Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

Primitive reflex burden and grasp-evoked cortical hemodynamics in older adults An exploratory cross-sectional functional near-infrared spectroscopy study with a focus on perirolandic motor regions

Erzsébet Stephens-Sarlós

stephens-sarlos.erzsebet@sze.hu

Széchenyi István University

Edmond Girasek

Széchenyi István University

Patrick Stephens

Széchenyi István University

Fanni Küplen

Széchenyi István University

Angéla Somogyi

Széchenyi István University

Edit Rangasz

Széchenyi István University

Attila Szabo

Széchenyi István University

Research Article

Keywords: primitive reflex burden, frontal release signs, grasping, functional near-infrared spectroscopy, cortical hemodynamics, aging

Posted Date: November 23rd, 2026

DOI: https://doi.org/10.21203/rs.3.rs-11614220/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License.
Read Full License

Additional Declarations: Competing interest reported. Competing interests Erzsébet Stephens-Sarlós developed the primitive-reflex assessment framework used in this study and is the author of educational materials related to primitive-reflex assessment and sensorimotor practice; these roles are disclosed as potential competing interests. The assessor training course referred to in the Methods is based on this framework. The remaining authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Primitive reflex burden and grasp-evoked cortical hemodynamics in older adults

An exploratory cross-sectional functional near-infrared spectroscopy study with a focus on perirolandic motor regions

* Erzsébet Stephens-Sarlós[1] : ORCID 0000-0001-7723-0128

Edmond Girasek[1]: ORCID 0000-0002-0579-6592

Patrick Stephens[1]: ORCID 0009-0007-9211-0512

Fanni Küplen[1]: ORCID 0009-0002-4733-9813

Angéla Somogyi[1]: ORCID 0000-0001-7966-1159

Edit Rangasz[1]: ORCID 0009-0007-0144-6732

Attila Szabo[1]: ORCID 0000-0003-2788-4304

[1] Faculty of Health and Sport Sciences, Széchenyi István University, Győr, Hungary

* Corresponding author: Erzsébet Stephens-Sarlós · stephens-sarlos.erzsebet@sze.hu

Abstract

Background: We examined whether aggregate primitive reflex burden (PRB), encompassing primitive reflexes and frontal release signs, was associated with cortical hemodynamic responses during voluntary grasping in older adults.

Methods: This exploratory cross-sectional study analyzed baseline functional near-infrared spectroscopy recordings from 65 older adults; 63 had complete 29-component PRB profiles. Standardized oxygenated-hemoglobin (HbO) task coefficients were summarized within montage-defined contralateral perirolandic regions. Spearman correlations, bootstrap confidence intervals, false-discovery-rate correction, covariate adjustment, and missing-item sensitivity analyses assessed regional and channel-level associations.

Results: Higher PRB was associated with lower contralateral perirolandic HbO coefficients during right-hand grasping ($\rho = -0.379$, 95% confidence interval −0.586 to −0.143; $q = 0.0043$) and left-hand grasping ($\rho = -0.311$, 95% confidence interval −0.550 to −0.040; $q = 0.0131$). Four channel-level associations survived correction across 276 tests. Two right-hand HbO findings remained supported across all nine bounded missing-item scenarios; two total-hemoglobin findings were less robust. No deoxygenated-hemoglobin association survived correction. After adjustment for age, sex, and diagnosed dementia, all PRB coefficients had confidence intervals including zero.

Conclusions: Greater aggregate reflex burden was accompanied by lower standardized grasp-related HbO coefficients. The findings identify an exploratory physiological correlate of the clinical reflex profile and specific targets for replication. They do not establish causality, direct cortical disinhibition, anatomical specificity to primary motor cortex, or an association independent of age, sex, and dementia.

Keywords: primitive reflex burden; frontal release signs; grasping; functional near-infrared spectroscopy; cortical hemodynamics; aging

Statements and Declarations

Ethics statement

Approval was granted by the Scientific Ethics Committee of the University Scientific Advisory Board, Széchenyi István University (SZE/ETT-19/2025 [V.12.], 12 May 2025). Written informed consent and, where applicable, guardian consent and participant assent were obtained. Separate written consent for publication of the supplementary experimental photograph is held by the authors.

Funding Declaration

On behalf of all authors, I hereby declare that this research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Competing interests

Erzsébet Stephens-Sarlós developed the primitive-reflex assessment framework used in this study and is the author of educational materials related to primitive-reflex assessment and sensorimotor practice; these roles are disclosed as potential competing interests. The assessor training course referred to in the Methods is based on this framework. The remaining authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability statement

The supplementary material provides the study setup, montage, anatomical channel descriptions, complete channel-level results, and sensitivity analyses. The standardized reflex-examination protocol is available in Mendeley Data (https://doi.org/10.17632/k7kyn8v987.1). CSV files containing the full 54-channel inventory, machine-readable statistical outputs, and results for all nine bounded missing-item scenarios are available from the corresponding author upon reasonable request for further research. Analysis code and participant-level beta and clinical data are also available upon reasonable request, subject to consent documentation, ethical approval, and applicable data-protection requirements. Any sharing of participant-level information is subject to these conditions. Raw clinical records, raw fNIRS files, linkage keys, and consent documentation remain under controlled access. The analysis code reproduces beta-level analyses and does not reproduce raw-signal processing.

Supplementary information

Online Resource 1 Supplementary methods and results, including channel definitions, adjusted models, sensitivity analyses, complete channel-level estimates, experimental setup, montage, and signal-processing documentation.
Online Resource 2 Completed STROBE checklist for the cross-sectional study.

Introduction

Primitive reflexes are stereotyped motor responses that are prominent early in development and generally become less readily elicitable as the nervous system matures. Their persistence or re-emergence later in life has attracted interest as an accessible manifestation of altered sensorimotor regulation. Although commonly discussed as frontal release signs, these responses differ in their eliciting stimuli, functional roles, and neural organization, and their expression cannot be assigned to a single cortical site (Schott and Rossor 2003). A recent conceptual framework proposes that primitive reflex expression may index distributed, hierarchically organized inhibitory control spanning spinal, brainstem, and cortical levels, and explicitly calls for multimodal physiological correlation of standardized reflex profiles (Stephens-Sarlós and Szabo 2026). Quantifying the overall burden of elicitable responses may help investigate whether a broader behavioral reflex profile accompanies measurable differences in the neural systems supporting voluntary movement.

Evidence from older adults provides a clinical rationale for this approach. The number of elicitable primitive reflexes has been associated with lower handgrip strength, functional fitness, and physical activity (Stephens-Sarlós et al. 2025), with lower Mini-Mental State Examination performance in residential-care residents (Horváth-Pápai et al. 2025), and reflex counts decreased after a 16-week seated sensorimotor program in a non-randomized trial (Stephens-Sarlós et al. 2024). A recent longitudinal cohort also associated the presence of two or more frontal release signs with increased dementia incidence among initially cognitively intact participants (hazard ratio 1.78, 95% CI 1.02–3.09) (Bojarski et al. 2026), whereas the Maastricht Aging Study found no relationship between reflex measures and subsequent cognitive change in healthy adults (van Boxtel et al. 2006). These findings indicate that reflex expression is context dependent. In a study of the glabellar response, an abnormal response had limited specificity for Parkinson's disease versus essential tremor and was not associated with striatal dopamine-transporter binding after adjustment (Nuuttila et al. 2021). They motivate closer examination of its physiological correlates rather than assuming that the presence of a reflex has a uniform clinical meaning.

