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**Research Article**

**Keywords:** grip force, embodied cognition, language, aphantasia, Bayesian analysis, RSVP

**Posted Date:** February 24th, 2026

**DOI:** https://doi.org/10.21203/rs.3.rs-8910208/v1

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**Additional Declarations:** No competing interests reported.

**Version of Record:** A version of this preprint was published at Psychological Research on October 21st, 2026. See the published version at https://doi.org/10.1007/s00426-026-02393-4.

# Grip-Force Modulation During Action Word Reading: An RSVP Paradigm with Bayesian Temporal Analysis

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**Abstract**

Grip force provides a behavioral index of motor engagement during action language processing, but prior studies have relied on auditory presentation and fixed analysis windows. We adapted grip force methodology to Rapid Serial Visual Presentation (RSVP) and used a Time-resolved Bayesian Evidence Display (TBED) to characterize motor resonance without predefined time windows. We tested two boundary conditions on language-induced motor activation: grammatical aspect (present vs. inceptive constructions) and conscious imagery ability (typical imagery vs. aphantasia). In participants with typical imagery, present-tense action sentences elicited higher grip-force modulation, in line with previous studies. Inceptive constructions showed no reliable motor resonance, with Bayesian evidence supporting the absence of effects. Direct comparisons revealed stronger motor modulation for present-tense than inceptive actions, with inceptive actions

patterning like non-action sentences. Participants with aphantasia showed no motor resonance for either construction, although interpretation is limited by increased noise associated with the smaller sample size. Methodologically, RSVP affords fine temporal control but may be associated with greater signal variability; TBED complements this approach by distinguishing evidence of absence from absence of evidence in time-resolved data.

**Keywords:** grip force, embodied cognition, language, aphantasia, Bayesian analysis, RSVP

# 1 Introduction

Processing action-related language activates motor regions of the brain (Hauk et al. 2004; Pulvermüller 2005; Rizzolatti & Arbib 1998). Grip force recordings—measuring the force applied when holding a sensor—provide a continuous behavioral index of this motor activation by capturing unintentional, sub-threshold fluctuation in grip force without overt movement (Aravena et al. 2012, Aravena et al. 2014, Frak et al. 2010, Nazir et al. 2017). Studies using grip force recordings have shown increased grip force during the processing of action-related language, with greater force for action verbs compared to non-action words (Aravena et al. 2012; Aravena et al. 2014; Frak et al. 2010, Reinecke et al. 2022, da Silva et al. 2018, Juárez et al. 2019). Critically, this motor response is sensitive to linguistic context—appearing for literal but not volitional or negated uses of the same verbs (Aravena et al. 2012; Aravena et al. 2014). It is also modulated by information layering: grip-force increases are observed for asserted and factive-presupposed action content, but are attenuated for nonfactive embeddings (Reinecke et al. 2022). Together, these findings suggest that language-induced motor activation reflects dynamic situation modeling rather than simple verb-driven activation (Cayol & Nazir, 2020).

To our knowledge, all grip force studies on language processing have used auditory presentation of sentences (Aravena et al. 2012; Aravena et al. 2014; Frak et al. 2010; Reinecke et al. 2022). The present study adapts this methodology to visual presentation using rapid serial visual presentation (RSVP), in which words appear sequentially at a fixed location for controlled durations (Forster, 1970). Visual presentation offers several practical advantages: stimulus creation is typically more straightforward and less time-consuming than audio recording, and RSVP provides precise experimental control over verb onset and duration, without requiring post-hoc acoustic alignment. Importantly, motor resonance effects appear to be modality-independent, as neuroimaging studies demonstrate that reading action words activates motor regions similarly to hearing them (e.g., Aziz-Zadeh et al. 2006; Hauk et al. 2004), suggesting that visual and auditory modalities might yield comparable grip force effects. In addition to modality considerations, our implementation incorporates individual calibration at two levels: participants adjust RSVP word duration to a comfortable reading rate, and grip force is anchored to an individual pretrial target (IPT) rather

than a fixed force criterion (Nazir et al. 2017), ensuring a comparable and comfortable reference level across participants.

Beyond replicating established motor resonance effects with visual presentation, the present study also advances the methodological framework by implementing a Time-resolved Bayesian Evidence Display (TBED). Previous grip force studies have typically relied on averaging within predefined post-lexical time windows and testing effects using frequentist statistics (e.g., 600-900ms from critical word onset; Aravena et al. 2012; Aravena et al. 2014; Reinecke et al. 2022). This time window was selected in prior work as it corresponds to a late stage of sentence-level semantic integration, a period during which motor resonance effects could be observed. While alternative time-resolved approaches such as the permutation cluster test (Miklashevsky, 2022) allow effects to be identified without restricting the analysis to fixed windows, they rely on p-value thresholds and multiple-comparison corrections to determine significance. In contrast, the TBED represents the evolution of the strength of evidence over time, illustrating graded support for one hypothesis relative to another through a transparent and interpretable visual display.

Taken together, these methodological adaptations constitute the primary contribution of the present study. We illustrate this approach with two theoretically motivated test cases. First, we examine whether aspectual constructions that describe actions as beginning (inceptive aspect; e.g., "starts to grab"), rather than as ongoing, modulate motor resonance. Specifically, we test for an action advantage by comparing Action and Non-Action sentences within both present and inceptive constructions to see if resonance is consistently elicited. We also directly compare action conditions across these two constructions to determine if framing an action as "about to begin" alters the magnitude or time course of motor resonance compared to ongoing actions. Second, we investigate whether self-reported conscious visual imagery is necessary for automatic motor resonance by comparing individuals with aphantasia (absent voluntary visual imagery) to individuals with typical mental imagery. These questions address whether motor activation depends on simulating full action execution versus anticipation (i.e., motor activation tied to the initiation of an action), and whether it requires conscious imagery or operates through automatic associations established during language acquisition (Pulvermüller, 2013).

## 1.1 Aspectual Modulation of Motor Resonance

Building on evidence that language-induced motor responses vary with sentence interpretation (e.g., Aravena et al. 2012; Aravena et al. 2014; Reinecke et al. 2022; Tettamanti et al. 2008; Vitale et al. 2025), we examine whether grammatical aspect similarly modulates motor resonance. Specifically, we test inceptive constructions that highlight the initial phase of an action (e.g., "starts to grab"). Unlike negation, which explicitly cancels the action, inceptive aspect refers to the beginning of an ongoing event. This raises the theoretical question of what language-evoked motor activation indexes: does it primarily reflect simulation of full action execution (as in present-tense descriptions), or can it also recruit motor processes associated with early stages of the action (when actions are described in inceptive form), potentially producing smaller or temporarily distinct effects compared to full execution?

We compared inceptive action sentences (e.g., "Marie starts to write a letter") with inceptive non-action controls (e.g., "Martin starts to deceive his colleagues"), holding sentence structure and aspectual marking constant while varying the action content of the embedded verb. If motor resonance primarily reflects simulation of full action execution, inceptive constructions-describing only the initial part of an action-may produce little or no difference between action and non-action sentences (similar to volition effects; e.g., Aravena et al. 2014). Alternatively, if motor resonance can also reflect early stages of an unfolding action, we may observe grip force differences between conditions, potentially with smaller magnitude or altered timing compared to full present-tense actions.

## 1.2 The Role of Conscious Imagery in Motor Resonance

Complementing the linguistic manipulation, we next test an individual-differences boundary condition: whether conscious imagery is required for motor resonance. Aphantasia—typically defined as a lifelong absence of voluntary imagery, estimated to affect a few percent of the population (Zeman et al., 2015; Zeman, 2024)—provides a test case for understanding the mechanisms underlying language-induced motor activation.

Sensorimotor simulation is typically viewed as automatic and not necessarily consciously accessible (e.g., Pulvermüller 2005), whereas imagery is typically conceptualized as consciously reportable mental content grounded in such simulation (e.g., Cayol & Nazir 2020; Grush 2004; Jeannerod 1995, 2001). On this view, reduced imagery vividness could reflect limited access to simulated content rather than an absence of underlying representations (Cayol & Nazir, 2020; Yavuz & Nazir, 2026). Consistent with this possibility, recent neuroimaging studies suggest that individuals with aphantasia can recruit broadly similar regions during imagery tasks as controls, with differences emerging primarily in connectivity with frontoparietal areas (Liu et al., 2025).

Embodied accounts in which language–motor links are learned through experience therefore predict preserved motor resonance in aphantasia. For instance, according to Pulvermüller (1999; 2005; 2013), language–motor associations are established through Hebbian learning during acquisition: repeated co-activation of linguistic and motor representations strengthens their connections. Because individuals with aphantasia acquire language in the same sensorimotor environment as individuals with intact imagery skills, they should still form robust links between action words and motor representations. Thus, even if aphantasia limits conscious access to simulated content, the learned language–motor links should still support automatic activation of motor representations during comprehension, producing motor resonance. In line with this, Muraki et al. (2023) argue that simulation during language comprehension may be largely automatic and only partly accessible to awareness, such that aphantasia could impair conscious imagery without necessarily abolishing simulation. On this basis, we predict comparable grip force modulation in participants with aphantasia and those with typical imagery.

Note though, other recent fMRI work reports that imagery-attempt activity in individuals with aphantasia does not show perception-like representational overlap in

early visual cortex, which has been taken to argue against unconscious visual imagery and to suggest alternative, non-perceptual strategies during imagery attempts (Chang et al., 2025; Scholz et al., 2025). These findings suggest that the format of representations engaged during imagery attempts may differ qualitatively from typical imagery. If aphantasia reflects differences in the functional organization or connectivity of sensorimotor–associative systems (Cayol & Nazir, 2020), motor recruitment during action-language processing may be attenuated, qualitatively altered, or differently sensitive to contextual factors in the aphantasia group. Such differences may be expressed not only in effect magnitude but also in temporal profile. The Bayesian temporal analysis is therefore well suited to detect differences in onset latency, persistence, or shifts in the time window over which motor resonance is expressed.

