Musical syntactic structure improves memory for melody: evidence from the processing of ambiguous melodies

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Abstract

Memories of most stimuli in the auditory and other domains are prone to the disruptive interference of intervening events, whereby memory performance continuously declines as the number of intervening events increases. However, melodies in a familiar musical idiom are robust to such interference. We propose that representations of musical structure emerging from syntactic processing may provide partially redundant information that accounts for this robust encoding in memory. The present study employs tonally ambiguous melodies which afford two different syntactic interpretations in the tonal idiom. Crucially, since the melodies are ambiguous, memory across two presentations of the same melody cannot bias whether the interpretation in a second listening will be the same as the first, unless a representation of the first syntactic interpretation is also encoded in memory in addition to sensory information. The melodies were presented in a Memory Task, based on a continuous recognition paradigm, as well as in a Structure Task, where participants reported their syntactic interpretation of each melody following a disambiguating cue. Our results replicate memory-for-melody's robustness to interference, and further establish a predictive relationship between memory performance in the Memory Task and the robustness of syntactic interpretations against the bias introduced by the disambiguating cue in the Structure Task. As a consequence, our results support that a representation based on a disambiguating syntactic parse provides an additional, partially redundant encoding that feeds into memory alongside sensory information. Furthermore, establishing a relationship between memory performance and the formation of structural representations supports the relevance of syntactic relationships towards the experience of music.

Keywords: memory; music; musical syntax; interference; robust encoding

Introduction

Memory for sensory stimuli is generally prone to disruptive interference due to new intervening information and to the passing of time (Eysenck & Keane, 2015). However, specific types of stimuli in different sensory modalities have been shown not to exhibit such a disruptive effect. For example, robust memory with respect to intervening items is observed for drawings (but not for photographs; Berman, Friedman, & Cramer, 1991; Friedman, 1990; Konkle, Brady, Alvarez, & Oliva, 2010), for poetry (but not for prose; Tillmann & Dowling, 2007), and for melodies in a familiar musical idiom (but not for pitch sequences in unfamiliar tunings; Herff, Olsen, Dean, & Prince, 2018). In order to account for such phenomena, it was proposed under the Regenerative Multiple Representations conjecture (RMR) that some stimuli may afford additional representations that constitute memory traces coding partially redundant information, which can be used to compensate for interference effects (Herff, Olsen, & Dean, 2018; Herff, Dean, & Olsen, 2017). In fact, redundant information is in general a key tool for robust encoding, since redundancy affords to reconstruct missing or compromised data (MacKay, 2003; Shannon, 1948). As such, redundancy is of great importance for the robustness of computational (e.g., Merkey & Posner, 1984) as well as perceptual and cognitive processing (Barlow, 2001; Puchalla, Schneidman, Harris, & Berry, 2005). In the context of memory, the RMR extends previous redundancy-based frameworks such as the multiple-trace (Hintzman, 1988) and the dual-coding theory (Paivio, 1969) to account for the aforementioned phenomena.

Robust memory for melody and musical structure

Predictions from the RMR are supported by converging evidence in the auditory domain, specifically addressing memory for melodies. Memory for novel melodies has been shown not to be disrupted by the passing of time (Schellenberg & Habashi, 2015) nor by the interference of other melodies intervening between first and second presentation (Herff, Olsen, & Dean, 2018). On the contrary, melodies in unfamiliar tuning systems (Herff, Olsen, Dean, & Prince, 2018; Herff, Olsen, Prince, & Dean, 2018) as well as rhythmic patterns obtained by removing pitch information from melodies (Herff, Olsen, Prince, & Dean, 2018) do exhibit a significant decay in recognition performance as a function of the number of intervening trials. A direct comparison against words and photographs showed that memory for melody is not generally better but instead deploys a mechanism that, after encoding, makes melodic memories resilient to interference (Herff, Olsen, Anic, & Schaal, 2019). This is further supported by the literature on 'earworms' (Jakubowski, Finkel, Stewart, & Müllensiefen, 2017) as well as clinical studies (Baird & Samson, 2014; Cuddy, Sikka, & Vanstone, 2015).

