J Cult Cogn Sci
https://doi.org/10.1007/s41809-025-00171-z

RESEARCH PAPER

# The interplay of sensory and motoric information on processing emotions in narrative texts

**Fernando Marmolejo-Ramos · Nemanja Vaci · Florencia Reali · Petar Milin**

Received: 12 August 2024 / Revised: 30 March 2025 / Accepted: 24 May 2025


**Abstract** This study examines the comprehension of characters' emotional states in written narrative texts. Recent theories of embodied cognition suggest that emotions are grounded in somatosensory information involving 'reexperiencing' of actions and perceptions. In addition, views of graded embodied cognition suggest that there are levels of the embodiment of language, focusing on how perceptual and motor information interact during text comprehension. In the present experiment, one-paragraph stories were written to express six basic emotions: fear, sadness, anger, disgust, happiness, and surprise. Four stories were written for each emotion and for each story four critical sentences were composed. The critical sentences comprised a combination of emotion- and action-based components that matched or mismatched the story. Participants read the stories and the critical sentences. Their task was to respond to a question about the emotional state of the story's main character, while we measured response latencies and errors. The results of the error rate analyses suggest that, while reading texts, sensory knowledge about characters' emotional states is activated, but this knowledge is significantly moderated by action-based knowledge. A computational model was used to further confirm these results. The model was trained to predict emotion and action words from critical sentences using linguistic context from stories. Both, the action and emotional words activations showed a distinct effect on participants' comprehension accuracy.

**Keywords** Narrative text · Text comprehension · Character's emotion · Graded embodied cognition · Situation model

F. Marmolejo-Ramos (✉)
College of Education, Psychology, and Social Work, Flinders University, Adelaide, Australia
e-mail: fernando.marmolejoramos@flinders.edu.au

N. Vaci
Department of Psychology, University of Sheffield, Sheffield, UK
e-mail: n.vaci@sheffield.ac.uk

F. Reali
Departamento de Neurociencia y Aprendizaje, Universidad Católica del Uruguay, Montevideo, Uruguay
e-mail: florencia.reali@ucu.edu.uy

P. Milin
Department of Modern Languages, University of Birmingham, Birmingham, UK
e-mail: p.milin@bham.ac.uk

## Introduction

Comprehension of a text/narrative requires continuous interaction of discourse context, information from the text itself, and general or background knowledge. Theories of discourse comprehension posit that, while reading a text, readers form different levels of representation: the surface code that preserves the

Published online: 08 June 2025

exact wording and syntax of clauses; the textbase containing propositions that include meaning, and a micro-world of what the text is about or situation model (Garnham, 2010; Graesser et al., 2002; van Dijk et al., 1983). A situation model arises through the integration of the reader's knowledge about the world with information embedded in the text (Kintsch & van Dijk, 1978). On ce the situation model is established, it is assumed that the reader has comprehended the text.

While reading, the reader obtains and updates multiple dimensions of information in the situation model, including the dimension of space (Hoeben Mannaert et al., 2021; Sundermeier et al., 2005), causation (Egidi & Gerrig, 2006; Trabasso & Wiley, 2005), time (Kelter et al., 2004), as well as characters' memories, goals (Cook et al., 2023; Gernsbacher et al., 1998) and emotional states (de Vega, 2021; Gernsbacher et al., 1998; León et al., 2010). In relation to character´s emotional states, De Vega et al. (1996) have shown that readers continuously update and change information about the protagonist's emotions. Other studies have addressed similitudes and differences between readers' and characters' emotions (Dijkstra et al., 1995; Komeda & Kusumi, 2006), or the emotions elicited directly by the text structure (Hoeken & van Vliet, 2000). Beyond experiencing character's emotions, reading a story essentially involves "taking a mental journal into the story world" (Cook et al., 2023; p. 1303), as comprehenders encode different attributes of the story through the character's special and temporal perspectives (Chan et al., 2018). Similarly, other studies have showed that readers' memory is influenced by a character's cognitive experience (e.g., Houghton & Klin, 2019) and goals (e.g., Gunraj et al., 2017). Moreover, readers evaluate negative emotional events and characters as interesting and complex and remember them more vividly (e.g., Maslej et al., 2021). Consistent with these findings, fMRI studies have shown that changes in a character's goals are accompanied by changes in brain activity in areas normally associated with observing or acting out goal-directed actions (Speer et al., 2010). Also, activation in the amygdala and hippocampus has been reported for emotional sentences in a fashion similar to activation in response to threatening images (Sambuco et al., 2020). Taken together, these findings suggest that readers may encode character's goal-related information and simulate a character's emotions (e.g., Brunyé et al., 2011) and perceptual experiences (Brunyé et al., 2012).

Some have addressed the question of the nature of the knowledge involved in emotion comprehension (de Vega, 2021; Marmolejo-Ramos & Jiménez, 2006; Molinari et al., 2011). According to theories of embodied cognition, comprehension of situation models entails the formation of sensorimotor representations of actions and events described in a text (de Vega, 2021; Matheson & Barsalou, 2018; Pecher & Zwaan, 2005; Schomers & Pulvermuller, 2016; Zwaan, 2016; Zwaan & Taylor, 2006). Specifically, chains of events described in narratives may trigger dynamic representations in sensorimotor domains known as *simulations*, making text comprehension possible (Johnson-Laird & Oatley, 2022; Oatley, 1999). According to Barsalou (2008), a simulation is "the reenactment of perceptual, motor, and introspective states acquired during experience with the world, body, and mind" (p. 618). In the context of the text/narrative comprehension, embodied perspectives posit that simulations of actions and events are actively formed while reading.

Under this perspective, situation models, entail the activation of the same sensorimotor systems deployed when actual perceptions and actions are executed (Gallese & Sinigaglia, 2011; Siakaluk et al., 2008; Speer et al., 2010; Tang et al., 2023). Work on comprehension and construction of situation models suggests that these models have spatial properties (Bower & Morrow, 1990; Glenberg et al., 1987; Speer et al., 2010; Zwaan, 2016), supporting the claim that they depend on physical characteristics of the situation described (Morrow & Clark, 1989). In the same line of argumentation, Franklin and Tversky (1990) showed that readers, while reading narratives, behave as though they were physically in the situation described. A slightly different question is whether characters' actions are simulated while reading about them. Some research has investigated this topic (e.g., Glenberg et al., 2008; Meteyard et al., 2012; Taylor et al., 2008).