## 2 The Present Study

The present study introduces two methodological extensions to the grip force paradigm in language processing: the use of visual sentence presentation via RSVP, and the application of the Bayesian approach—Time-resolved Bayesian Evidence Display (TBED)—to examine the temporal dynamics of the grip force signals. Two experiments were conducted using an identical protocol and stimulus set, differing only in participant population: Experiment 1 tested typical imagers, and Experiment 2 individuals with aphantasia. Our primary focus was how grammatical aspect shapes the presence and temporal dynamics of action-related motor resonance.

In both experiments, participants read sentences presented using rapid serial visual presentation (RSVP) while grip force was continuously recorded as an index of motor resonance. Comprehension was assessed intermittently to ensure task engagement.

Experiment 1 (typical imagery) evaluates whether established grip force effects observed with auditory presentation generalize to visual presentation, and whether TBED can capture action-related modulation under different grammatical constructions. Grammatical aspect serves as a central test case: Action and non-action sentences are contrasted within present-tense constructions and within inceptive aspectual constructions (e.g., *starts to grab*). Beyond these within-construction contrasts, we directly compare action sentences across present and inceptive aspect to determine whether framing an action as ongoing versus about to begin modulates the magnitude or temporal profile of motor resonance. Based on prior auditory studies, (Aravena et al. 2012; Aravena et al. 2014; Frak et al. 2010), greater grip force modulation is expected for action than non-action sentences in present-tense constructions, whereas inceptive constructions are expected to show reduced or absent action-related differentiation.

Experiment 2 (aphantasia) applies the same protocol to test whether action-related motor modulation depends on voluntary visual imagery. By holding the design constant, this experiment evaluates whether an Action/Non-Action motor-resonance effect can be observed in individuals who report an absence of voluntary visual imagery. If grip force modulation reflects automatic language–motor associations acquired during language learning (Pulvermüller, 2013), comparable action-related modulation should be observed in aphantasia. TBED analysis further allows us to characterize the effect's temporal profile (e.g., onset and duration) and to quantify evidence for its absence when no modulation is observed.

Across both experiments, analyses focus on the temporal dynamics of grip force modulation. A time-resolved Bayesian analysis is employed to examine when evidential support for motor resonance effects emerges, peaks, and subsides.

# 3 Method

The methodology was consistent across the two experiments, which differed only in the participant population (typical imagery vs. aphantasia). The linguistic stimuli were identical in both experiments. Both studies were approved by the Research Ethics Committee of the University of Lille (CER U-Lille; 2021-474-S91).

## 3.1 General Participant Criteria

Participants across both experiments were right-handed, native French-speaking adults with normal or corrected-to-normal vision and no reported history of neurological or psychiatric disorders. All participants provided informed consent and received €12 for a session lasting approximately 35–40 minutes. Details on recruitment, sample sizes, and participant characteristics for each experiment are provided in the respective sections.

## 3.2 Stimuli and Design

The linguistic stimuli consisted of 148 French sentences adapted from (Reinecke et al., 2022), featuring 37 action verbs and 37 non-action verbs. The critical sentences were in the present indicative tense and incorporated inceptive aspectual constructions, marked by the verbs "*commencer à*" (*start to*) and "*se mettre à*" (*begin to*).

To counterbalance these aspectual verbs across participants, the stimuli were divided into two lists (List A and List B). Each list contained all 148 sentences. The key difference between the lists was the specific inceptive verb used in these constructions; a given sentence would appear with "commencer à" (start to) in List A and with "se mettre à" (begin to) in List B, or vice-versa. A demonstration of this counterbalancing is provided in Table 1. Participants were randomly assigned to one of the two lists at the start of the experiment.

The sentences were presented in 16 blocks. The first block contained 1-3 sentences, while the others varied randomly between 2 and 14 sentences. Sentences within each block were randomized under the constraint that no more than two consecutive sentences were from the same aspectual condition. The order of the blocks was randomized for each participant. A complete list of all stimuli is available in Appendix A.

## 3.3 Apparatus and Data Acquisition

Grip force was recorded using a 6-axis load cell (Mini-40, SI-40-2, ATI Industrial Automation, USA). The cell is mounted between 2 aluminum plates secured with double-sided tape leading to an apparatus weighing 68 g and with dimensions of 8 × 8 × 2 cm (height × width × depth). Although three force components were recorded (longitudinal $F_x$, radial $F_y$, and compression $F_z$), only the compression force ($F_z$) was analyzed, as it is the most reliable indicator of grip force modulation in language

**Table 1**: Stimulus Examples for Experiments 1 and 2

| Type | Verb | List A | | List B | |
|---|---|---|---|---|---|
| | | **Inceptive** | **Present** | **Inceptive** | **Present** |
| Action | lacer | Marie commence à **lacer** ses chaussures.<br>*(starts to lace)* | Marie **lace** ses chaussures.<br>*(laces)* | Marie se met à **lacer** ses chaussures.<br>*(begins to lace)* | Marie **lace** ses chaussures.<br>*(laces)* |
| Action | toquer | Paul se met à **toquer** à la porte.<br>*(begins to knock)* | Paul **toque** à la porte.<br>*(knocks)* | Paul commence à **toquer** à la porte.<br>*(starts to knock)* | Paul **toque** à la porte.<br>*(knocks)* |
| Non-action | berner | Martin commence à **berner** ses collègues.<br>*(starts to deceive)* | Martin **berne** ses collègues.<br>*(deceives)* | Martin se met à **berner** ses collègues.<br>*(begins to deceive)* | Martin **berne** ses collègues.<br>*(deceives)* |
| Non-action | tester | Laure se met à **tester** de nouvelles méthodes.<br>*(begins to test)* | Laure **teste** de nouvelles méthodes.<br>*(tests)* | Laure commence à **tester** de nouvelles méthodes.<br>*(starts to test)* | Laure **teste** de nouvelles méthodes.<br>*(tests)* |

processing studies (e.g., Aravena et al. 2012; Frak et al. 2010; Nazir et al. 2017). Stimulus presentation was controlled using PsychoPy, running on the same computer that recorded grip force via a Python script at a sampling rate of 200 Hz. Markers and force data were streamed over a local network using LabStreamingLayer (LSL, Kothe et al. 2025) and recorded on a second computer via LabRecorder. This configuration ensured a millisecond-level synchronisation between stimulus presentation and grip force acquisition. A third computer was used for the questionnaire at the end of the experimental session.

## 3.4 Procedure

The experiment was conducted in individual sessions under controlled laboratory conditions with a mean temperature of 20.02°C ($SD = 0.95$). Upon arrival, participants cleaned their hands with disinfectant gel. The grip-force sensor was also cleaned with alcohol (90–99%) to ensure a consistent grip by removing the artifacts that could cause it to slip out of the hand.

**Setup and calibration.** Participants held a grip-force sensor between their fingers while silently reading sentences presented word-by-word on the screen using a Rapid Serial Visual Presentation (RSVP) paradigm (see Figure 1). In RSVP, words from each sentence appeared sequentially at a fixed location, with each word displayed at the word's "optimal viewing position" (OVP)—the within-word fixation location that maximizes word recognition efficiency (Brysbaert & Nazir, 2005). Following Nazir et al. (1991), the OVP was calculated as the position at word length (in cm) / 1.8 from the word's beginning. To guide fixation, two short markers were continuously

displayed above and below the OVP, leaving a small gap between them, and words were horizontally positioned so that their OVP coincided with this gap.

At the start of the experiment, participants adjusted the duration of each word on the screen to achieve a comfortable reading pace. They could select values between 200 ms and 300 ms, in 10 ms increments, while reading an example sentence (*"Anaïs ajuste la vitesse pour une lecture confortable" / "Anaïs adjusts the speed for comfortable reading"*).

For inceptive constructions, the French inceptive marker "se met" (begin) was presented as a single unit (i.e., displayed together) to preserve its meaning. This ensured that verbs were always positioned in the fourth position in inceptive constructions and in the second position in present constructions. Example RSVP sequences for each condition are shown below, together with their English translations, and the RSVP setup is illustrated in Figure 1.

a. [Marie] [lace] [ses] [chaussures.] /
[Marie] [ties] [her] [shoes.]
b. [Marie] [commence] [à] [lacer] [ses] [chaussures.] /
[Marie] [starts] [to] [tie] [her] [shoes.]
c. [Marie] [se met] [à] [lacer] [ses] [chaussures.] /
[Marie] [begins] [to] [tie] [her] [shoes.]

Participants were instructed to hold the load cell between the thumb, index, and middle fingers, without support from the remaining fingers (see Figure 2A). The elbow rested on a foam pad on the table, with the forearm held at approximately a 45° angle. The cell was held vertically, with the cable oriented toward the screen. In addition, the correct grip posture was demonstrated on the experimental computer screen. Once participants had adopted the required posture, they were instructed to adjust their seat so that their eyes aligned with the central fixation cross on the screen; this position was marked on the floor to ensure consistent seating throughout the experiment. The experimenter then measured the viewing distance from the participant's eyes to the screen (approximately 70–80 cm) while the participant maintained the correct sensor-holding position (see Figure 2B).

**Individual pretrial target measurement.** Participants were instructed to hold the sensor comfortably using minimal force—just enough to prevent slipping—and to avoid excessive grip force (>4 N) while viewing a fixation cross for approximately 60 seconds. If grip force consistently exceeded 4 N, participants were reminded to loosen their grip. Once the signal stabilized, an Individual Pretrial Target (IPT) was recorded, defined as the mean grip force exerted during this 60-second resting hold period without any task ($M = 2.01$ N, $SD = 0.18$ in Experiment 1; $M = 2.25$ N, $SD = 0.16$ in Experiment 2). This individualized target served as a common reference level for each participant, allowing task-related grip force changes to be interpreted relative to a stable holding state while accounting for inter-individual differences in preferred grip force.