Memory performance in music is improved by the presence of structure, as quantified by the degree of adherence to idiom-specific music-theoretical norms (Cuddy, Cohen, & Miller, 1979; Cuddy, Cohen, & Mewhort, 1981; Deutsch, 1980). In particular, previous studies have suggested that the structured organisation of auditory events in time, which is a shared feature of music and poetry, may be responsible for the peculiar behaviour in memory of these types of stimuli (Tillmann & Dowling, 2007). Overall, embedding musical

stimuli within a coherent formal structure is necessary for the robustness of memory, but if and how specific syntactic relationships linking musical events are relevant towards memory performance is uncertain (Dowling, Tillman, & Ayers, 2001). Here, we propose and test the hypothesis that the beneficial effect of musical structure on memory, specifically the robustness in memory for melody, is mediated by the formation of representations of syntactic structure. In particular, we hypothesise that a representation of a stimulus' syntactic structure, distinct from its sensory representation, may constitute an additional representation encoding partially redundant information and hence contribute to robust encoding in memory as predicted by the RMR. For example, memory of the sensory information identifying the pitch of a note may be lost due to memory decay. However, if the note belongs to an idiomatic melody, syntactic relationships link that particular note with those preceding it. Such relationships form expectations (Rohrmeier, 2013) that point towards a specific pitch, thus potentially helping to recover its memory. Note that syntactic relationships would not be perceived within, e.g., melodies in an unfamiliar musical system, which would explain the different behaviour of melodies in an unfamiliar tuning as opposed to idiomatic ones.

Musical syntax as representation

Generative accounts of hierarchical musical structure distinguish between the musical surface, comprising a representation of the sensory events, and its syntactic interpretation, comprising the mutual interpretive relationships that recursively connect events with one another (Lerdahl & Jackendoff, 1983; Rohrmeier, 2020a). Examples of such interpretive relationships are preparation and prolongation in the context of tonal harmony (Rohrmeier, 2020a) and rhythm (Rohrmeier, 2020b), or contrapuntual elaborations (neighbouring motion, passing motion, etc.) in the context of monodic or polyphonic structure (Schenker, 1935; Finkensiep, Widdess, & Rohrmeier, 2019; Yust, 2015). Interpretive relationships and the way they can be combined recursively to account for a given musical surface are specific to each musical idiom.

Computational accounts of musical syntactic processing formalise music-theoretical expert-knowledge and also capture many aspects of the experience of musical structure (Herff, Harasim, Cecchetti, Finkensiep, & Rohrmeier, 2021). This includes predictions for harmonic pattern completions (Herff et al., 2021), expectations arising from hierarchical dependency relations (Cheung, Meyer, Friederici, & Koelsch, 2018; Koelsch, Rohrmeier, Torrecuso, & Jentschke, 2013), and interference with linguistic syntactic processing (Patel, 1998; Slevc, Rosenberg, & Patel, 2009). In particular, a core prediction of hierarchical syntactic models of music cognition is that a representation of the syntactic interpretation is formed through a process of parsing, (Jackendoff, 1991; Rohrmeier, 2013, 2020a), and it is a challenge for both theoretical and empirical research to understand how the availability of such a representation would manifest itself in and
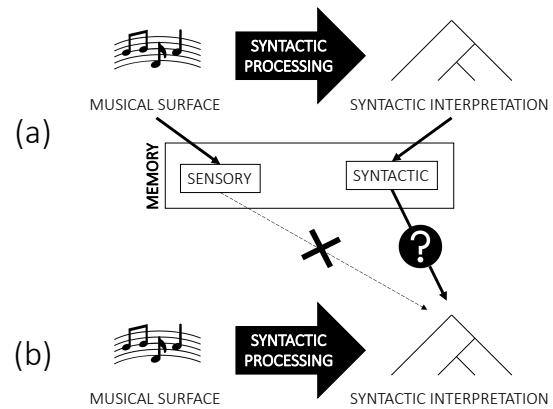

Figure 1: Memory of the first presentation (a) of an ambiguous musical surface cannot influence the outcome of syntactic processing in a second presentation (b), whereas memory of the syntactic interpretation, if encoded in memory, could.

impact upon other cognitive functions.

