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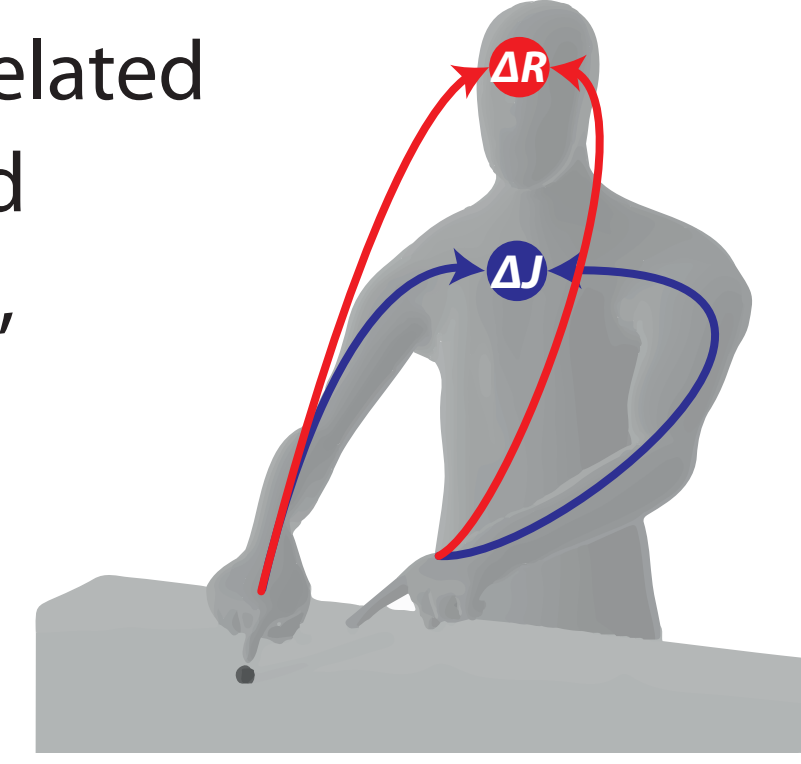
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Proprioceptive deficits and visual compensation in stroke patients: a theoretical approach to reinterpret upper-limb sensory assessments.

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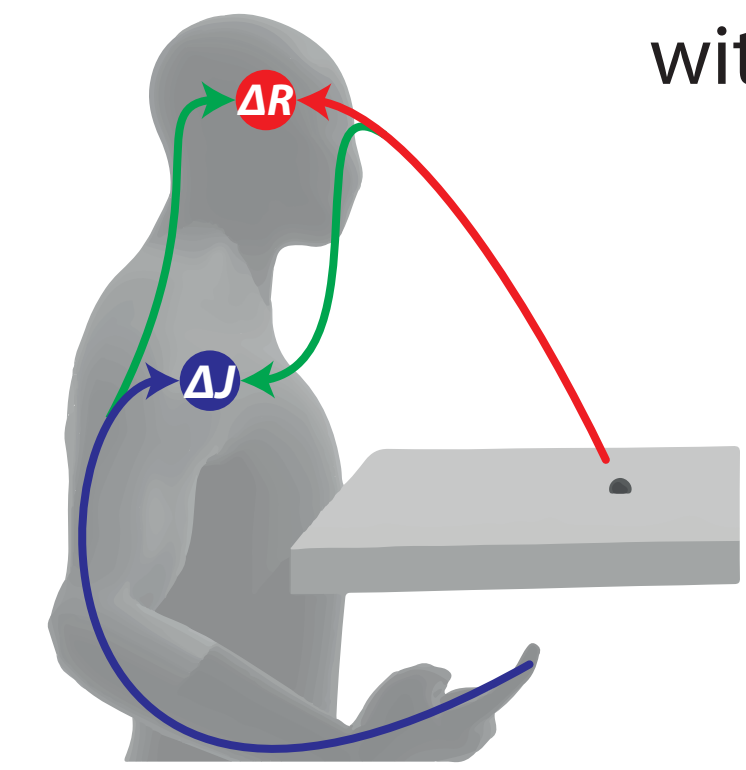
1 Multisensory processing: theoretical framework

When reaching an object, experimental evidence suggests that object-related and hand-related **visual** and **proprioceptive** signals, such as object- and hand-position, are compared in **multiple, parallel reference frames** [1], i.e. in retinal (ΔR) and joint (ΔJ) reference frames respectively.