Voluntary grasping offers a relevant experimental task because it combines descending motor commands with ongoing somatosensory feedback. The primary motor cortex, corresponding broadly to Brodmann area 4 (BA4), is a central component of this system. Human functional magnetic resonance imaging has shown that power grip is dominated by contralateral primary sensorimotor cortex activity, whereas precision grip additionally engages ventral premotor and parietal regions (Ehrsson et al. 2000). Because repetitive ball squeezing is closer to a power grip

than to a precision grip, a BA4-oriented motor rationale supports particular attention to contralateral perirolandic measurements, while the distributed organization of grasp control also justifies examining the other cortical regions sampled by the recording montage.

Functional near-infrared spectroscopy (fNIRS) is well suited to seated motor assessments because it permits repeated task performance while measuring changes in oxygenated and deoxygenated hemoglobin. Multimodal research has demonstrated spatial correspondence between motor-task fNIRS responses and fMRI activation in primary and premotor cortex (Pereira et al. 2023). However, interpreting a response requires consideration of both task demands and aging. Instrumented grip studies have reported greater hemodynamic recruitment alongside less accurate force regulation in older adults (Berger et al. 2020), and grip-force magnitude itself influences motor-system activation (Noble et al. 2011). Age-related differences in neurovascular coupling provide an additional source of variation in response amplitude and timing (Csipo et al. 2019).

The relationship between an aggregate primitive-reflex burden and grasp-evoked hemodynamics is consequently an empirical question. A summed burden score characterizes the extent of elicitable responses across the examined battery; it does not establish a single underlying physiological mechanism. Likewise, fNIRS general-linear-model beta coefficients quantify the fitted task-related hemodynamic response rather than directly measuring neuronal inhibition. Anatomical interpretation must also reflect the available localization information. Template-based probe placement can guide region selection, but Brodmann-area specificity requires appropriate anatomical and optical-sensitivity information beyond scalp labels alone (Koessler et al. 2009; Tsuzuki and Dan 2014; Zimeo Morais et al. 2018).

The primary research question was whether greater aggregate expression of primitive reflexes and frontal release signs was associated with differences in cortical hemodynamic responses during voluntary grasping in older adults. To our knowledge, no previous study has related a standardized primitive reflex profile to task-evoked cortical hemodynamics in this population. We addressed this question in an exploratory cross-sectional analysis of total PRB and baseline fNIRS task beta coefficients during left- and right-hand grasping. The focused analyses evaluated oxygenated-hemoglobin responses in the perirolandic channels contralateral to each active hand, motivated by the role of BA4 and neighboring sensorimotor cortex. Whole-montage summaries, deoxygenated and total hemoglobin, and a multiplicity-controlled survey of all long-separation channels characterized the broader pattern. Sensitivity analyses examined demographic and dementia-related adjustment and uncertainty in incomplete reflex profiles. The objective was to establish the direction, magnitude, spatial distribution, and robustness of the observed associations, providing an empirical basis for more specifically localized studies of reflex expression and voluntary motor function.

Materials and methods

Study design and participants

This exploratory cross-sectional analysis used the baseline assessment wave (November 2025) of a six-month, non-randomized seated sensorimotor exercise study in older adults with and without diagnosed dementia (Stephens-Sarlós et al. 2026b). The original fNIRS measurement cohort comprised 65 community-dwelling or day-care-attending adults aged 60 years or older from six centers in Budapest and Győr, Hungary. Eligibility required regular attendance at the center, the ability to understand simple verbal instructions, and the ability to undertake the motor and fNIRS assessments. Reflex examination and fNIRS were part of a fixed assessment sequence, with approximately 20 minutes between assessments. Only baseline reflex observations and baseline task-related fNIRS coefficients were analyzed here; follow-up measurements did not enter the analyses. Reporting was guided by STROBE (von Elm et al. 2007); the completed reporting checklist is provided in Online Resource 2.

All 65 participants originally included in the fNIRS measurement cohort contributed baseline recordings; participant-level beta and standard-error exports were available for all 65. Records were linked using pseudonymous participant identifiers. Identifier formats differed for 12 records and were reconciled before linkage. Clinical variables were obtained from the curated baseline dataset. PRB required all 29 component scores: two participants each lacked one component and were excluded from the complete-profile primary analyses, leaving 63 participants. One of these 63 lacked age, giving 62 complete cases for covariate-adjusted models. No missing component was assigned zero in the primary analysis. No a priori sample-size calculation was performed, and this analysis was not preregistered.

The Scientific Ethics Committee of the University Scientific Advisory Board, Széchenyi István University, approved the protocol, including fNIRS acquisition and clinical–fNIRS linkage (SZE/ETT-19/2025 [V.12.], 12 May 2025). The study followed the Declaration of Helsinki. Participants without diagnosed dementia provided written informed consent; guardian consent and participant assent were obtained when applicable for participants with dementia. Data were pseudonymized before analysis. Documented dementia was based on an available neurologist's specialist opinion rather than a research-team diagnosis.

Aggregate primitive reflex burden

The study profile comprised 17 reflex types and 29 scored components. Twelve were examined bilaterally: symmetric tonic neck, asymmetric tonic neck, tonic labyrinthine forward, tonic labyrinthine backward, spinal Galant, Moro, palmar grasp, Babkin, Babinski, plantar grasp, rooting, and plantar tonic reflex (PTR). Five additional components were sucking, Perez, fear paralysis, glabellar, and snouting responses. Each component was scored 0 for absent, 1 for

partially elicitable, and 2 for fully elicitable. PRB was the unweighted sum of all 29 components, with a theoretical range of 0–58; greater scores indicated greater aggregate reflex expression. Primitive reflexes and frontal release signs were represented within this single composite, not analyzed as separate burden scores. The plantar tonic reflex is present from the early months of life and is not specific to infancy; it was included as part of this broader sensorimotor reflex profile.

Eight assessors performed reflex examinations after a registered 130-hour continuing-education course. Assessors were not informed of documented dementia status and did not have access to other clinical assessment results. Explicit elicitation procedures and scoring anchors are available in the standardized protocol (Stephens-Sarlós and Stephens 2026); inter-rater (weighted κ 0.91–1.00) and intra-rater (κ 0.91–0.98) reliability of the protocol in 565 participants are reported in a validation preprint (Stephens-Sarlós et al. 2026a). Reliability was not re-estimated in this sample. The present total was treated as a descriptive composite of ordinal observations, rather than a validated interval measure of cortical inhibition.

Acquisition and grasping task

Continuous-wave NIRSport2 systems (NIRx Medical Technologies, Berlin, Germany) acquired 760- and 850-nm signals using Aurora version 2023.9.6 at 5.09 Hz. Caps of 56 or 58 cm were selected according to head circumference. Optodes were placed in the same study-specific bilateral 10–10 configuration in both cap sizes, following the same placement protocol for every participant. The realized montage comprised 16 sources, 15 long-separation detectors, and eight short-separation detectors, producing 46 long-separation and eight short-separation channels. Nominal source–detector distances were 30–41 mm and 7–8 mm, respectively. The study setup and montage are shown in Supplementary Figures S1 and S2 (Online Resource 1).

Participants remained seated and repeatedly squeezed a small soft ball. A custom PsychoPy program presented simultaneous visual and auditory cues and transmitted time-locked event markers to Aurora through Lab Streaming Layer (Peirce et al. 2019). Each cycle comprised 10 seconds of left-hand grasping, 15 seconds of rest, 10 seconds of right-hand grasping, and 15 seconds of rest. Ten cycles yielded 500 seconds of recording, with 100 seconds of active grasping per hand and 300 seconds of rest. Both hand conditions used the same ball, instructions, cueing, acquisition, and processing protocol. All participants were right-handed. Force, movement amplitude, and pace were not instrumentally recorded. The left-before-right order was fixed.

