“From Load to Learning:” Attention/Workload Failures in Adaptive CCT for MCI, and a Redesign via Mental Models & Situation Awareness

Santhusha Mallawatantri

1 Introduction

Computerised cognitive training (CCT) aims to improve cognitive abilities in older adults with mild cognitive impairment (MCI) via adaptive difficulty [1], yet it suffers from low adherence [2]. Users report that "adaptive" algorithms induce high workload and frustration [3], creating a "CCT Paradox" where the interface's extraneous load overwhelms limited resources. This essay argues that opaque adaptations misallocate attention (per Load Theory [4] and MRT [5]) and inflate workload (per CLT [6]), widening Norman's gulf of evaluation [7]. A redesign is proposed to resolve this by scaffolding Mental Models [8] and Situation Awareness [9], with a clear evaluation plan based on NASA-TLX [10] and objective error rates.

2 Analysis of Attention and Workload Failures in Adaptive CCT

The ergonomic conflict of adaptive CCT is best observed at the precise moment of adaptation or known as the "level-up" event. This section will analyse the cognitive failures during this micro-interaction initially by defining the task and then moving on to apply the theories of attention and cognitive load.

2.1 The Task and Moment of Peak Demand

The system is a tablet-based CCT application for MCI patients, featuring a visual-spatial N-back task. The moment of peak demand is the **adaptive difficulty transition** from a 1-back to a 2-back task after three correct trials. This transition event is composed of three simultaneous UI elements:

1. A brief, centrally-located celebration animation (confetti)
2. A score ticker in the top right corner that increments.
3. A small, low-contrast text box in the top-left corner stating, "New Rule: Match 2 back!"

A common failure occurs when the user's attention, captured by the animation, misses the rule change. The user subsequently applies the old 1-back rule, leading to a string of errors and high frustration (see ***Figure 1***).

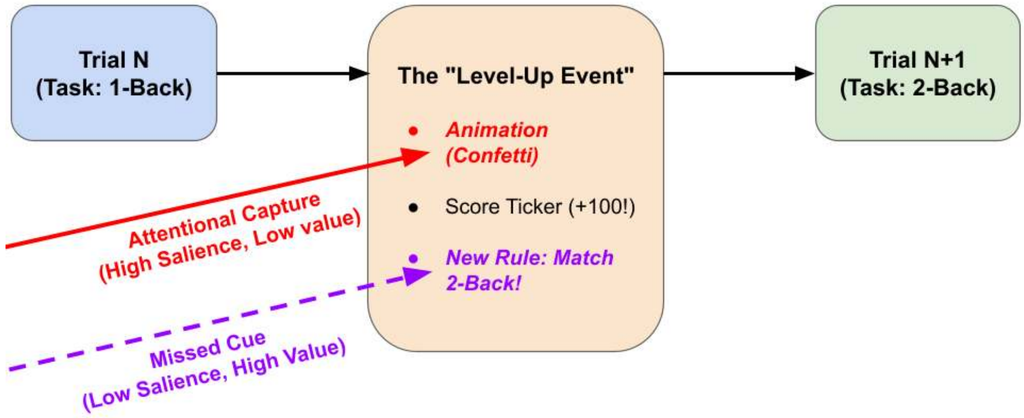

Figure 1: Timeline of the "level-up" event, showing how high-salience extraneous elements capture attention at the critical moment of rule updating.

2.2 Attention Misallocation at the Point of Adaptation

The failure to notice the rule change is a predictable outcome of attentional mechanisms. During the low-load N-back task, spare capacity "spills over" and is involuntarily captured by the high-salience, low-value confetti animation [4]. This results in **change blindness**, as the low-salience, high-value rule text is ignored [11]. This failure is exacerbated by a **split-attention effect** [12], forcing a costly visual search (see ***Figure 2***).

2.3 Extraneous Workload and Resource Conflict

The attention failure is compounded by a critical inflation of cognitive workload. At the "level-up" event, extraneous UI load from the interface (e.g., animation, ticker) spikes, leaving too little spare capacity for the germane processing required for rule-updating [6]. This conflict, detailed in ***Table 1***, is represented by the cognitive load budget:

$$L_{germane} = R_{total} - (L_{intrinsic} + L_{extraneous})$$

Total cognitive capacity (R_{total}) is finite. $L_{\text{extraneous}}$ consumes the resources needed for L_{germane}, causing the rule-update to fail. This issue is amplified by a severe modality conflict, as the simultaneous visual-visual demands at the same processing stage create high interference, per Multiple Resource Theory (MRT) [5]. This dual-task cost is detailed in ***Table 2***.