Participants were then instructed on how to return to their IPT before each block, using a visual feedback system: a green circle indicated the force was within the IPT

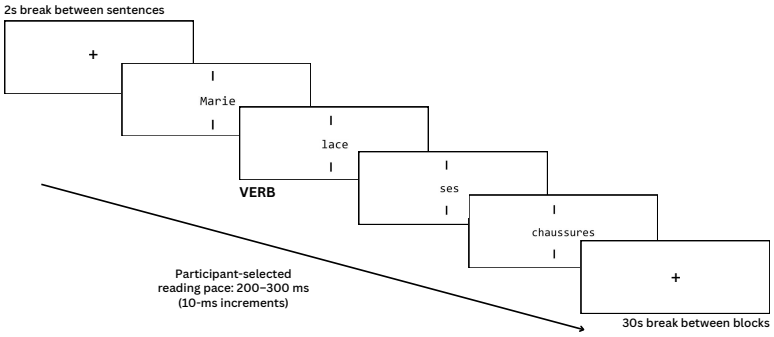
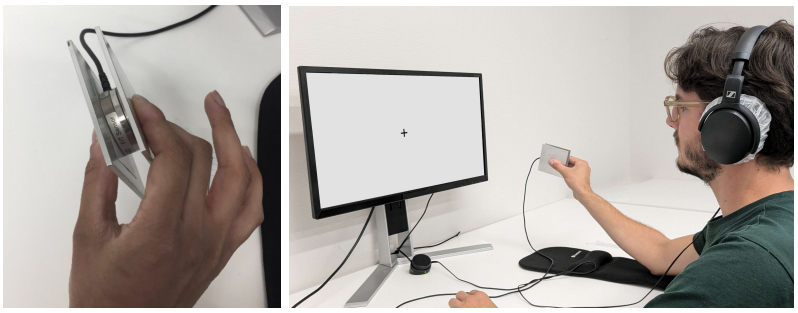



**Fig. 1**: Example demonstration of RSVP trials



(A) Correct grip posture: the load cell held between thumb, index, and middle fingers; forearm at approximately 45°.

(B) Experimental setup: participant seated at the correct viewing distance with eyes aligned to the fixation cross.

**Fig. 2**: Experimental setup. (A) Demonstration of the required sensor-holding posture. (B) Overview of the testing environment showing screen distance and seating position.

range, whereas a red circle accompanied by "+" or "–" prompted participants to increase or decrease force, respectively. Blocks began automatically once participants maintained force within IPT ± 0.4 N for 3 s. This procedure minimized force drift across blocks. To prevent instrumental drift, the sensor was tared after each block–i.e., the baseline reading was reset so that when no force was applied, the sensor correctly recorded 0 N, compensating for any drift that occurred during the block.

**Familiarization phase.** Before the main experiment, participants completed a practice block. They returned to the IPT and were presented with 5 example sentences (e.g., *"Océane écrit une lettre" / "Océane writes a letter"*). After each sentence, presented with a 2000 ms inter-stimulus interval, they answered two consecutive comprehension questions to ensure they understood the task.

**Experimental phase.** To minimize distractions, an opaque panel separated the participant from the experimenter, and the participant wore a headset. The experimenter could still monitor task progress remotely.

During sentence presentation, each sentence actor was randomly assigned a name sampled from a predefined name pool, with each name appearing in two sentences. At the end of each block of sentences (except the last), participants put down the cell and answered a comprehension-check question about the last sentence they saw, with no time constraints. To prevent boredom and ensure sustained attention to the stimuli, these questions were either sentence-based or picture-based (see Figure 3 for picture examples). Pictures were created using an AI-based image generator DALL·E (OpenAI), accessed in February 2025.

Overall, participants completed 15 comprehension-check questions in picture- and sentence-based formats. Picture-based items required selecting the matching image or judging correspondence on a slider scale. Sentence-based items included single- and multiple-sentence questions varying in difficulty, from clear mismatches to paraphrases and closely related alternatives. Performance was near ceiling across both experiments (98.6% correct overall; median = 15, range = 12–15), indicating sustained attention to the stimuli. Given the very low error rate, comprehension performance was not analyzed further in the main results.

**Post-experiment questionnaire.** Following the main task, participants completed a final questionnaire. The content of this questionnaire differed between the two experiments. Participants in Experiment 1 (typical imagery group) completed the Vividness of Mental Imagery Questionnaire (VVIQ; Marks 1973) in the lab, followed by questionnaires on demographics, reading habits, and sports habits. In contrast, participants in Experiment 2 (aphantasia group) had already completed the VVIQ online as part of the pre-screening process; therefore, they completed only the demographic and habit-related questionnaires during the lab session.



**Fig. 3**: Example pictures used in attention questions

## 3.5 Data Processing

Data processing and visualisations were carried out using custom in-house Python scripts. Grip force data was retained at the acquisition sample rate of 200 Hz and low-pass filtered prior to trial segmentation (to avoid edge effects) using a Butterworth filter (`filfilt`, 4th order, cutoff = 15 Hz), following prior Fourier analyses showing little meaningful signal content above 15 Hz (Nazir et al., 2017). Because compression force was recorded with a negative sign in our acquisition convention, raw values were sign-inverted and converted from Newtons to milliNewtons, by multiplying each data point by $-1000$.

To allow direct comparison of grip force trajectories across trials with variable RSVP presentation rates, time series were normalized to a common temporal scale. Across participants, the mean word duration was 279 ms ($SD$ = 18.7 ms, range = 240 − 300 ms), corresponding to approximately 56 samples at the 200 Hz sampling rate. Each word-related signal segment was therefore resampled to 56 points using linear interpolation. This time-normalization procedure preserved the overall shape of the signal while enabling alignment of word-locked trajectories across participants.

Following the procedures established by Nazir et al. (2017) and Reinecke et al. (2022), a baseline correction was applied to account for global changes in grip force over the session and to isolate stimulus-locked modulations. For each trial, the mean amplitude of the baseline period (–300 to 0 ms before the target word onset) was calculated. This baseline mean was then subtracted from every data point in the entire post-stimulus epoch for that trial.

An automatic artifact rejection protocol was then applied to the processed grip-force data. Building on the criteria described by Nazir et al. 2017, we implemented a participant-specific adaptation to account for individual differences in grip force. Rather than applying a fixed 1.5 N reference with a ±200 mN rejection threshold, we opted for IPT values. To index the exclusion process on the amplitude of each participant's IPT, we propose a weighted threshold approach. For each participant, a scaling factor was calculated as the ratio between their IPT and the 1500 mN reference value used by Nazir et al. (Scaling factor = IPT / 1500 mN). This factor was then applied to the standard ±200 mN rejection threshold to create participant-specific bounds (Scaled threshold = 200 mN × Scaling factor). This approach maintains the proportional logic of Nazir et al.'s method while adapting it to individual grip force profiles.

We extended the detection window to 1200 ms (compared to 1000 ms in Reinecke et al. 2022), as this time point corresponded to sentence offset in the majority of trials. Note that sentence length varied between 3–7 words in the present-tense condition and 6–10 words in the inceptive condition, necessitating this longer window to capture the full temporal extent of potential motor responses. Importantly, the position of the verb within each condition remained constant, with variability occurring mainly at the end of the sentences.

Trials were excluded if the baseline-corrected grip-force signal (centered at 0 mN) exceeded the participant's scaled threshold (±scaled threshold) or if the signal exhibited amplitude changes greater than 100 mN within a 100 ms window (see Figure 4 for an example illustration), indicative of abrupt finger movements. This individualized

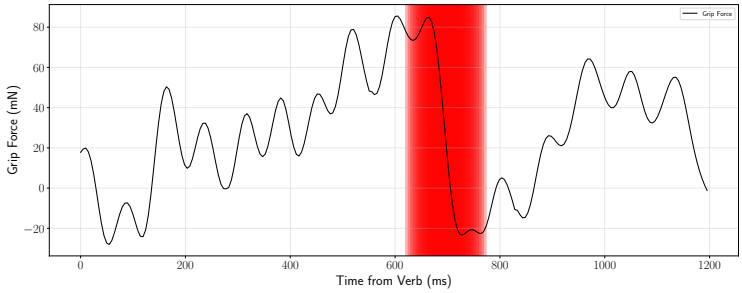



**Fig. 4**: Detection of abrupt amplitude changes in grip force signal during artifact rejection. The plot shows baseline-corrected grip force (black line) from verb onset (0 ms) to 1200 ms for an individual participant. Red shaded regions indicate 100 ms sliding windows where grip force amplitude changes exceeded the 100 mN rejection threshold.

procedure ensured that participants with higher baseline forces had proportionally larger allowable deviations, while those with lower baselines had smaller ones, maintaining comparable artifact sensitivity across participants. Participants were excluded from further analyses if they exceeded this trial rejection criterion in more than one condition, with a rejection rate greater than 7 out of 37 trials (approximately 19–20%) per condition.

## 3.6 Statistical Analyses

The same data preprocessing and statistical procedures were applied to both experiments. To address our research questions comprehensively, we report two complementary analyses that capture different aspects of motor resonance during sentence processing. These analyses are described in the following sections.