In one of the pioneer studies, Glenberg and Kaschak (2002), showed that after reading a sentence such as 'He closed the drawer' participants were faster to initiate an action to respond a yes/no sensibility judgment when the movement was in the same direction as that described in the sentence, concluding that readers formed a visual or motor simulation of the

movement the agent in the sentence. More recently, Gunraj et al. (2014) showed that readers form simulations of the character's linguistic actions as well: only when reader's and the character's actions matched—when both were reading or both were speaking—was a rate effect found, with participants reading/speaking more slowly when the character was described as reading/speaking slowly.

Although much of the research has focused on simulations of character's actions, less work has explored readers' simulations of characters' emotions. Conceptualization of emotions seems to be related to long-term language experience. In a recent study, Niedenthal and collaborators showed that experience with fiction reading affects emotion recognition abilities, suggesting that emotion concepts depend on the simulation of fictional minds during exposure to descriptions of emotions in context (Schwering et al., 2021). They found that if access to the sensory basis of emotion is required by the task, the processing of emotions involves the reexperience of a particular emotion.

One of the challenges for embodied approaches, related to the aim of this paper, is to understand how emotion concepts are bodily grounded, that is, to determine the nature of sensorimotor information involved in the simulation of emotions. Specifically, it is not clear whether action-based knowledge (declaratively and separately construed) interacts with sensory-based emotion knowledge while readers comprehend characters' emotional states. Recent studies have demonstrated that emotion concepts involve somatovisceral simulations; namely, that emotions are grounded in perception and action, so that the processing of emotional information involves 'reenactment' of somatosensory experience in the brain's modality-specific systems (Niedenthal, 2007; Niedenthal et al., 2005). Moreover, it has been shown that sensorimotor interaction with the environment does aid in the construction of emotional contexts (Atkinson et al., 2004; Ikeda & Watanabe, 2009). In these experiments, participants looked at video sequences of body motions and then rated the most probable emotion the video yielded. The results showed that, despite various experimental manipulations, participants were able to identify the emotion depicted by the body motion, suggesting that the processing of emotions may require sensorimotor knowledge. Similarly, Strack et al. (1988) shifted participants into happy or unhappy states, using a pen that participants could hold between their teeth forcing a partial smile or with their lips forcing a partial frown. They concluded that facial configurations differentially affected participants' emotional assessment of stimuli (Coles et al., 2022; Havas et al., 2007; Marmolejo-Ramos et al., 2020).

In the context of the text/narrative comprehension, however, the activation of multiple systems while understanding character's emotions have been less explored. In line with graded embodied approaches (Khatin-Zadeh et al., 2021; Tirado et al., 2018), here we focus on how sensory-based emotional information interacts with action-based knowledge while readers construct a situation model that involves character's emotion (Mahon, 2008).

## Research problem and hypothesis

The revised studies suggest that embodied processes may explain how readers understand characters' emotions in narratives. However, the question remains of the nature of the embodied knowledge involved in the comprehension of protagonists' emotional states. The main goal of the present study is to determine whether sensory-based emotion knowledge and action-based information interact while readers comprehend emotionally-valenced stimuli embedded in narratives. Manipulating descriptions of the character's emotions and actions, we sought to explore the extent to which the reader's comprehension of characters' emotional states is affected.

A reading task was devised to this end. Participants read stories that referred to the main character's emotions followed by a critical sentence that could be action- and emotion-wise congruent or incongruent with the story. Finally, they answered a question about the main character's emotional state.

The structure of the effect should reveal whether comprehension of emotions requires emotional and/or action-based knowledge. A sole main effect of emotional congruence would imply that only emotional information influences story comprehension, the kind of information proven to be most influential in previous findings (Niedenthal, 2007; Niedenthal et al., 2005).

An interaction between emotional and action-based information components would support the interpretation that action-based knowledge moderates the

effect of sensory-based emotional knowledge on story comprehension. This particular structure of effect is expected in the present study, as it is assumed that sensory-based emotional information and action information are actively integrated in a situation model while the story unfolds. Such a view aligns with both the graded embodied cognition approach (Chatterjee, 2010; Mahon, 2008), as well as other embodied models in language comprehension (e.g., Zwaan & Madden, 2005). On the other hand, we do not expect solely an action-congruence effect on comprehension of emotions embedded in a story. This pattern would suggest that action-based information is the only relevant factor in the processing of emotional stimuli, at odds with previous findings (Niedenthal, 2007; Niedenthal et al., 2005).

Our general assumption is that the cognitive system uses all information at its disposal when constructing a situation model. Studies in computational psycholinguistics support this claim, suggesting that the cognitive system, while processing linguistic input, detects and exploits available information from multiple sources (An, 2013; Norris & Phillips, 1987). Following this, we hypothesize that action-related word cues ought to be integrated with other cues during construction of a situation model, subserving comprehension of emotion. To test this, we further developed a computational model using a simple associative error-correction learning rule (Widrow & Hoff, 1960Rescorla & Wagner, 1972; Baayen et al., 2011; Milin et al., 2017). The model was trained on over 65 million words where we modelled the association between critical words from stories and sentences by calculating their co-occurences in natural language use. This model was then used to generate four additional measures per experimental trial: diversity and activation of the emotion word, and diversity and activation of the action word (see 'data availability' section). Finally, we used these measures to predict the accuracy from an experimental setting.

## Method

### Participants

Sixty-five undergraduate psychology students from the University of Novi Sad participated in the experiment in exchange for course credits. All participants were native speakers of Serbian with normal or corrected-to-normal vision. Prior to their involvement, all participants provided written informed consent. The consent form detailed the nature of the experiment, potential risks and benefits, and participants' rights to confidentiality and to withdraw from the study at any time without penalty. The study protocol, including the informed consent procedure, was reviewed and approved by the Institutional Review Board of the University of Novi Sad. All procedures were conducted in accordance with the ethical standards of the Declaration of Helsinki.