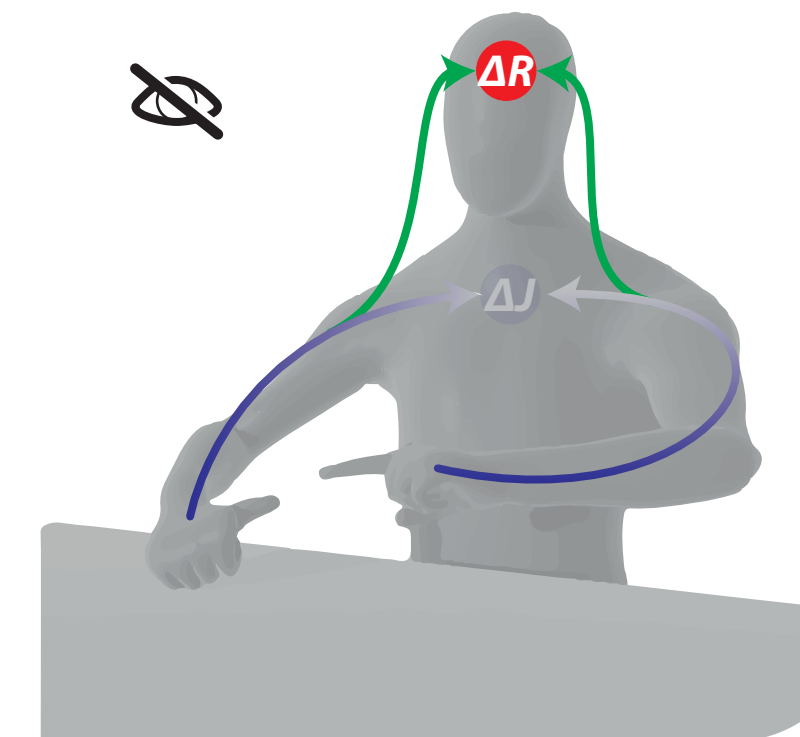


If hand and object positions cannot be compared within the same frame of reference, the brain can encode the position of the hand, originally encoded in the joint space, in the visual space (and vice versa) [1].

This process is referred to as **cross-reference transformations**.



Even in the absence of vision, proprioceptive signals can be **re-encoded** in visual space, or relative to another reference frame (gravity, trunk...) [2].



2 Post-stroke proprioceptive assessments

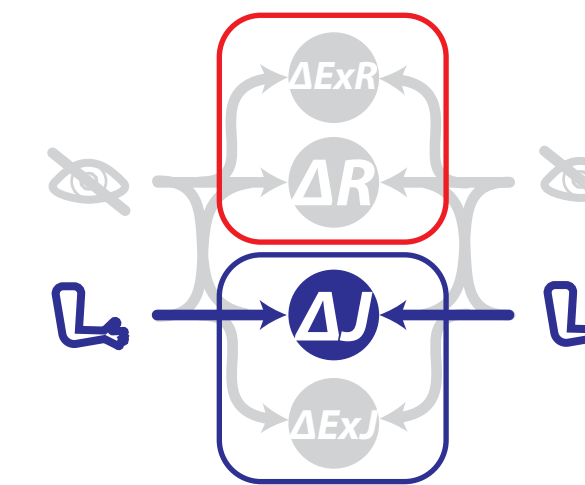
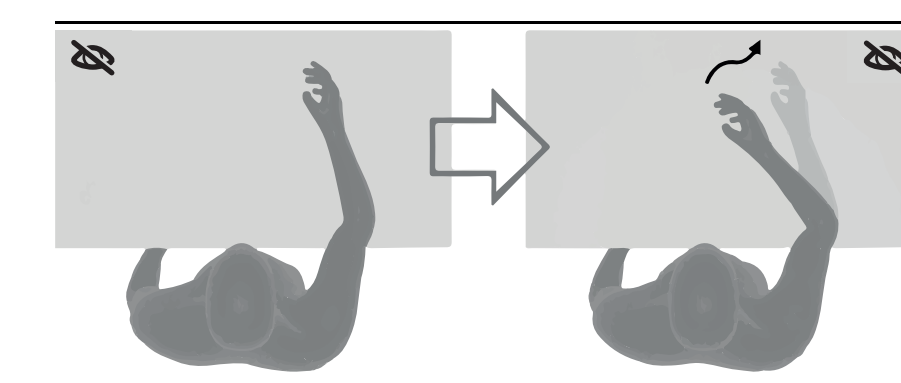
Proprioceptive deficits are very common in post-stroke patients, and **contribute to the motor deficits**.

