

Perturbation across the lifespan: Learning, disorder, rehabilitation, and ageing

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Abstract This article extends Lowie's CDST framework by proposing a typology of perturbations in language development. Drawing on research across trial-level learning, emotional states, sensory degradation, speech disorders, and ageing, we show perturbations vary along four dimensions: timescale (milliseconds to decades), nature (discrete or continuous), origin (external or internal), and directionality (facilitative, maladaptive, or redirectable). Understanding perturbations as richly differentiated forces has direct methodological and pedagogical implications for supporting language development across the lifespan.

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1 Introduction

Consider a child learning to ice skate. Each wobble is a micro-perturbation – a momentary destabilization corrected unconsciously within milliseconds. A fall is more dramatic: disruptive, painful, yet instructive. Anxiety about falling may narrow the child's willingness to attempt new moves, while the exhilaration of gliding freely broadens their movement repertoire. Over years, gradual changes in strength, coordination and confidence continuously reshape the skating system. As the skater moves into adulthood, further perturbations emerge: changes in balance, reaction time, and stamina interact with accumulated experience and shifting motivations – skating for recreation or social connection rather than competition. For some, medical conditions introduce chronic and progressive perturbations, reorganizing the entire motor system in ways no single correction can address.

This is the landscape that Lowie's discussion of Complex Dynamic Systems Theory (CDST) framework opens up. Lowie (2026) describes how perturbations, such as

a person walking through sand, can temporarily disrupt self-organization patterns which then re-emerge if the subsystems remain unchanged. “However, when one or more of the subsystems change, this can lead different patterns to emerge” (p. 2). This captures the mechanism of perturbation-driven change, but the nature of that change depends on what kind of perturbation, at what level it manifests, and in what (sub)system. To our knowledge, no typology of perturbations exists within CDST – no systematic account of how perturbations differ or of consequences for system reorganization.

This commentary proposes such a typology. Drawing predominantly on (Dutch) research in Second Language (L2) Development, we show that perturbations vary along four dimensions: timescale, nature, origin, and directionality. In terms of timescale: perturbations operate from milliseconds (as measured by EEG) to decades (lifelong language learning, ageing). Nature: perturbations can be discrete events (corrective feedback, emotional breakthrough) or continuous processes (sensory degradation, progressive neurological disorder). Origin: perturbations may be external to the individual (feedback, emotional social interaction) or internal and bodily (cochlear implant-mediated signal degradation, neurodegeneration). Finally, directionality: perturbations can be facilitative (error correction, positive emotions), maladaptive (disease progression), or redirectable through intervention (modality shifts in CI users, speech therapy as counter-perturbation).

Critically, each case exemplifies multiple dimensions simultaneously. Task-level perturbations in learning foregrounds timescale (milliseconds) while being external and facilitative. Emotional perturbations span multiple timescales with shifting directionality. Sensory degradation perturbations are chronic, internal, and partly maladaptive yet redirectable. Speech disorders reveal continuous, internal, maladaptive perturbations countered by discrete, external, facilitative therapy. Aging demonstrates how perturbations at all dimensions interact across the longest timescales. Our contribution suggests the CDST framework can benefit from treating perturbations as richly differentiated forces shaping language development across the human lifespan.

2 Task-level perturbations: Feedback in L2 learning

At a small timescale, perturbations can be observed at trial level in a feedback-guided L2 learning task comprising multiple rounds. In such tasks, errors in performance can be disruptions, or destabilizations, leading to long-term changes in representational knowledge. Data by German learners of Dutch (Bultena et al., 2017) illustrate this: learners were asked to decide on the correct definite article (‘de’ or ‘het’) for 96 Dutch nouns and received corrective feedback including the correct response after each trial. Gender-incongruent cognates in German and Dutch (e.g., ‘het strand’ [neuter], ‘der Strand’ [masculin]) were particularly error-prone (‘de strand’ [masculin]) in the first round, but

showed remarkable learning in subsequent rounds. Feedback-locked EEG components associated with attention and memory indicated differences between feedback for errors that were corrected in the subsequent round versus those that persisted. Interestingly, response times to erroneous answers in the second round – after learners had received corrective feedback on this item once before – indicated a similar pattern. At the moment of making the error, response times for errors that were corrected in the third round were significantly slower compared to those that persisted in the third round.

Performance adaptations thus seem to be triggered by feedback as well as internal error monitoring. To capture such fluctuations that give rise to change, analyses should include individual performance measures (accuracy, response times) across multiple rounds. What is evident from these findings is that CDST principles already operate at the trial level even in controlled experimental designs – a finding that contrasts with the longer timescales examined in sensory, speech, and aging perturbations below.