### Materials

Six basic emotions (according to Keltner & Ekman, 2000) were selected: happiness, surprise, sadness, anger, disgust, and fear. Then, four stories and four critical sentences per story (matching a 2 × 2 experimental manipulation), were construed for each of the six emotions. The experimental materials consisted of 24 stories and 96 critical sentences. One extra story and four critical sentences were constructed to serve as a practice trial.

The congruence of the critical sentences was manipulated in relation to its emotional (E) and action-based component (A). The emotional and action component could be either consistent (E + , A +) or not (E−, A−) with the emotion and action implied in the story. Critical sentences were thus the product of combining the two levels of each factor: E + A + , E-A + , E + A−, E−A− (see Table 1). All sentences were grammatical, plausible in Serbian, and syntactically similar. They were matched for length, as confirmed with the Kruskal–Wallis rank sum test: $\chi^2$ (3) per word = 0.100, $p$ = n.s; and $\chi^2$ (3) per character = 0.269, $p$ = n.s. To ensure validity of the experimental setting, we run two norming studies, where we checked that stories are conveying expected emotions and that readers find critical sentences acceptable when it comes to the words used to describe emotions and actions, as well as that they logically flow from the previously described situation in the story's critical sentences (for more details see Norming studies in supplementary materials).

**Table 1** Example of a story and the critical sentences for the emotion of happiness

| |
|---|
| Andrea was awakened by a ray of sunshine coming in through her window. She rose and looked out of find a beautiful day. Because last week had been so productive, she knew that there was nothing urgent that needed to be done today. Her essay due in last week was already finished and the presentation she gave yesterday had gone really well. She knew she could take the day off. The whether was beautiful and warm. She could hear the birds singing. She made herself a cup of herbal tea and went out to stretch on a deck chair. She wanted to spend all day simply basking in ths sun. |
| **Critical sentences** |
| E+A+ |
| Andrea was cheerful, and she was drinking tea. |
| E−A+ |
| Andrea was worried, and she was drinking tea. |
| E+A− |
| Andrea was cheerful, and she was gardening tea. |
| E−A− |
| Andrea was worried, and she was gardening tea. |

## Design and procedure

For each emotion, four stories were counterbalanced using a four-by-four Latin-square design to randomise the allocation of participants to the experimental lists. Each participant in each experimental list read four different stories about each of the six emotional states, followed by a critical sentence presenting a combination of the emotion and action components. Trials consisted of several events as illustrated in the Fig. 1 and explained in detail in Experimental Methods section in supplementary materials.

## Computational model

Naive Discriminative Learning (NDL) is an incremental learning algorithm based on the Rescorla-Wagner learning rule (1972; also see Widrow & Hoff, 1960). The incremental learning part of the NDL algorithm updates its knowledge by associating new data, as it becomes available, with learning outcomes. The NDL algorithm implements the Rescorla-Wagner equilibrium equations, proposed by Danks (2003), to learn probabilistic distributional patterns. As such, NDL provides a framework for understanding how to learn and classify data (cf., Baayen, 2011).

In previous NDL applications letter n-grams (typically bigrams or trigrams) are mapped onto lexical meanings (cf., Baayen et al., 2011; Milin et al., 2017); one line of research has led to a computationally more powerful Linear Discriminative Learning, LDL (Baayen et al., 2019). Our present research goal, however, asked for some adjustments of what should be treated as input cues and what as the outcomes. We retrieved content words from the short, one-paragraph story to be the input cues, while the outcomes were one emotion-charged word and one action-charged word from a critical sentence that followed a given story (see Milin et al., 2017 for the first attempt to use NDL in learning to associate words with other words in context). The modelling goal, thus, was to test how well content words from a given story associate with respective emotion and action words, which appeared immediately in the critical sentence. We trained the model on large collection of news text (Medica Documentation Ebart: http://www.arhiv.rs; > 65M words), where the congruency is operationalized as terms of association weights between critical words as they occur and co-occur in natural language usage (for details please refer to the supplementary materials). Using the trained model, we quantified four measures: the diversity and activation of the emotional and action words, which are used to predict experimental outcomes. The diversity of activations, generally, represents the amount of competition between possible outcomes given the relevant input cues (cf., Milin et al., 2017). However, in the context of the present study, it also quantifies deviation or divergence of the relevant cues, indicating whether they are all equally positive, weak, or negative for a given outcome.