### 3.6.1 Analysis 1: Verb-Locked Motor Resonance

This analysis follows the standard approach in the grip-force literature and examines whether our RSVP paradigm reproduces previously reported verb-evoked modulation. For each trial, the grip-force signal was time-locked to the onset of the critical lexical verb (e.g., *lacer* "to lace", *toquer* "to knock", *berner* "to deceive", *tester* "to test"). We tested the Action vs. Non-Action contrast within each construction type (Present vs. Inceptive) using two approaches:

**Frequentist analysis.** For each participant, grip force values were averaged within a 600–900 ms window after verb onset—a period associated with peak sentence-level semantic integration—for all four conditions (Action/Non-Action × Present-tense/Inceptive). Paired-samples $t$-tests compared Action and Non-action sentences within Present and Inceptive constructions.

**Bayesian analysis.** To complement the static time-window frequentist analyses, we examined the temporal dynamics of the grip force signals using a Bayesian approach. The *Time-resolved Bayesian Evidence Display (TBED)* provides a graphical representation of the evidence for a difference versus the absence of a difference at each time point of two time series. Unlike approaches that restrict inference to preselected time

windows, the TBED is designed to make visible how the time series diverge or converge over time, underpinned by formal statistical evidence. This enables a principled characterization of the unfolding of the underlying processes, even when the evidence remains weak or inconclusive over parts of the trial.

The TBED is based on a Bayesian t-test (`pingouin.ttest()` Vallat 2018), configured with a non-informative prior (Cauchy, $r = 0.707$; Jeffreys, 1961; Rouder et al., 2009). The test produces a Bayes factor (BF) that quantifies how much more likely the data are under a model assuming a difference between the two time series at each time point ($H_1$) than under a model assuming no such difference ($H_0$; Kass & Raftery, 1995; Wagenmakers, 2007).

For clarity and to allow for a more robust evaluation of how signals differ over time, we express the BF in decibans (dBan), a logarithmic transformation defined as $10 \times \log_{10}(\text{BF})$. As illustrated in Figure 5, this transformation yields a symmetric and interpretable metric: positive values (displayed in green) provide evidence for a difference ($H_1$), whereas negative values (displayed in red) support the absence of a difference ($H_0$). Larger absolute values, represented by increasing color opacity, correspond to stronger evidence for one hypothesis relative to the other (see Jeffreys, 1961 for more details on conventional interpretive guidelines). Finally, to reduce local fluctuations and align the analysis with the time scale of language processing, deciban values are averaged within 25 ms bins (5 samples).

Crucially, the TBED makes visible changes in evidential support over time by distinguishing between the absolute level of evidence at any given moment and the way this evidence evolves dynamically. Standard p-value thresholding creates a binary framework of significant versus non-significant results, potentially masking incremental shifts in evidence that do not meet traditional significance criteria. In contrast, the TBED tracks the ongoing development of evidential strength as a continuous measure, which is particularly well suited to the study of psychological processes and their unfolding over time.

In the context of Analysis 1, the TBED was used to evaluate the time-resolved Action–Non-Action contrast within Present and Inceptive constructions, complementing the fixed-window frequentist tests by characterizing when evidential support for motor divergence emerges, strengthens, or dissipates following verb onset.

### 3.6.2 Analysis 2: Sentence-Level Trajectory Comparisons

While Analysis 1 examines motor modulation time-locked to individual verbs, Analysis 2 tests whether motor modulation depends on how the event is constructed at the sentence level. This analysis used TBED to compare grip force trajectories across different sentence constructions, aligned to a shared baseline that allows direct comparison of temporal profiles.

Specifically, two cross-construction comparisons were conducted: (a) Present Action vs. Inceptive Action, investigating whether framing an action as ongoing (Present-tense) versus about to begin (Inceptive) modulates the magnitude or temporal profile of motor resonance for identical action verbs, (b) Present Non-Action vs. Inceptive Action, which is a control comparison investigating whether any observed

| | | | |
|---|---|---|---|
| **20** | Decisive | **-20** | |
| **15** | Very strong | **-15** | |
| **10** | Strong | **-10** | |
| **5** | Moderate | **-5** | |
| **0** | Anecdotal | **0** | |
| **H1** | evidence for... | **H0** | |

**Fig. 5**: Bayes Factor description

differences in the first comparison reflect action-specific motor resonance or simply structural differences between Present and Inceptive constructions.

For both comparisons, all trials are aligned to a shared baseline at W1 (0ms), corresponding to the verb onset in Present Constructions; and the aspectual verb onset (e.g., *se met* "begins," *commence* "starts") in Inceptive constructions, with the particle "à" (to) presented as a separate word. This alignment strategy allowed us to directly compare how grip force unfolds across the entire sentence duration, revealing whether aspectual framing impacts the temporal dynamics of motor engagement.

# 4 Experiment 1: Typical Imagery Group

## 4.1 Participants

A total of 31 participants were recruited from the Université Catholique de Lille participant pool. One participant reported having dyslexia but indicated they could read comfortably at the minimum required speed; their data was therefore retained. One participant was reassigned to Experiment 2 because their VVIQ score fell within the range for that experimental group. Data from one additional participant could not be registered due to a technical problem. The final sample thus consisted of 29 participants aged 18–26 ($M = 20.3$, $SD = 1.90$), predominantly female (21 female, 72.4%; 8 male, 27.6%), with VVIQ scores ranging from 39 to 76 ($M = 59.1$).

Regarding education level, the majority was pursuing an undergraduate (bachelor-level) program ($n = 16$, 55.2%). The remaining participants reported high school completion($n = 5$, 17.2%), a two-year postsecondary qualification ($n = 5$, 17.2%), or a Master degree ($n = 4$, 13.8%). Most participants reported reading between 30–60 minutes per day ($n = 15$, 51.7%), with fewer reading less than 30 minutes ($n = 9$, 31.0%), 1–2 hours ($n = 3$, 10.3%), or more than 2 hours daily ($n = 2$, 6.9%). A small proportion reported experience with rapid reading ($n = 5$, 17.2%).

More than half of the participants engaged in regular sports practice ($n = 16$, 55.2%), with most of them practicing 1–2 times per week ($n = 12$, 75.0%). Among those involved in competitive sports ($n = 11$, 37.9%), the majority participated at an amateur level ($n = 9$, 81.8%), with a small number at semi-professional level ($n = 2$, 18.2%).

## 4.2 Stimuli

The sentences featured action and non-action verbs in present indicative and inceptive aspectual constructions (marked by *commencer à* "to start (to)" or *se mettre à* "to begin (to)"). As noted in the 'Stimuli and Design' section, participants were assigned

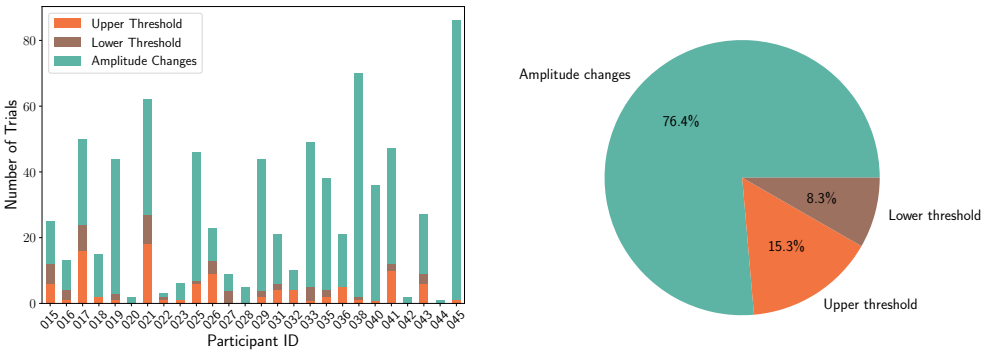
to either List A or List B, which contained the same sentences, but the inceptive marker was swapped at the item level: an inceptive sentence that used *commencer à* in List A used *se mettre à* in List B, and vice versa.

## 4.3 Results

As detailed in the Methods section, participants were excluded if their trial rejection rate exceeded 19–20% (more than 7 out of 37 trials) in more than one condition. Among the 4,292 trials collected, 640 (14.9%) were rejected. Sudden amplitude changes accounted for 76.4% of rejections, followed by upper threshold violations (15.3%) and lower threshold violations (8.3%). Figure 6 displays rejection reasons by participant and overall rejection patterns. Ten participants were excluded based on these criteria, resulting in a final sample of $N = 19$. Two participants reported having a medical condition affecting their grip force, but they were not excluded from the analysis because their rejection rates were not unusually high.

For transparency, the comparisons between action and non-action conditions conducted on the full sample ($N = 29$) are reported in the Appendix (Figure B1) at two stages of preprocessing: prior to any trial rejection, and after trial-level rejection based on the criteria described above, but before participant-level exclusion. For this latter stage, individual grip force patterns are also detailed in the Appendix (Figure D4).

In the present analysis, we report results obtained from the refined sample of $N = 19$, i.e., after applying both trial- and participant-level exclusion criteria.




(A) Rejection reasons by participant

(B) Overall rejection distribution

**Fig. 6**: Trial rejection analysis for the typical imagery group (N=29 participants, Experiment 1). (A) Distribution of rejection reasons by participant. Stacked bars show the number of trials rejected due to exceeding upper threshold (orange), lower threshold (brown), or amplitude changes (teal). Only participants with at least one rejected trial are shown (n=26); 3 participants with 0% rejection rates (024, 030, 034) are not included in this panel. (B) Overall distribution of rejection reasons across all 4,292 trials. A total of 640 trials (14.9%) were rejected using participant-specific scaled thresholds (±200 mN baseline equivalent, see Methods) applied to the entire trial duration from verb onset. Trials were rejected if the force exceeded individual thresholds or if amplitude changes exceeded 100 mN within 100 ms windows.