We postulated that some clinical assessments might **confound proprioceptive and cross-reference functions**.

The latter can add variability in the movement to be performed during the assessment task, and could be, misleadingly, interpreted as a proprioceptive deficit [3].

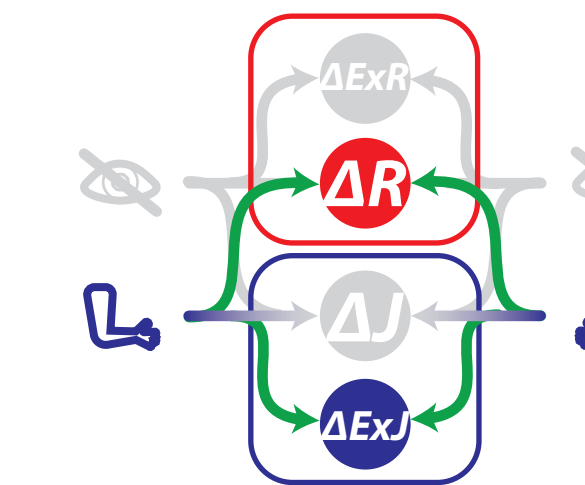
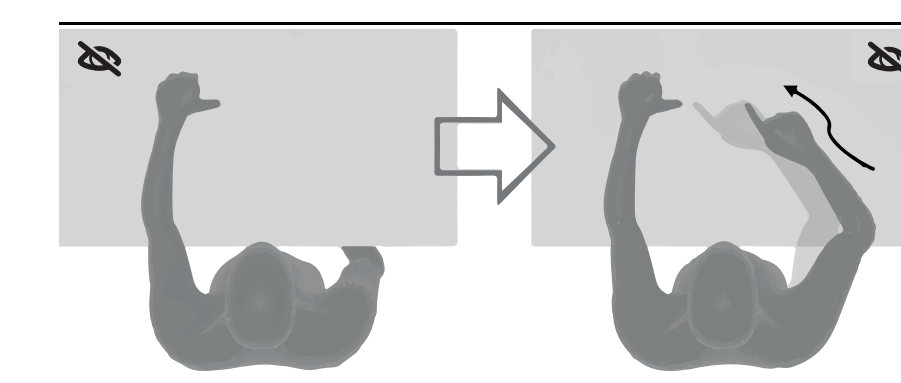
4 categories of clinical tests were identified:

Within-arm (W-A_p)
(e.g. position matching task)



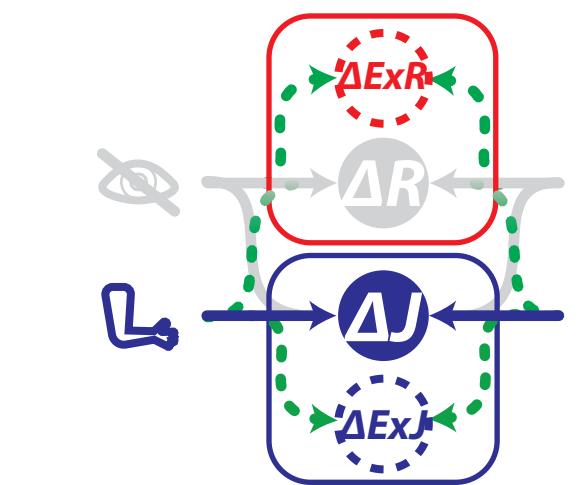
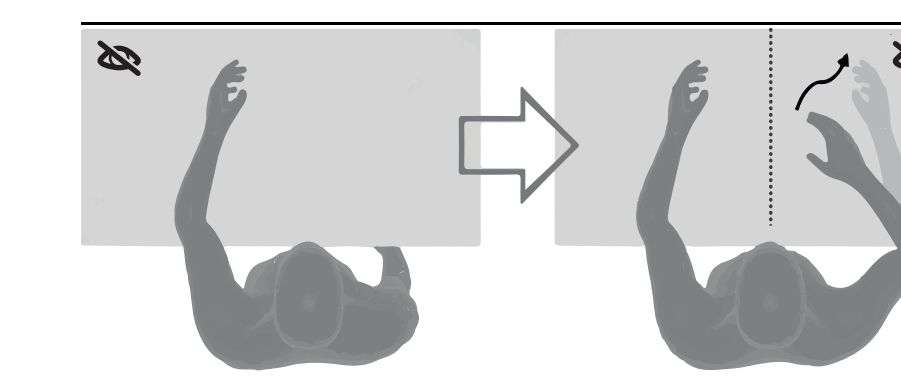
Direct **joint angle** comparison (ΔJ)

