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Dynamics of mental imagery

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ABSTRACT

Phenomenology of mental imagery can reveal the structure of underlying mental representations, yet progress has been limited because of its private nature. Through a phenomenology-recreation task we elucidate the dynamics of mental imagery. Specifically, the temporal grain, speed of object manipulation, smoothness of contents unfolding, and temporal extent of stability of imagined contents. To gauge these properties, we asked a large cohort of participants ($N = 827$) to recreate these aspects of their imagination in six tasks. Results showed that temporal features of imagination unfold at distinct timescales, though a factor analysis showed that variance in these tasks could be accounted for via two factors; temporal ability and stability of mental imagery. Additionally, we contrast these regularities with those documented for visual perception, showing that imagined contents are sluggish but more stable than perception. However, both imagination and perception share a common constraint; maintaining identically sized temporal windows of conscious experience.

1. Introduction

The study of mental imagery has informed the foundational basis of mental representations in psychology (Pylyshyn, 2002), philosophy (Nanay, 2023), and neuroscience (Kosslyn, Ganis, & Thompson, 2001). Moreover, it has been used to understand common principles that govern mental representations across sensory-cognitive domains (Marks, 1999; J. Pearson & Kosslyn, 2015). However, from Zhuangzi's butterfly dream to the present day, a large obstacle to investigating principles of mental imagery is its inherent subjectivity. How do we empirically show that two people have similar experiences when they imagine an event unfolding? This challenge stems not only from the fact that imagined contents are private, but also because there is no correspondence between real world objects and the contents of imagination (Schwarzkopf, 2024).

Previous studies attempted to circumvent this challenge by showing how imagery abilities vary in vividness (McKelvie, 1995; Cui, Jeter, Yang, Montague, & Eagleman, 2007), richness, and modalities across individuals (Sulfaro, Robinson, & Carlson, 2024). Moreover, investigations of the phenomenology of imagery have tried to pin down the extent of the field of imagery, its spatial resolution, and how attention scans this imagined space (see Finke (1989) for a review). Similarly, studies have shown that imagined contents are indeterminate (Bigelow, McCoy, & Ullman, 2023) and are accompanied by overt movements. These findings have led to speculations of relations between mental imagery and perception (Nanay, 2016), and the nature of mental representations.

However, this century's long endeavor has yet to uncover the temporal profile of imagined contents. Elucidating the temporal properties of imagery could offer new dimensions to compare how imagined contents evolve across people. Additionally, given the rich

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literature of temporal structures of perception, time offers a novel dimension for comparing mechanisms of imagination and perception.

1.1. Temporal properties of imagery

We do not yet know the temporal grain over which contents of imagination unfold, nor do we know the time-limits at which we can manipulate imagined contents. Similarly, there are no phenomenological or empirical data on how contents of imagination unfold; are they smooth and continuous or do they seem to jump and skip? Finally, how long can we hold an imagined scene in our mind's eye before it dissipates (i.e. persistence of imagined contents)? These temporal properties of imagined content are richer than knowing just the onset of imagined content. While the latter is only informative about when imagery begins, the former can help contextualize the dynamics of mental imagery. Specifically, we seek here to elucidate temporal features of the phenomenal experience of imagery by understanding the temporal resolution of imagined contents (granularity), the degree of smoothness in transitions between imagined contents (smoothness), and the stability of imagined scenarios over time (persistence).

For visual perception, such questions have been investigated in great detail. For perceptual contents, we know the temporal grain required to parse order (~ 30—–50 ms), recognize objects (~ 300—–500 ms), and exhaust perceptual information (the average duration before which a bistable image inadvertently switches; ~ 3—–5 s) (Pöppel, 1997). More importantly, there are models of the temporal structure of perception which predict relationships between different temporal regularities of perception (Singhal & Srinivasan, 2021; Pöppel, 1997; Dorato & Wittmann, 2020; Kornmeier, et al., 2017; Wolff et al., 2022). For instance, the ability to parse order of stimuli at a finer temporal grain is linked with longer dwell times while viewing bistable images (Kornmeier et al., 2017). Similarly, the timing of perception reciprocally corresponds to the resolution of perceptual inputs, where flicker-induced illusions of depth correspondingly correlate with a better temporal grain for regions seen as the background (Singhal & Srinivasan, 2024). Additionally, the ability to detect transient unexpected changes (on the order of ~ 30 ms) while viewing scenes or video clips is linked to the stability of perceptual representations maintained over a few seconds (Andermane, Bosten, Seth, & Ward, 2019). These regularities in the temporal structure of perception elucidate not just the timescales of different perceptual processes, but also their interactions. Characterizing the dynamic features of experience as relations between the temporal grain and persistence of representations allows us to understand the evolution of perceptual content over time (Pöppel, 1997; Singhal & Srinivasan, 2021). In

