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Mechanisms of change during exposure therapy for persistent post-concussion symptoms: insights from session-level process data

Skye King[a,b], Fenna Konings[a], Ieke Winkens[a,b], Joukje van der Naalt[c], Marleen Rijkeboer[a], and Caroline van Heugten[a,b]

[a]Faculty of Psychology and Neuroscience, Maastricht University, Maastricht, The Netherlands; [b]Limburg Brain Injury Centre, Maastricht, The Netherlands; [c]University Medical Centre Groningen, University of Groningen, Groningen, The Netherlands

ABSTRACT

Background: Persistent post-concussion symptoms affect a substantial subgroup of individuals following mild traumatic brain injury. Intensive exposure therapy may be an effective intervention by directly targeting psychological mechanisms underlying symptom maintenance. This study provides insight into the clinical processes of this therapy.

Materials and methods: Therapy session-level data from two single-case experimental design studies with a total of eight participants was analyzed using mixed-methods.

Results: The most frequently targeted feared expectations included: cognitive failure, task breakdown, catastrophic consequences of physical symptoms; and exposure tasks: cognitive challenges, sensory rich environments, social interaction. Quantitative analyses demonstrated a significant within-session reduction in belief strength about expected outcomes (mean decrease = 38.49, $p < 0.001$), with notable individual differences. Belief reduction was consistent across the exposure sessions. Despite observed reductions, participants often retained some concerns after therapy, most commonly due to generalization doubts or uncertainty under higher task demands.

Conclusions: Findings highlight the multidimensional and personalized nature of feared beliefs in persistent symptoms and underscores the clinical value of individualized behavioral experiments. The study provides process-level insights that may inform more confident and targeted implementation of (intensive) exposure therapy in mild traumatic brain injury treatment.

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After a mild traumatic brain injury, the majority of individuals fully recover within weeks or months (1). However, a substantial number of people (approximately 15%-35%) experience persistent post-concussion symptoms, which interfere with daily functioning (2–4). Persistent post-concussion symptoms are a multifactorial cluster of physical (i.e., headaches, sleep disturbances), psychological (i.e., irritability, anxiety), and cognitive (i.e., attention and memory difficulties) complaints that can persist for months or years, often preventing return to work and daily activities (5). A psychological framework that helps explain how such persistent symptoms may be maintained is the Fear Avoidance Model (6,7). According to this model, persistent symptoms are not merely determined by the severity of the initial injury but are also maintained by psychological processes. For example, common symptoms (e.g., headaches, sensory symptoms etc.) may be appraised as threatening or indicative of ongoing damage, and these interpretations can elicit fear and catastrophizing, which may promote avoidance of physical and cognitive activities (eg., work, social engagement, etc.). While avoidance may provide short-term relief, it reduces learning opportunities and functional recovery, leading to increased symptom monitoring, and heightened emotional distress. Over time, this pattern contributes to sustained symptoms, increased functional disability, depressed mood, and reduced participation in daily life, reinforcing maladaptive beliefs about symptoms and activity (7). Importantly, this model is not proposed as an explanation for symptom origin in persistent post-concussion symptoms, but rather as a framework for understanding potential maintenance processes such as avoidance and threat appraisal for symptom persistence.

Although alternative cognitive-behavioral or neurobiological models have been proposed to explain persistent post-concussion symptoms, the Fear Avoidance Model is particularly relevant in the current context as it specifies modifiable psychological mechanisms, including fear, avoidance, expectancy violation (5), which can be directly targeted through exposure-based interventions grounded in inhibitory learning principles. The model has shown significant explanatory value in understanding disability after mild traumatic brain injury and highlights fear-avoidance thoughts as a central factor in predicting outcomes such as depression, reduced mental activity, and impaired functioning (7). Moreover, this conceptual framework is supported by empirical evidence demonstrating that higher levels of fear-avoidance behaviors in the subacute phase after mild traumatic brain injury are associated with increased symptom severity, functional disability, and risk of psychiatric complications several months post-injury (8).