Raw-signal quality assessment

An initial technical evaluation by NIRx (18 May 2026) assessed cardiac-frequency content using power spectral density, scalp coupling index (SCI; Pollonini et al. 2014), and coupling signal-to-

noise ratio (cSNR). Distributions and topographic summaries were examined across dementia and intervention/control subgroups within the broader study protocol. The preliminary assessment reported no general data-quality issues, but did not establish adequate coupling for every participant and channel or equivalent signal quality across subgroups. The present analysis pooled the 65 baseline recordings.

No channels were rejected using SCI or another quality metric, and no task blocks or individual recordings were excluded for quality reasons within the 65-recording sample. All recorded data were retained in the preprocessing and GLM workflows. Thus, the 46 long-separation channels were retained for each participant before the clinical complete-profile exclusions; the eight short-separation channels were used for nuisance-signal correction and were not cortical outcomes. No additional numerical quality-control exclusion thresholds were applied. Supplementary Methods S6 describes the processing settings and the scope of the technical quality evaluation.

Signal processing and beta exports

Participant-level beta coefficients were regenerated in Satori version 2026.9.0.19 (Brain Innovation, Maastricht, the Netherlands/NIRx Medical Technologies), using the same preprocessing workflow for all 65 participants. The processing documentation specifies raw light-intensity conversion to optical density, spike removal (10 iterations, lag setting 5, threshold 3.50, influence 0.50, monotonic interpolation), and temporal derivative distribution repair with high-frequency restoration (Fishburn et al. 2019). Short-separation regression (Gagnon et al. 2011) used one principal component and was applied to HbO and HbR. Temporal processing used a 0.01-Hz Butterworth high-pass filter and Gaussian smoothing with a 0.4-Hz setting. Butterworth low-pass filtering and linear detrending were disabled.

Optical-density-to-concentration conversion used the modified Beer–Lambert law with the Moaveni extinction-coefficient set selected in Satori 2026.9.0.19. Z-transformation was enabled and percentage transformation was disabled. Task events were edited to define the left- and right-hand conditions, and the preprocessed concentration-change data were saved as SNIRF files for the GLM. Preprocessing and GLM workflow logs are retained by the investigators. The processing settings are detailed in Supplementary Methods S6. Pathlength-factor documentation is discussed below.

Satori's Multi-Subject GLM workflow was run on the preprocessed concentration-change SNIRF datasets. The design matrix included separate left- and right-hand task predictors and constant terms for HbO, HbR, and HbT. Task predictors were convolved with a two-gamma hemodynamic response function with onset at 0 seconds, response peak at 6 seconds and dispersion 1, undershoot peak at 16 seconds and dispersion 1, an HRF ratio parameter of 6, and a kernel-width setting of 32. Ordinary least squares was selected, with serial-correlation correction

and its iterative option enabled (Huppert 2016). No separate motion-related, short-channel, or additional physiological nuisance regressors were added to the GLM; short-separation regression was performed during preprocessing.

The combined beta export retained separately estimated participant, channel, hand-condition, and chromophore coefficients; it did not collapse the two task predictors or participants into a group-average response. Export of confound-predictor betas was disabled. The present analyses used the left- and right-hand task beta coefficients rather than first-level contrast statistics. Exported beta values from standardized signals are reported as model coefficients rather than absolute concentration changes. HbT was analyzed from its own exported coefficient and was not reconstructed by adding separately standardized HbO and HbR betas.

The differential pathlength-factor (DPF) setting could not be verified: the available workflow documentation did not explicitly report whether a DPF was applied, and demographic.inf or JSON sidecar files were unavailable. Their absence does not establish that pathlength correction was omitted. The specific serial-correlation model and residual-whitening diagnostics underlying the enabled serial-correlation correction were also not documented. Age-dependent optical scaling and neurovascular variation therefore remain relevant to interpretation (Scholkmann and Wolf 2013; Yücel et al. 2021).

Anatomical regions and outcomes

The motor-focused analysis was motivated by BA4 and adjacent cortex involved in voluntary grasping. Because individual optode digitization, structural MRI registration, and study-specific optical-sensitivity estimates were unavailable, the regions were defined by the recorded 10–10 montage, not by verified Brodmann boundaries. For right-hand grasping, the contralateral left perirolandic set comprised S2–D1, S2–D2, S2–D4, S3–D1, S3–D4, and S4–D4. For left-hand grasping, the available mirrored right set comprised S16–D15, S16–D14, S13–D15, S13–D14, and S14–D14. A right C2–CP2 counterpart was not recorded, so the two sets contained six and five channels, respectively. Channel endpoints and region membership are listed in Supplementary Table S1. These are perirolandic sampling regions, not isolated BA4 measurements. Published cranio-cerebral correspondences for the same 10–10 positions (Koessler et al. 2009) and for the same optode pairs in other fNIRS studies informed the subsequent anatomical interpretation; no new atlas registration or sensitivity simulation was performed for this cohort.

Each participant's arithmetic-mean HbO beta within the contralateral set was the focused outcome for the corresponding hand. Secondary outcomes were whole-montage HbO means across all 46 long channels and the analogous regional and whole-montage HbR and HbT means. All long-channel coefficients were also examined individually for each hand and chromophore.

The eight short-separation channels were excluded from cortical outcomes. Both hands contributed repeated measurements from the same participants, never additional independent participants.

Statistical analysis and sensitivity checks

Analyses used Python 3.12.14, NumPy 2.3.5, pandas 2.2.3, and SciPy 1.17.0. Scores were checked against the stored totals and restricted to the observed 0–2 coding. Continuous variables were summarized with means, standard deviations, medians, interquartile ranges, and ranges. Two-sided Spearman correlations quantified PRB–beta associations. Pointwise percentile 95% confidence intervals used 5,000 participant-level bootstrap resamples, with ties re-ranked in each draw and random seed 20261012. These intervals were not simultaneous multiplicity-adjusted confidence intervals.

Benjamini–Hochberg correction (Benjamini and Hochberg 1995) was applied separately to the two focused contralateral HbO tests and the ten secondary aggregate tests. The exploratory channel survey used one correction across all 276 comparisons (46 channels × two hands × three chromophores). All 276 estimates are reported, and global 276-test q values determine channel-level statistical support. Because every channel estimate is computed from the same 63 participants, channel-level results are correlated and the count of same-signed estimates is a descriptive feature, not a tally of independent confirmations. The focused regions and test families were specified before the current coefficient analyses, but this did not constitute prospective preregistration. Statistical support was defined as $q < 0.05$ within the stated family.

Exported-beta screening examined completeness and channel-wise robust z scores, computed across participants as $0.6745 \times (\text{beta} - \text{channel median})/\text{median absolute deviation}$, with $|z| > 5$ flagged. No outcome-based channel selection was performed. This coefficient-level screening was distinct from raw-signal quality assessment and did not establish the optical quality of every retained channel. HbO aggregation sensitivity used channel medians, symmetric 10% trimmed means, and inverse-standard-error-squared weighted channel means. Weighting used the matching first-level standard-error export and was a sensitivity summary, not a channel-independence assumption or a group-level precision model. Within-person means of the two hand summaries were also examined. With only five or six channels, 10% trimming removes no observations and consequently reproduces the regional arithmetic mean.

Four sensitivity regressions modeled the regional and whole-montage HbO summaries for each hand from PRB, adjusting for age, recorded sex, and diagnosed dementia. PRB and the outcome were standardized within the complete covariate sample; age was centered and sex and dementia were binary indicators. Heteroskedasticity-consistent HC3 covariance estimates used Student t inference with $n - 5$ residual degrees of freedom. A separate four-test correction covered the

PRB coefficients. No other clinical outcome was included. To aid interpretation, PRB was summarized by diagnosed dementia status, and its association with age was examined using Spearman correlation.