3 Emotional perturbations: Affective states shaping learning trajectories

While trial-level feedback represents external, discrete perturbations, emotions constitute internally experienced perturbations and can interact with external perturbations like feedback. Although research in foreign language learning has often viewed emotions as relatively stable traits, emotions fluctuate across different timescales: from lifespan trajectories to moment-to-moment shifts in experience (Growney et al., 2025). Within a CDST framework, this matters because emotions are interconnected with cognitive, social, and behavioral aspects of foreign language learning, shaping individual learning trajectories.

A learner may experience anxiety during early stages of the learning process, but an eye-opening event – like a successful oral presentation – may intensify feelings of pride and accomplishment, triggering a perturbation that shifts an emotional state toward enjoyment. Crucially, positive and negative emotions are not simply opposites; rather, they function differently. Fredrickson's broaden-and-build theory (Fredrickson, 2001) shows negative emotions tend to narrow attention and restrict the range of potential language input, whereas positive emotions broaden thought-action repertoires, opening individuals to new learning. In the literature on foreign language learning and emotion, the negative effects of anxiety have been well documented, leading to withdrawal, avoidance, and self-protection. Although less well documented, positive emotions, such as foreign language enjoyment (Dewaele & MacIntyre, 2014), help broaden learners' perspectives and foster exploration. Yet, they appear to be more fleeting and context-dependent, making them prone to situational triggers and vulnerable to fading without sustained support (Resnik et al., 2025).

Moreover, learners often experience positive and negative emotions simultaneously. Feeling anxious about speaking while wanting to participate creates emotional ambiva-

lence (MacIntyre, 2007). From a CDST perspective, such ambivalence creates motivational instability; a state ripe for perturbation.

4 Sensory perturbations: Hearing loss and degraded auditory input

Sensory-level perturbations form a distinct class of disruptions: rather than targeting behavior or motivation, they reshape the input channel through which linguistic information enters the system. Hearing loss creates chronic, internally rooted perturbations that alter the auditory signal available to learners. For cochlear implant (CI) users, the signal is spectro-temporally degraded, especially in fundamental frequency (f_0) resolution. Consequently, established processing routines are challenged in ways that cannot necessarily be resolved through short-term adjustment.

This degraded input produces clear perceptual effects. Reduced f_0 transmission lowers prosody identification accuracy (Everhardt et al., 2020) and affects how (non)native listeners interpret prosodic prominence (Everhardt et al., 2023). Crucially, these changes do not reliably trigger compensatory cue reweighting: listeners still heavily depend on f_0 even when it is unreliable (Everhardt et al., 2024a). This persistence suggests that entrenched cue-weighting strategies constrain adaptation, revealing local stability within a chronically perturbed system.

Longer-term consequences appear in language learning. Adolescent CI users studying a foreign language show disproportionate difficulty in listening-based tasks, while reading and gap-fill performance remain comparable to hearing peers (Everhardt et al., 2024b). Faced with persistent sensory degradation, learners seem to reroute their pathways by relying more on orthographic and contextual information when auditory input lacks reliability. This reflects systemic reorganization rather than local adjustment.

From a CDST perspective, sensory degradation represents a chronic, internal, partly maladaptive perturbation that nonetheless generates redirectable developmental trajectories. Such cases show that perturbations do more than reduce performance: they shift modality balances, reshape long-term learning routes, and demonstrate the system's capacity for reorganization under sustained pressure.

5 Speech perturbations: Progressive destabilization in disorders and counter-perturbation

Speech disorders demonstrate how perturbations manifest as ongoing destabilizations. Parkinson's disease (PD) exemplifies this: neurodegeneration acts as chronic perturbation continuously altering multiple coupled subsystems – a progressive destabilization where each subsystem change cascades through the entire speech production system.

A longitudinal study of one bilingual Dutch-English speaker with PD over 3.6 years (36 recordings) documented system-wide reorganization driven by disease progression

(Verkhodanova et al., 2023). f_0 showed significant rising trends in both languages, maximum phonation time declined, and the second formant showed centralization – all hypokinetic dysarthria indications (Brabenec et al., 2017). These changes occurred in parallel across both languages, suggesting the perturbation operates at a level deeper than language-specific phonetic representations.

This case also illustrates therapeutic intervention as strategic counter-perturbation. When the speaker received LSVT-based therapy in Dutch (Ramig et al., 2004), pattern shifts occurred across both Dutch and English. Specifically, significant f_0 distribution changes were found before-during-after therapy in both languages, and speech rate in English reading – the untreated language – significantly shifted across therapy stages, being slower during therapy. This cross-linguistic transfer demonstrates how perturbations reorganize the entire coupled systems, not isolated components.

The PD case reveals the need to distinguish perturbation types along multiple dimensions. PD represents continuous, degenerative, systemic perturbation driving maladaptive self-organization. Speech therapy becomes discrete, facilitative, localized counter-perturbation redirecting reorganization toward functional patterns. Both PD- and therapy-related perturbations follow CDST principles of system reorganization through destabilization, but with profoundly different clinical implications.

