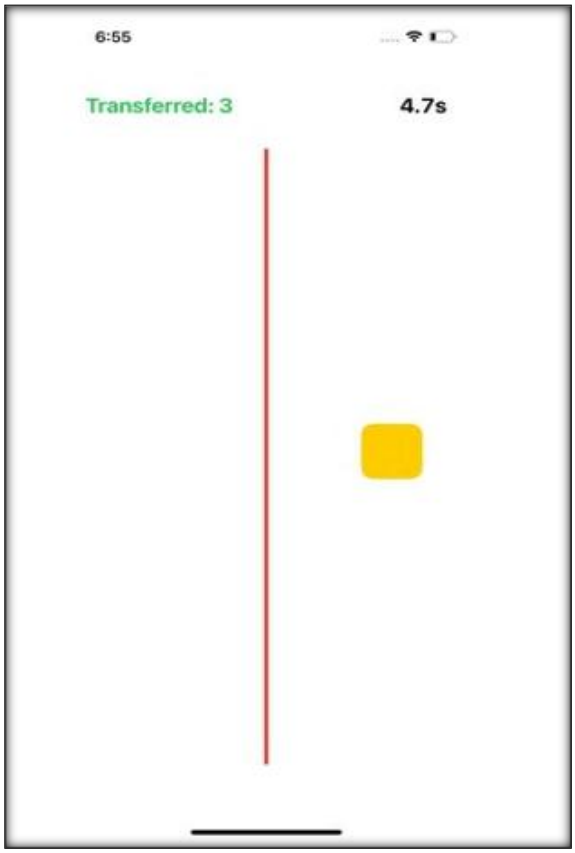

Figure 19: Box & Block — mid-session. Transferred: 3, Time: 4.7s. Count updates in real time with each successful block transfer across the centre line.

From Assessment to Therapeutics: The Case for Dynamic Titration: The clinical implications of continuous neuro-dexterity monitoring extend considerably beyond early detection. The most immediately actionable use, though, is tuning pharmacological treatment for Parkinson's disease.

Levodopa therapy involves a fundamental pharmacokinetic tension. The drug's half-life is 60–90 minutes while dosing schedules are fixed and coarse. As the disease progresses and neuronal reserve diminishes, patients cycle through "on" and "off" states with increasing regularity but unpredictable timing. Managing this wearing-off phenomenon currently depends on patient diaries and subjective recall, both of which are known to be unreliable.

Digital biomarker data transforms this problem qualitatively. If a smartphone records kinematic precision and held-contact accuracy throughout the day, the resulting dataset constitutes a medication heatmap: a time-stamped graph showing when the drug is working, when it is beginning to wear off, and how that pattern evolves across days. A neurologist reviewing this remotely can adjust dosing timing or magnitude based on objective evidence rather than a patient's recollection of a week that is difficult to reconstruct accurately.

The foundational smartphone PD trial validation found that digital biomarkers detected motor abnormalities in patients simultaneously rated as having no signs on corresponding UPDRS items at the clinical visit — meaning the digital measure was more sensitive than the clinical scale in direct, contemporaneous comparison.[1] Exploratory digital outcome measures from the PASADENA prasinezumab clinical trial, which used daily smartphone motor tasks and passive smartwatch monitoring in 316 early-stage PD patients over two years, demonstrated that tapping variability and hand-turning metrics progressed numerically less in treated versus placebo groups at week 52.[9] The same infrastructure that supports daily patient monitoring can serve as a clinical trial endpoint.

Commodity hardware and the equity argument

Neurological care is among the most geographically concentrated medical specialties. Movement disorder centres are clustered in large metropolitan areas. Patients in rural, low-income, or geographically remote settings frequently wait years for a specialist appointment and travel hours to reach one. The hardware used in specialist assessment — specialised gait laboratories, EMG suites, force plates — is capital-intensive and exists predominantly in well-resourced urban facilities.

Smartphone penetration tells a structurally different story. The foundational clinical trial validation study demonstrated that smartphone-sensor technologies provide reliable, valid, clinically meaningful, and highly sensitive phenotypic data in Parkinson's disease using only a commercial mobile application in a patient's home.[1] The sensors in a consumer iPhone are, for the purpose of tremor and gait

analysis, not meaningfully inferior to laboratory-grade motion capture equipment.

NeuroDex takes this principle to its logical conclusion. A patient in a city with a major teaching hospital and a patient in a rural town with access only to primary care both own iPhones compatible with the app. Both have access to the same continuous motor monitoring infrastructure. The differential in specialist access does not disappear — interpretation and treatment adjustment still require clinical expertise — but the gap in diagnostic data quality that most delays early intervention narrows to near zero.

NeuroDex's decision to be distributed at no cost, with no data collection, and with no account creation requirement is a deliberate implementation of this equity principle. The technical barrier to entry is a compatible iPhone. Nothing else is required.

DISCUSSION

The case made in this paper is broad, and it would be incomplete without a frank account of what remains unresolved.

The most significant limitation is the gap between feasibility studies and regulatory-grade validation. The studies cited here demonstrate that smartphone sensors detect meaningful neurological signals with clinically significant accuracy. They do not yet constitute the body of evidence required for regulatory approval of these tools as diagnostic devices. Building that evidence requires large, longitudinal, multicentre prospective studies with pre-specified endpoints, standardised protocols, and diverse patient populations.[12]. NeuroDex provides the infrastructure for such studies. The studies themselves remain to be conducted.

There is also the question of normative calibration. Touchscreen sensitivity, accelerometer precision, and screen dimensions vary across iPhone models. Individual factors — age, hand size, baseline dexterity, digit length — influence performance independently of disease state. Normative databases stratified by age, sex, handedness, and device model will be required before individual session scores can be interpreted with clinical confidence. The settings panel in NeuroDex already collects date of birth, dominant hand, and primary goal precisely for this reason.

Algorithmic transparency is a related concern. Machine learning classifiers trained on digital biomarker data can achieve impressive accuracy, but clinicians and regulators reasonably require explanations for how a model reaches its outputs. NeuroDex currently presents raw scores — drift counts, transfer counts, accuracy percentages, matched time proportions — without attempting clinical interpretation. This is intentional and appropriate for a version 1.0 application. The interpretive layer that maps scores onto clinical risk stratification remains future work.

Finally, there is a risk of over-medicalisation. As motor assessment tools enter consumer health applications, individuals without clinical disease may receive performance feedback that causes anxiety or prompts unnecessary medical consultations. Calibration of alert thresholds for consumer versus clinical contexts is a design challenge NeuroDex will need to address as its user base scales.

CONCLUSION

Parkinson's disease and related neurodegenerative conditions are, at their core, diseases of movement and rhythm: the rhythm of a step, a spoken sentence, a deliberate grip on an object. The clinical tools developed over the past century to measure these rhythms are indispensable achievements, but they are bound to the brief rhythms of the clinic. They cannot hear what happens at 3 AM when a patient's medication wears off. They cannot see the 2-Hz tremor that lasted forty minutes on a Tuesday and then resolved. They cannot measure whether the tremor is incrementally worse this month compared to last.

Neuro-dexterity monitoring — through applications like NeuroDex, with its five validated interactive assessments, its zero-data-collection architecture, and its deployment on the Apple App Store in the Medical category — is a concrete first step toward closing that gap. It does not replace the neurologist. It equips the neurologist with data from the 99.9% of the patient's life that currently goes unmeasured.

The hardware is already in the patient's pocket. The signal is there. The regulatory and clinical validation work ahead is substantial but tractable. This paper is offered as a contribution to both the conceptual foundation and the empirical motivation for that work.

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