Source-sensitivity analyses repeated aggregate correlations using only complete original baseline clinical records, without supplementing missing entries from the curated dataset. To evaluate the two incomplete reflex profiles, the missing left Babinski and left tonic-labyrinthine-forward components were each assigned every possible 0, 1, or 2 score, yielding nine bounded scenarios with 65 participants. Aggregate and full 276-test channel analyses were repeated in each scenario. These analyses bracketed uncertainty and did not replace the complete-profile primary results. Sensitivity estimates were interpreted descriptively; they did not generate additional primary claims.

ChatGPT (OpenAI) assisted with manuscript drafting, statistical-code generation and checking, and preparation of tables and figures from author-supplied data. The authors reviewed and verified the outputs and take responsibility for the final work.

Results

Participants and data integrity

All 65 beta records were linked to unique clinical records. The primary sample comprised 63 participants with complete reflex profiles, including 46 women (73.0%) and 30 people with diagnosed dementia (47.6%). Mean age among 62 with recorded age was 77.16 years (SD 7.11; range 62–93). Mean PRB was 21.44 (SD 9.35), with median 22, interquartile range 15.5–27, and observed range 2–47 (Table 1). Mean PRB was higher in participants with diagnosed dementia (26.30, SD 7.68; n = 30) than in those without (17.03, SD 8.59; n = 33). Its correlation with age was negative but did not reach nominal statistical significance ($\rho = -0.228$, $p = 0.074$; n = 62). The beta and standard-error workbooks had identical participant and predictor structures; every coefficient was finite and all exported standard errors were positive. No long-channel beta exceeded the prespecified robust-z threshold across the 65 exported participants. The reduction from 65 processed recordings to 63 complete-profile participants, and then to 62 covariate-complete participants, resulted from missing clinical information, not quality-based exclusion of fNIRS recordings.

Motor-focused and whole-montage HbO associations

Higher PRB was associated with lower right-hand HbO in the contralateral left perirolandic region ($\rho = -0.379$, 95% CI −0.586 to −0.143; $p = 0.00217$; $q = 0.00434$). For left-hand grasping, the contralateral right perirolandic association was also negative ($\rho = -0.311$, 95% CI −0.550 to

−0.040; p = 0.01310; q = 0.01310). Fig. 1 displays the participant-level observations. These two tests constituted the focused HbO family.

The whole-montage HbO association was similar for right-hand grasping (ρ = −0.379, 95% CI −0.576 to −0.138; secondary-family q = 0.01502) and for left-hand grasping (ρ = −0.315, 95% CI −0.540 to −0.060; q = 0.02982). Across all 92 channel-by-hand HbO estimates, 90 were negative (these estimates share participants and are not independent). The broad direction of the pattern is visible in Fig. 2. The complete aggregate results are reported in Table 2.

Additional chromophores and spatial findings

Right-hand HbT was negatively associated with PRB both in the contralateral region (ρ = −0.368; q = 0.01502) and across the whole montage (ρ = −0.347; q = 0.01760). Left-hand HbT and all aggregate HbR correlations lacked support after correction. The global 276-test channel survey identified four associations (Table 3). During right-hand grasping, HbO at S2–D2 (C1–CP1; ρ = −0.460; q = 0.02590) and S6–D6 (C5–CP5; ρ = −0.452; q = 0.02590) was lower at higher PRB. Two HbT associations also survived: S2–D4 during right-hand grasping (C1–C3; ρ = −0.427; q = 0.03279) and S4–D6 during left-hand grasping (CP3–CP5; ρ = −0.443; q = 0.02590). No HbR channel association survived global correction. Complete estimates, pointwise confidence intervals, and p and q values are provided in Supplementary Tables S5A–S5F.

Robustness and adjusted estimates

Right-hand HbO estimates remained negative across median, trimmed-mean, and standard-error-weighted aggregation. Regional estimates ranged from −0.400 to −0.379, and whole-montage estimates from −0.402 to −0.386. Left-hand estimates were more variable; the whole-montage channel median gave ρ = −0.248 and nominal p = 0.0501. The within-person two-hand HbO mean was associated with PRB at ρ = −0.394 for the contralateral summaries and ρ = −0.363 for the whole montage. These were descriptive sensitivity analyses (Supplementary Table S3).

Repeating aggregate calculations using the complete original baseline clinical records gave 62 participants and closely similar estimates: contralateral HbO ρ = −0.384 for right-hand and −0.314 for left-hand grasping. In all nine bounded scenarios including the two incomplete profiles, S2–D2 and S6–D6 right-hand HbO remained supported after correction across 276 tests (ρ ranges −0.470 to −0.466 and −0.469 to −0.464, respectively; q = 0.0122–0.0139). The two primary-sample HbT channel discoveries did not survive global correction in any of those scenarios (Supplementary Table S4).

All four adjusted PRB coefficients had 95% HC3 confidence intervals that included zero (Table 4). For right-hand contralateral HbO, the standardized PRB coefficient was −0.224 (95% CI −0.543 to 0.096; p = 0.167); for left-hand contralateral HbO it was −0.142 (95% CI −0.576 to 0.293; p = 0.516). In every model the dementia coefficient was negative (−0.37 to −0.59 SD of

the outcome; Supplementary Table S2), and the adjusted PRB coefficients were smaller in magnitude than the corresponding unadjusted rank correlations, although a standardized regression coefficient and a Spearman ρ are not strictly comparable. These estimates did not establish an association independent of age, sex, and diagnosed dementia. Because the covariates were entered together, these models do not isolate the contribution of dementia to the attenuation of the PRB coefficient. Full covariate coefficients appear in Supplementary Table S2.

Results tables

Table 1. Characteristics of the complete-profile analysis sample

Characteristic	n	Mean (SD) or n (%)	Median (IQR)	Range
Age in years	62	77.16 (7.11)	76.00 (72.25–83.00)	62.00–93.00
Primitive reflex burden	63	21.44 (9.35)	22.00 (15.50–27.00)	2.00–47.00
Women	63	46 (73.0%)	—	—
Diagnosed dementia	63	30 (47.6%)	—	—
Right-hand perirolandic HbO	63	0.629 (0.450)	0.639 (0.305–1.025)	−0.222–1.335
Left-hand perirolandic HbO	63	0.724 (0.402)	0.797 (0.415–1.049)	−0.221–1.508
Right-hand whole-montage HbO	63	0.387 (0.303)	0.389 (0.177–0.610)	−0.229–1.070
Left-hand whole-montage HbO	63	0.371 (0.308)	0.386 (0.183–0.621)	−0.386–0.911

PRB theoretical range: 0–58. Beta values are coefficients from standardized hemodynamic signals. All regional summaries are contralateral to the active hand; the left region has six channels and the right region five.