### 4.3.1 Analysis 1: Verb-Locked Motor Resonance

**Present-Tense Constructions.** The frequentist analysis (paired-samples $t$-test) comparing Action and Non-Action sentences in Present-tense constructions (Figure 7A) revealed a significant difference in the 600-900 ms window following verb onset, with Action sentences eliciting greater grip force modulation than Non-Action sentences (Present Action $M = 13.35$, $SD = 19.05$ vs. Present Non-Action $M = 8.95$, $SD = 16.93$), $t(18) = 2.141$, $p = .046$, $d = 0.49$.

The TBED analysis (Figure 7C) revealed Bayesian evidence that remained largely negative during the first 750 ms after verb onset. A transient window of positive evidence emerged between approximately 750 ms and 1000 ms, peaking at 4.94 dBan shortly before the 1000 ms mark. Notably, although this peak remained below the conventional +5 dBan threshold and therefore does not constitute "strong" evidence, it follows a substantial reweighting (from -5 dBan to 4.9 dBan within 400ms) in favor of the hypothesis of a difference between Action and Non-Action conditions. Following this peak, the profile shifted rapidly back towards $H_0$, with a sustained period of negative evidence observed between 1250 ms and 1750 ms.

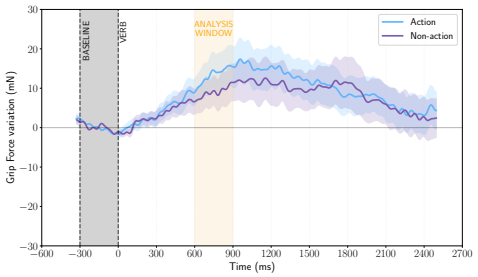
**Inceptive Constructions.** In contrast to the Present-Tense constructions, the frequentist comparison for Inceptive constructions (Figure 7B) within the same 600-900 ms window after verb onset revealed no significant difference between Action and Non-Action sentences (Inceptive Action $M = 3.11$, $SD = 9.72$ vs. Inceptive Non-action $M = 3.86$, $SD = 15.78$), $t(18) = -0.322$, $p = .751$, $d = -0.07$.

The TBED analysis of the Inceptive constructions corroborated this null result (Figure 7D). Throughout the entire post-verb epoch, the Bayesian evidence consistently favored $H_0$, reaching a minimum of $-6.24$ dBan.

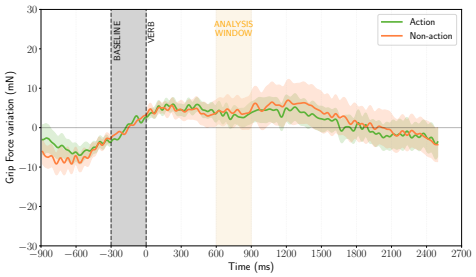
### 4.3.2 Analysis 2: Sentence-Level Trajectory Comparisons

**Present Action vs. Inceptive Action.** The TBED comparison between Present Action and Inceptive Action sentences (Figure 8A) revealed similar grip force dynamics ($\leq$ 5 dBan) across two segments of the signal: from the shared baseline (W1) to approximately 600 ms, and again from around 1450 ms to the end of the trial. Between approximately 750 ms and 1400 ms, the evidence shifts in favor of a difference between the two conditions ($H_1$), reaching a peak of 9.52 dBan. During this temporal window, present-tense action sentences elicited stronger motor modulation than their inceptive counterparts.

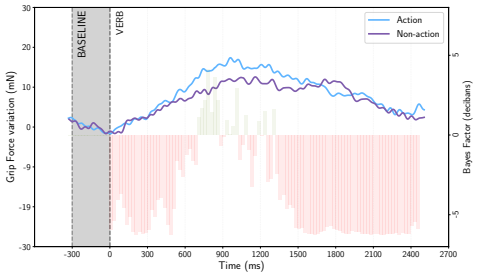
**Present Non-Action vs. Inceptive Action.** The control comparison between Present Non-Action and Inceptive Action sentences (Figure 8B) revealed consistent and robust evidence in favor of $H_0$. The evidence balance remained negative, reaching a minimum of $-6.23$ dBan. This pattern indicates that sentences describing actions as beginning elicit grip force patterns functionally indistinguishable from sentences describing no action at all.



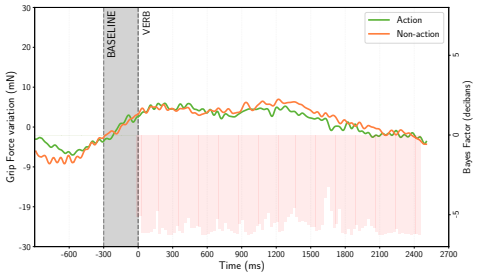

(A) Present: Refined Sample




(B) Inceptive: Refined Sample




(C) Present: Refined Sample




(D) Inceptive: Refined Sample

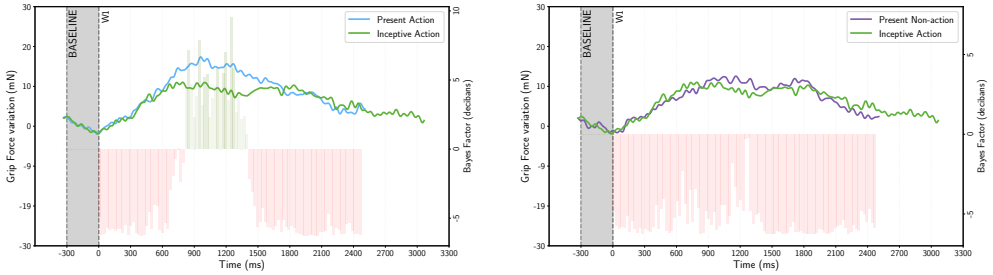
**Fig. 7**: Comparison between Action vs. Non-Action sentences within Present and Inceptive constructions for Experiment 1. Figures A and B show the frequentist analysis, Figures C and D show the TBED analysis.

# 5 Experiment 2: Aphantasia Group

## 5.1 Participants

Participants were recruited via flyers distributed at the Université de Lille. Interested individuals completed the VVIQ questionnaire online using LimeSurvey and could optionally provide an email address for follow-up. Based on established criteria for identifying aphantasia (VVIQ scores between 16 and 32; Zeman 2024), 20 participants were initially recruited; one additional participant from Experiment 1 (VVIQ = 33) was reassigned to this group. Although some participants' VVIQ scores fell marginally outside the standard range (overall range: 16–36, M = 25.0), the VVIQ is not highly sensitive to small score differences. Inclusion was therefore further validated through follow-up questions assessing participants' subjective imagery experiences and their awareness of lacking mental imagery. The final sample comprised 21 participants aged 18–31 ($M = 22.5$, $SD = 3.14$), predominantly female (13 female, 61.9%; 6 male, 28.6%; 2 preferred not to say, 9.5%).

Regarding education level, the majority was pursuing an undergraduate (bachelor-level) program ($n = 10$, 47.6%). The remaining participants reported high school completion ($n = 5$, 23.8%), a Master's program ($n = 4$, 19.1%), a two-year post-secondary qualification or a doctoral program ($n = 1$, 4.8% each). Equal number of participants reported reading between either less than 30 minutes or 30–60 minutes




(A) Action Sentences in Present-Tense vs. Inceptive Constructions

(B) Present-Tense Non-Action vs. Inceptive Action Sentences

**Fig. 8**: TBED analysis of cross-construction comparisons in the typical imagery group (Experiment 1). (A) Comparison between Action sentences in Present-Tense versus Inceptive constructions (B) Comparison between Present-Tense Non-Action sentences and Inceptive Action sentences. All analyses are aligned to a shared baseline at W1 (0 ms), corresponding to the action verb onset in Present conditions and the aspectual marker onset (e.g., se met "begins", commence "starts") in Inceptive conditions.

per day ($n = 7$, 35.0% each), with five reporting 1–2 hours (25%) and one reading more than 2 hours per day (5%). A small proportion reported experience with rapid reading ($n = 3$, 14.3%).

More than half of the participants engaged in regular sports practice ($n = 12$, 57.1%), with most of them practicing 1–2 times per week ($n = 6$, 66.7%), followed by 5 times or more ($n = 2$, 22.2%) and 3–4 times ($n = 1$, 11.1%). All participant who were involved in competitive sports ($n = 5$, 23.8%) were at an amateur level.

## 5.2 Stimuli

The stimuli were identical to those used in Experiment 1.

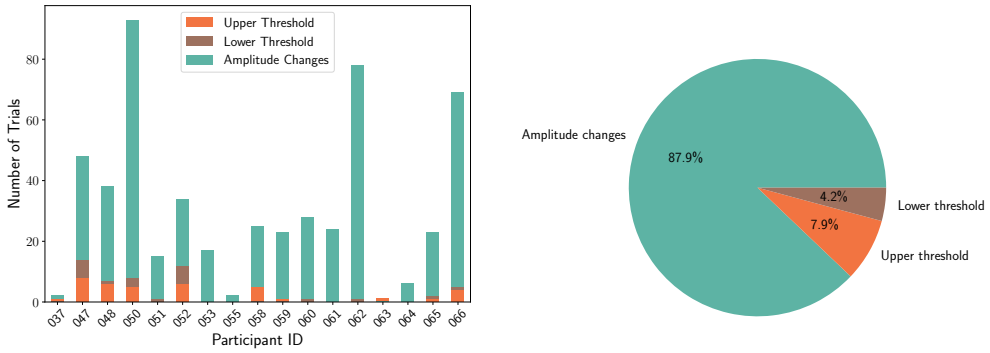
## 5.3 Results

Among the 3,108 trials collected, 479 (15.4%) were rejected (87.9% amplitude changes, 7.9% upper threshold violations and 4.2% lower threshold violations). Figure 9 displays rejection reasons by participant and overall rejection patterns. Five participants were excluded based on these criteria, including two participants who reported a medical condition affecting their grip force, whose trials showed high rejection rates, resulting in a final sample of $N = 16$.