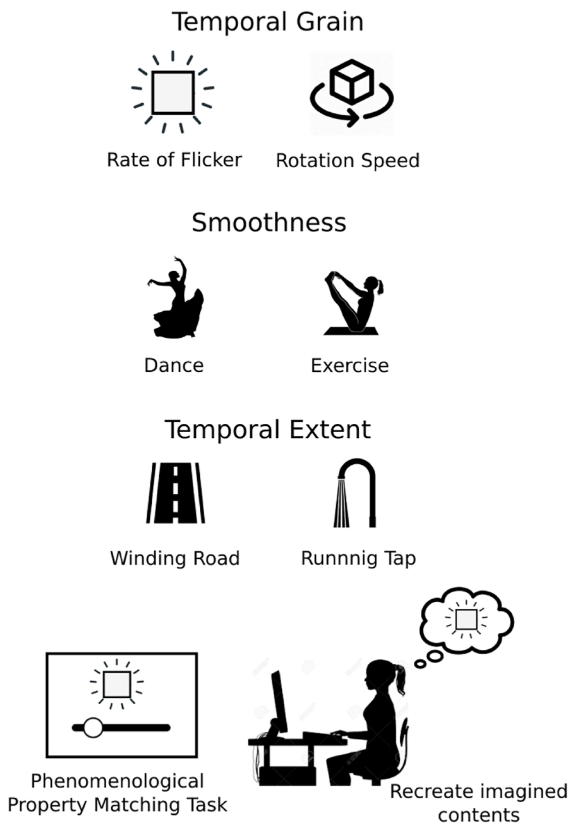

Fig. 1. The figure illustrates the three temporal properties of mental imagery studied using the six tasks. The properties measure the temporal granularity, flow, and extent of mental imagery. For each of the properties, participants are asked to imagine and recreate the relevant phenomenological property in a Phenomenological Property Matching Task.

addition, these temporal properties have been used to understand the temporal quanta in which perceptual experience unfolds irrespective of stimulus modality and inter-individual differences (Pöppel, 1997; Dorato & Wittmann, 2020; Singhal & Srinivasan, 2021).

In comparison, temporal phenomenological regularities of mental imagery remain unknown. The only available comparison of the dynamics of perception and imagery shows that it takes longer to imagine a picture than to perceive it (~70 ms for perception vs. ~300 ms for imagery, see Dijkstra et al. (2018)). These results investigate only the initiation of imagination, but speak little to the evolution, grain, and extent of imagined contents. To be able to elucidate the temporal structure of mental imagery, estimates of its temporal grain, flow dynamics, and stability are necessary. Not only would this allow a novel way to naturalise the phenomenological aspects of mental imagery for scientific investigation, but it would also grant another way to compare imagination and perception.

1.2. Phenomenological property matching tasks

Empirical investigations of imagery have mostly progressed by the use of questionnaires, think-aloud narrations, and interviews (D. G. Pearson, Deeprose, Wallace-Hadrill, Heyes, & Holmes, 2013). In rarer cases, participants have been asked to draw, play, dance, and perform routines to explore the properties that govern mental imagery (Marks, 2023). However, all of these techniques have drawbacks. Verbal methods are plagued with limitations of linguistic labels, while performance-based measures require training and are limited by skill and expertise. To circumvent these confounds, a paradigm is needed where participants can recreate the contents of their imagery. These recreations can be of individual phenomenal properties that are present in contents of imagination. While recreating mental contents is in itself not a novel tool, a modification that asks participants to 'match' instead of creating avoids the problems faced by recreation where skill or retrieval from memory is required (for example, drawing what one imagines). We designed six tasks where participants were asked to recreate the contents of their mental imagery (see Fig. 1). The six tasks allowed participants to recreate four temporal properties of their imagery experience.

These properties were the rate of flicker, rotation speed, smoothness of imagined action sequences, and temporal extents of imagined contents. In each of these tasks, participants were first asked to imagine an event, and then on a subsequent screen they were prompted to adjust a slider which changed the relevant phenomenal property. For instance, participants were asked to imagine a white square flickering as fast as possible. To report the flicker rate, participants changed the flicker rate of an actual square visible on the screen, and submitted their response when they felt it matched the flicker rate of the square in their imagination. Participants were told that they were free to continuously imagine the events as they recreated them. The same procedure was used for other properties as well (described in each section below). Participants were also given the option to report a failure to visualise the instructed events.