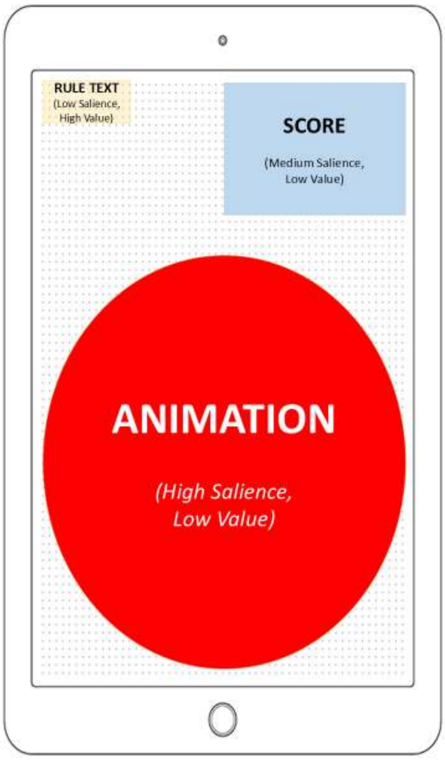

Figure 2: A "heat map" of the level-up screen. Attentional resources are drawn to high-salience, low-value elements (animation, score), leaving the high-value rule change unnoticed. The split-attention layout forces a costly saccade sequence across three disparate locations (animation → score → rule text), increasing the attentional cost and the likelihood of missing the critical rule.

Table 1: Cognitive Load Classification of Level-Up Event Elements

UI Element	**Load Type (CLT)**	**Why it Imposes Load**	**Cognitive Consequence**
Confetti Animation	Extraneous	High-salience motion automatically captures attention.	Distracts from processing the new rule
Score Ticker	Extraneous	Continuous visual change requires monitoring	Splits attention and increases dwell time away from task
"New Rule" Text	Germane	The core information required to build the new mental model	Low salience leads to it being processed last or missed entirely
Task Stimuli (Next Trial)	Intrinsic	The inherent difficulty of the N-back task itself	Resumes immediately, forcing the user to act before they are ready

Table 2: MRT Analysis of the "Level-Up" Event

Resource Dimension	**Task A: Read New Rule**	**Task B: Prep for Next Stimulus**	**Analysis/Consequence**
Modality	Visual (Text)	Visual (Shape/Location)	**SEVERE Conflict:** Both tasks demand the same high-load visual input channel
Processing Code	Verbal (Reading)	Spatial (Location of target/stimulus)	**PARTIAL Conflict:** Competing processing codes (reading language vs. judging location) overload cognition)
Stage	Perception/ Cognition	Perception/ Cognition	**SEVERE Conflict:** Both tasks occur at the same processing stages (perceiving cues, understanding rules)
Response	Not yet	Manual (preparing to tap)	**NO Conflict:** Response stages are separate

2.4 Linking Analysis to Measurement

This analysis predicts a cascade of specific, measurable failures: we expect **NASA-TLX subscales** (*Mental Demand, Temporal Demand, Effort, Frustration*) to rise, and objective metrics (first-trial error rate, time-to-first-correct) to worsen post level-up [10]. The redesign in the next section must reverse these specific indicators, which are mapped to their causal mechanisms in ***Table 3***

Table 3: Mapping of Cognitive Failures to Mechanisms and Predicted Metrics

Identified Issue	Cognitive Mechanism (The "Why")	Predicted Metric (The "Symptom")
Attentional Capture (Animation)	Low perceptual load → spare capacity "spills over" to high-salience, low-value confetti [4]	↑ **NASA-TLX** *(Frustration & Effort)* ↑ **Time-to-first-correct response**
Resource Conflict (Visual-Visual)	Simultaneous **Visual-Visual** demands (reading rule + prepping task) at the same **Stage** (Perception) creates high interference [5]	↑ **First-trial error rate (post-level-up)**
Opaque Rule Text (Poor Germane Load)	High **Extraneous Load** (animation, ticker) consumes resources, leaving no capacity for **Germane Load** (rule encoding) [6]	↑ **NASA-TLX** *(Mental Demand subscale)* **User continues applying old rule** *(mode error)*

2.5 Critique and Counter-Evidence

Critically, the evidence for CCT efficacy in MCI is mixed; a *major Cochrane review* found CCT has **little to no effect** on cognitive function compared to active controls [13]. This essay argues these null findings may be a human-factors artefact: users are not failing the *task* but the *interface*, as high extraneous load from opaque adaptation prevents engagement with the intended germane load.