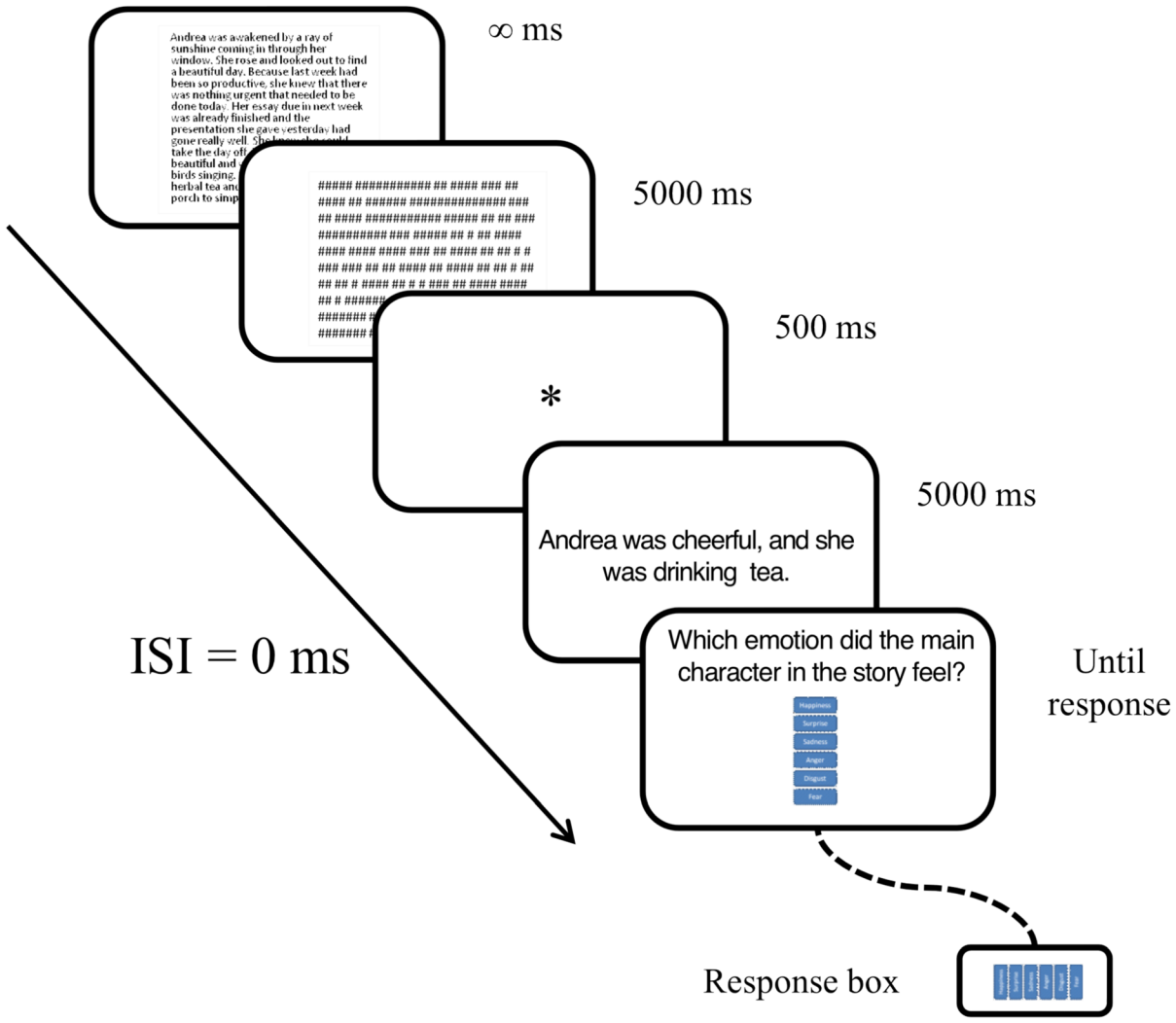


**Fig. 1** Example of the experimental sequence used in the experiment. ISI = interstimulus interval

## Results

After preliminary data analyses, two participants were excluded due to having many response-errors (> 30%). For the same reason two stimuli – two stories that described the emotion surprise – were excluded too. One extremely short latency was excluded as a possible result of an accidental key press (< 300 ms). Reaction times were log-transformed to approximate normality (see Baayen & Milin, 2010; Marmolejo-Ramos et al., 2015;). Analyses of the data were carried out in the R software environment for statistical computing (R core team, 2023). The reaction time analyses yielded non-significant results, which are included in the supplementary materials.

### Error analysis

A logistic mixed-effect regression was applied to binary error indicators (1 = no error, 0 = error), using the lme4 package in R (see Bates, 2005; also see Jaeger, 2008, for application of the logistic mixed-effect regression using lme4). The fixed effects in the model were the emotional and the action congruency of a critical sentence, and we introduced acceptability of the critical sentence in connection to the story as a covariate, while logicality even though high, was

collinear with other variables in the model. The random effects were participants, items (i.e., the stories). The referent levels in the analysis were the cases of emotional and the action congruence (i.e., E + and A +), while the $\beta$ coefficient signalled trends in the contrasting levels (i.e., E− and A−).

Results revealed significant interaction between emotional and actional congruence (see Table 2 and Fig. 2). As show in Fig. 2, the interaction reveals a very interesting pattern: under conditions of emotional congruence, participants were more accurate when motor information was congruent with the story. However, the opposite is observed under conditions of emotional incongruence. In addition to the main effects, we also tested differences between mean levels of each factor combination. Results show significant difference between E + A + and E + A- condition ($z = 2.72$, $p < 0.05$), as well as difference between E + A + and E-A + condition ($z = 3.13$, $p < 0.05$).

### Computational modelling

Generalized Additive Mixed Modelling (GAMM) using the mgcv package (Wood, 2011) for the R software environment (R core team, 2023) was applied to the NDL measures. Using GAMM with NDL measures was justified in previous studies, revealing various non-linear interactions (see, for example, Milin et al., 2017; Divjak & Milin, 2023). We followed a similar procedure in the present analysis. For detailed explanation of the NDL and description of the used measures refer to the Naïve Discriminative Learning modelling section in the supplementary materials.

The results revealed a significant nonlinear interaction (i.e., a tensor product) of action word activation and emotion word diversity (Edf = 4.139; Ref.df = 4.811; Chi.sq = 19.56; $p$-value = 0.0012). This effect is presented in Fig. 3.

The results reveal a noteworthy interaction between the diversity of emotion words and the activation of action words on accuracy. When emotion words exhibit low diversity, meaning that they are all equally strong positive, negative, or weak cues for a given outcome, the influence of action word activation on accuracy remains negligible. This is depicted by the green-shaded region around diversity of -2, indicating reduced accuracy, and nearly vertical isolines suggesting limited impact from action word activation (see leftmost part in Fig. 3). Conversely, at peak diversity (e.g., Diversity = 1.5), heightened activation of action words corresponds to increased accuracy. The peak in accuracy is attained when emotion words differ widely in their association with the target word (outcome), while action words vigorously activate specific target terms. Evidently, the comprehension of emotions within short stories is intricately shaped by both action- and emotion-related content.

## Discussion

The goal of the present research was to explore the degree of interplay between sensory/emotion and motor/action knowledge during comprehension of characters' emotional states, while reading short emotionally saturated narratives. Accuracy results showed a significant interaction between emotional and action congruency: participants were more accurate when action information was congruent but only under conditions of emotional congruency. This suggests that emotional and action information is being processed in an integrated manner rather than independently. The results of our NLD model supported the conclusion that comprehension of emotions during reading of short stories is influenced by both action and emotion information presented in the text. The model can serve as a possible explanatory mechanism of how we ground environmental

**Table 2** Error analysis results

| A. Parametric coefficients | Estimate | Std. Error | $t$ value | $p$-value |
|---|---|---|---|---|
| Intercept | 3.791 | 0.540 | 7.017 | < 0.001 |
| Acceptability | −0.023 | 0.069 | −0.341 | 0.733 |
| emotional congruency (incongruent) | −1.007 | 0.321 | −3.133 | 0.001 |
| action congruency (incongruent) | −0.907 | 0.333 | −2.721 | 0.006 |
| emotional incongruence × action incongruence | 1.342 | 0.448 | 2.992 | 0.002 |