2. Method

2.1. Participants

Overall, 827 participants completed at least one of the six tasks on our online portal. For analysis.

of individual tasks, data from all participants were considered. To analyse the relations across tasks, only those participants' data were considered who had completed all the tasks (N = 731 (330 females), average age = 24.3 years, SD = 6.7, age range = 18 to 82). We used a time-based stopping criterion for data collection. The study was available online for a period of four months during which we tried to recruit as many participants as possible.

2.2. Phenomenological property matching tasks

Each of the six tasks are described in detail below. Participants performed each of the tasks once and were instructed to close their eyes when imagining. The tasks were listed on the online portal in the same order as described below. An online repository hosts a demo version of these tasks (https://pratyabhijna.github.io/pratyabhijna/).

2.2.1. Rate of flicker

The task was introduced to participants by showing them a flickering electric bulb. To make sure the flicker rate of the instructional demo did not bias participant responses, the instructions presented a bulb with a non-periodic flicker. Thereafter, they were shown a slowly blinking white square and were asked to imagine it flickering as fast as possible. When participants were ready to report the flicker rate of the imagined square, they proceeded to access a slider-scale. The slider was inactive until clicked, to remove any bias of initial positions. As participants adjusted the slider, they could control the flicker rate of a square drawn in their web browser. Participants adjusted the slider until they were satisfied, and submitted their response. The values in the scale ranged from 50 ms to 3000 ms. Participants did not see these values, their responses were based solely on whether the flicker rate of the square on the screen matched how fast they could flicker it in their imagination.

2.2.2. Rotation speed

The second PPMT that participants performed was by recreating the imagined speed of rotating a box. Participants were shown a clip of a ceiling fan to introduce the concept of rotation. Here too, we used a clip of the ceiling fan that rotated very slowly in a range well outside than speeds participants reported in a pilot study. After the instructional demo, participants saw a transparent box drawn by a white outline. They were asked to imagine this box rotating as fast as possible. Once again, when participants were ready, they recreated their mental contents by adjusting the speed of a rotating box in their web browser. The slider had values ranging from 0.2

rotations per second to 3 rotations per second.

2.2.3. *Smoothness of imagined sequences*

To gauge how smoothly imagined contents unfold, we gave participants two action sequences to imagine. By recreating smoothness of imagined action sequences, we could measure the degree of continuity and flow in mental imagery. We chose two 10-second clips for participants to imagine. The first was a clip of a short dance sequence, and the second was an exercise routine (Yoga). These were chosen based on the rationale that our target population would be familiar with at least one of these action sequences. Participants first watched these clips to familiarize themselves with the order of dance or Yoga steps, before they imagined them. Participants were free to watch the clips as many times as they wished. To reduce any network lag in replaying the clips, the clips were presented as GIFs. Participants were asked to imagine the sequence of the clip as presented, as if they were "viewing" the clip play out in their imagination. Thus, they imagined the actors performing the movement sequences as best they could. When participants were ready to recreate their imagined smoothness, they were taken to a response screen. Here, the original clip played on the side of the screen, while participants recreated their response using a slider. The two ends of the slider were labelled 'jumpy' and 'smooth'. Participants could adjust the slider to alter the rate of smoothness of the response clip. When participants adjusted the slider, the original clip was made jumpy by dropping frames (50, 75, 90 or 95 percent of the frames). Participants did these tasks for both the clips (dance and Yoga). Note that to rule out any memory and retrieval related confounds, the original clip was always accessible on one side of the response screen. The same was done for all the tasks.

2.2.4. *Temporal extent of imagined content*

The final two tasks measured the duration of persistence of an imagined repeating sequence of events. For this, we choose events that were necessarily repetitive. These events were drifting road stripes, and a continuously flowing tap. Participants were again first familiarized with these video clips, and then asked to imagine them continuously moving or flowing. They were told that their task is to see when the content of their imagination 'breaks'. That is when they either were no longer to imagine the stripes or water as flowing, or simply unable to hold the imagined event as occurring any longer. To recreate this 'break' in the contents of their imagination, participants were redirected to a response screen. The response screen had a slider which ranged from 'broken' to 'does not break'. Participants could adjust the slider to place a break inside the original video clip at varying time intervals (750, 1500, 2900, 4500 or 10,000 ms). This was done by inserting a black blank screen inside the clip. The measure allowed us to know the closest duration at which the imagined event breaks down for the participant.