Table 2. Aggregate primitive reflex burden and regional or whole-montage beta coefficients

Hand	Summary	Hb	ρ	95% CI	p	BH q
Right	Perirolandic	HbO	−0.379	−0.586 to −0.143	0.00217	0.00434
Right	Whole montage	HbO	−0.379	−0.576 to −0.138	0.00216	0.01502
Right	Perirolandic	HbR	−0.028	−0.262 to 0.217	0.82989	0.83164
Right	Whole montage	HbR	−0.074	−0.333 to 0.184	0.56181	0.70226
Right	Perirolandic	HbT	−0.368	−0.569 to −0.140	0.00300	0.01502
Right	Whole montage	HbT	−0.347	−0.564 to −0.098	0.00528	0.01760
Left	Perirolandic	HbO	−0.311	−0.550 to −0.040	0.01310	0.01310
Left	Whole montage	HbO	−0.315	−0.540 to −0.060	0.01193	0.02982

Hand	Summary	Hb	ρ	95% CI	p	BH q
Left	Perirolandic	HbR	0.082	−0.171 to 0.323	0.52323	0.70226
Left	Whole montage	HbR	0.027	−0.209 to 0.259	0.83164	0.83164
Left	Perirolandic	HbT	−0.113	−0.364 to 0.152	0.37592	0.62653
Left	Whole montage	HbT	−0.186	−0.422 to 0.072	0.14499	0.28999

n = 63 throughout. The two perirolandic HbO rows form the focused two-test family; the remaining ten rows form the secondary family. Confidence intervals are pointwise 5,000-resample participant-bootstrap intervals. q values are family-specific.

Table 3. Channel-level associations supported after correction across all 276 tests

Channel and endpoints	Hand	Hb	ρ	95% CI	p	BH q
S2-D2 C1–CP1	Right	HbO	−0.460	−0.644 to −0.235	0.00015	0.02590
S6-D6 C5–CP5	Right	HbO	−0.452	−0.626 to −0.247	0.00020	0.02590
S4-D6 CP3–CP5	Left	HbT	−0.443	−0.641 to −0.219	0.00028	0.02590
S2-D4 C1–C3	Right	HbT	−0.427	−0.622 to −0.187	0.00048	0.03279

n = 63. Endpoints denote 10–10 scalp positions and do not establish specific Brodmann-area localization. Both HbO discoveries remained supported in all nine bounded missing-item scenarios; both HbT discoveries lost global FDR support in those scenarios.

Table 4. Demographic sensitivity of the PRB–HbO associations

Hand	HbO summary	n	Std. β	95% HC3 CI	p	BH q
Right	Perirolandic	62	−0.224	−0.543 to 0.096	0.167	0.251
Right	Whole montage	62	−0.242	−0.544 to 0.060	0.114	0.251
Left	Perirolandic	62	−0.142	−0.576 to 0.293	0.516	0.516
Left	Whole montage	62	−0.270	−0.677 to 0.136	0.189	0.251

Models include PRB, age, female sex, and diagnosed dementia with an intercept. PRB and HbO were standardized within the 62 complete cases. HC3 covariance used Student t inference with 57 residual degrees of freedom; q values cover the four PRB coefficients.

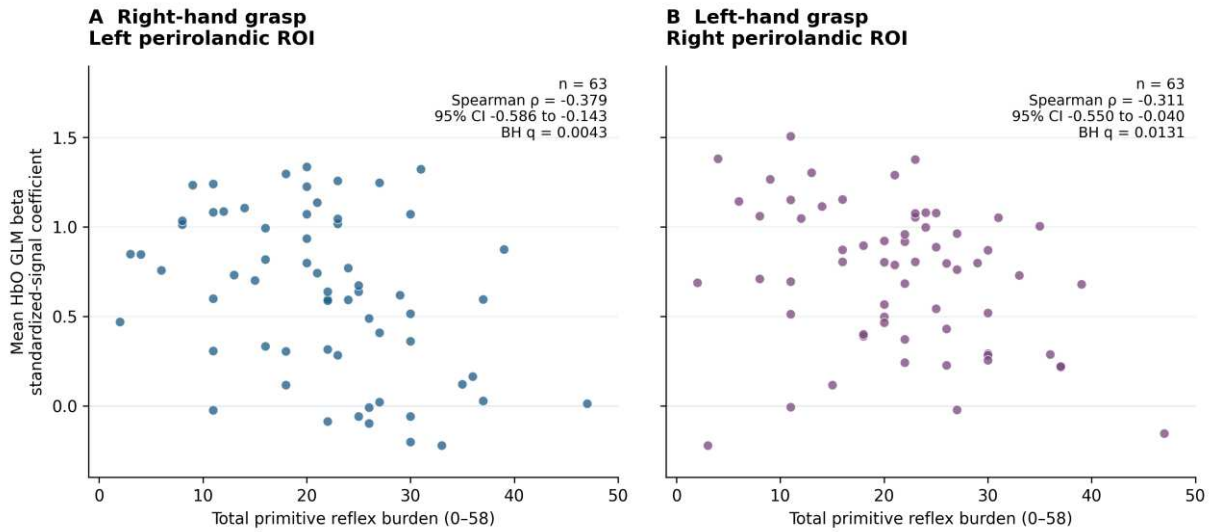

Fig. 1 Aggregate primitive reflex burden and contralateral perirolandic HbO. Each point represents one participant with a complete 29-component reflex profile (n = 63). Panel A shows right-hand grasping over the six-channel left region; panel B shows left-hand grasping over the five-channel right region. Beta values are fitted coefficients from standardized concentration-change signals. Spearman correlations, pointwise bootstrap confidence intervals, and q values from the focused two-test family are displayed. No regression fit is imposed on these rank-based associations

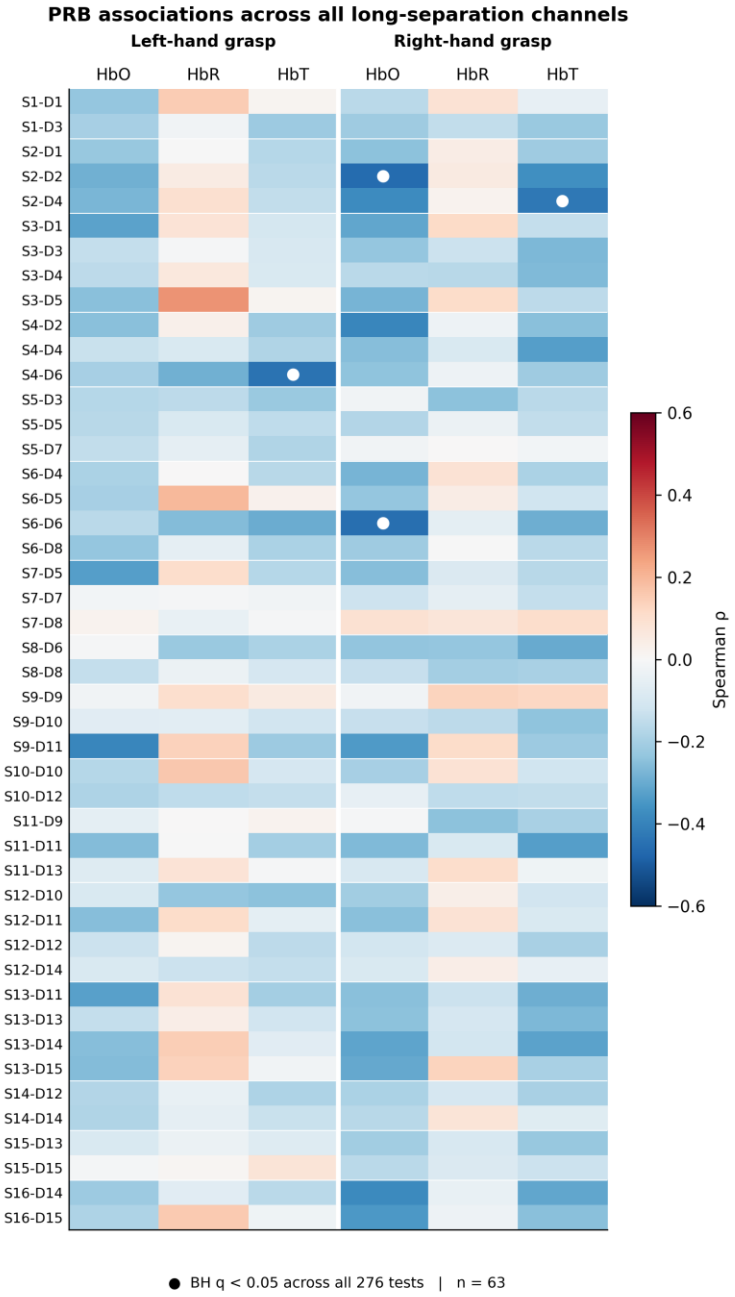

Fig. 2 Full channel-level association pattern. Colors show Spearman correlations between PRB and each long-channel beta (n = 63). White dots identify q < 0.05 after a single Benjamini–Hochberg correction across 276 comparisons. HbO = oxygenated hemoglobin; HbR = deoxygenated hemoglobin; HbT = total hemoglobin. Channel labels are source–detector identifiers and do not indicate atlas-verified cortical areas