Between-arms asymmetric (aB-A_p)
(e.g. thumb localizing task)



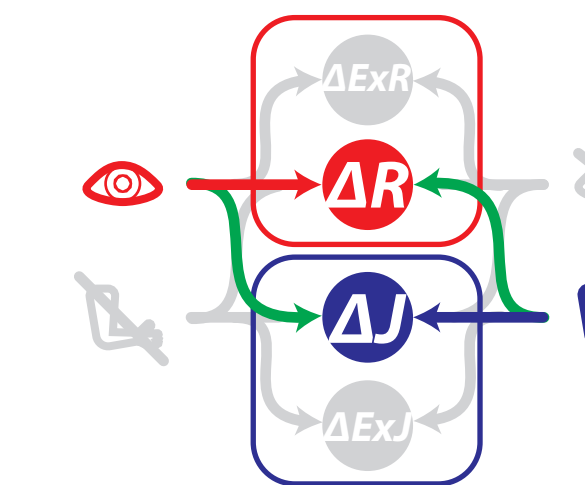
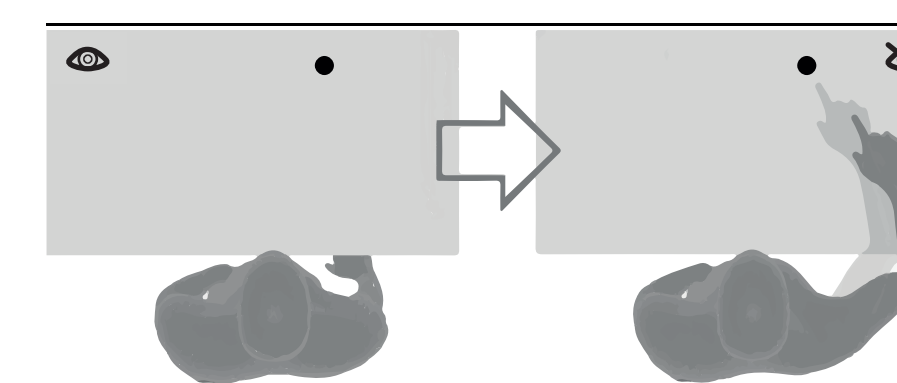
Indirect **joint angle** comparison (ΔEx)
Direct **retinal** (reconstructed) comparison (ΔR)

Between-arms symmetric (sB-A_p)
(e.g. mirror matching task)



Direct **joint angle** comparison (ΔJ)
Indirect **retinal** (reconstructed) comparison (ΔExR)