2.3. *Stimuli*

The video clips used for the action sequences (dance and Yoga) were downloaded from YouTube shorts and edited down to 10s. For the temporal extent tasks, the video of a continuously flowing tap was downloaded from a stock footage website. Finally, the video of the road stripes drifting was recorded by one of the authors inside the institute campus. There was no associated auditory content with any of the clips, they were presented as GIFs. For the purposes of the response screens, all of these videos were spatially blurred. This was done to make it easier for participants to report temporal properties of their imagination without the burden of remembering fine spatial details.

3. Results

We detail the descriptive statistics of the six phenomenological property matching tasks (see Table 1). It is important to point out the direction of these results. Note that smaller values for flicker rate and smoothness reflect better temporal separation of contents and smoother transitions in imagination (respectively). Whereas larger values for speed and persistence reflect the ability to rotate objects faster and maintain imagined scenarios for longer. We averaged responses across the smoothness and persistence tasks and calculated a 4 x 4 correlation matrix between different temporal properties (flicker, speed, smoothness, and persistence). We found that speed and flicker were negatively correlated, while persistence and smoothness were positively correlated (see Table 3).

In an attempt to excavate latent variables that constrain the dynamical evolution of imagined contents, we ran an exploratory factor analysis (EFA) on the different temporal properties. We expected that these temporal properties would be governed by mutually exclusive latent variables. Prior to subjecting the data to an EFA, several assumption tests were done. First, a Kaiser-Meyer-Olkin test was done to calculate the adequacy of the sample for a factor analysis. Next, we tested whether the correlation matrix of the data was

Table 1
Averaged responses across all participants for the 6 tasks.

Task	Mean (SD)	Unit	N
Flicker	299.89 (423.5)	Milliseconds	827
Speed	1.85 (0.93)	Rotations/s	782
Dance	157.57 (172.3)	Milliseconds	764
Yoga	191.18 (221.6)	Milliseconds	750
Road	4500.76 (3316.1)	Milliseconds	750
Tap	4883.24 (3481.6)	Milliseconds	735

significantly different from an identity matrix, using a Bartlett's test. Finally, we ensured that the data did not violate assumptions of normality. After these assumptions were satisfied, an EFA was performed.

The EFA was done via an oblique promax rotation on the correlation matrix of the four temporal phenomenal parameters of interest. Based on a criterion of factors requiring a greater eigenvalue than 1 to be considered a latent variable, two factors were selected. The loadings of the two factors for the different variables is given in Table 2. One of the factors explained maximum variability in the flicker and speed tasks, whereas the other factor explained maximum variability in the persistence and smoothness tasks (see Table and Fig. 2).

3.1. Scaling ability and stability of imagined contents

We investigated whether temporal ability scales with temporal stability. In perception, the stability of percepts (~ 3000 ms) scales with the ability to discriminate fine temporal order (~ 30 ms), this relationship can be specified by

$$T = \frac{(t_0)^2}{\Delta t}$$

as suggested by (Kornmeier et al., 2017). Here, t_0 is a perceptual window of ~ 300 ms, which is maintained by scaling the perceptual stability (T) and the temporal order threshold (Δt). In models of temporal phenomenology, the length of this window is interpreted as the duration it takes to pin down the features of a novel object (Kornmeier et al., 2017; Singhal & Srinivasan, 2021). The parameter Δt denotes the time it takes to update an internal state, in perception this is the duration at which order between two successive stimuli can be discriminated (Kornmeier et al., 2017; Pöppel, 1997). Finally, the variable T denotes the stability of representation, in perception, this is derived from the average dwell time durations while viewing bistable images.

The equation describes how the temporal ability and stability (Δt and T) are scaled to maintain this window of temporal integration (t_0). Specifically, higher temporal ability results in poorer stability of percepts, and better stability of percepts results in poorer temporal ability. If imagination shares the same structure as perception, then this relationship should also hold true for temporal ability and stability in imagination.

To test this, we scaled each participants' persistence duration and flicker rate estimates. The reported flicker rate gave us the time step at which internal representations of imagination could be updated (a Δt of imagination), while the persistence of imagined contents gave us the stability of representations in imagination (T). Using the same equation, the t_0 of imagery was on average 322.22 ms. This finding suggests that while the dynamics of imagination are more sluggish in updating internal representations, they have greater stability. More interestingly, this trade-off appears to be scaled to maintain a window of temporal experience (t_0) similar in size across both imagination and perception.