Currently, no single intervention is recommended as a standard treatment for persistent post-concussion symptoms (9,10), underscoring the continued need for targeted, mechanism-based therapies. Given the explanatory strength of the fear

CONTACT Skye King s.king@maastrichtuniversity.nl Faculty of Psychology and Neuroscience, Maastricht University, Maastricht 6229 ER, The Netherlands
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symptoms, psychological interventions targeting avoidance behaviors, such as exposure therapy, may offer a promising treatment approach for individuals with persistent post-concussion symptoms (11,12). Within this framework, symptom-related avoidance – particularly of cognitive and physical activities – can reinforce maladaptive beliefs (e.g., that symptoms signal permanent brain damage), fueling further disability and emotional distress (7,10). Exposure therapy directly addresses this cycle by helping patients test and disconfirm these catastrophic expectations in a controlled, therapeutic context. Rather than aiming for symptom resolution, exposure promotes inhibitory learning, a process through which patients develop new, safety-based associations that weaken prior fear-based expectations (13,14). In the context of persistent symptoms, gradually engaging in feared or avoided tasks (e.g., reading, multitasking, social interactions) could possibly help reduce cogniphobia and increase confidence in one's cognitive abilities. By interrupting the avoidance-disability cycle identified in the fear avoidance model, exposure therapy aligns closely with the mechanisms driving persistence of symptoms, making it a theoretically and clinically relevant intervention worth further investigation in this population. Recent studies have shown promising results on the use of exposure-based interventions in individuals with persistent post-concussion symptoms, using graded (11), 14-week (12), or intensive (15,16) exposure therapy formats.

While clinicians have shown interest in the application of exposure therapy for patients with persistent symptoms, they may be hesitant in terms of setting treatment goals and starting behavior experiments due to concerns about treatment safety, unfamiliarity with specific procedures, or uncertainty with appropriate implementation (17). In particular, process-level insight into what participants actually work on during exposure, what kinds of feared outcomes and activities are addressed, and how beliefs in feared consequences change over time, is still lacking. This study aimed to fill these gaps by examining session-level data from the intensive exposure-based intervention for persistent post-concussion symptoms by our group (15,16), with a particular focus on the types of treatment goals participants formulate, the feared outcomes they address, and the structure of behavior experiments. By providing insight into these clinical processes, the study aims to inform and support more confident application of exposure therapy in treatment. The following research questions were addressed: 1) What types of feared problems and activities do individuals with persistent post-concussion symptoms most commonly address and target during intensive exposure therapy? 2) How do participants' beliefs about feared outcomes change within and across exposure sessions, and how do these changes vary between individuals? 3) What explanations do participants give for any lingering concerns after completing exposure tasks, and how do these reasons differ between individuals?

Methods

Design

Data used for the current study were collected as part of a larger single-case experimental design project, featuring the efficacy of an intensive exposure therapy for individuals with persistent symptoms following mild traumatic brain injury. Specifically, therapy session data collected during the exposure sessions of the pilot (15) and replication (16) studies was utilized. The study was approved by the Ethics Review Committee Psychology and Neuroscience (ERCPN-284_87_07_2024) and was conducted in accordance with the ethical standards provided in the 1964 Declaration of Helsinki and the amendments.

Participants

The therapy session data from all of the participants (pilot study $n = 4$, replication study $n = 4$) with no additional selection (eight participants in total), who completed the intensive exposure therapy during the pilot (15) or replication (16) experiments at the university, was utilized in the current study. Participants were included in the study if they were: a) between 18 and 65 years of age; b) having sustained a single, uncomplicated concussion 6–18 months prior to inclusion; c) self-reporting at least 3 persistent symptoms as indicated on the Rivermead Postconcussion Symptoms Questionnaire (RPQ, (18)); d) fluent in Dutch. Participants were excluded from the study if they had any of the following: a) history of moderate or severe TBI; b) current psychiatric disorder requiring specialized treatment; c) other neurological or medical conditions potentially accounting for symptoms; d) ongoing litigating related to the injury; e) prior exposure therapy targeting concussion-related problems; f) concurrent participation in another treatment study.