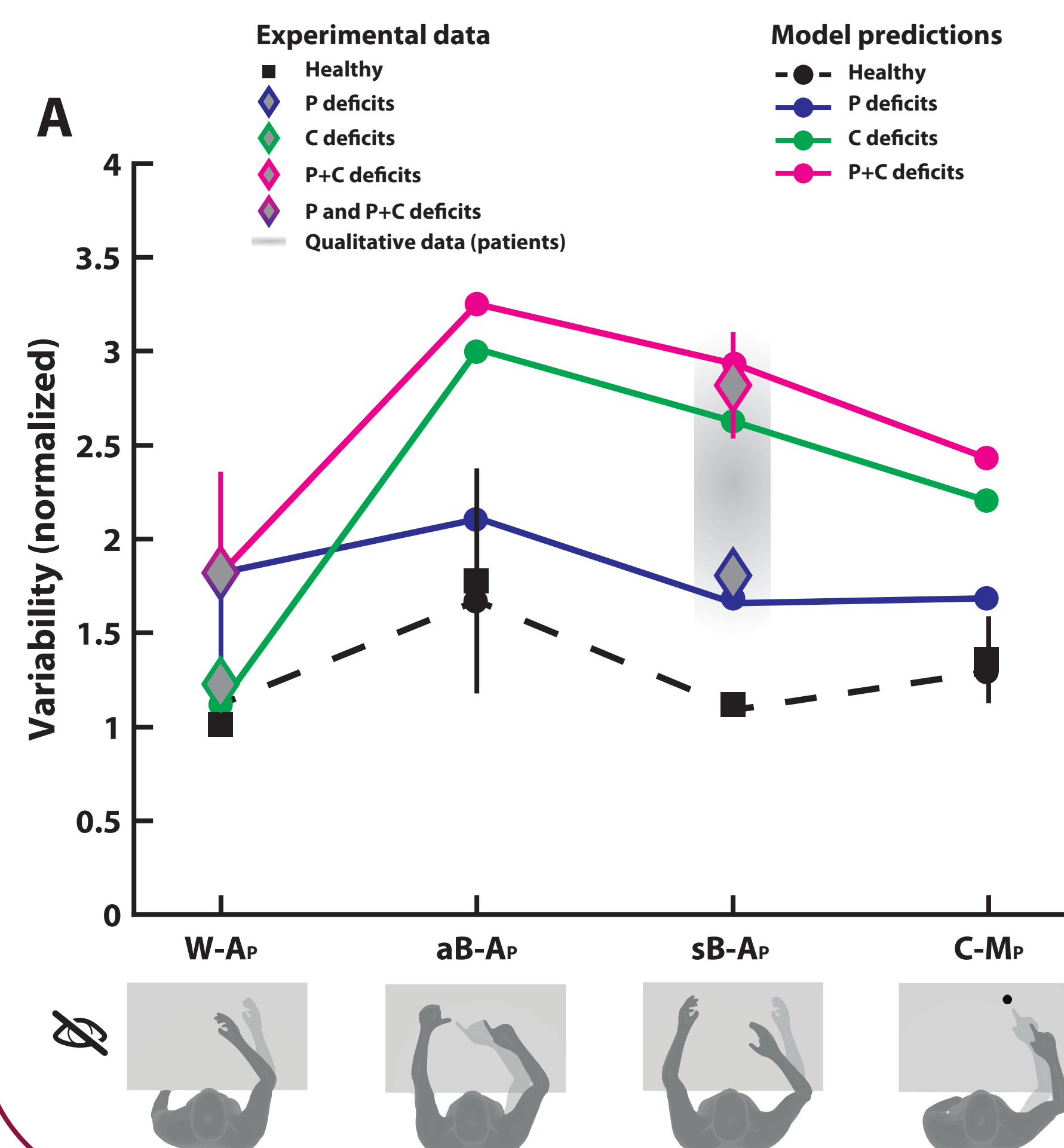
Cross-modal (C-M_p)
(e.g. reaching task eyes closed)



Direct **joint angle** (reconstructed) comparison (ΔJ)
Direct **retinal** (reconstructed) comparison (ΔR)

3 Results: reinterpretation of experimental observations

This **categorization of clinical tests**, together with **optimal sensory integration modeling**, can reconcile the apparently contradictory results of a large number of clinical studies and can explain why different tests lead, in the same patients, to different outcomes.



Based on the literature, we identified 3 categories of post-stroke sensory deficits:

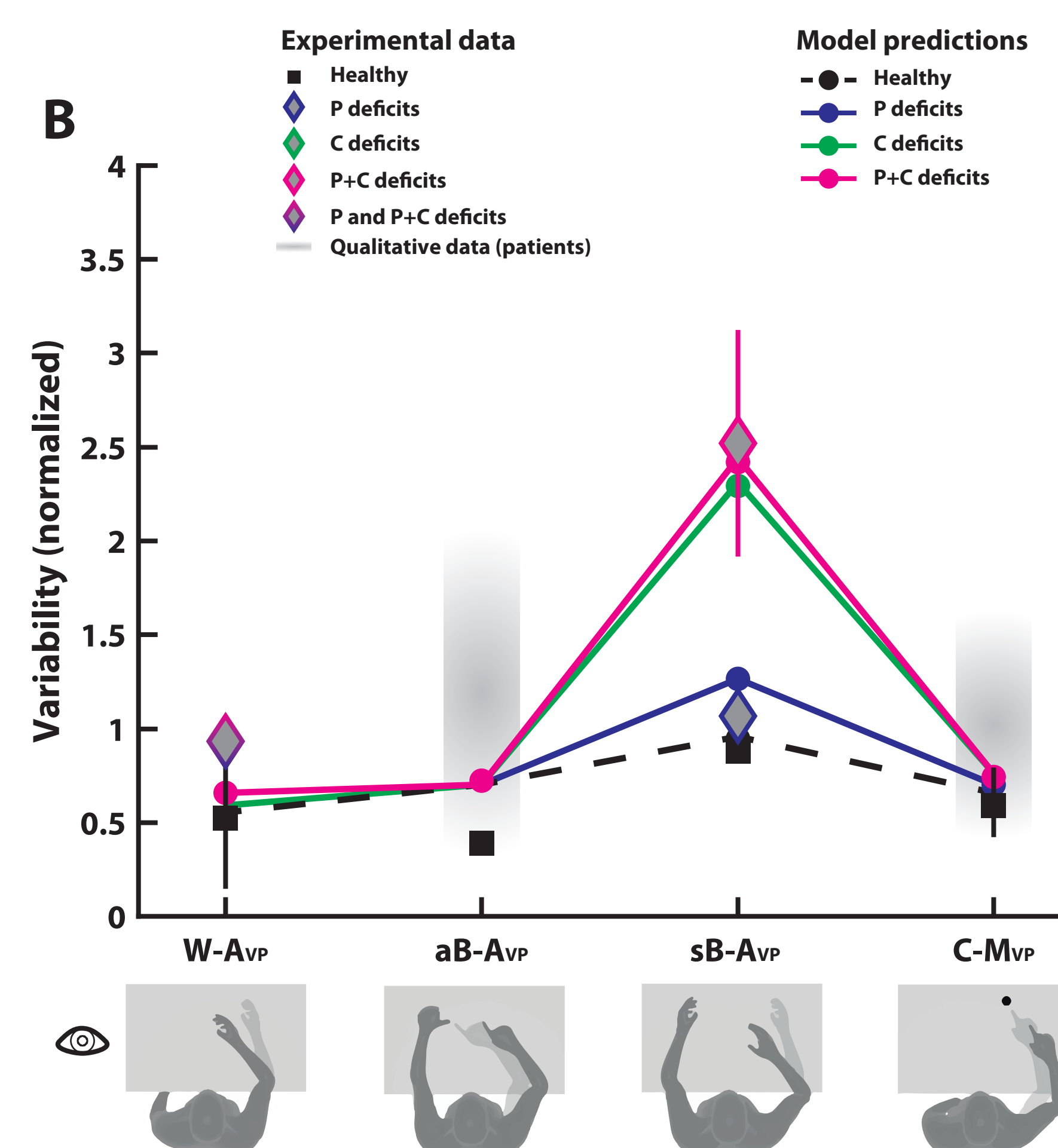
- **Purely proprioceptive (P)**
- **Purely cross-reference (C)**
- **Mixed (P+C)**

A. Proprioceptive tasks:

We predicted the variability of the behavioral performance of stroke patients in the 4 categories of tasks depending on the sensory deficit (P, C or P+C).

B. Visuo-proprioceptive tasks:

This theoretical approach can also predict the ability or inability [4] of patients to compensate for the proprioceptive deficits using vision.