3.2. Differences between timescales of imagination and perception

While imagination and perception both seemed to follow a scaling of temporal ability an stability, we also compared the differences between the temporal regularities of them both. As is obvious from Fig. 3, the temporal grain of imagination was remarkably longer than that of perception. On the other hand, the duration of persistence of imagined contents was, on average, longer than that normally reported for perception. Another stark difference between the dynamics of imagery and perception was in individual differences. While both imagination and perceptual abilities show large variation across individuals (Schwarzkopf, 2024), our results show that the variability in the dynamics of imagination is much larger across individuals compared to perception.Fig. 4..

4. Discussion

In this study, we asked a large pool of participants to recreate different temporal properties of their imagination. Our results showed the general time ranges for these different properties, the latent variables that explain their variance, and the manner in which these relationships are scaled. These temporal phenomenological principles should inform future studies of the timescales of imagination, the properties which govern them, and whether imagination shares additional similarities with perception.

4.1. Timescales of imagination

We investigated the timescales over which different aspects of mental imagery unfold. Our results show the range over which imagined contents can be manipulated (flickered or rotated), and the steps in which they unfold (smoothness of flow), are remarkably

Table 2
Factor loading for the four temporal properties of imagery.

Task	Factor 1	Factor 2
Flicker	− 0.317	
Speed	0.756	
Smoothness		− 0.185
Persistence	0.167	0.641

Table 3
The Spearman correlation coefficients along with significance values (in brackets) for the relationship between the four measured temporal aspects of imagination.

Task	Flicker	Speed	Smoothness	Persistence
Flicker	–	–	–	–
Speed	−0.44 (<0.001)	–	–	–
Smoothness	0.07 (0.038)	0.05 (0.18)	–	–
Persistence	−0.1 (0.007)	0.14 (<0.001)	−0.22 (0.001)	–

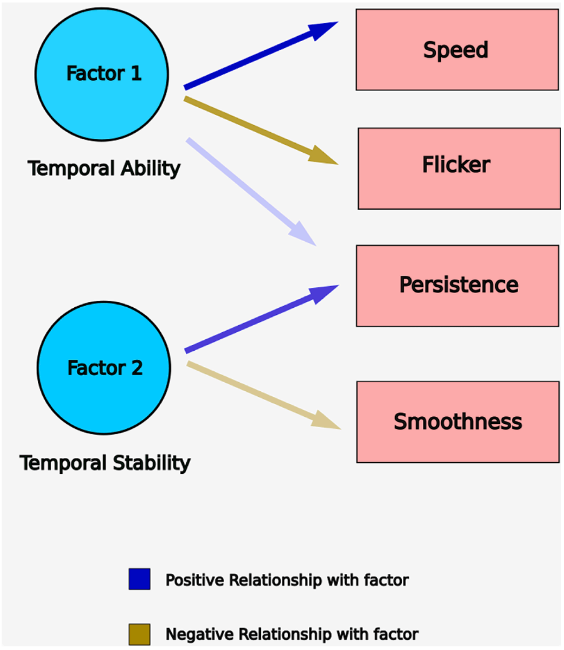

Fig. 2. The path diagram shows the two factors which modulate distinct temporal properties of imagined contents. Factor 1 (temporal ability) accounts for variance of the speed and flicker rate of imagined contents. Greater temporal ability permits higher rotation speed in imagination and lower flicker rate (finer temporal grain). Factor 2 on the other hand explains the stability of mental imagery. Stability is linked with longer persistence duration and more smooth unfolding of contents (finer gaps between events). The opacity of the arrow represents the strength of the factor loading, see also Table 2.

different from the extent of maintaining the sequence of events in imagination (persistence). Thus, the temporal grain and flow of imagery has a temporal range of 150–300 ms, while the stability in persisting with an imagined scene is around 4500–4800 ms.

Our results highlight the fact that studying time-resolved decodability of imagery through neural markers is insufficient to capture the richness of the temporal structure of imagery (Dijkstra et al., 2018; Shatek, Grootswagers, Robinson, & Carlson, 2019). This is because finding the earliest point in time where imagined contents are decodable within neural recordings may only show the onset of imagery, but not the evolution and persistence of imagined contents. Furthermore, distinct timescales of imagination demonstrate that the study of mental imagery requires a multi-timescale view. Just like in perception, where the temporal grain, recognition, and saturation of contents happens at different timescales, the study of imagination requires acknowledging its multi-faceted time-course.