The RMR provides a framework to test the cognitive relevance of syntactic representations by showing their impact on the formation and retrieval of memory (Milne & Herff, 2020). Idiomatic melodies are peculiar among non-linguistic auditory stimuli, insofar as they can be perceived as syntactically-interpretable units by listeners who are familiar with the syntactic principles of the given musical idiom. In turn, if information related to the syntactic interpretation is stored in memory alongside sensory information, this may provide the necessary redundancy for the robust encoding of melodies. Furthermore, from a computational perspective, syntactic organisation affords higher encoding compression, resulting in more efficient representations potentially saving memory resources and improving performance (Rohrmeier & Pearce, 2018).

Structural ambiguity: the present approach

In order to test the hypothesis that representations of musical structure contribute to memory, we focus here on a set of novel tonally-ambiguous melodies. These melodies are constructed so that two different syntactic interpretations can be attributed to the same set of sensory events comprising the musical surface. Specifically, each melody may be heard in two different keys in the tonal idiom. As a consequence, a representation of the sensory information alone (e.g., the pitch of each note) is insufficient to uniquely determine a syntactic interpretation. The latter constitutes a separate representation that has to be processed upon listening based on the listeners' syntactic competence.

The presentation of a key-defining chord at the end of a melody, however, may retrospectively bias listeners towards one or the other plausible syntactic interpretation (cf. Fodor and Ferreira, 1998 in language). Across multiple presentations of the same melody with different key-defining chords, participants may then change their syntactic interpretation of the melody according to the key-defining chord itself. How-

ever, it is also possible that a specific syntactic interpretation is formed during the first presentation and then remains *stable* across successive presentations, even if the key-defining chord presented at the end of the melody changes. Note that, in principle, the stability of a syntactic interpretation characterises the syntactic processing of a melody, not its memory: it indicates that the outcome of syntactic processing on that particular input is the same in two different attempts. However, the outcome of syntactic processing (the syntactic interpretation) may be represented and stored in memory alongside sensory information (the musical surface), forming an additional memory trace for the melody (Figure 1a). If such syntactic information from previous parsing attempts complements sensory information in memory, retrieving the memory of syntactic information upon a subsequent presentation of the same melody may influence the subsequent parsing attempt (Figure 1b, solid arrow). Specifically, a stronger memory trace of the syntactic information would result in a higher likelihood for the syntactic interpretation to be stable across multiple parsing attempts. Crucially, when dealing with ambiguous stimuli, memory of the sensory information alone would not be able to bias the outcome of subsequent parsing attempts (Figure 1b, dashed arrow), sensory information being ambiguous. As a consequence, evidence for a predictive relationship between memory performance and stability of syntactic interpretations in the same melody stimuli supports the existence of a representation of syntactic information in memory.

Furthermore, if such a syntactic representation concurs towards the robustness of melodic memory, for example by sensory and syntactic representations coding partially redundant information that can be used to recover each other, it should also exhibit robustness to interference. Our paradigm affords to test this hypothesis by showing whether the likelihood for syntactic interpretations to be stable across multiple presentations decreases with increasing number of intervening trials.

Aims and hypotheses

In this experiment, we investigate whether the emergence of a syntactic interpretation is related to the formation and retrieval of memory for a melody, as predicted by the RMR conjecture under the additional hypothesis that syntactic interpretations specifically contribute to redundancy in memory for melody. In particular, we hypothesise (1) that the melodies are robust to memory interference, as suggested by previous evidence concerning idiomatic melodies, (2) that stronger memory performance is associated with higher likelihood for stable syntactic interpretations, and (3) that this likelihood does not decay with the number of intervening trials.

Methods

Participants

Sixty-two participants (median age 25.5, range 18-74) took part in the online experimental session. Participants were re-
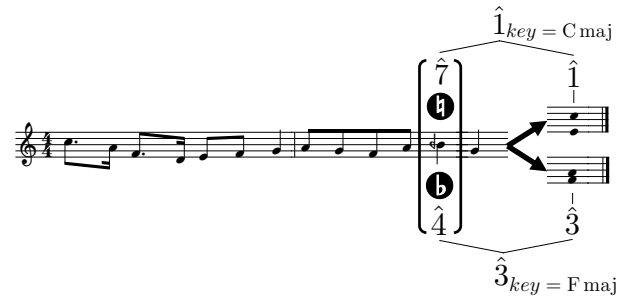