Materials

Data in the current study were sourced from the structured therapy session logs completed by the therapists in collaboration with participants during each exposure session. These logs were designed to document the content and cognitive outcomes of each exposure experiment, following a consistent format across sessions and participants grounded in the inhibitory learning framework (13).

At the beginning of each session, participants were asked to formulate an observable, testable 'if-then' belief statement, representing the core catastrophic expectation associated with a specific activity (e.g., 'If I try to read for 15 minutes, then I will have word finding problems'). Next, the specific exposure task intended to test this belief was described in detail (e.g., Read a document on the computer for 20 minutes). In addition, the specific feared consequences (e.g., 'that I will have word finding problems') were identified in behavioral, testable terms. Lastly, before starting the task, participants indicated their level of belief in the feared outcome on a 0 to 100 Visual Analogue Scale, with higher scores reflecting stronger expectancy. After each exposure task, participants completed a structured evaluation in which they reflected on the outcome of the behavioral experiment. They were first asked to indicate whether the feared outcome had actually occurred (c.f., prediction error) and to describe how they had reached this they had learned from the exposure experience, for example, whether their expectations had been realistic, and what new insights they had gained about their own functioning. Participants then re-rated the perceived likelihood of their original expectation using the same 0–100 scale as before. If their belief had not fully diminished, they were asked to reflect on what still contributed to the remaining level of expectancy. Finally, participants were asked to consider what would be needed to further test or challenge the feared expectation.

Intervention and procedure

Participants were recruited via online advertisements and initially contacted one of the researchers to express their interest. A preliminary eligibility screening was conducted to assess whether basic inclusion and exclusion criteria were met, and candidates were provided with an information letter. Candidates who passed this initial screening were invited for a more comprehensive intake procedure, which included an online clinical interview with a neurologist to evaluate medical history, concussion-related symptoms, and whether participants met the diagnostic criteria for persistent post-concussion symptoms and mild traumatic brain injury, in accordance with the updated guidelines of the American Congress of Rehabilitation Medicine (1). Eligibility was further verified through an online meeting with a clinical psychologist and a neuropsychologist, who jointly assessed suitability for participation (i.e., whether the participant employed safety behaviors to avoid post-concussion symptoms arising). Participants provided written informed consent.

The therapy consisted of three parts, first the exploration phase where idiosyncratic case conceptualizations were developed, second the active exposure therapy phase where the exposure session took place, and third the booster phase (15,16). The current study focuses exclusively on data collected during the active exposure therapy phase. This phase consisted of individual, 90-minute, in-person, therapy sessions delivered over five consecutive days at the university. The first session focused on psychoeducation and goal setting, while the final two sessions addressed generalization to the home environment. These three sessions were excluded from the current analyses. The remaining ten or nine sessions (pilot/replication studies respectively) served as the core exposure component. The exposure sessions focused on performing and evaluating behavioral experiments to test the negative expectations of the participants, including activities that participants avoided (14). The structured process described in the materials section was repeated across sessions and documented using the standardized therapy log, enabling the collection of both quantitative and qualitative data relevant to the current analysis. The exposure tasks were individually tailored through a structured, collaborative process between the therapist and participant during two individual case conceptualization sessions which preceded the exposure sessions. Task selection was guided by each participant's personally relevant feared outcomes, avoided activities, and symptom-related expectations, as identified during the initial exploration phase and further conceptualized using the structured session format (as described in specific cognitive, physical, and social concerns maintaining each individual's symptoms. The exposure sessions were delivered by psychologists at different stages of their clinical training. Therapist rotation was implemented such that participants met with a different therapist each session to optimize treatment effects and reduce relapse risk. To ensure treatment consistency, all therapists completed standardized training in the treatment protocol and exposure procedures, provided by the clinical psychologist who developed the treatment protocol (MR). Therapists were provided with supervision by the clinical psychologist during the provision of the therapy.