Discussion

Principal findings

Greater total primitive-reflex burden was associated with lower grasp-evoked oxygenated-hemoglobin beta coefficients in both task-motivated contralateral perirolandic regions. Among the 63 participants with complete 29-component reflex profiles, the associations were moderate for right-hand grasping over the left region ($\rho = -0.379$) and smaller for left-hand grasping over the right region ($\rho = -0.311$); both survived correction within the focused two-test family. Whole-montage associations were similar. The exploratory survey identified four channel-level associations after correction across 276 tests, comprising two HbO and two total-hemoglobin findings. No HbR association survived correction. Together, these results identify an association between a broad behavioral reflex profile and standardized grasp-related HbO task coefficients, with convergent findings at regional and whole-montage levels. To our knowledge, this is the first report of a task-evoked cortical hemodynamic correlate of a standardized primitive reflex profile in older adults; a recent perspective proposed exactly this type of fNIRS test during grasping but reported no data (Stephens-Sarlós et al. 2026c).

BA4 rationale and the spatial pattern

The emphasis on BA4 follows directly from the voluntary grasp task. Primary motor cortex participates in the production of hand movements, while sensory and premotor regions contribute to their coordination and adjustment (Ehrsson et al. 2000). The two robust HbO associations occurred during right-hand grasping at S2–D2 (C1–CP1; $\rho = -0.460$) and S6–D6 (C5–CP5; $\rho = -0.452$), both over the left hemisphere.

The consistent 10–10 configuration in the 56- and 58-cm caps supports approximate anatomical interpretation of these channels. S2–D2 lies over the dorsal perirolandic region. The cortical projection of the C1 and CP1 positions themselves lies in the central and parietal region, where projection variability across individuals is greatest (Koessler et al. 2009). Published mapping of the same C1–CP1 pair (midpoint MNI −27, −36, 71) identifies postcentral gyrus/BA3 cortex (Iester et al. 2023), while another study assigns the same coordinate to BA4 with a specificity of only 31.6%, which its authors themselves describe as low (Xia et al. 2023). The differing labels for an identical coordinate illustrate uncertainty in assigning this channel to a single cortical area from published mappings. Taken together, these correspondences support a left sensorimotor interpretation with possible BA4 contribution. The neighboring C1–C3 pair (S2–D4), which carried a right-hand HbT association, is mapped to precentral gyrus/BA4 by both sources (Iester et al. 2023; Xia et al. 2023), making it the most M1-like of the four supported channels. S6–D6 lies over the lateral central-to-centroparietal region; published mapping of C5–CP5 (midpoint MNI −66, −30, 28; overlap probability 0.73) identifies the supramarginal gyrus in the inferior parietal cortex, corresponding approximately to BA40 (Zhang et al. 2018). These published

mappings provide anatomical context for the standard montage. They were derived in other participants with other cap placements and, in one case, with 10/5-system positions (Zhang et al. 2018); their coordinates and specificity estimates were not treated as participant-specific measurements, and neither channel was considered to sample a single Brodmann area exclusively.

These regions have complementary roles in grasping. Primary somatosensory cortex processes information about skin contact and limb position or movement, providing feedback about the hand and its interaction with an object (Rausch et al. 1998). Primary motor cortex contributes to voluntary hand and finger movements and to the anticipatory scaling and timing of grip force; experimental perturbation of M1 and S1 produces distinguishable changes in precision grip–lift performance (Schabrun et al. 2008). The left supramarginal gyrus contributes to specifying appropriate finger placement for object use: stimulation of this region selectively slowed judgments about where the thumb and index finger should contact an object (Andres et al. 2017). Repeated ball squeezing provides a plausible setting for these interacting sensory, motor, and hand–object processes. The cited precision-grip and object-use tasks differ from the present squeezing task, so their findings provide a functional rationale without establishing which particular process explains the PRB–HbO associations.

The total-hemoglobin findings involved S2–D4 during right-hand grasping and S4–D6 during left-hand grasping. S4–D6 was ipsilateral to the active left hand and was outside the focused contralateral region; the HbO finding at S6–D6 also lay outside the focused perirolandic set. Alongside the two robust HbO findings, their spatial distribution motivates investigation of the wider sensorimotor network, including sensory feedback as well as motor output. More precise localization would require registration or optical-sensitivity modeling of the actual montage (Tsuzuki and Dan 2014; Zimeo Morais et al. 2018).

Hand conditions and hemoglobin measures

The negative regional HbO associations in both hand conditions suggest that the finding was not restricted to performance with the dominant right hand. Their consistency is informative, although the two estimates come from the same participants and do not constitute independent replication. The numerically stronger right-hand association cannot establish a laterality difference without a direct comparison. Similarly, comparable regional and whole-montage correlations show consistency across aggregation levels but do not demonstrate motor-region specificity. Total-hemoglobin associations provided some additional information, particularly for right-hand grasping, but require more cautious emphasis. Both channel-level HbO discoveries remained supported ($q < 0.05$) under all nine bounded scenarios for the two incomplete reflex profiles; the two HbT discoveries did not retain that level of robustness. The HbT findings were therefore less robust and remain exploratory. The absence of supported HbR associations also

means that the observed pattern was not reproduced across all hemoglobin measures. An association involving HbO without a corresponding supported HbR association may reflect differences in sensitivity between chromophores; it also leaves open a contribution from systemic or extracerebral blood-volume effects that short-separation regression may not fully remove (Yücel et al. 2021).

Relation to previous evidence

These findings extend previous associations between primitive-reflex measures and physical function in older adults by relating the aggregate reflex profile to a task-evoked physiological measurement (Stephens-Sarlós et al. 2025). They also connect two previously separate lines of evidence. Clinically, multiple frontal release signs predict incident dementia in cognitively intact older adults (Bojarski et al. 2026) and higher reflex counts accompany poorer cognitive screening performance (Horváth-Pápai et al. 2025). Physiologically, clinical features of motor disorders have been linked to altered regional HbO responses during hand grasping using an analytic approach similar to ours, with covariate adjustment and false-discovery-rate control (Wang et al. 2026). The present data add a cortical hemodynamic correlate of reflex burden to the first line and a behavioral reflex correlate of grasp-evoked activation to the second. A lower fitted HbO coefficient in the standardized signals could reflect differences in motor recruitment, sensory processing, task execution, or the vascular response accompanying neural activity. Existing motor-aging research helps frame these alternatives: older adults can exhibit greater hemodynamic recruitment despite poorer grip-force control (Berger et al. 2020), and recruitment varies with force demands (Noble et al. 2011). Age-related neurovascular differences further affect the recorded response (Csipo et al. 2019). Because grip force was not measured, a lower HbO coefficient at higher PRB could equally reflect weaker or less sustained squeezing, consistent with the lower handgrip strength previously associated with reflex counts (Stephens-Sarlós et al. 2025). Consequently, the negative association is a consistent descriptive feature of the present beta-level analyses, while its functional meaning remains a target for subsequent investigation. It provides a concrete relationship to test within models of distributed hierarchical inhibitory control and sensorimotor regulation (Stephens-Sarlós and Szabo 2026), without requiring the summed reflex score or HbO amplitude to represent a direct measure of inhibitory neurotransmission.