Figure 2: Example stimulus. The quarter-tone B can be interpreted as the lower-neighbour elaboration of $\hat{1}$ in C major, to be tuned upwards as a B natural ($\hat{1} \to \hat{7}\ \hat{1}$, top), or as the upper-neighbour elaboration of $\hat{3}$, to be tuned downwards as a B flat ($\hat{3} \to \hat{4}\ \hat{3}$, bottom). In the Structure Task, each presentation of the stimulus is followed by one of the two key-defining chords shown on the right.

cruited among students and professional musicians from several European music academies, as well as through the online recruitment platform Prolific Academic. As a result, various degrees of musical expertise are represented (Goldsmith Music Sophistication Index (MSI), Musical Training subscale: median 0.61, range 0.14-0.92; Müllensiefen, Gingras, Musil, & Stewart, 2014), with all participants reporting at least one genre within Western musical practices (e.g., classical, Jazz, Rock/Pop) as their main listening habit. To control for potential mediating effects of musical expertise, we include musical sophistication in our statistical analyses. However, no effects were observed. The participants' involvement was reimbursed with CHF 15, and ethics approval was granted by the research-ethics board of the host institution (HREC 037-2020).

Stimuli

Fifteen original melodies, each spanning 2 bars in 4/4 meter at 120bpm, were synthesized in MuseScore 3.5.0 in the default piano timbre, ranging from C4 to G5 with 440Hz tuning. Melodies were made tonally ambiguous by means of two compositional criteria. First, each melody supports a tonal harmonisation in two different keys (C major and F major) provided that the key-discriminating note B (the only pitch class that is not shared between the two keys) is given the appropriate accidental; furthermore, all occurrences of the key-discriminating pitch class B are de-tuned by a quarter tone, so as to fall halfway between B and B flat (Figure 2).

General procedure

Within the online experimental session, lasting 45 minutes, participants were administered two behavioural tasks, a Memory Task and a Structure Task, both comprising the same set of stimuli described above, followed by the Goldsmith MSI (Müllensiefen et al., 2014). The experimental interface was implemented in PsychoPy3 (Peirce et al., 2019) and administered online through the platform Pavlovia (https://pavlovia.org/).

In the Memory Task each melody was presented twice, in random order and transposition, within a continuous recognition paradigm (Shepard & Teghtsoonian, 1961). As a consequence, the Memory Task comprised 30 consecutive trials, and the number of intervening trials between two presentations of the same melody was randomised within and across participants. In each trial, following the presentation of a melody, participants were asked to report whether they believed the melody to be 'new' or 'repeated'. Participants were instructed, by means of an example, to consider the second occurrence of a melody in a different transposition as a repetition.

In the Structure Task, the same melodies were also presented twice throughout the experiment in random order, and each time they were completed with a different key-defining chord. The chord provided post-hoc information to bias the listeners in favour of one out of the two plausible tonal interpretations of the melody. Two behavioural measures were collected in each trial: first, participants were asked to rate how surprising the chord sounded to them; then, participants were asked to reproduce the melody by selecting the 12-equal-tempered tuning of B or B flat for the de-tuned note. This response is taken as a proxy of the participants' syntactic interpretation of the melody. Selecting the sharp or the flat tuning of the quarter-tone note indicates a preference for hearing that note in the syntactic role of an upper-neighbour or a lower-neighbour elaboration (Figure 2).

Results

In order to account for inter-subject and inter-stimulus variability, statistical analyses are conducted with Bayesian mixed effects models (implemented in the R package *brms;* Bürkner, 2018) allowing for cross-random intercepts for individual participants and stimuli. All non-categorical variables are scaled to null mean and unitary standard deviation. Models were provided with weakly informative priors $t(3, 0, 1)$ (Gelman, Jakulin, Pittau, & Su, 2008), and we report coefficient estimates (β), estimated errors in the coefficients (EE), and Evidence ratios ($Odds$) for the individual hypotheses. An asterisk (*) identifies parameters such that $Odds(\beta \lessgtr 0) > 19$, corresponding to statistical significance at the conventional 95% confidence level (Milne & Herff, 2020). Data, code and stimuli can be accessed at https://osf.io/ujnef/.