Data analysis

Qualitative data from therapy logs were thematically analyzed (19) to identify the most commonly targeted feared outcomes and activities during intensive exposure sessions. Categories were generated inductively and assigned to each session, and descriptive frequencies were calculated in SPSS (v.28) (20). Thematic analysis was conducted by a single coder, who developed and applied the codebook. Given the exploratory nature of this study, no formal inter-rater reliability metrics were calculated, and no independent double-coding procedures were implemented.

To assess belief change across sessions, pre- and post-exposure ratings (0–100 scale) were analyzed from 96 exposure sessions across the 8 participants of the 2 studies. Of the 96 sessions, 83 included valid pre- and post-expectancy ratings and were included in the analyses. Expectancy data were missing possibly due to administration oversight or missing registrations due to the busy therapy session or schedule. Sessions with missing expectancy data were excluded on a per-analysis basis; no imputation procedures were applied. Paired-sample t-tests were used to compare pre- and post-exposure scores, with descriptive statistics and Cohen's d used to quantify change. Interindividual differences were examined by calculating each participant's mean Δscore (pre–post difference) and variability across sessions. A one-way ANOVA tested between-participant differences, with eta-squared reported as effect size. Assumptions were checked, and given unequal variances, Games–Howell post hoc tests were used for pairwise comparisons. Alpha was set at .05.

Finally, participants' reasons for any residual belief in feared outcomes were coded thematically and summarized using descriptive frequencies. Individual differences in concern patterns were examined by tallying category frequencies across sessions and comparing participants descriptively.

Results

An overview of participant characteristics can be found in Table 1.

Types of feared problems and activities addressed and targeted during therapy

Based on qualitative analysis of the structured therapy logs, ten content categories of feared outcome if-then expectations were

Gender, *n* (%)	
Male	1 (12.5)
Female	7 (87.5)
Age (years), *M* (SD)	26 (4.6)
Education, High education[a], *n* (%)	
High education[a], *n* (%)	4 (50)
Secondary vocational education, *n* (%)	1 (12.5)
University students, *n* (%)	3 (37.5)
Time since injury (months), *M* (SD)	11.5 (4.1)
Cause of injury, *n* (%)	
Sports Accident	3 (37.5)
Fall	3 (37.5)
Traffic Accident	2 (25)
Loss of consciousness, yes, *n* (%)	5 (62.5)
Post-traumatic amnesia, yes, *n* (%)	4 (50)
Work hours pre-injury, *M* (SD) [range]	29 (14.3) [10–40]
Work hours at the start of treatment, *M* (SD) [range]	4.9 (10.6) [0–30]
History of psychological treatment[b], yes, *n* (%)	3 (37.5)

[a]Higher education level includes completion of a college or university degree.
[b]History of psychological treatment refers to previous psychological treatment not related to persistent post-concussion symptoms.

inductively developed. These represent thematically distinct types of feared outcomes. These categories were used to code 96 exposure sessions, of which 94 contained at least one codable expectation. Category assignment was not mutually exclusive; each session could be coded with as many categories as necessary to capture the full scope of the participant's expectation. The maximum number of categories assigned to a single session was five. On average, 2.7 categories were assigned per session ($SD = 1.0$). Table 2 shows the frequency with which each category occurred and provides an example for each category. The most frequently reported expectation themes included concentration/memory problems ($n = 49$), functional shutdown/task failure ($n = 47$), and catastrophic consequences of physical symptoms ($n = 46$). Less frequently mentioned were negative beliefs about recovery ($n = 7$) and safety risk/dangerous behavior ($n = 8$).