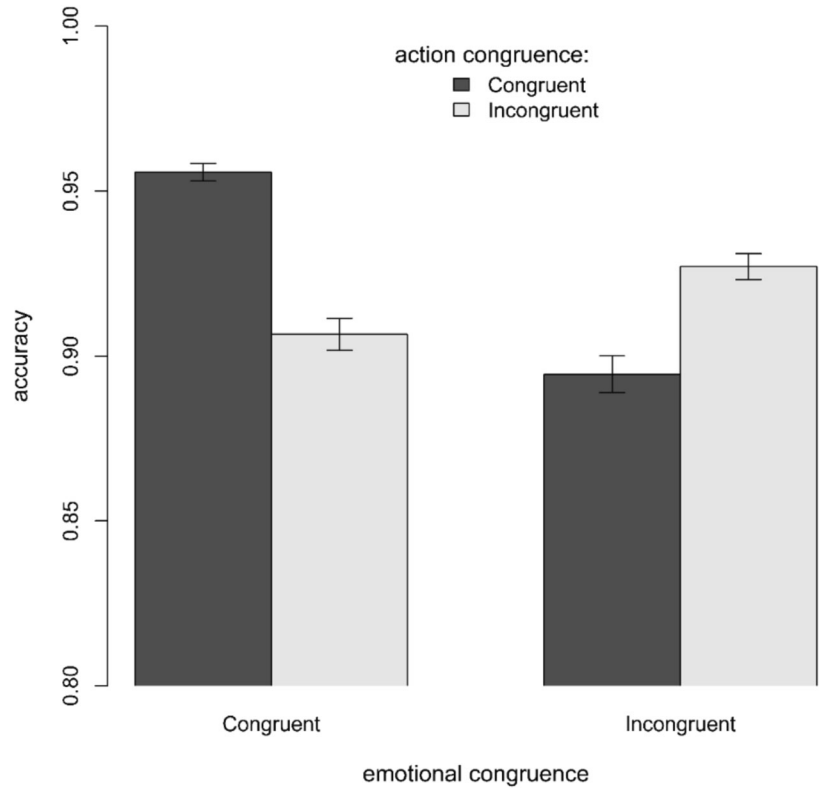


**Fig. 2** The interaction between emotional and actional congruence on the accuracy. Error bars represent 95% CIs

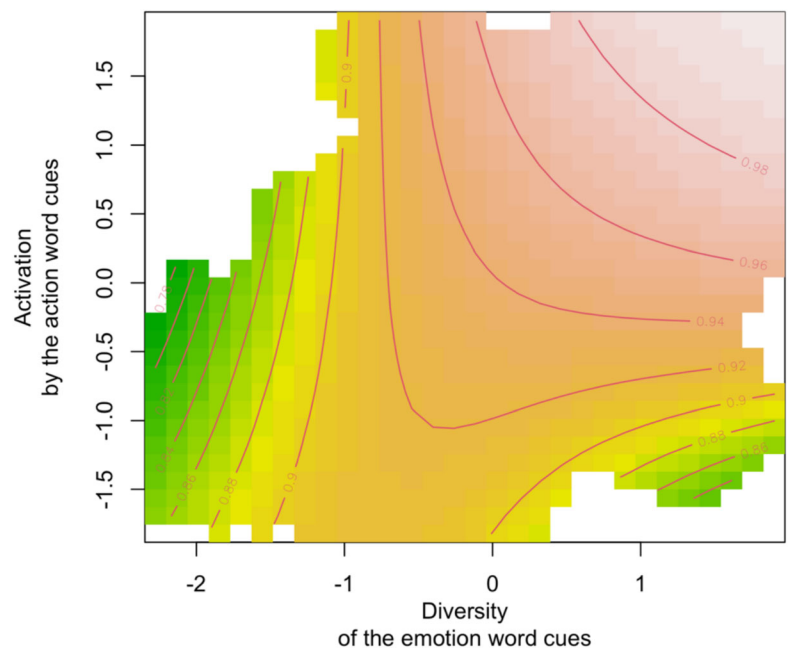


**Fig. 3** Non-linear interaction between emotion word diversity and action word activation on the accuracy

information for adaptive purposes (Divjak & Milin, 2023; Ellis, 2006; Milin et al., 2023; Ramscar & Yarlett, 2007; Rescorla & Wagner, 1972).

Taken together, these results support theories of embodiment that propose that emotional and action information may interact during comprehension of emotions in narratives. Grounded approaches posit that multimodal information integrates into a situation model during narrative comprehension (Kintsch & van Dijk, 1978). Within this approach, simulations of basic sensorimotor neural activity have been proposed as the functional, explanatory mechanism (Barsalou, 2008; Zwaan, 2016). Su ch simulations entail the re-enactment of events and situations described in a given text. In series of studies, Niedenthal and her associates (Niedenthal, 2007; Niedenthal et al., 2005) showed that perceptual and somatovisceral re-enactments are essential for building situation models when we comprehend emotions from a written narrative. Here we re-examined Niedenthal et al.'s claims (Niedenthal, 2007; Niedenthal et al., 2005) and tested the degree of effect of motor-based knowledge in processing emotionally-valenced texts.

According to the embodied framework, congruent action (motor) information should modulate emotional (sensory) processing in emotionally charged texts, improving comprehension. However, our findings present a challenge: accuracy was unexpectedly high even when both emotion and action cues were incongruent with the story's emotion (Fig. 2). The most straightforward explanation – that participants simply ignored the conflicting critical sentence and used only the story context – is difficult to reconcile with embodiment theory, as simulations should be triggered by all relevant text. An alternative perspective, grounded in error-correction learning, may resolve this. This view posits that participants learn to disregard cues that prove uninformative. Thus, if the critical sentence cues consistently misled, participants would learn to ignore them, explaining the high accuracy despite incongruence. Crucially, this learning mechanism is not opposed to embodiment; instead, it offers an account of how embodied representations are potentially modulated by learned cue reliability.