4.2. Temporal structure of mental imagery

Our results also uncover possible temporal constraints which govern how imagined contents unfold. Through exploratory factor analysis, we extracted two latent variables that mutually exclusively account for variance in the flicker and speed tasks (Factor 1), and smoothness and persistence tasks (Factor 2). We interpret these factors as revealing the temporal ability, and stability of mental imagery.

Previously, a study that looked to predict change detection performance in participants across a multitude of variables, showed that variance in change detection performance was explained by a cluster of two factors (Andermane et al., 2019). The authors interpreted these factors as the strength (ability) and stability of visual representations. The ‘ability’ factor accounted for behavioural performance in a perceptual temporal order judgement task. The other factor the authors termed ‘visual stability’ accounted for individual variance in perceptual rivalry (bistable stimuli switch rates) tasks.

Along the same lines, we interpret the two factors that account for our results as the temporal ability and stability of representations

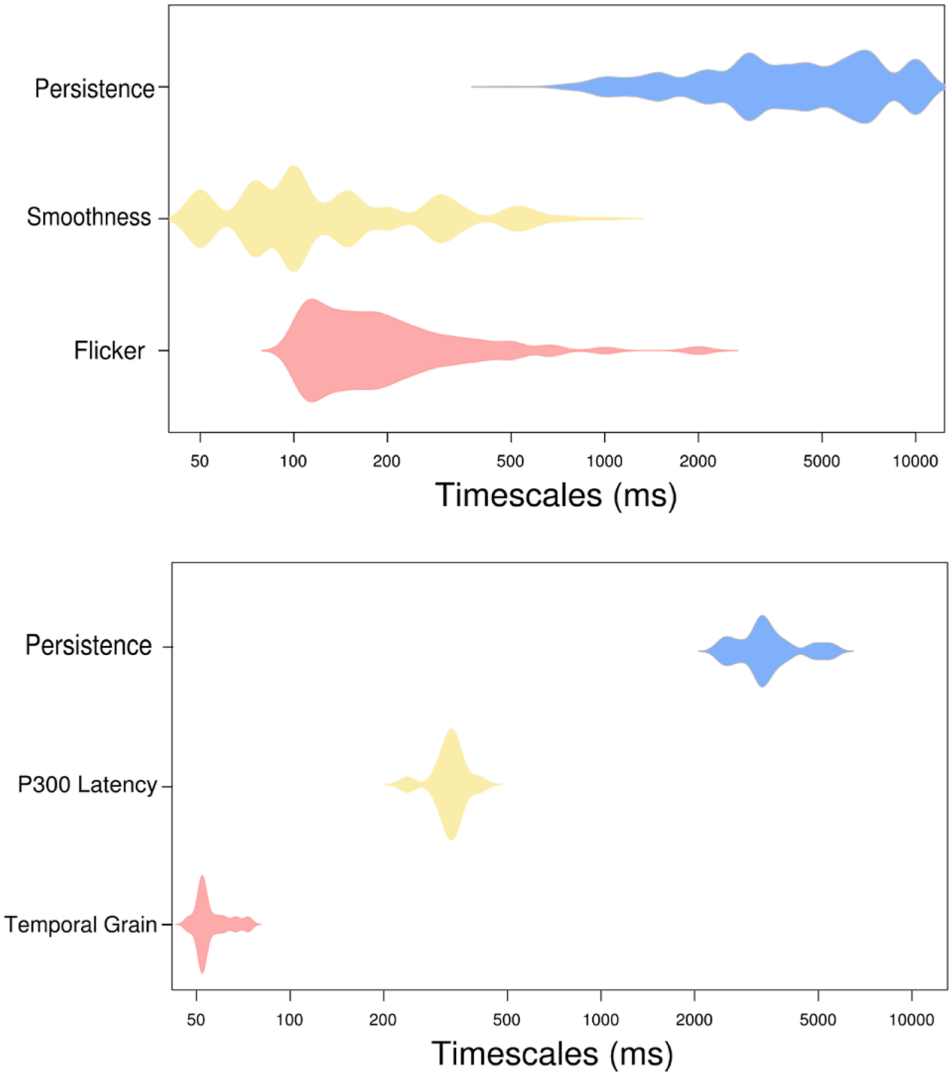

Fig. 3. The plot depicts distinct timescales of the different temporal properties of mental imagery (top panel). Flicker rate (temporal grain) and smoothness values cluster around a few hundred milliseconds, while the persistence of imagined contents extends into a few seconds. This is contrasted by the timescales of visual perception (bottom panel). The temporal properties of perception are based on estimates of previous studies (Fink et al., 2006; Nishida et al., 1997; Polgari et al., 2020). These estimates are used as being representative of timescales of perception and contrasted here with imagination (see Main Text and Table 4).

invoked in mental imagery. Similar to Andermane et al. (2019), where the latent factor of ability accounts for the limits of temporal resolution of visual perception, in our study we interpret it as accounting for the temporal grain of mental imagery. In perception, visual stability explains the duration of perceiving a bi-stable image in one of the perspectives, and retaining information in visual short term memory. Analogously, temporal stability of representations in imagery predicts the duration for which one can maintain the content of imagination.