In total, 96 experiments were completed across 76 sessions, yielding an average of 1.26 experiments per session. The number of experiments per session varied, with each session including at least one experiment and some sessions including multiple experiments depending on individual treatment needs and the nature of the exposure tasks. Nine distinct categories of exposure task domains were inductively identified by analysis of the therapy logs ($n = 94$). These categories reflected the nature and structure of behavioral experiments used to test participants' feared outcome expectations. These categories were used to code 96 exposure sessions, of which 94 sessions included at least one codable activity. Activity assignment was not mutually exclusive; each session could involve multiple task domains. The maximum number of activity categories assigned to a single session was six. On average, 3.0 activity categories were assigned per session ($SD = 1.4$), indicating that most behavioral experiments engaged multiple domains simultaneously. Table 3 shows the frequency with which each activity category occurred and provides examples. The most frequently targeted domains were *cognitive tasks* ($n = 66$), followed by *sensory stimulation* ($n = 40$) and *social interaction* ($n = 39$). Less commonly assigned were *multitasking* ($n = 8$) and *unpredictable tasks* ($n = 14$).

Changes within and across exposure sessions in participants' beliefs about feared outcomes

To assess whether participants' beliefs in feared outcomes decreased during an individual exposure session, a paired-

Table 2. Frequency of feared outcome expectations.

Category	Frequency	Example
Concentration/Memory problems	49	'If I have to do the groceries, I'm afraid that I will forget something'
Functional shutdown/Task failure	47	'If I have to perform a difficult cognitive task, I'm unable to do it'
Catastrophic consequences of physical symptoms	46	'If I have to concentrate intensely, I get such a severe headache and become so fatigued that I can't do anything for the rest of the day.'
Sensory overload	33	'If there are a lot of sensory stimuli and I also have to think, it becomes too much').
Reduced social engagement	20	'If I feel pressure in the middle of my head (and actually feel like lying down) but still go cycling . . . then I won't be able to talk with the therapist during the ride or take in what she says. In the worst case, I won't be able to talk . . . at all.'
Emotional dysregulation	19	'If I drive a car, I panic so severely that I can't continue driving.'
Physical inability	14	'If I go climb the stairs now, after having done several physical activities yesterday and today, I won't be able to climb the stairs anymore and won't understand how to move.'
Loss of structure/Planning ability	10	'If I go to a busy store, I lose my sense of overview.'
Safety risk/Dangerous behavior	8	'If I'm in the car for more than 20 minutes, I startle easily and may hit the brakes abruptly, which could endanger other road users.'
Negative beliefs about recovery	7	'If I get a blow to the head, I'll be back to square one and everything will have been for nothing.'

Cognitive task	66	Remembering a grocery list
Sensory stimulation	40	Visiting a busy restaurant
Social interaction	39	Conversations, phone calls, or public speaking
Attentional Control	34	Completing a sudoku puzzle while lights are switching on and off
Physical activity	34	Walking or jumping
Mobility	24	Taking the bus, driving a car, cycling
Response prevention (of safety behaviors)	19	Not wearing sunglasses, not taking breaks, or avoiding checking behaviors
Unpredictable tasks	14	Entering a situation without knowing what would happen
Multitasking	8	Driving and maintaining a conversation simultaneously

samples t-test was conducted on 83 sessions with valid pre- and post-exposure scale ratings (0–100 scale). Participants' beliefs in feared outcomes decreased significantly within sessions. Before exposure, the mean belief rating was 60.66 (SD = 17.41), while after exposure it dropped to 22.16 (SD = 19.53). This difference was statistically significant (t (82) = 18.63, p < 0.001). The average reduction was 38.49 points (SD = 18.82). The effect size was large (d = 2.05).

To examine the extent to which within-session change in belief strength varied across individuals, Δscore were calculated separately for each participant. A total of 83 exposure sessions with valid pre- and post-exposure ratings were included in the analysis. Individual mean reductions ranged from 23.75 (Participant 5) to 51.55 points (Participant 3), with standard deviations between 9.05 (Participant 3) and 29.42 (Participant 5). To statistically assess these differences, a one-way ANOVA was conducted with participant as the between-subjects factor and Δscore as the dependent variable. Results indicated a significant between-subjects effect (F (7, 75) = 3.72, p = 0.002). The effect size was large (η^2 = .26), indicating that approximately 26% of the variance in belief reduction was attributable to individual differences between participants. Post-hoc analysis revealed that belief reductions for Participant 5 were significantly smaller than those of Participant 3 (M difference = −27.80, SE = 6.57, p = 0.010, 95% CI [−48.25, −7.36]) and Participant 2 (M difference = −24.50, SE = 5.96, p = 0.012, 95% CI [−44.78, −4.22]). Other comparisons between participants were not significant. Detailed Games-Howell post-hoc results are presented in the supplemental material Table S1.