Another aspect requiring comment is the five-second delay between the presentation of the paragraph and the critical sentence. The five-second ISI, chosen to match critical sentence duration, may have been too long to capture automatic embodied processes. This duration likely allowed participants time for more deliberative retrieval and strategic evaluation rather than automatic sensorimotor integration. Consequently, the observed interaction between emotional and action congruency, along with related computational findings, might reflect explicit reasoning or post-comprehension integration, rather than the rapid, online processes predicted by embodiment theories. Future research examining automatic embodiment during reading comprehension would benefit from more temporally sensitive methods, such as shorter ISIs or online measures like eye-tracking or ERPs.

Overall, our findings are in line with the weak embodiment framework, which claims that text comprehension is mediated or modulated by different sources of grounded knowledge (Meteyard et al., 2012), and that cognitive systems make use of all relevant information at its disposal to fulfil specific tasks. Zwaan (2016) pro poses that situational co-occurrences between words and concepts influence the grounding of language. This is exactly how associative learning can fill in harmony with embodiment theories. Comprehension of a word or concept involves prior experience with an outcome, which is at least in part based on the cues frequently observed in the same situational context (cf., Ramscar & Yarlett, 2007). Ou r computational model, based on a simple error-correction rule (Rescorla & Wagner, 1972), showed that emotions in short stories can be informed by both action and emotion cues from the immediately following sentence. Under this view, grounding involves learning the sensorimotor cues that co-occur with the outcome of interest. Our results then, align with the view that readers learn to predict outcomes from multiple information sources (e.g., Ramscar & Yarlett, 2007), in line with modern learning models that assume explanatory mechanisms for grounded approaches to language.

**Author contributions** Conceptualization: Fernando Marmolejo-Ramos; Methodology: Fernando Marmolejo-Ramos, Nemanja Vaci, and Petar Milin; Formal analysis and investigation: Nemanja Vaci, and Petar Milin; Writing—original draft preparation: Fernando Marmolejo-Ramos; Writing—review and editing: Fernando Marmolejo-Ramos, Nemanja Vaci, Petar Milin, and Florencia Reali. Fernando Marmolejo-Ramos and Nemanja Vaci are joint first authors.

**Funding** Open Access funding enabled and organized by CAUL and its Member Institutions. No funding was received for conducting this study.

**Data availability** Data availability: R codes and materials related to this article can be found at https://cutt.ly/HwrsYkrI.

**Declarations**

**Conflicts of interest** The authors declare no competing interests.

**Financial interests** The authors declare they have no financial interests.

**Ethical approval** All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

**Informed consent** Informed consent was obtained from all individual participants included in the study.



## References

An, S. (2013). Schema theory in reading. *Theory & Practice in Language Studies, 3*(1), 130–134.

Atkinson, A. P., Dittrich, W. H., Gemmell, A. J., & Joung, A. W. (2004). Emotion perception from dynamic and static body expressions in point-light and full-light displays. Perception, *33*(6), 717–746.

Baayen, R. H., & Milin, P. (2010). Analyzing reaction times. *International Journal of Psychological Research, 3*, 12–28.

Baayen, R. H., Milin, P., Filipović Đurđević, D., Hendrix, P., & Marelli, M. (2011). An amorphous model for morphological processing in visual comprehension based on naive discriminative learning. *Psychological Review, 118*, 438–481.

Baayen, R. H., Chuang, Y. Y., Shafaei-Bajestan, E., & Blevins, J. P. (2019). The discriminative lexicon: A unified computational model for the lexicon and lexical processing in comprehension and production grounded not in (de) composition but in linear discriminative learning. Complexity, 2019.

Baayen, H. (2011). Corpus linguistics and naive discriminative learning. *Revista Brasileira de Linguística Aplicada*, *11*(2), 295–328.

Barsalou, L. W. (2008). Grounded cognition. *Annual Review of Psychology, 59*, 617–645.

Bates, D. (2005). Fitting linear mixed models in R.R News, 5, 27–30.

Bower, G. H., & Morrow, D. G. (1990). Mental models in narrative comprehension. *Science, 247*(4938), 44–48.

Brunyé, T. T., Ditman, T., Mahoney, C. R., & Taylor, H. A. (2011). Better you than I: Perspectives and emotion simulation during narrative comprehension. *Journal of Cognitive Psychology, 23*(5), 659–666. https://doi.org/10.1080/20445911.2011.559160

Brunyé, T. T., Mahoney, C. R., Rapp, D. N., Ditman, T., & Taylor, H. A. (2012). Caffeine enhances real-world language processing: Evidence from a proofreading task. *Journal of Experimental Psychology Applied, 18*(1), 95–108. https://doi.org/10.1037/a0025851

Chan, G. C., Magliano, J. P., & O'Brien, E. J. (2018). Processing the outcomes of characters' actions: The impacts of character goals and situational context. *Discourse Processes, 55*(5–6), 497–509. https://doi.org/10.1080/0163853X.2018.1435147

Chatterjee, A. (2010). Disembodying cognition. *Language and Cognition, 2–1*, 79–116.

Coles, N. A., et al. (2022). A multi-lab test of the facial feedback hypothesis by the many smiles collaboration. *Nature Human Behavior, 6*, 1731–1742. https://doi.org/10.1038/s41562-022-01458-9

Cook, A. M., Klin, C. M., Westerman, D. L. (2023). Surviving with story characters: What do we remember? Memory & Cognition, 51(6), 1303–1316. https://doi.org/10.3758/s13421-022-01391-2

de Vega, M. (2021). Revisiting the embodiment of narrative language. *Revista Signos, 54*(107), 985–1003.

de Vega, M., León, I., & Díaz, J. M. (1996). The representation of changing emotions in reading comprehension. *Cognition and Emotion, 10*, 303–323.

Dijkstra, K., Zwaan, R. A., Graesser, A. C., & Magliano, J. P. (1995). Character and reader emotions in literary texts. *Poetics, 23*(1–2), 139–157.

Divjak D. & Milin, P. (2023). Using computational cognitive modeling in usage-based linguistics. In M. Diaz-Campos & S. Balasch (Eds.) The handbook of usage-based linguistics. Wiley.

Egidi, G., & Gerrig, R. (2006). Readers' experiences of characters' goals and action. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 32*, 1322–1329.