Robustness to interference

In order to test the robustness of memory to the interference of intervening trials, we quantify the predictive power of the number of intervening trials towards the correctness of the participants' recognition responses. In order to account for potential participant- and stimulus-specific biases in how participants' recognition responses vary during the course of the task, we estimate the Dynamic Response Tendency for each participant and use it to correct participant-wise for false-alarm rates over the course of the experiment (DRT; Herff, Olsen, & Dean, 2018). The DRT is the probability for the first presentation of a melody to be recognised
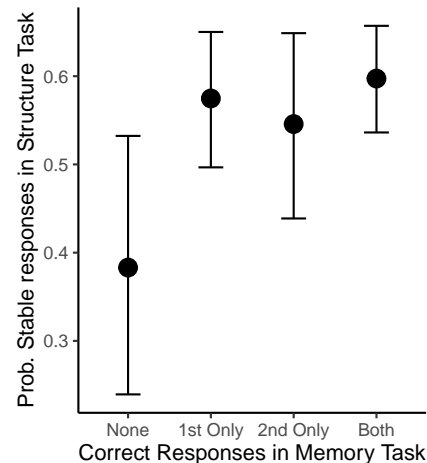

Figure 3: Correct response in First presentation only, Second presentation only, or Both presentations of a melody in the Memory Task predicts higher probability of stable responses in the Structure Task (estimates with 95% Confidence Interval).

(incorrectly) as repeated, estimated with a linear mixed effects model predicting the recognition response based on the trial number. The DRT, alongside the number of intervening trials, appears then as a predictor in a Bayesian mixed-effects model predicting recognition responses to the second presentations of melodies. As hypothesised, the number of intervening trials separating the repetition of a melody from its first occurrence in the experimental task carries no predictive power towards the participants' recognition responses to the second presentations of melodies ($\beta = -.04$, $EE = .05$, $Odds(\beta < 0) = 3.59$).

Linking memory and structure

We then assess whether memory performance for a given melody carries predictive power towards the stability of the syntactic interpretation of the melody itself, i.e. whether the Tuning Response remains the same across the two presentations of the melody in the Structure Task irrespective of the key-defining chord. To this end, a Bayesian mixed-effects model predicting the stability of the Tuning Response for a given melody is provided with several predictors: the memory performance for that melody from the Memory Task; the participant's musical training score from the musical-sophistication questionnaire, and its interference with memory performance; the difference in Surprise Rating between the two presentations of the melody in the Structure task; finally, the number of intervening trials between the two presentations of the melody in the Structure task. Specifically, the memory performance is expressed as a categorical predictor indicating which presentations of the melody (none, the first only, the second only, or both) were correctly identified.

As hypothesised, strong evidence supports that memory performance in the Memory Task carries predictive power to-

wards the stability of syntactic interpretations in the Structure Task (Figure 3). Melodies that are correctly identified as new or repeated at least once in the Memory Task are predicted to exhibit stable syntactic interpretations in the Structure Task with significantly higher likelihood compared to melodies that are never identified correctly in the Memory Task (First: $\beta = .78$, $EE = .34$, $Odds(\beta > 0) = 121.45^*$; Second: $\beta = .66$, $EE = .37$, $Odds(\beta > 0) = 31.88^*$; Both: $\beta = .87$, $EE = .33$, $Odds(\beta > 0) = 377.95^*$).

No evidence is found for an effect of any other predictor. Specifically, the stability of syntactic interpretations is not influenced by the difference in Surprise Rating between the two presentations of the same melody in the Structure Task ($\beta = -.005$, $EE = .07$, $Odds(\beta > 0) = 1.11$), nor by the number of intervening trials separating them ($\beta = -.07$, $EE = .07$, $Odds(\beta > 0) = 5.07$). Furthermore, musical training does not influence the likelihood of stable Tuning Responses ($\beta = -.12$, $EE = .29$, $Odds(\beta > 0) = 2.02$) and also does not modulate the effect of memory performance (all $Odds(\beta > 0) < 10$).

Discussion

In this experiment, we investigate the relationship between memory performance, as captured in a continuous recognition task, and the stability of syntactic interpretations of tonally ambiguous melodies across multiple presentations. Our results, obtained over two experimental tasks involving a novel set of tonally-ambiguous melodies, support our first hypothesis and previous evidence that the recognition of previously-heard melodies is robust to the interference of intervening trials (Herff et al., 2019; Tillmann & Dowling, 2007). As an explanation for this phenomenon, it has been proposed that multiple partially redundant representations concur to compensate for disrupted memory performance. Here, we further tested the hypothesis that representations emerging as a result of syntactic processing contribute to robust memory encoding. Our results indicate that increased memory performance in a melody predicts higher stability of syntactic interpretations in the same melody, suggesting that the outcome of syntactic processing does play a role in the formation of memory traces.