Full-sample comparisons at each preprocessing stage are available in the Appendix (Figure C2), with individual patterns shown in Figure E6.

### 5.3.1 Analysis 1: Verb-Locked Motor Resonance

**Present Tense Constructions.** The frequentist analysis (paired-samples $t$-test) comparing Action and Non-Action sentences in the Present-tense constructions (Figure 10A) revealed no significant difference in the 600-900 ms window following verb onset (Present Action $M = 12.32$, $SD = 18.99$ vs. Present Non-Action $M = 12.56$, $SD = 13.99$), $t(15) = -0.105$, $p = .918$, $d = -0.03$.




(A) Rejection reasons by participant

(B) Overall rejection distribution

**Fig. 9**: Trial rejection analysis for the aphantasia group (N=21 participants, Experiment 2). (A) Distribution of rejection reasons by participant. Stacked bars show the number of trials rejected due to exceeding upper threshold (orange), lower threshold (brown), or amplitude changes (teal). Only participants with at least one rejected trial are shown (n=17); 4 participants with 0% rejection rates are not included in this panel. (B) Overall distribution of rejection reasons across all 3,108 trials. A total of 479 trials (15.4%) were rejected using participant-specific scaled thresholds (±200 mN baseline equivalent, see Methods) applied to the entire trial duration from verb onset. Trials were rejected if the force exceeded individual thresholds or if amplitude changes exceeded 100 mN within 100 ms windows.

The TBED analysis (Figure 10C) showed negative values throughout the entire post-stimulus epoch, reaching a minimum of −5.93 dBan. This pattern indicates consistent evidence in favor of $H_0$ between Action and Non-Action conditions in Present-tense constructions. With a maximum value of 0.00 dBan, no interval within the post-stimulus epoch favored the alternative hypothesis.

**Inceptive Constructions.** Similar to the Present-tense constructions, the frequentist comparison for Inceptive constructions (Figure 10B) within the same 600-900 ms window after verb onset revealed no significant difference between Action and Non-Action sentences (Inceptive Action $M = 7.65$, $SD = 16.33$ vs. Inceptive Non-Action $M = 9.74$, $SD = 15.37$), $t(15) = -1.273$, $p = .222$, $d = -0.32$.

The TBED analysis showed two transient spikes of positive deciban values observed at approximately 300 ms and 600 ms following verb onset, reaching a maximum peak of 5.72 dBan (Figure 10D). These brief but pronounced shifts in evidence support a higher grip force modulation in the non-action condition, but did not constitute a sustained condition-specific effect, as the profile rapidly returned to favor the absence of a difference ($H_0$) between Inceptive Action and Inceptive Non-Action sentences. Notably, while the evidence remained negative throughout the later stages of processing, the profile moved closer to 0 dBan at approximately 1500 ms before returning to sustained support for $H_0$ ($min = -5.93$ dBan) towards the end of the trial.

### 5.3.2 Analysis 2: Sentence-Level Trajectory Comparisons

**Present Action vs. Inceptive Action.** The TBED analysis comparing Present Action and Inceptive Action sentences within the aphantasia group revealed an inconsistent evidence profile marked by high volatility (Figure 11A). Even if Bayesian




(A) Present Tense Constructions

(B) Inceptive Aspectual Constructions

(C) Present Tense Constructions TBED

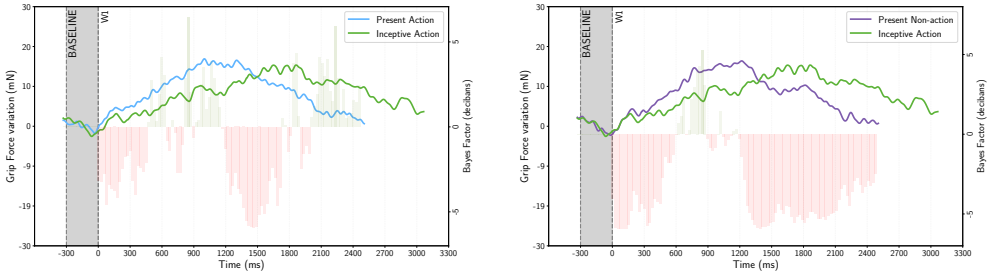
(D) Inceptive Aspectual Constructions TBED

**Fig. 10**: Comparison between Action vs. Non-Action sentences within Present and Inceptive constructions for Experiment 2. Figures A and B show the frequentist analysis, Figures C and D show the TBED analysis.

evidence reached a maximum peak of 6.46 dBan, this occurred within isolated, narrow spikes rather than a sustained window of divergence. Specifically, transient shifts toward the alternative hypothesis between 600–1100 ms and after 1800 ms were rapidly countered by shifts favoring $H_0$, which reached a minimum of $-5.91$ dBan.

**Present Non-Action vs. Inceptive Action.** The control comparison between Present Non-action and Inceptive Action sentences (Figure 11B) identified distinct temporal phases of evidence. From the shared baseline (W1) to approximately 600 ms, the evidence supported similar grip force variations between the two conditions, with the profile favoring $H_0$ and reaching a minimum of $-6.24$ dBan. Following this initial phase, the signal exhibited a substantial reweighting of evidence: the profile shifted rapidly to a peak of 5.26 dBan at approximately 850 ms. While this transient window technically reached the threshold for strong evidence favoring a difference, the trajectories quickly returned to similarity. From approximately 1200 ms until the end of the trial, the trajectories remained intertwined, with Bayesian evidence consistently favoring $H_0$ and maintaining a floor near $-5.92$ dBan.

Notably, across both comparisons, a distinct pattern emerged where the grip force trajectories crossed at appropximately 1500 ms, potentially identifying a consistent temporal feature of the motor response within the aphantasia group.




(A) Action Sentences in Present-Tense vs. Inceptive Constructions

(B) Present-Tense Non-Action vs. Inceptive Action Sentences

**Fig. 11**: TBED analysis of cross-construction comparisons in the aphantasia group (Experiment 2). (A) Comparison between Action sentences in Present-Tense versus Inceptive constructions (B) Comparison between Present-Tense Non-Action sentences and Inceptive Action sentences. All analyses are aligned to a shared baseline at W1 (0 ms), corresponding to the action verb onset in Present conditions and the aspectual marker onset (e.g., se met "begins", commence "starts") in Inceptive conditions.

# 6 Discussion

The present study introduces two methodological extensions to the grip force paradigm in language processing: visual sentence presentation via RSVP and time-resolved Bayesian evidence display (TBED). These advances allow characterization of motor modulation dynamics beyond predefined analysis windows. Our implementation incorporated individual calibration of RSVP rate and grip-force reference level (Individual Pretrial Target, IPT), ensuring comfortable reading pace and stable force references across participants. We used this RSVP and TBED pipeline as a methodological platform to probe two theoretically motivated boundary conditions—grammatical aspect and mental imagery ability—as demonstration cases for the methodology.

Previous grip-force studies have typically focused on average force within a predefined window (often 600–900 ms after verb onset; Aravena et al. 2012, Aravena et al. 2014, Reinecke et al. 2022), corresponding to a relatively late stage of sentence processing. While effective for detecting robust effects within this theoretically motivated interval, this approach provides limited insight into temporal dynamics and offers ambiguous interpretation of null results. TBED complements this strategy by providing continuous evidence traces favoring either an Action–Non-Action difference ($H_1$) or evidence for an absence of difference ($H_0$) at each time point. This allows identification of when divergence emerges, peaks, and dissipates over time. Importantly, when Bayes factors reach conventional evidence thresholds (e.g., beyond ±5 dBan), TBED permits distinction between evidence for absence and mere absence of evidence, while intermediate values reflect genuinely inconclusive periods.

We examined aspectual manipulation through multiple complementary contrasts: (1) within-construction comparisons of Action versus Non-Action sentences for both present-tense and inceptive forms, (2) direct cross-construction comparison of Present Action versus Inceptive Action sentences, and (3) a critical control comparison of Present Non-Action versus Inceptive Action sentences to determine whether inceptive action processing patterns more closely with ongoing actions or with non-action content.

In *the typical imagery group*, Present-tense Action sentences elicited higher grip-force modulation relative to Non-Action controls in the conventional 600–900 ms window, in line with previous studies. However, TBED indicated that evidence for this effect remained weak overall ($< 5$ dBan), with only a transient shift toward $H_1$ emerging approximately 750–1000 ms post-verb onset. For Inceptive constructions, TBED profiles predominantly favored $H_0$, with Bayesian evidence remaining consistently negative. This pattern suggests active support for the absence of Action/Non-Action differentiation when actions are framed as incipient rather than ongoing—not merely a failure of detection.

Direct comparison between Present Action and Inceptive Action sentences revealed that Present-tense descriptions of ongoing actions elicited substantially stronger motor modulation, whereas Inceptive Actions patterned closely with Non-Action sentences. Notably, the comparison between Present Non-Action and Inceptive Action sentences showed consistent absence of difference, suggesting that under RSVP conditions, when an action is framed as merely beginning, motor engagement is functionally equivalent to processing non-action content.

This pattern is consistent with the idea that motor recruitment during language comprehension depends on how strongly the context commits to an action being carried out, rather than being triggered solely by verb category. Inceptive constructions foreground an action's onset or imminence rather than ongoing execution; if grip-force modulation primarily tracks simulation of execution-related motor features, then inceptives may attenuate the motor signature relative to present-tense descriptions of ongoing actions. This interpretation aligns with evidence that grammatical aspect guides attention toward different phases of events (Ferretti et al., 2007; Madden & Zwaan, 2003; von Stutterheim et al., 2012) and can interact with verb semantics in a way that either reinforces or conflicts with the temporal structure encoded in the verb (Yap et al., 2009).