Strengths and limitations

Strengths include the examination of both hand conditions, a standardized reflex assessment with documented reliability, a complete-profile primary analysis, and explicit separation of focused regional tests from the broader channel survey. Reporting all channels and chromophores reduces selective emphasis. The scoring audit and bounded analyses of incomplete profiles also clarify which findings depend on missing-item assumptions. Preserving the participant as the

unit of analysis avoids treating the large number of channel measurements as independent participants.

Several limitations define the inference. This observational cross-sectional analysis cannot establish temporal order, causality, or prognostic value. The sample was modest and heterogeneous, and all adjusted PRB coefficients had confidence intervals spanning zero after accounting for age, sex, and diagnosed dementia. Thus, an association independent of these characteristics was not established. Diagnosed dementia was present in almost half the sample and may be related to both primitive reflex expression and cortical hemodynamics. With 30 participants with and 33 without diagnosed dementia, the study provides limited precision for separating these relationships. These models should be interpreted alongside the unadjusted estimates rather than attributed automatically to either confounding or insufficient precision. Generalizability to older adults outside the participating centers, to populations with different dementia prevalence, and to individuals unable to follow the task instructions remains uncertain. The composite combines ordinal responses with different physiological substrates, and its total cannot be assumed to represent a single latent neural process. In addition, the examiners were trained in, and the composite derives from, an assessment framework developed by the first author (see Competing interests); independent replication with examiners trained elsewhere would strengthen the finding.

Measurement limitations are also consequential. Grasp force, pace, movement amplitude, and task compliance were not instrumentally quantified; the fixed left-before-right sequence leaves hand condition partly entangled with order effects. The 10-s task blocks separated by 15-s rest intervals are short relative to the modeled hemodynamic response (undershoot peak at 16 s), so the convolved left- and right-hand predictors overlap and the rest periods may not have permitted full return to baseline; this reduces the separability of the two hand coefficients and should be addressed with longer rest intervals or jittered timing in future designs. Anatomical interpretation relied on standard optode positions and published correspondences rather than participant-specific cortical registration, and the two regional channel sets were not identical in size. The documented workflow addressed motion and superficial physiology through spike removal, TDDR, and one-component short-separation regression, and serial-correlation correction was enabled in the GLM. However, no channel, block, or recording was excluded on signal-quality grounds. The preliminary descriptive quality report did not establish equivalent signal quality across subgroups or adequate coupling for every channel. The DPF setting and detailed residual diagnostics were not documented in the available processing records; beta and standard-error exports alone cannot establish raw event timing or first-level model adequacy. Residual physiological and movement-related contributions remain possible. Transparent reporting of

these elements is especially relevant to interpreting fNIRS measurements in heterogeneous older populations (Yücel et al. 2021).

In future studies, we aim to obtain both fNIRS and fMRI measurements from the same participants during comparable voluntary grasping tasks, to assess whether fMRI findings corroborate or challenge the associations between primitive reflex expression and task-evoked cortical responses observed here.

Implications for further research

A focused replication should preregister the regional and channel-level comparisons, instrument grip force and timing, counterbalance hand order, use longer or jittered rest intervals, and document raw-signal quality and preprocessing. Individual optode localization would allow BA4 to be distinguished more precisely from adjacent somatosensory and premotor cortex. Concurrent systemic physiology and a vascular-reactivity measure would help interpret response amplitude, while a larger cohort could evaluate whether the relationship persists within dementia strata. Because the parent study includes a six-month sensorimotor intervention during which reflex burden declined (Stephens-Sarlós et al. 2026b), repeating the fNIRS task at follow-up would test whether within-person change in PRB is accompanied by change in grasp-evoked HbO, a far stronger test than the cross-sectional association reported here. The present results identify contralateral regional HbO associations for both hands and two comparatively robust right-hand HbO channel findings as specific targets for that next stage of investigation.

Conclusions

In 63 older adults, greater aggregate primitive reflex and frontal release sign burden was associated with lower standardized grasp-evoked HbO task coefficients in contralateral perirolandic regions for both hands and across the whole montage. Two left-hemisphere channels during right-hand grasping, S2–D2 and S6–D6, survived correction across 276 tests and all nine bounded missing-item scenarios. These findings connect a clinical reflex profile with task-evoked cortical hemodynamic measurements, while leaving their physiological mechanism unresolved. An association independent of age, sex, and diagnosed dementia was not established, and the channel findings do not establish BA4 specificity. The results support a preregistered longitudinal investigation of whether within-person changes in reflex burden are accompanied by changes in grasp-evoked cortical hemodynamics.

Acknowledgments

The authors thank the participating older adults, their relatives and caregivers, and the staff and colleagues who assisted with assessments at the collaborating centers. The authors acknowledge

Széchenyi István University for institutional support and thank Armin Heinecke and Adam Takacs of NIRx for technical guidance concerning the fNIRS system and software.

References

Andres M, Pelgrims B, Olivier E, Vannuscorps G (2017) The left supramarginal gyrus contributes to finger positioning for object use: a neuronavigated transcranial magnetic stimulation study. Eur. J. Neurosci. 46:2835–2843. https://doi.org/10.1111/ejn.13763

Benjamini Y, Hochberg Y (1995) Controlling the false discovery rate: a practical and powerful approach to multiple testing. J. R. Stat. Soc. B 57:289–300. https://doi.org/10.1111/j.2517-6161.1995.tb02031.x

Berger A, Steinberg F, Thomas F, Doppelmayr M (2020) Neural correlates of age-related changes in precise grip force regulation: a combined EEG-fNIRS study. Front. Aging Neurosci. 12:594810. https://doi.org/10.3389/fnagi.2020.594810

Bojarski LG, Jicha GA, Coskun EP, Schmitt FA, Van Eldik L, Abner EL (2026) Frontal release signs and future decline in research participants with intact cognition. JAMA Netw. Open 9(6):e2617060. https://doi.org/10.1001/jamanetworkopen.2026.17060

Csipo T, Mukli P, Lipecz A, Tarantini S, Bahadli D, Abdulhussein O et al (2019) Assessment of age-related decline of neurovascular coupling responses by functional near-infrared spectroscopy (fNIRS) in humans. GeroScience 41:495–509. https://doi.org/10.1007/s11357-019-00122-x

Ehrsson HH, Fagergren A, Jonsson T, Westling G, Johansson RS, Forssberg H (2000) Cortical activity in precision- versus power-grip tasks: an fMRI study. J. Neurophysiol. 83:528–536. https://doi.org/10.1152/jn.2000.83.1.528

Fishburn FA, Ludlum RS, Vaidya CJ, Medvedev AV (2019) Temporal derivative distribution repair (TDDR): a motion correction method for fNIRS. Neuroimage 184:171–179. https://doi.org/10.1016/j.neuroimage.2018.09.025

Gagnon L, Perdue K, Greve DN, Goldenholz D, Kaskhedikar G, Boas DA (2011) Improved recovery of the hemodynamic response in diffuse optical imaging using short optode separations and state-space modeling. Neuroimage 56:1362–1371. https://doi.org/10.1016/j.neuroimage.2011.03.001