2.6 Bridge to Redesign

This cascade of failures—from attentional capture ***(L1 SA)*** to resource conflict ***(L2 SA)***—represents a fundamental breakdown in Situation Awareness [9] and a failure to build a correct Mental Model [8]. The redesign must therefore scaffold these SA levels to be effective.

3 Redesign Recommendations and Evaluation

The analysis in previous section demonstrated that the CCT interface fails not because the *task* is too hard, but because the *interface* imposes high extraneous load and creates resource conflicts at the critical moment of adaptation. The following redesign recommendations directly target these failures.

3.1 Recommendation 1: Make Adaptation Transparent

- **Design:** The high-extraneous-load "level-up event" is redesigned: the distracting confetti animation is removed and replaced by a single, high-contrast, foveal banner (1.5s) paired with a non-speech auditory chime [14]. Enabling the separating of modalities as per MRT at the transition reduces visual–visual interference [5] (see ***Figure 3***).

- **Mechanism:** This redesign raises L1 SA (Perception) by making the rule-change cue salient, reduces extraneous load (CLT), and shrinks Norman's gulf of evaluation by placing "knowledge in the world" [7].
- **Data Plan:** This change is predicted to significantly decrease NASA-TLX subscales (Mental, Temporal, Frustration) and decrease first-trial errors and time-to-first-correct, as mapped in ***Table 3***.

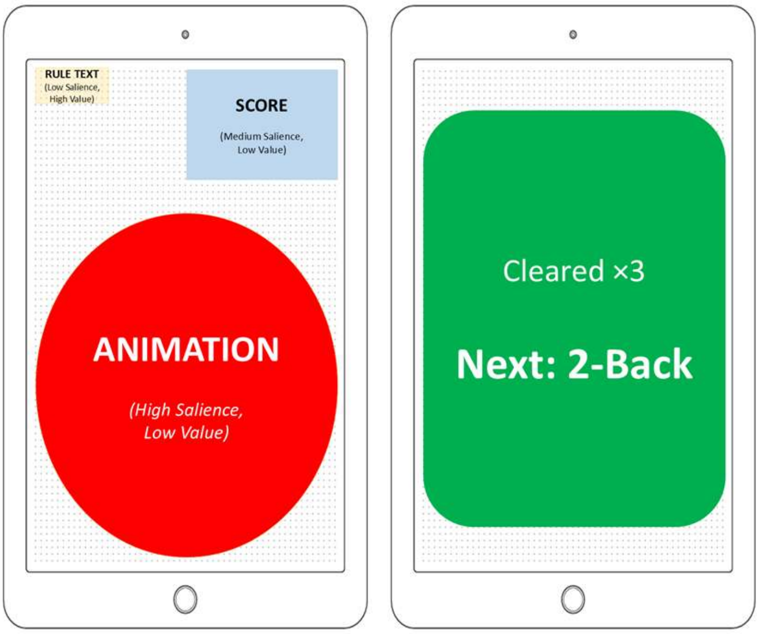

Figure 3: 'Before' (left) design shows high-salience distractors capturing attention. 'After' (right) redesign removes extraneous load and presents a single, high-salience, high-value cue (**$\geq$4.5:1 contrast, $\geq$24 pt font, 1.5 s duration, centred**) to scaffold L1 SA.

3.2 Recommendation 2: Stagger Modalities to Resolve MRT Conflict

- **Design:** The instructional cue is shifted from a purely visual channel, introducing an auditory-verbal pre-cue ("Two-back next") that plays while the visual field is quiet.
- **Mechanism:** This design separates resource demands across modalities (Auditory-Verbal vs. Visual-Spatial), explicitly resolving the high interference predicted by MRT (see ***Table 4***) and minimizing the dual-task cost.
- **Data Plan:** This change is predicted to reduce first-trial errors. The high baseline workload can be objectively measured by a secondary-task probe, with the redesign expected to significantly reduce the %ST Cost (see ***Equation 1***).

$$\%\text{ST Cost} = \frac{RT_{\text{dual}} - RT_{\text{single}}}{RT_{\text{single}}} \times 100 \tag{1}$$

Table 4: MRT Interference Analysis for Baseline vs. Redesign at Level-Up. Redesign staggers modalities (Auditory → Visual) and timing (600-800 ms pre-cue) to resolve conflict.