More broadly, the inceptive null is compatible with prior demonstrations that motor effects are sensitive to action construal and can be reduced or absent when the described event is not straightforwardly construed as an occurring action (e.g., negation and related contextual manipulations; Aravena et al. 2012, Aravena et al. 2014; see also information-layering effects in Reinecke et al. 2022). The finding that Inceptive Actions pattern with Present Non-Actions rather than ongoing actions extends prior work on how negation, volition, and presupposition structure influence motor resonance, demonstrating that aspectual framing can similarly gate motor activation by modulating commitment to action execution.

While our results provide novel evidence for aspectual gating of motor engagement, they also underscore methodological factors that may influence the stability and variability of grip-force measurements under RSVP. Robust grip-force effects in earlier work were obtained with auditory sentence presentation (e.g., Aravena et al. 2012,1; Frak et al. 2010; Reinecke et al. 2022). Although neuroimaging findings suggest that action-language processing can recruit motor regions independently of modality (Aziz-Zadeh et al., 2006; Hauk et al., 2004), RSVP reading may impose high attentional and working-memory demands. For instance, RSVP formats have been shown to impair literal comprehension and to increase visual fatigue relative to conventional reading,

indicating increased cognitive and perceptual load during reading (Benedetto et al., 2015). These demands may divert attentional resources toward maintaining a constant grip force, leading to compensatory micro-adjustments (e.g., re-gripping) that can obscure small simulation-related changes and introduce greater signal variability in the grip-force trace.

Our average IPT ($>$ 2 N in both experiments) was higher than the $\sim$ 1.5 N target commonly used in earlier grip-force protocols (following Nazir et al. 2017). Maintaining a higher tonic force may increase physiological variability and promote micro-adjustments of grip. Consistent with this interpretation, the large majority of rejected trials involved abrupt amplitude changes indicative of finger movements (e.g., re-gripping) rather than gradual drift. While force thresholds were scaled relative to each participant's IPT, the amplitude-change criterion (>100mN within 100 ms) was held constant. This fixed criterion may have contributed to the higher participant exclusion rate in the present study ($\sim$ 35%) relative to prior work ($\sim$ 20%).

In *the aphantasia group*, no reliable Action/Non-Action differentiation was observed for either construction, and time-resolved evidence favored absence of difference across much of the trial. Although Inceptive Action and Present Non-Action sentences showed broadly similar trajectories, this similarity is difficult to interpret because evidence profiles were generally weak and temporally unstable in this group, including for the Present Action vs. Inceptive Action comparison. Notably, both comparisons exhibited a distinct crossing of the signal trajectories. This recurrence across different condition contrasts might suggest a population-specific temporal signature in individuals with aphantasia, potentially reflecting lower temporal stability in the motor system's response to linguistic stimuli.

Importantly, the refined aphantasia sample ($N = 16$) was smaller than the refined typical imagery group ($N = 19$), limiting statistical power and increasing susceptibility to noise in time-resolved analyses. Such conditions can produce non-sustained, fluctuating evidence profiles, as observed here. Consequently, the present data do not allow firm claims regarding language–motor links in aphantasia, but instead highlight the need for larger samples to reliably assess construction-level motor modulation in populations with reduced imagery.

Evidence from TMS and implicit priming paradigms provides relevant context. Dupont et al. (2024) used TMS to index corticospinal excitability and observed the expected facilitation in typical imagers during kinaesthetic motor imagery and action observation, but no corresponding modulation in aphantasics—consistent with reduced engagement of both explicit and implicit motor simulation mechanisms. Similarly, Purkart et al. (2025) found that control participants showed reliable congruence effects in both explicit and implicit priming tasks, whereas aphantasics showed no priming, suggesting reduced generation of imagery-like representations in both deliberate and implicit conditions. As mentioned earlier, recent fMRI evidence further suggest that imagery attempts in aphantasia may not reliably engage perceptual representations in a perception-like format: activity patterns in early visual cortex show reduced (or absent) representational overlap with perception, consistent with the use of alternative, non-perceptual strategies during imagery attempts (Chang et al., 2025; Scholz et al., 2025).

Several limitations follow from our methodological emphasis. First, the absence of an auditory control condition prevents direct within-study assessment of whether RSVP introduces greater signal variability relative to auditory presentation. Second, future work would benefit from independent measures or manipulations of cognitive load to assess whether RSVP demands compete with motor resonance. A strong next step is a within-participant comparison of auditory and RSVP presentation using matched materials and the same TBED pipeline, which would clarify whether the inceptive null reflects a principled constraint on motor simulation or an interaction with RSVP demands. More naturalistic visual paradigms—such as self-paced reading or sentence-level display combined with eye-tracking—may provide a better balance between temporal control and sensitivity. Additionally, the relatively high tonic force maintained in the present experiments may have increased physiological variability and trial rejection, potentially reducing sensitivity to subtle grip-force modulations. Importantly, TBED (and related Bayesian approaches) can be carried forward into these designs to quantify not only whether an effect is present, but how its timing and uncertainty evolve across modalities, constructions, and participant groups.

# 7 Conclusion

This work argues for a shift in how grip-force "motor resonance" effects are studied and interpreted. Rather than treating motor modulation as something that either appears in a predefined window or "fails" to appear, our RSVP and TBED pipeline treats the phenomenon as temporally dynamic evidence—allowing researchers to visualize when a contrast is supported, when the data support no contrast, and how these patterns change with task constraints and participant characteristics.

Methodologically, the contribution is a transferable framework for moving beyond windowed significance testing toward time-resolved evidence tracking. The broader message is that language-related motor signatures may be subject to higher signal variability under demanding visual presentation conditions (e.g., RSVP), highlighting the importance of considering task demands when interpreting motor resonance effects.

Theoretically, our results reinforce the view that motor recruitment during comprehension is contingent—shaped by event construal and available representational resources—rather than an obligatory component of action word processing (Aravena et al., 2012; Reinecke et al., 2022; Tettamanti et al., 2008; Vitale et al., 2025). The functional equivalence we observed between Inceptive Action and Present Non-Action sentences provides novel evidence that motor engagement depends on commitment to action execution: describing an action as beginning does not recruit motor representations in the same way as describing ongoing actions, even when action content is held constant. This extends prior demonstrations that negation, volition, and presupposition structure modulate motor effects by showing that aspectual framing similarly gates access to motor simulation during comprehension.

Overall, our results support the notion that grip-force motor resonance is a context- and task-sensitive signal whose presence and timing are best evaluated with time-resolved evidence methods.

# Declarations

**Author Contributions Statement.** *Melisa Yavuz*: conceptualization, investigation, methodology, Writing – original draft, writing – review & editing, visualisation, formal analysis, validation, project administration.
*Florentin Vandeville*: methodology, software, writing – review & editing, project administration.
*Camille Mignard*: investigation, methodology.
*Jacques Jayez*: conceptualization, methodology, writing – review & editing, supervision.
*Tatjana A. Nazir*: conceptualization, methodology, funding acquisition, Writing – review & editing, supervision, validation.
*Olivier Capra*: conceptualization, methodology, software, funding acquisition, writing – review & editing, visualisation, formal analysis, supervision, validation, project administration.

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Olivier Capra: https://orcid.org/0000-0002-1812-6061

**Ethics approval and consent to participate.** At the start of each experiment, all participants provided informed consent. Both studies were approved by the Research Ethics Committee of the University of Lille (CER U-Lille; 2021-474-S91).

**Data, Code and Materials Availability.** The data, code and materials used in this study can be found in OSF: https://osf.io/3q9gt/overview?view_only=a70e9b0fa6ad4ec6897766bf6acf8569.

**Funding.** This research was supported by the Mission pour les Initiatives Transverses et Interdisciplinaires (MITI) of the Centre National de la Recherche Scientifique (CNRS), 80|Prime – 2022, through funding for the MMILA project (Mental Motor Imagery and Language Processing in Individuals with Aphantasia).

**Competing interests.** The authors report no competing interests.

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# Appendix A Experimental Stimuli

All inceptive sentences were distributed across two counterbalanced lists. For each sentence, the inceptive marker was either *commencer* or *se mettre*, such that if a given sentence appeared with *commencer* in List A, it appeared with *se mettre* in List B, and vice versa. Proper names were randomly assigned to sentence frames across participants. Below, we present one representative version of each sentence.