Ellis, N. C. (2006). Language acquisition as rational contingency learning. *Applied Linguistics, 27*(1), 1–24.

Franklin, N., & Tversky, B. (1990). Searching imagined environments. *Journal of Experimental Psychology: General, 119*, 63–76.

Gallese, V., & Sinigaglia, C. (2011). What is so special about embodied simulation? *Trends in Cognitive Sciences, 15*(11), 512–519.

Garnham, A. (2010). Models of processing: Discourse. *Wires Cognitive Science, 1*(6), 845–853.

Gernsbacher, M. A., Hallada, B. M., & Robertson, R. W. (1998). How automatically do readers infer fictional character's emotional states? *Scientific Studies of Reading, 2*, 271–300.

Glenberg, A. M., & Kaschak, M. P. (2002). Grounding language in action. *Psychonomic Bulletin & Review, 9*(3), 558–565. https://doi.org/10.3758/BF03196313

Glenberg, A. M., Meyer, M., & Lindem, K. (1987). Mental models contribute to foregrounding during text comprehension. *Journal of Memory and Language, 26*(1), 69–83.

Glenberg, A. M., Sato, M., Cattaneo, L., Riggio, L., Palumbo, D., & Buccino, G. (2008). Processing abstract language modulates motor system activity. *Quarterly Journal of Experimental Psychology, 61*(6), 905–919. https://doi.org/10.1080/17470210701625550

Graesser, A. C., Olde, B., & Klettke, B. (2002). How does the mind construct and represent stories? In M.C. Green, J. J. Strange & T. C. Brook (Eds.). Narrative impact: Social and cognitive foundations. Mahwah, NJ: Lawrence Erlbaum.

Gunraj, D., Upadhyay, S. S., Houghton, K., Westerman, D., & Klin, C. (2017). Simulating a story character's thoughts: Evidence from the directed forgetting task. *Journal of Memory and Language, 96*, 1–8. https://doi.org/10.1016/j.jml.2017.04.005

Gunraj, D. & Drumm-Hewitt, A., & Klin, C. (2014). Embodiment during reading: Simulating a story character's linguistic actions. *Journal of experimental psychology. Learning, memory, and cognition, 40*. https://doi.org/10.1037/a0034853

Havas, D. A., Glenberg, A. M., & Rinck, M. (2007). Emotion simulation during language comprehension. *Psychonomical Bulletin & Review, 14*(3), 436–441.

Hoeben Mannaert, L. N., Dijkstra, K., & Zwaan, R. A. (2021). Is color continuously activated in mental simulations across a broader discourse context? *Memory and Cognition, 49*, 127–147. https://doi.org/10.3758/s13421-020-01078-6

Hoeken, H., & van Vliet, M. (2000). Suspense, curiosity, and surprise: How discourse structure influences the affective and cognitive processing of a story. *Poetics, 27*(4), 277–286.

Houghton, K. J., & Klin, C. M. (2019). Do readers remember what story characters remember? *Discourse Processes, 57*(1), 1–16. https://doi.org/10.1080/0163853X.2019.1571782

Ikeda, H., & Watanabe, K. (2009). Anger and happiness are linked differently to the explicit detection of biological motion. *Perception, 38*, 1002–1011.

Jaeger, T. F. (2008). Categorical data analysis: away from ANOVAs (transformation or not) and towards Logit Mixed Models. *Journal of Memory and Language, 59*(4), 434–446.

Johnson-Laird, P. N., & Oatley, K. (2022). How poetry evokes emotions. *Acta Psychologica, 224*, Article 103506.

Kelter, S., Kaup, B., & Claus, B. (2004). Representing a described sequence of events: a dynamic view of narrative comprehension. *Journal of Experimental Psychology: Learning, Memory and Cognition, 30*(2), 451–464.

Keltner, D., & Ekman, P. (2000). Facial expression of emotion. In M. Lewis & J. Haviland-Jones (Eds.), *Handbook of Emotions* (2nd ed., pp. 236–249). Guilford Publications.

Khatin-Zadeh, O., Eskandari, Z., Cervera-Torres, S., Ruiz-Fernández, S., Farzi, R., & Marmolejo-Ramos, F. (2021). The strong versions of embodied cognition: Three challenges faced. *Psychology & Neuroscience, 14*(1), 16–33.

Kintsch, W., & van Dijk, T. A. (1978). Towards a model of text comprehension and production. *Psychological Review, 85*, 363–394.

Komeda, H., & Kusumi, T. (2006). The effect of a protagonist's emotional shift on situation model construction. Memory and Cognition, 34(7), 1548–1556.

León, I., Díaz, J. M., de Vega, M., & Hernández, J. A. (2010). Discourse-based emotional consistency modulates early and middle components of event-related potentials. *Emotion, 10*, 863–873.

Mahon, B. Z. (2008). Action recognition: Is it a motor process? *Current Biology, 18*(22), R1068–R1069.

Marmolejo-Ramos, F., & Jiménez, A.T. (2006). Inferencias, modelos de situación y emociones en textos narrativos. El caso de los niños de edad preescolar [Inferences, situation models, and emotions in narrative texts. The case for preschoolers]. *Revista Intercontinental de Psicología y Educación*, *8*(2), 93–138.

Marmolejo-Ramos, F., Cousineau, D., Benites, L., & Maehara, R. (2015). On the efficacy of procedures to normalise Ex-Gaussian distributions. *Frontiers in Psychology*, *5*(1548): https://doi.org/10.3389/fpsyg.2014.01548

Marmolejo-Ramos, F., Murata, A., Sasaki, K., Yamada, Y., Ikeda, A., Hinojosa, J.A., Watanabe, K., Parzuchowski, M., Tirado, C., & Ospina, R. (2020). Your face and moves seem happier when I smile. Facial action influences the perception of emotional faces and biological motion stimuli. *Experimental Psychology*, *67*(1), 14–22.

Maslej, M. M., Mar, R. A., & Kuperman, V. (2021). The textual features of fiction that appeal to readers: Emotion and abstractness. *Psychology of Aesthetics, Creativity, and the Arts, 15*(2), 272–283. https://doi.org/10.1037/aca0000282

Matheson, H. E., & Barsalou, L. W. (2018). Embodiment and grounding in cognitive neuroscience. *Wiley & Sons*. https://doi.org/10.1002/9781119170174.epcn310

Meteyard, L., Cuadrado, S. R., Bahrami, B., & Vigliocco, G. (2012). Coming of age: A review of embodiment and the neuroscience of semantics. *Cortex, 48*(7), 788–804.