4.3. *Imagination and Perception*

The temporal grain, flow, and persistence of imagined contents are remarkably sluggish compared to perception. Not only is the flicker rate of visual mental imagery an order of magnitude slower, but the temporal extent of imagined contents persist is also longer compared to perception. Even though imagination and perception have a different temporal profile, their temporal aspects are constrained by a common principle. Specifically, by the trade-off of stability and ability of phenomenal content in maintaining identically sized temporal windows of conscious experience (see Section 3.1. and 3.2.). It is noteworthy that a common principle of action executions also applies to both perceptual and imagined contents (Wong et al., 2013). Here too, imagined movement times are slower than perceived and executed movements, however both imagined and executed actions are constrained by the Fitts' Law. The trade-off

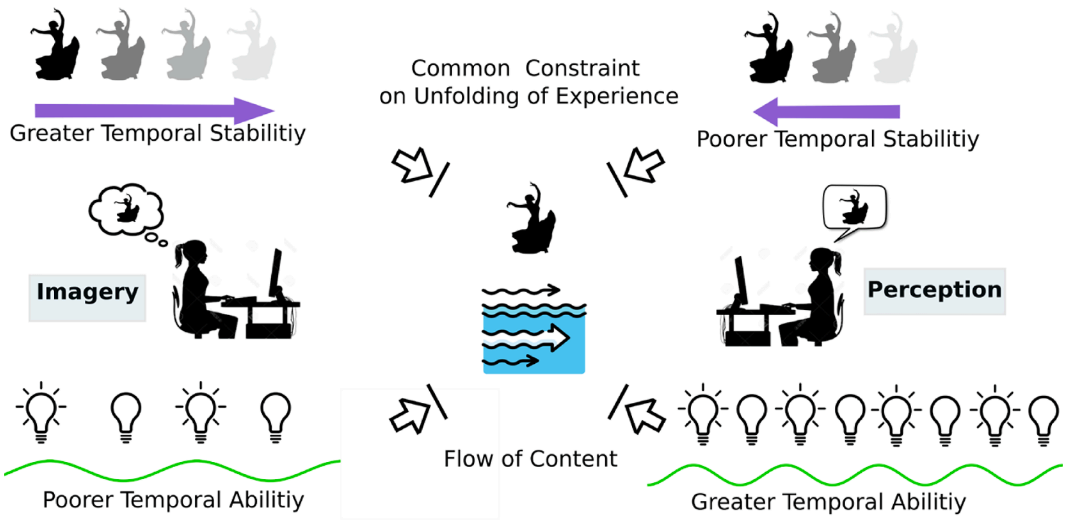

Fig. 4. The figure illustrates the common structural constraint that applies to both imagination and perception. Imagined contents show poorer temporal resolution, but greater persistence compared to perception. However, for both, the temporal ability and stability constrain the flow of experience similarly.

between accuracy and speed of movements is captured by Fitts' Law. Wong et al., (2013) showed that this trade-off applied in both imagined and actually executed movements, thereby arguing that a common coding principle of action applies to both real and imagined movements. We show here that another similarity between imagery and perception is that they are governed by a common coding princple of temporal windows of experience.

The present investigation, where participants directly recreate temporal features of their imaginary experience, offers support to brain imaging data which shows that imagined contents are decoded with a higher latency from brain signals compared to perception (Dijkstra et al., 2018). These results are consistent with a large pool of neurophysiological studies which have shown that imagined contents have a slower onset than perceptual contents. In a pioneering study, Farah et al., (1989) showed that event-related potentials (ERP) for imagined contents peaked slower and later (450—700 ms) when participants read words with and without imagery instructions. Similar results were found also in a late ERP component (400——600 ms) that was modulated by the amount of rotation participants had ot perform in a imagery task (Pegna et al. (1997)). Finally, another study (Proverbio et al., 2023) looked at differences in ERPs for various auditory and visual stimuli that were either perceived or imagined, to show that ERPs for imagination peaked always much after perception (by a delay of ~ 400 ms). These results have been replicated under different neuroimaging tools (MEG) and analysis (decoding, clustering etc) to show that imagination has a slower onset than perception (Dijkstra et al., 2018). However, such previous investigations have only been able to show a directional relationship (i.e. imagery slower than perception), the magnitude of sluggishness in these studies is a function of statistical decoding accuracy. Our results offer timescales from recreation of experiential properties as new constraints and heuristics to guide neural investigations and improve their precision.