6 Perturbations across the lifespan: Nonlinear trajectories in older adulthood

Lowie (2026, this issue) reiterates key characteristics of language development that follow from CDST laws. One could argue that these characteristics, pertaining perhaps most pertinently to non-linear relationships between cognitive, socio-emotional and language development and the consequential high variability across individuals, are most pronounced in older adulthood. At this stage, changes in brain structure, oscillatory patterns, and their coupling with cognition and psychosocial health interact with altered physiology (e.g., sensory acuity), rendering substantial individual differences further shaped by accumulated life experiences (cf. Radjenovic et al., 2025). These changes relate to age-related challenges in language processing and use (Peelle, 2018). A dynamic systems approach reframes dominant deficit views in aging research, instead interpreting these patterns as natural perturbations of a self-organizing system intensifying in later life.

Recent attention to later-life language learning (cf. Keijzer et al., 2023) further illuminates Lowie's work on the interplay of cognitive, socio-affective, and environmental predictors of language development. A study relating affect (measured with the PANAS; Watson et al., 1988) to language development in older adults enrolled in a three-month foreign language course showed that affect remained stable in healthy participants but followed non-linear patterns in peers with cognitive impairments, though not significantly. The strongest (significant) perturbations, particularly in positive affect, occurred

among those with (past) depression (Brouwer et al., 2024). These findings reinforce Lowie's emphasis on examining individual trajectories within group patterns, developing tools to interpret "wiggleness" between predictors and language learning outcomes, and adopting longitudinal lifespan perspectives.

7 Discussion

Returning to our ice skater: a wobble corrected in milliseconds, a fall that shifts confidence, years of training building automaticity, and a progressive neurological condition fundamentally reorganizing movement – these are not different magnitudes of the same phenomenon but qualitatively distinct perturbations types, each with different consequences for system reorganization. The same holds for language development across the lifespan.

Our typology involves four dimensions: timescale, nature, origin, and directionality. Critically, these dimensions interact in complex ways. Timescale often determines redirectability: millisecond wobbles tend to self-correct automatically, while chronic perturbations may require sustained therapeutic interventions or permanent pathway reorganization. Origin can determine whether it is accessible to intervention: external perturbations can be pedagogically designed, while internal bodily perturbations may require medical or rehabilitative approaches. Directionality is not fixed: what can begin as maladaptive can become redirectable through strategic counter-perturbation.

This typology carries direct methodological consequences. As Lowie emphasises, "the density and quantity of observations should align with the expected granularity of development" (Lowie, 2026, p. 4). Our examples demonstrate this: trial-level EEG analyses capture millisecond-scale perturbations; monthly recordings over years reveal progressive speech disorder trajectories. Different perturbation types also demand different analytical approaches. Discrete perturbations are better captured with event-related analyses; continuous perturbations require longitudinal modeling capturing gradual system reorganization. Crucially, we need tools that can interpret the "wiggleness" in developmental trajectories. The full landscape of perturbations requires a methodological toolkit as diverse as the phenomena themselves.

This typology opens future research avenues. How do perturbations at different levels interact? Learners experiencing cognitive decline may respond differently to feedback than younger learners. Older adults with hearing loss face compounded sensory, cognitive, and socio-emotional perturbations. The question is not simply additive but dynamic: how do perturbations at different timescales create emergent constraints or affordances? Does prior emotional perturbation create resilience or vulnerability to later cognitive perturbations? Do sensory compensatory strategies transfer to neurological challenges?

The typology also highlights research gaps. We extensively document facilitative perturbations in learning and maladaptive perturbations in clinical populations, but know less about everyday disruptions shaping most individuals' language development. What are the effects of moderate hearing decline in middle age? How do non-clinical anxiety levels interact with language learning? How do life transitions (migration, retirement) function as perturbations to language systems?

Our master skater, trained for decades, demonstrates that perturbations never cease. Lifelong learning – acquiring languages in older adulthood or adapting to sensory or neurological change – is fundamentally a process of navigating and responding to perturbations. The system continuously reorganizes in response to changing internal and external conditions. A rich perturbation typology within CDST thus becomes practical support for language development across the lifespan. Understanding how perturbations drive, shape, and sometimes constrain the system's capacity for reorganization allows designing interventions that work with the system's dynamics rather than against them.

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Author contributions

Vass Verkhodanova: conceptualization, writing – original draft, review and editing, project administration; Sybrine Bultena: conceptualization, writing – original draft, review and editing; Anna Pot: conceptualization, writing – original draft, review and editing; Marita K. Everhardt: conceptualization, writing – original draft, review and editing; Merel Keijzer: conceptualization, writing – original draft, review and editing.

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Statement of technology use

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