Resource	Baseline (High Conflict)	Redesign (Conflict Resolved)
Modality	**Visual** (Reading rule) + **Visual** (Prepping task)	**Auditory** (Hearing rule) → **Visual** (Prepping task)
Code	**Verbal** (Reading text) + **Spatial** (Task location)	**Verbal** (Hearing text) → **Spatial** (Task location)
Stage	**Perception/Cognition** (Both tasks simultaneously)	**Perception/Cognition** (Staggered in time)
Verdict	**SEVERE INTERFERENCE** (High dual-task cost, high errors)	**LOW INTERFERENCE** (Resources **separated** by modality and time)

3.3 Recommendation 3: Scaffold Situation Awareness & Mental Models

- **Design:** A persistent, high-contrast "Status Chip" is added to the UI, acting as "knowledge in the world" [7] by showing the current rule and the upcoming rule.
- **Mechanism:** This design directly scaffolds all three levels of Endsley's SA model [9] and teaches the user the system's mental model [8], as detailed in ***Figure 4***.
- **Data Plan:** This is predicted to reduce mode errors (e.g., applying the old 1-back rule) and increase successful trials, serving as an objective proxy for SA.

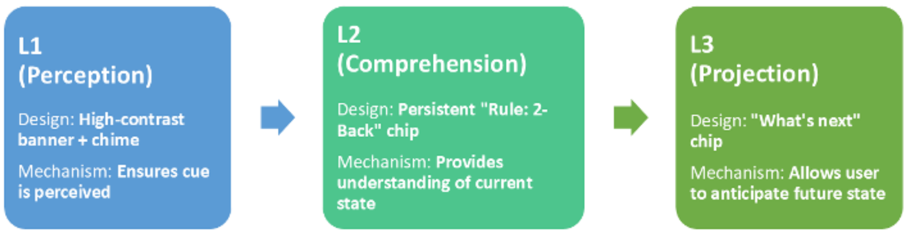

Figure 4: Mapping Redesign Elements to Endsley's SA Levels. **L1 (Perception):** Consistent, high-contrast cues. **L2 (Comprehension):** "Rule: 2-Back" chip provides current state. **L3 (Projection):** "Next: 2-Back in 2 trials" chip allows anticipation.

3.4 Critique and Measurement Plan

This redesign is based on established cognitive principles, but it must be tested. The literature on adaptive training in MCI shows mixed findings; a major Cochrane review found CCT has little to no effect on cognitive function for MCI populations compared to active controls [13]. This essay argues that these null findings may themselves be a human-factors artefact: users are not failing the *task*, they are failing the *interface*, as high extraneous load from opaque adaptation prevents engagement with the intended germane load.

The proposed evaluation will be a **within-subjects, counterbalanced A/B test**. Participants (MCI users) must pass vision/hearing checks with standardised device volume. **Primary endpoints** will be **event-locked objective metrics** (first-trial post-level-up error rate; time-to-first-correct) and **post-block subjective workload** (NASA-TLX Mental, Temporal, Effort, and Frustration subscales). A **successful redesign** would be defined by a statistically significant (e.g., $\geq$15–20% drop in first-trial errors and a $\geq$0.5 SD drop in TLX-Frustration and TLX-Effort), thus linking the theoretical failures from previous section to a verified design intervention.

4 Conclusion

In conclusion, this essay identifies a "CCT Paradox" where adaptive algorithms, intended to help, instead induce high extraneous load and break user Situation Awareness. The proposed redesign framework resolves this conflict by prioritising a transparent, workload-aware interface that scaffolds Mental Models. This human-factors-adaptive approach is predicted to significantly reduce cognitive workload—measured by event-locked metrics like NASA-TLX (Frustration, Effort) and first-trial error rates. While limitations like sensory variability and cue habituation must be considered, the proposed event-locked A/B test provides a clear path to validate this solution, ultimately moving CCT from a source of frustration to a tool for genuine learning.

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