Horváth-Pápai A, Tóth EE, Barthalos I, Alföldi Z, Takács J, Ihász F (2025) Primitive reflexes as behavioral biomarkers of cognitive aging: associations with physical activity and resilience—a pilot study. Front. Aging Neurosci. 17:1687512. https://doi.org/10.3389/fnagi.2025.1687512

Huppert TJ (2016) Commentary on the statistical properties of noise and its implication on general linear models in functional near-infrared spectroscopy. Neurophotonics 3:010401. https://doi.org/10.1117/1.NPh.3.1.010401

Iester C, Biggio M, Cutini S, Brigadoi S, Papaxanthis C, Brichetto G et al (2023) Time-of-day influences resting-state functional cortical connectivity. Front. Neurosci. 17:1192674. https://doi.org/10.3389/fnins.2023.1192674

Koessler L, Maillard L, Benhadid A, Vignal JP, Felblinger J, Vespignani H et al (2009) Automated cortical projection of EEG sensors: anatomical correlation via the international 10-10 system. Neuroimage 46:64–72. https://doi.org/10.1016/j.neuroimage.2009.02.006

Noble JW, Eng JJ, Kokotilo KJ, Boyd LA (2011) Aging effects on the control of grip force magnitude: an fMRI study. Exp. Gerontol. 46:453–461. https://doi.org/10.1016/j.exger.2011.01.004
Nuuttila S, Eklund M, Joutsa J, Jaakkola E, Mäkinen E, Honkanen EA et al (2021) Diagnostic accuracy of glabellar tap sign for Parkinson's disease. J Neural Transm 128:1655–1661. https://doi.org/10.1007/s00702-021-02391-3
Peirce J, Gray JR, Simpson S, MacAskill M, Höchenberger R, Sogo H et al (2019) PsychoPy2: experiments in behavior made easy. Behav. Res. Methods 51:195–203. https://doi.org/10.3758/s13428-018-01193-y
Pereira J, Direito B, Lührs M, Castelo-Branco M, Sousa T (2023) Multimodal assessment of the spatial correspondence between fNIRS and fMRI hemodynamic responses in motor tasks. Sci. Rep. 13:2244. https://doi.org/10.1038/s41598-023-29123-9
Pollonini L, Olds C, Abaya H, Bortfeld H, Beauchamp MS, Oghalai JS (2014) Auditory cortex activation to natural speech and simulated cochlear implant speech measured with functional near-infrared spectroscopy. Hear. Res. 309:84–93. https://doi.org/10.1016/j.heares.2013.11.007
Rausch M, Spengler F, Eysel UT (1998) Proprioception acts as the main source of input in human S-I activation experiments: a functional MRI study. Neuroreport 9:2865–2868. https://doi.org/10.1097/00001756-199808240-00034
Schabrun SM, Ridding MC, Miles TS (2008) Role of the primary motor and sensory cortex in precision grasping: a transcranial magnetic stimulation study. Eur. J. Neurosci. 27:750–756. https://doi.org/10.1111/j.1460-9568.2008.06039.x
Scholkmann F, Wolf M (2013) General equation for the differential pathlength factor of the frontal human head depending on wavelength and age. J. Biomed. Opt. 18:105004. https://doi.org/10.1117/1.JBO.18.10.105004
Schott JM, Rossor MN (2003) The grasp and other primitive reflexes. J. Neurol. Neurosurg. Psychiatry 74:558–560. https://doi.org/10.1136/jnnp.74.5.558
Stephens-Sarlós E, Stephens P (2026) Standardized Primitive Reflex Examination Protocol (Version 1) [Data set]. Mendeley Data. https://doi.org/10.17632/k7kyn8v987.1
Stephens-Sarlós E, Szabo A (2026) Primitive reflexes as candidate quantitative readouts of hierarchical inhibitory control across the lifespan. Front. Hum. Neurosci. 20:1860053. https://doi.org/10.3389/fnhum.2026.1860053
Stephens-Sarlós E, Tóth E, Ihász F, Alföldi Z, Somogyi A, Szabo A (2024) Changes in primitive reflexes in older adults and their relationship to mental health indices: an experimental investigation. Exp. Gerontol. 196:112583. https://doi.org/10.1016/j.exger.2024.112583
Stephens-Sarlós E, Horváth-Pápai A, Tóth EE, Ihász F, Somogyi A, Szabo A (2025) Relationship between primitive reflexes, functional fitness, handgrip strength, and physical activity in older adults aged 65 and over. Physiol. Rep. 13:e70229. https://doi.org/10.14814/phy2.70229
Stephens-Sarlós E, Girasek E, Avena N, Boran L, Pagkratidou M, Stephens P et al (2026a) A standardized and validated protocol for primitive reflex assessment: reliable measurements across the lifespan for clinical and research practice. Research Square [Preprint]. https://doi.org/10.21203/rs.3.rs-9031441/v1
Stephens-Sarlós E, Szabo A, Küplen F, Stephens P, Somogyi A, Girasek E (2026b) Seated sensorimotor exercise for functional mobility in older adults with and without diagnosed dementia: a six-month non-randomised controlled study. Research Square [Preprint]. https://doi.org/10.21203/rs.3.rs-11414735/v1

Stephens-Sarlós E, Stephens P, Szabo A (2026c) Primitive-reflex profiling after sport-related concussion: an athlete-centered framework for testing a candidate behavioral state marker. Brain Sci. 16:968. https://doi.org/10.3390/brainsci16090968
Tsuzuki D, Dan I (2014) Spatial registration for functional near-infrared spectroscopy: from channel position on the scalp to cortical location in individual and group analyses. Neuroimage 85:92–103. https://doi.org/10.1016/j.neuroimage.2013.07.025
van Boxtel MPJ, Bosma H, Jolles J, Vreeling FW (2006) Prevalence of primitive reflexes and the relationship with cognitive change in healthy adults: a report from the Maastricht Aging Study. J. Neurol. 253:935–941. https://doi.org/10.1007/s00415-006-0138-7
von Elm E, Altman DG, Egger M, Pocock SJ, Gøtzsche PC, Vandenbroucke JP, for the STROBE Initiative (2007) The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement: guidelines for reporting observational studies. Lancet 370:1453–1457. https://doi.org/10.1016/S0140-6736(07)61602-X
Wang K, Guo J, Liu D, Wu Q, Qiao J (2026) Distinct brain activation patterns linked to clinical symptoms during hand grasping in Parkinson's disease. Front. Aging Neurosci. 18:1895333. https://doi.org/10.3389/fnagi.2026.1895333
Xia N, He C, Wei X, Li Y-A, Lou W, Gu M et al (2023) Altered frontoparietal activity in acoustic startle priming tasks during reticulospinal tract facilitation: an fNIRS study. Front. Neurosci. 17:1112046. https://doi.org/10.3389/fnins.2023.1112046
Yücel MA, von Lühmann A, Scholkmann F, Gervain J, Dan I, Ayaz H et al (2021) Best practices for fNIRS publications. Neurophotonics 8:012101. https://doi.org/10.1117/1.NPh.8.1.012101
Zhang D, Zhou Y, Yuan J (2018) Speech prosodies of different emotional categories activate different brain regions in adult cortex: an fNIRS study. Sci. Rep. 8:218. https://doi.org/10.1038/s41598-017-18683-2
Zimeo Morais GA, Balardin JB, Sato JR (2018) fNIRS Optodes' Location Decider (fOLD): a toolbox for probe arrangement guided by brain regions-of-interest. Sci. Rep. 8:3341. https://doi.org/10.1038/s41598-018-21716-z

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- SupplementJournalofNeuralTransmission.docx