Participants explanations for lingering concerns after completing exposure tasks

Based on qualitative analysis of structured therapy logs, ten content categories were inductively developed to describe the reasons participants gave for persistent beliefs in feared outcomes, even after completing an exposure task. The ten categories represent thematically distinct types of residual concerns. These categories were used to code 96 exposure sessions, of which 66 contained at least one codable expectation. Category assignment was not mutually exclusive; each session could be coded with as many categories as necessary to capture the full scope of the participant's expectation. The maximum number of categories assigned to a single session was two. On average, 1.04 categories were assigned per session (SD = 0.21). Table 4 shows an overview of the frequency with which every category occurred and an example per category. The most commonly cited category was *generalization concerns* (n = 17), followed by *doubts under higher demands* (n = 14). By contrast, several explanations occurred only sporadically. For instance, *residual fear* and *task (partially) failed* were each mentioned only three times.

To further examine interindividual differences in post-exposure concern persistence, the frequency of each residual concern category was calculated separately for each participant (see Table 5). These counts reflect the frequency with which a given concern type was coded, based on participants' post-exposure reflections. Visual inspection of the data reveals substantial variation in the distribution of concern types across individuals. For instance, generalization concerns were mentioned by most participants but ranged from zero instances (Participant 8 - P8) to four instances (P1). Doubts under higher demands were particularly frequent for P4 and P6 (6 and 3 instances, respectively), whereas participants such as P1 and P2 did not report this type of concern at all. Certain concern types, such as high standards and residual fear, were generally less frequent overall but still showed some interindividual variability (e.g., high standards were only reported by P4, P7, and P8).

Table 4. Frequency of remaining concerns.

Category	Frequency	Example
Generalization concerns	17	'It went well now, just like this morning, but maybe this is an exceptional day.'
Doubts under higher demands	14	'The uncertainty when I'd have to run for a longer time (15–20 min) and in busy traffic situations.'
Physical symptoms	8	'I did feel dizzy and definitely blurry-eyed.'
No more concern	7	Participants no longer held any meaningful expectation of the feared outcome
Need for repetition	6	'If I would do this more often then, I would trust more that it wasn't a coincidence.'
Accepted baseline risk	4	"There can always be an accident while driving."
High standards	4	"I'm not fully satisfied with the content of the summary; the essence is in it, but the bar is high."
Residual fear	3	'The fear is still in the body.'
Task (partially) failed	3	'I didn't hold out the task as long as I thought I would.'
Other	3	

Generalization concerns	4	3	2	2	1	3	2	0
Doubts under higher demands	0	0	3	6	1	3	1	0
Physical symptoms	1	3	0	0	2	0	1	1
No more concern	2	1	3	0	0	0	1	0
Need for repetition	1	3	0	0	1	0	0	1
Accepted baseline risk	1	2	0	0	0	1	0	0
High standards	0	0	0	1	0	0	1	2
Residual fear	0	0	0	0	1	0	1	1
Task (partially) failed	0	1	0	1	1	0	0	0
Other	0	1	0	0	1	1	0	0