4.4. Limitations and future Considerations

Another crucial aspect in which imagination and perception differ is in the variability of its temporal profile. Not only is imagery more sluggish, its grain, smoothness, and persistence show much more variability than in perception (see Table 4). For perceptual representations, this variability has been shown to be linked with trade-offs of temporo-spatial resolution (Yeshurun & Levy, 2003), attentional mechanisms (Matthews & Meck, 2016), ageing (Díaz-Santos et al., 2017), psychopathologies (Kent, Nelson, & Northoff, 2023), meditation training (Srinivasan, Tripathi, & Singhal, 2020), and stimulus properties (Fink et al., 2006). Another factor that can

Table 4
The table lists the different parameters of the dynamics of representations in perception from the work of Atmanspacher et al. (2008), alongside actual empirical values from various studies of perception. These are contrasted by results of this study in showing the temporal profile of representations in imagination (see Main text for details).

Parameter	Perception	Imagination
Temporal Grain ($\Delta t = \sim 30$ ms)	31.24 (36.89)[1] ms	284.61 (383.79) ms
Temporal Extent ($t_0 = \sim 300$ ms)	342 (33.91)[2] ms	322.22 (235.14) ms
Stability of Representation ($T = 3000$ ms)	3425.68 (1505.1)[3] ms	4695.54 (2804.92) ms

[1]Estimates of differentiating order of rapidly presented clicks (Fink et al., 2006).
[2]Variability in P300 latency as a marker of temporal integration windows in perception (Nishida et al., 1997).
[3]Dwell time distributions of perceptual switches while viewing a Necker cube(Polgari et al., 2020).

explain the variability in these tasks is vividness and multi-modality in mental imagery. For instance, that clarity and richness of imagined contents vary highly across individuals. This could lead to interactions in whether participants imagine the clip of flowing water with audio-visual components or only visual contents.

Our results demonstrate the possibility of a new line of research inquiries into individual differences in the dynamics of mental imagery. First, future research can investigate whether temporal structures of perception and imagination reliably co-vary at the level of individuals such that ability and stability of representations of both show similar dynamics over time and different scenarios. Second, future research may investigate how the dynamics of imagined contents change with other aspects of imagery like vividness, commitment (determinacy of representations), multi-modality, working memory capacity, and attentional processes. If imagination and perception share structurally similar dynamics (instead of magnitudes of timescales), then one would assume that more vivid imagery would correlate with poorer temporal ability but greater stability of imagined contents. These tasks could also be done in a lab setting for more stringent control over experimental apparatus and ambience. Thus, our study opens up a structural route for asking a variety of comparative questions about the relationship between imagination and perception.

5. Conclusion

In this study, we successfully asked a large cohort of participants to recreate distinct temporal properties of their mental imagery. Using this data, we demonstrate that imagined contents evolve at multiple timescales which are remarkably different from the timescales of perception. However, both imagination and perception appear to be governed by the same temporal structure, wherein ability and stability of representations account for the temporal grain and persistence of mental contents.

Research Transparency Statement.

Disclosures.

Conflicts of interest: None. Funding: None. Artificial intelligence: No artificial intelligence assisted technologies were used in this research or the creation of this article. Ethics: This research received approval from a local ethics board.

Experiments.

Preregistration: The hypotheses, methods, and analyses were not preregistered. Materials: All study materials and data files will be made publicly available on an OSF repository (https://osf.io/r3dju/). The experiment protocol is hosted for a demo, access or further use on Github (https://pratyabhijna.github.io/pratyabhijna/).

Authorship Contribution Statement.

Author1 and Author2 conceptualized the study. A1 designed experiments, collected data, and performed analysis. A1 and A2 interpreted results and wrote the manuscript.

CRediT authorship contribution statement

Ishan Singhal: Writing – review & editing, Writing – original draft, Visualization, Software, Methodology, Formal analysis, Data curation, Conceptualization. **Nisheeth Srivastava:** Writing – review & editing, Writing – original draft, Supervision, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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