Milin, P., Feldman, L. B., Ramscar, M., Hendrix, P., & Baayen, R. H. (2017). Discrimination in Lexical Decision. *PLoS ONE, 12*(2), Article e0171935.

Milin, P., Tucker, B. V., & Divjak, D. (2023). A learning perspective on the emergence of abstractions: the curious case of phone(me)s. *Language and Cognition*, 1–23.

Molinari, C., Barreyro, J. P., Cevasco, J., & van den Broek, P. (2011). Generation of emotional inferences during text comprehension: Behavioral data and implementation through the landscape model. *Escritos De Psicología, 4*(1), 9–17.

Morrow, D. G., & Clark, H. H. (1989). Interpreting words in spatial descriptions. *Language and Cognitive Processes, 3*, 275–291.

Niedenthal, P. M. (2007). Embodying emotion. *Science, 316*, 1002–1005.

Niedenthal, P. M., Barsalou, L. W., Winkielman, P., Krauth-Gruber, S., & Ric, F. (2005). Embodiment in attitudes,

social perception, and emotion. *Personality and Social Psychology Review, 9*(3), 184–211.
Norris, S. P., & Phillips, L. M. (1987). Explanations of reading comprehension: Schema theory and critical thinking theory. *Teachers College Record, 89*(2), 281–306.
Oatley, K. (1999). Meetings of minds: Dialogue, sympathy, and identification, in reading fiction. *Poetics, 26*, 439–454.
Pecher, D., & Zwaan, R. (2005). *Grounding cognition: The role of perception and action in memory, language, and thinking*. Cambridge University Press.
R Core Team (2023). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.
Ramscar, M., & Yarlett, D. (2007). Linguistic self-correction in the absence of feedback: A new approach to the logical problem of language acquisition. *Cognitive Science, 31*(6), 927–960.
Rescorla, R. A., & Wagner, A. R. (1972). A theory of Pavlovian conditioning: Variations in the effectiveness of reinforcement and non-reinforcement. *Classical Conditioning II: Current Research and Theory, 2*, 64–99.
Sambuco, N., Costa, V. D., Lang, P. J., & Bradley, M. M. (2020). Assessing the role of the amygdala in fear of pain: Neural activation under threat of shock. *Journal of Affective Disorders, 276*, 1142–1148. https://doi.org/10.1016/j.jad.2020.07.110
Schomers, M., & Pulvermuller, F. (2016). Is the sensorimotor cortex relevant for speech perception and understanding? An Integrative Review. Frontiers in Human Neuroscience, 21 https://doi.org/10.3389/fnhum.2016.00435
Schwering, S. C., Ghaffari-Nikou, N. M., Zhao, F., Niedenthal, P., & Maryellen, C. (2021). Exploring the relationship between fiction reading and emotion recognition. *Affective Science, 2*, 178–186. https://doi.org/10.1007/s42761-021-00034-0
Siakaluk, P. D., Pexman, P. M., Sears, C. R., Wilson, K., Locheed, K., & Owen, W. J. (2008). The benefits of sensorimotor knowledge: Body-object interaction facilitates semantic processing. *Cognitive Science, 32*, 591–605.
Speer, N. K., Reynolds, J. R., Swallow, K. M., & Zacks, J. M. (2010). Reading stories activates neural representations of visual and motor experiences. *Psychological Science, 20*(8), 989–999.
Strack, F., Martin, L. L., & Stepper, S. (1988). Inhibiting and facilitating conditions of the human smile: A nonobtrusive test of the facial feedback hypothesis. *Journal of Personality and Social Psychology, 54*(5), 768–777.
Sundermeier, B. A., van den Broek, P., & Zwaan, R. A. (2005). Causal coherence and the avaliability of locations and objects during narrative comprehension. *Memory and Cognition, 33*(3), 462–470.
Tang, D., Fu, W., Wang, H., Liu, B., Zang, A., & Kärkkäinen, T. (2023). The embodiment of emotion-label words and emotion-laden words: Evidence from late Chinese–English bilinguals. *Frontiers in Psychology*, 22. https://doi.org/10.3389/fpsyg.2023.1143064
Taylor, L. J., Lev-Ari, S., & Zwaan, R. A. (2008). Inferences about action engage action systems. *Brain and Language, 107*(1), 62–67. https://doi.org/10.1016/j.bandl.2007.08.004
Tirado, C., Khatin-Zadeh, O., Gastelum, M., Jones, N. L., & Marmolejo-Ramos, F. (2018). The strength of weak embodiment. *International Journal of Psychological Research, 11*(2), 77–85.
Trabasso, T., & Wiley, J. (2005). Goal plans of action and inferences during comprehension of narrative. *Discourse Processes, 39*, 129–164.
Van Dijk, T. A., & Kintsch, W. (1983). *Strategies of discourse comprehension*. Academic Press.
Widrow, B., & Hoff, M. E. (1960). Adaptive switching circuits. In *Paper presented at the WESCON Convention Record Part IV*.
Wood, S. N. (2011). Fast stable restricted maximum likelihood and marginal likelihood estimation of semiparametric generalized linear models. *Journal of the Royal Statistical Society Series B: Statistical Methodology, 73*(1), 3–36.
Zwaan, R. A. (2016). Situation models, mental simulations, and abstract concepts in discourse comprehension. *Psychonomic Bulletin & Review, 23*, 1028–1034. https://doi.org/10.3758/s13423-015-0864-x
Zwaan, R. A., & Taylor, L. J. (2006). Seeing, acting, understanding: Motor resonance in language comprehension. *Journal of Experimental Psychology: General, 135*, 1–11.
Zwaan, R., & Madden, C. (2005). Embodied sentence comprehension. In D. Pecher & R. Zwaan (Eds.), Grounding Cognition: The role of perception and action in memory, language, and thinking (pp. 224–245). Cambridge: Cambridge University Press. https://doi.org/10.1017/CBO9780511499968.010