While this evidence does not directly identify a causal relationship between the formation of syntactic interpretations and memory performance, it does indicate that memory for melody includes a representation of a syntactic interpretation beyond the sensory representation of the stimulus. In fact, if increased syntactic stability is the byproduct of a stronger memory trace of the melody, this memory trace must include a representation of the syntactic interpretation itself, since sensory information does not point to a single syntactic interpretation in presence of ambiguity. In other words, a strong memory of the syntactic interpretation generated during the first presentation primes the perception and interpretation of the second presentation.

While this observation parallels analogous phenomena ex-

plored in the psycholinguistic literature (cf. Branigan & Pickering, 2017), evidence for this manifestation of syntactic priming in music is still scarce. Previous priming paradigms in music have shown effects of processing facilitation that cannot be explained in terms of sensory information alone (e.g., Tekman & Bharucha, 1998; Bigand, Tillmann, Poulin-Charronnat, & Manderlier, 2005), and demonstrated that the perception of subsequent syntactic structures can be influenced by abstract features of priming and target stimuli such as harmonic (Bharucha & Stoeckig, 1986) or stylistic (Vuvan & Hughes, 2019) relatedness. However, the present results specifically support the hypothesis that syntactic representations formed at different moments in time influence one another. Such an effect has only been previously observed in the cross-domain interaction of simple, non-idiomatic musical stimuli and linguistic sentences (Van de Cavey & Hartsuiker, 2016). As a consequence, our results provide new evidence for an effect of musical syntactic priming based on the tonal idiom, which may be further investigated in future studies.

We further observed that the number of intervening trials separating two presentations of the same melody in the Structure Task does not influence the likelihood for the syntactic interpretation of that melody to be stable. This suggests that any influence on the second parsing attempt due to the syntactic memory trace from the first parsing attempt does not decline with increasing number of intervening trials. As discussed above, sensory information alone declines over time and, for ambiguous melodies, it is not sufficient to determine the stability of a syntactic interpretation, yet both melody recognition and the stability of syntactic interpretations do not decline with the number of intervening items, when both are available. This is consistent with the hypothesis that the additional existence of representations of syntactic information in memory is robust to such interference and may account for the peculiar behaviour of memory for melody in this respect, either on its own or because of the reciprocal regenerative interaction with sensory information when both are available.

Overall, syntactic structure is shown to be a viable candidate in the role of an additional, partially redundant representation explaining the peculiar robust behaviour of memory for melody under the RMR. Critically, the experimental paradigm based on syntactically ambiguous stimuli affords to discriminate sensory and syntactic information, so that the latter can be shown to constitute an additional representation which is not reducible to the sensory one, i.e. the musical surface. The observed impact on the operation of memory highlights a specific cognitive function of musical syntactic structures which has been suggested on theoretical grounds (Rohrmeier & Pearce, 2018).

Finally, it is important to note that memory is subject to expertise effects, with expert musicians showing better memory for music (Cohen, Evans, Horowitz, & Wolfe, 2011; Herff & Czernochowski, 2019) especially when presented with a fa-

miliar idiom (Halpern & Bower, 1982). Nevertheless, while our study involved a wide spectrum of participants comprising musically naive listeners as well as highly sophisticated musicians, results suggest that generic familiarity with the Western tonal idiom seems to be sufficient to determine the observed interplay between syntactic processing and memory, and musical expertise does not mediate the strength of this relationship. Further analyses on data from this and future studies may shed light on the role of formal training and explicit domain-specific knowledge.

Conclusion

We have shown evidence that musical syntactic processing and memory performance are mutually predictive. While supporting converging evidence concerning the robust behaviour of melody for melody, our results further substantiate the hypothesis that representational redundancy plays a role in the formation and retrieval of such memory. Specifically, results are consistent with the hypothesis that syntactic interpretations arising as the outcome of musical syntactic processing constitute an additional memory representation that is involved in the resilience of memory for melody towards interference.

Acknowledgments

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