Discussion

This study demonstrates that individuals with persistent post-concussion symptoms enter therapy with complex, multidimensional fears that extend beyond isolated outcomes to encompass cognitive, physical, functional, and social concerns. While many of these mirrored established symptoms (e.g., memory problems, fatigue, dizziness) and cogniphobia (21), participants also voiced higher-order worries about autonomy, planning, and recovery not typically captured by standardized measures such as the Rivermead Postconcussion Symptoms Questionnaire (18). By drawing on therapy logs, we showed how idiographic methods can uncover these nuanced, individualized concerns and translate them into ecologically valid exposure tasks. Rather than targeting single domains, tasks frequently combined cognitive, sensory, physical, and social elements—such as engaging in conversation in a noisy, crowded setting—thereby maximizing prediction error, addressing multiple feared outcomes simultaneously, and enhancing real-world relevance. This individualized, context-driven approach aligns with broader exposure therapy literature (13,14) emphasizing expectancy violation and personalized fear targets, and is consistent with frameworks highlighting symptom misattribution and maladaptive expectation-driven symptom persistence.

Belief ratings collected within sessions revealed substantial reductions, suggesting that participants revised their expectations when feared outcomes failed to occur. This pattern is consistent with inhibitory learning models, in which disconfirmation of expectations drives cognitive change rather than gradual habituation (13). At the same time, significant individual differences in belief change highlight the need for flexible, personalized treatment pathways: while some participants responded rapidly, others required repeated or varied exposures to achieve similar shifts. This is consistent with findings on exposure therapy in anxiety disorders, where individual variation is common and varied or repeated exposures may be needed (22). The observed individual differences in belief change may reflect variability in baseline symptom severity and symptom profiles, differences in the specific feared outcomes targeted during exposure, and individual differences in learning processes and expectations regarding symptom persistence, although these factors were not systematically examined in the current study.

Crucially, residual doubts often persisted even when initial fears were disconfirmed. Participants questioned whether success would generalize to more challenging circumstances, while others attributed outcomes to chance, or linked them to persistent symptoms, or high standards. These explanations reveal that belief change tends to be incomplete, variable, and context-dependent. Reflections made immediately after each task were particularly useful for bringing such doubts to light, highlighting that a decrease in belief rating does not necessarily signal a full cognitive shift. Capturing the nature of these residual fears adds empirical depth to inhibitory learning accounts and highlights the value of designing subsequent exposures that specifically address remaining uncertainties to strengthen early cognitive gains.

Notably, these process-level observations align with outcomes from our previous efficacy studies (pilot (15) and replication (16)) of intensive exposure therapy for persistent symptoms, which demonstrated consistent improvements across participants in active avoidance, satisfaction with daily functioning, and overall symptom experience. Taken together, these findings suggest that exposure therapy for persistent symptoms is effective when the therapy collaboratively identify personally meaningful fears, translating them into ecologically valid behavioral experiments, and addressing both initial expectations and residual doubts (22). This individualized approach holds promise not only for reducing symptom-related fears, but also for rebuilding confidence, autonomy, and engagement in everyday life after mild traumatic brain injury.

This study offers several key strengths. First, it provides one of the most detailed accounts to date of what actually occurs during exposure therapy for persistent post-concussion symptoms, integrating quantitative and qualitative data from 96 sessions to address a major gap in the literature. Second, by examining feared outcomes, task design, belief change, and post-exposure reflections, it captures multiple layers of therapeutic processes rather than relying solely on efficacy metrics, yielding clinically useful insights into how expectations are formulated, tested, and revised. Third, the use of a standardized yet flexible therapy log balanced consistency with ecological validity, enabling meaningful comparisons while preserving individualized treatment. Finally, to our knowledge, this is the first session-by-session investigation of exposure therapy in persistent post-concussion symptoms, extending prior work in anxiety (23), and psychosis populations (24) by directly documenting therapeutic processes as they unfold in neurorehabilitation contexts. Together, these strengths advance understanding of how exposure functions in practice and bridge theoretical models with real-world clinical application. Nevertheless, the current study also has some limitations that should be acknowledged. First, the sample ings—particularly those based on comparisons between participants. Although single case experimental design studies are well-suited for detecting individual-level effects, caution is warranted when drawing broader conclusions about interindividual variability. Additionally, as the data were nested in structure, with multiple sessions clustered within participants, dependencies between observations may be present. Second, missing expectancy data were not formally examined for patterns of missingness, and no sensitivity analyses were conducted which may limit the robustness of the findings. Third, the sample was relatively homogeneous in terms of demographic characteristics. Most participants were female and young adults, likely reflecting the nature of the recruitment procedures. This is consistent with evidence indicating sex difference in concussion incidence and recovery trajectories, where higher rates and prolonged symptom trajectories of persistent post-concussion symptoms are seen among women following mild traumatic brain injury (4). However, as a result of the homogeneity of the sample, the findings may not generalize to patients with different gender identities, age ranges, or sociocultural backgrounds. This limits the external validity of the study. Finally, the motivational profile of participants may have influenced the outcomes. All participants actively opted in to the study, which likely reflects above-average levels of treatment engagement, expectancy, and openness. This may limit the generalizability of findings to routine healthcare populations where patients might be less motivated (25).