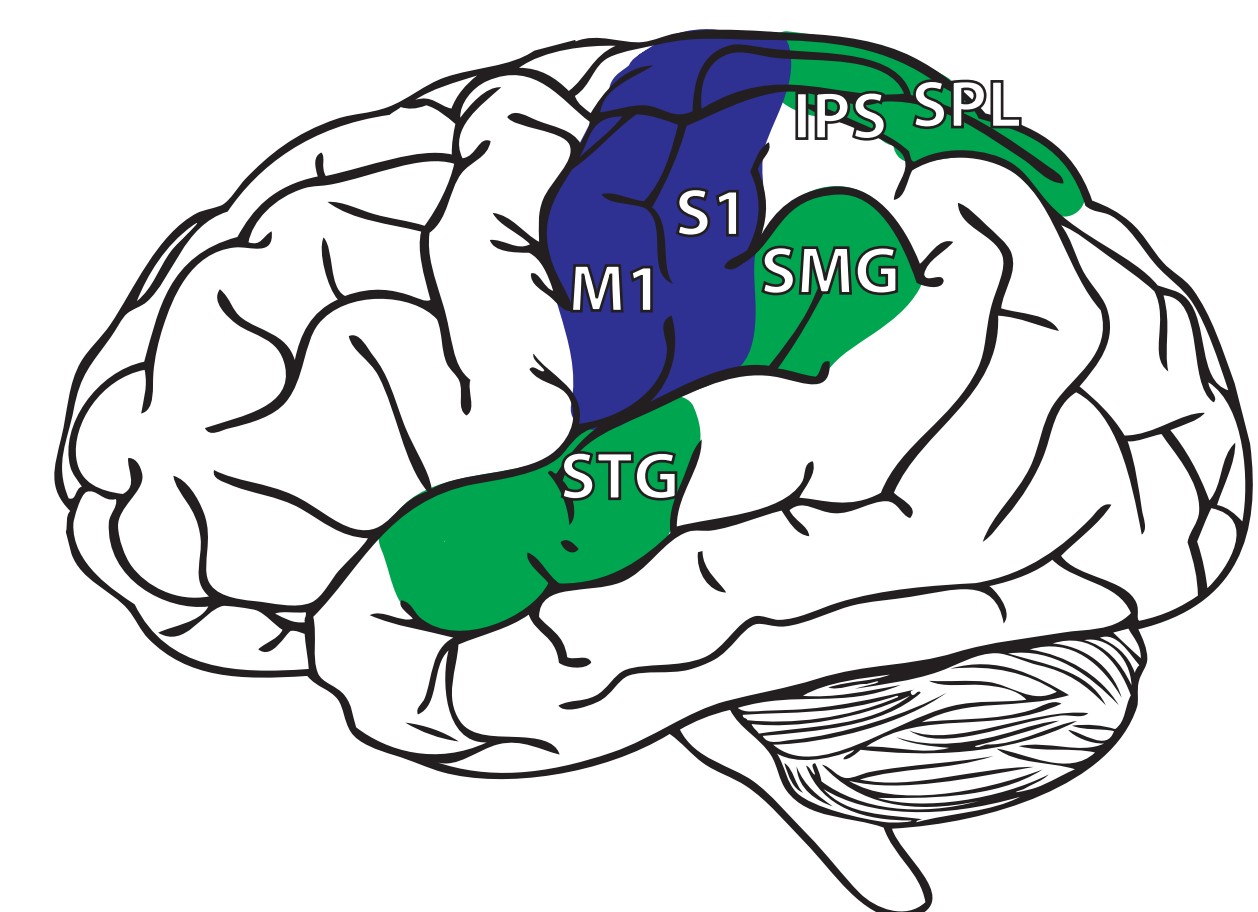


4 Insights from lesion and fMRI studies

Reinterpreting the relation between cerebral structures [5,6] and proprioceptive functions in the light of our theoretical approach provides a novel rationale for an improved stratification of stroke patients [3].

“Pure” proprioceptive processing (W-A_p tasks)

- appears to involve mainly **S1**, whereas tasks requiring **cross-reference processing** involve the regions within the **superior temporal** and **posterior parietal cortex**:
- Superior Temporal Gyrus (STG)
 - Supramarginal Gyrus (SMG)
 - Superior Parietal Lobule (SPL)
 - Intraparietal Sulcus (IPS)



5 Perspectives

This **novel classification of post-stroke sensory deficits** may lead to innovative approaches to **stroke assessment and rehabilitation**.

Targeted training of proprioception and/or cross-reference transformations, depending on the patient's specific sensory deficit, may be key to **improved recovery**. Furthermore, correlations between lesion site and size with behavioral performance in various tasks could bring new insights to identify **neural networks** that are **specific to proprioception or cross-reference processing**.

[1] Tagliabue & McIntyre (2011). J Neurosci 3:1397-1409.

[2] Arnoux et al. (2017). J Neurophys 118:1598-1608.

[3] Bernard-Espina et al. (2021). Front Neurosci 15:646698.

[4] Semrau et al. (2018). Cortex 109:245-259.

[5] Butler et al. (2004). Hum Brain Mapp 21(3):165-77.

[6] Pellijeff et al. (2006) Neuropsychologia 44(13):2685-90.