Future research should focus on enhancing the generalizability and clinical applicability of these findings. Larger and more diverse samples are needed to examine whether the observed patterns hold across different demographic and psychosocial groups. Replication in routine clinical settings would clarify whether similar processes occur among less self-selected patients, thereby informing feasibility and scalability. Comparative studies could evaluate different formats of exposure delivery—such as intensive versus weekly schedules (12), or group versus individual formats—and test the benefits of combining exposure with adjunctive interventions like psychoeducation or cognitive restructuring. Additionally, early risk profiling would target the population that may benefit the most from exposure therapy as resources are often limited (and expensive) to provide. Finally, systematic investigation of exposure task design is warranted to identify how factors such as complexity, domain specificity, and personal relevance influence outcomes. Such work could inform clinical guidelines that balance standardization with flexibility and optimize the impact of exposure therapy for this target group.

Clinicians should assess the specific feared expectations that maintain persistent post-concussion symptoms—particularly fears of cognitive failure, task breakdown, and catastrophic interpretations of physical sensations—and use these as direct targets for individualized exposure-based interventions. The findings support integrating structured behavioral experiments that include cognitive challenges, sensory-rich environments, and social activities, as these appear to meaningfully reduce retain residual doubts or generalization concerns, clinicians may improve outcomes by incorporating strategies that promote transfer of learning to more demanding or novel situations, such as varied-context exposure, graded increases in cognitive load, and explicit planning for real-world application. Overall, the results encourage a more confident, process-informed implementation of exposure therapy in mild traumatic brain injury rehabilitation, emphasizing personalization, careful belief monitoring, and iterative adjustment of exposure tasks.

In conclusion, this study provides one of the first detailed accounts of how intensive exposure therapy is applied and experienced by individuals with persistent post-concussion symptoms. The results show that participants' feared expectations can be successfully challenged. The findings highlight the importance of personalizing exposure therapy and attending not only to initial expectations, but also to residual doubts that may remain after exposure. By mapping the structure of feared beliefs, the design of exposure tasks, and the dynamics of belief change, this study offers clinically relevant insights that can help therapists better understand, structure, and personalize exposure for this population. These findings contribute to a better theoretical understanding of fear and avoidance after mild traumatic brain injury, and support the confident, informed application of exposure in neuropsychological rehabilitation.

Author contributions

CRediT: **Skye King:** Conceptualization, Data curation, Investigation, Methodology, Project administration, Supervision, Writing – original draft; **Fenna Konings:** Conceptualization, Data curation, Formal analysis, Methodology, Writing – original draft, Writing – review & editing; **Ieke Winkens:** Conceptualization, Methodology, Supervision, Writing – review & editing; **Joukje van der Naalt:** Conceptualization, Funding acquisition, Methodology, Supervision, Writing – review & editing; **Marleen Rijkeboer:** Conceptualization, Funding acquisition, Methodology, Supervision, Writing – review & editing; **Caroline van Heugten:** Conceptualization, Funding acquisition, Methodology, Project administration, Supervision, Writing – review & editing.

Disclosure statement

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Data availability statement

The data that support the findings of this study are availability from the corresponding author, upon reasonable request.

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