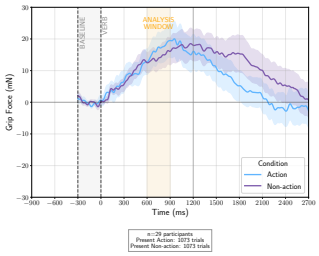
## A.1 Present-tense constructions

| **Action** | **Non-action** |
|---|---|
| Marie lace ses chaussures. | Martin berne ses collègues. |
| Paul toque à la porte. | Laure teste de nouvelles méthodes. |
| Sophie claque des doigts. | Juliette souhaite le succès. |
| Claire repasse la chemise. | David conseille ses clients. |
| Marc caresse le chat. | Sandra impose ses idées. |
| Anne vernit la table. | Alexandre déplore la situation. |
| Julie emballe les cadeaux. | Amélie questionne les décisions. |
| Luc scie du bois. | Maxime loupe ses cours. |
| Emma déballe les cartons. | Fanny recrute des volontaires. |
| Jean pointe du doigt. | Benjamin heurte les sentiments de ses amis. |
| Léa taille le crayon. | Élodie situe le problème. |
| Thomas jongle avec les balles. | Mathis solde les dettes. |
| Alice presse les oranges. | Léna hausse le ton. |
| Nina aplatit la pâte. | Lucas enregistre les données. |
| Pierre agrafe les documents. | Robin nuance ses opinions. |
| Hugo casse les œufs. | Nathan vend ses services. |
| Chloé serre la vis. | Raphaëlle compte les jours. |
| Max gifle l'adversaire. | Léo scrute les étoiles. |
| Sarah frappe à la porte. | Marine gagne la confiance des autres. |
| Laura ouvre la fenêtre. | Sophie part en vacances. |
| Louise recoud le bouton. | Théo détecte des problèmes. |
| Camille peigne sa poupée. | Antoine plume les investisseurs. |
| Adrien étale la crème sur le pain. | Bénédicte contemple l'avenir. |
| Élise tend la corde. | Inès offre des opportunités. |
| Margot cueille des fleurs. | Philippe cite des sources. |
| Lucas allume la lampe. | Émilie étonne ses professeurs. |
| Jeanne frotte le sol. | Romain prouve sa théorie. |
| Manon coud une robe. | Elsa fâche ses amis. |
| Hugo lance la balle. | Victor roule sur l'autoroute. |
| Clara savonne la planche. | Zoé démasque le coupable. |
| Emma brosse le chien. | Louis ruine sa réputation. |
| Léon épluche les pommes. | Maëlle rembourse ses prêts. |
| Pauline tamponne les documents. | Jules dément les rumeurs. |
| Simon branche le câble. | Lina fausse les données. |
| Lucie tord la serviette. | Thibault trouble les esprits. |
| Arthur chatouille son ami. | Mélissa relance le débat. |
| Charlotte lave la vaisselle. | Cédrick gêne ses collègues. |

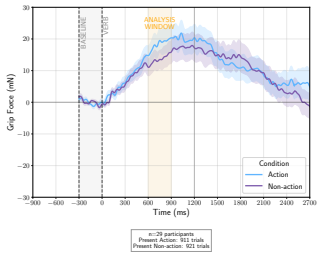
## A.2 Inceptive constructions

| Action | Non-action |
|---|---|
| Marie commence à lacer ses chaussures. | Martin se met à berner ses collègues. |
| Paul se met à toquer à la porte. | Laure commence à tester de nouvelles méthodes. |
| Sophie commence à claquer des doigts. | Juliette se met à souhaiter le succès. |
| Claire se met à repasser la chemise. | David commence à conseiller ses clients. |
| Marc commence à caresser le chat. | Sandra se met à imposer ses idées. |
| Anne se met à vernir la table. | Alexandre commence à déplorer la situation. |
| Julie commence à emballer les cadeaux. | Amélie se met à questionner les décisions. |
| Luc se met à scier du bois. | Maxime commence à louper ses cours. |
| Emma commence à déballer les cartons. | Fanny se met à recruter des volontaires. |
| Jean se met à pointer du doigt. | Benjamin commence à heurter les sentiments de ses amis. |
| Léa commence à tailler le crayon. | Élodie se met à situer le problème. |
| Thomas se met à jongler avec les balles. | Mathis commence à solder les dettes. |
| Alice commence à presser les oranges. | Léna se met à hausser le ton. |
| Nina se met à aplatir la pâte. | Lucas commence à enregistrer les données. |
| Pierre commence à agrafer les documents. | Robin se met à nuancer ses opinions. |
| Hugo se met à casser les œufs. | Nathan commence à vendre ses services. |
| Chloé commence à serrer la vis. | Raphaëlle se met à compter les jours. |
| Max se met à gifler l'adversaire. | Léo commence à scruter les étoiles. |
| Sarah commence à frapper à la porte. | Marine se met à gagner la confiance des autres. |
| Laura se met à ouvrir la fenêtre. | Sophie commence à partir en vacances. |
| Louise commence à recoudre le bouton. | Théo se met à détecter des problèmes. |
| Camille se met à peigner sa poupée. | Antoine commence à plumer les investisseurs. |
| Adrien commence à étaler la crème sur le pain. | Bénédicte se met à contempler l'avenir. |
| Élise se met à tendre la corde. | Inès commence à offrir des opportunités. |
| Margot commence à cueillir des fleurs. | Philippe se met à citer des sources. |
| Lucas se met à allumer la lampe. | Émilie commence à étonner ses professeurs. |
| Jeanne commence à frotter le sol. | Romain se met à prouver sa théorie. |
| Manon se met à coudre une robe. | Elsa commence à fâcher ses amis. |
| Hugo commence à lancer la balle. | Victor se met à rouler sur l'autoroute. |
| Clara se met à savonner la planche. | Zoé commence à démasquer le coupable. |
| Emma commence à brosser le chien. | Louis se met à ruiner sa réputation. |
| Léon se met à éplucher les pommes. | Maëlle commence à rembourser ses prêts. |
| Pauline commence à tamponner les documents. | Jules se met à démentir les rumeurs. |
| Simon se met à brancher le câble. | Lina commence à fausser les données. |
| Lucie commence à tordre la serviette. | Thibault se met à troubler les esprits. |
| Arthur se met à chatouiller son ami. | Mélissa commence à relancer le débat. |
| Charlotte commence à laver la vaisselle. | Cédrick se met à gêner ses collègues. |

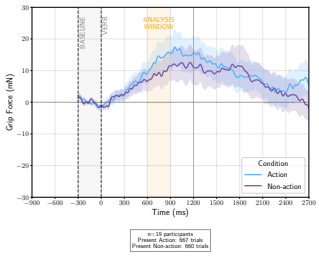
# Appendix B Preprocessing Trajectory in Experiment 1 (Typical Imagery Group)



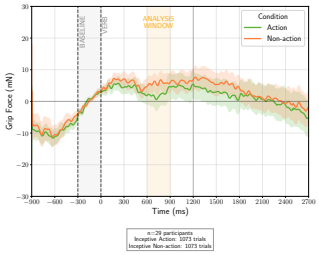

(A) Present Tense: Full Sample, No Rejection



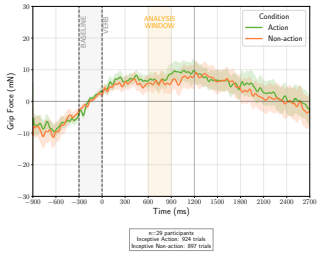

(B) Present Tense: Full Sample, With Rejection



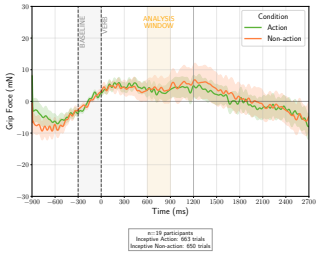

(C) Present Tense: Refined Sample, With Rejection




(D) Inceptive: Full Sample, No Rejection



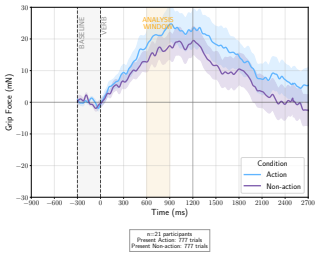

(E) Inceptive: Full Sample, With Rejection



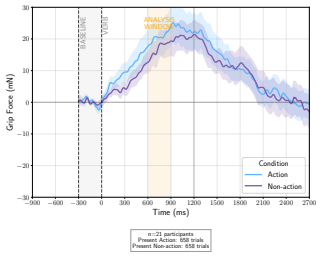

(F) Inceptive: Refined Sample, With Rejection

**Fig. B1**: Preprocessing trajectory in Experiment 1 (Typical Imagery Group). Top row: Present tense constructions showing progressive refinement from (A) full sample without artifact rejection, (B) full sample with artifact rejection, to (C) refined sample with artifact rejection. Bottom row: Inceptive aspectual constructions following the same progression from (D) full sample without artifact rejection, (E) full sample with artifact rejection, to (F) refined sample with artifact rejection.

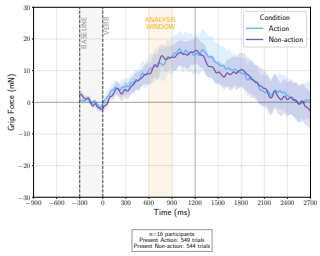
# Appendix C Preprocessing Trajectory in Experiment 2 (Aphantasia Group)



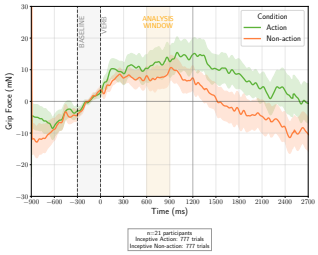

(A) Present Tense: Full Sample, No Rejection



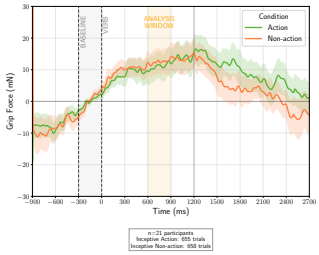

(B) Present Tense: Full Sample, With Rejection



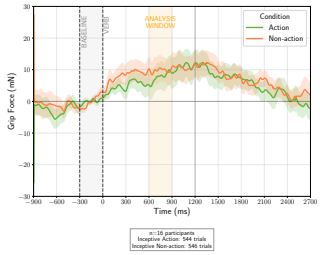

(C) Present Tense: Refined Sample, With Rejection




(D) Inceptive: Full Sample, No Rejection




(E) Inceptive: Full Sample, With Rejection




(F) Inceptive: Refined Sample, With Rejection

**Fig. C2**: Preprocessing trajectory in Experiment 2 (Aphantasia Group). Top row: Present tense constructions showing progressive refinement from (A) full sample without artifact rejection, (B) full sample with artifact rejection, to (C) refined sample with artifact rejection. Bottom row: Inceptive aspectual constructions following the same progression from (D) full sample without artifact rejection, (E) full sample with artifact rejection, to (F) refined sample with artifact rejection.

# Appendix D Individual Participant Data from Experiment 1 (Typical Imagery Group)

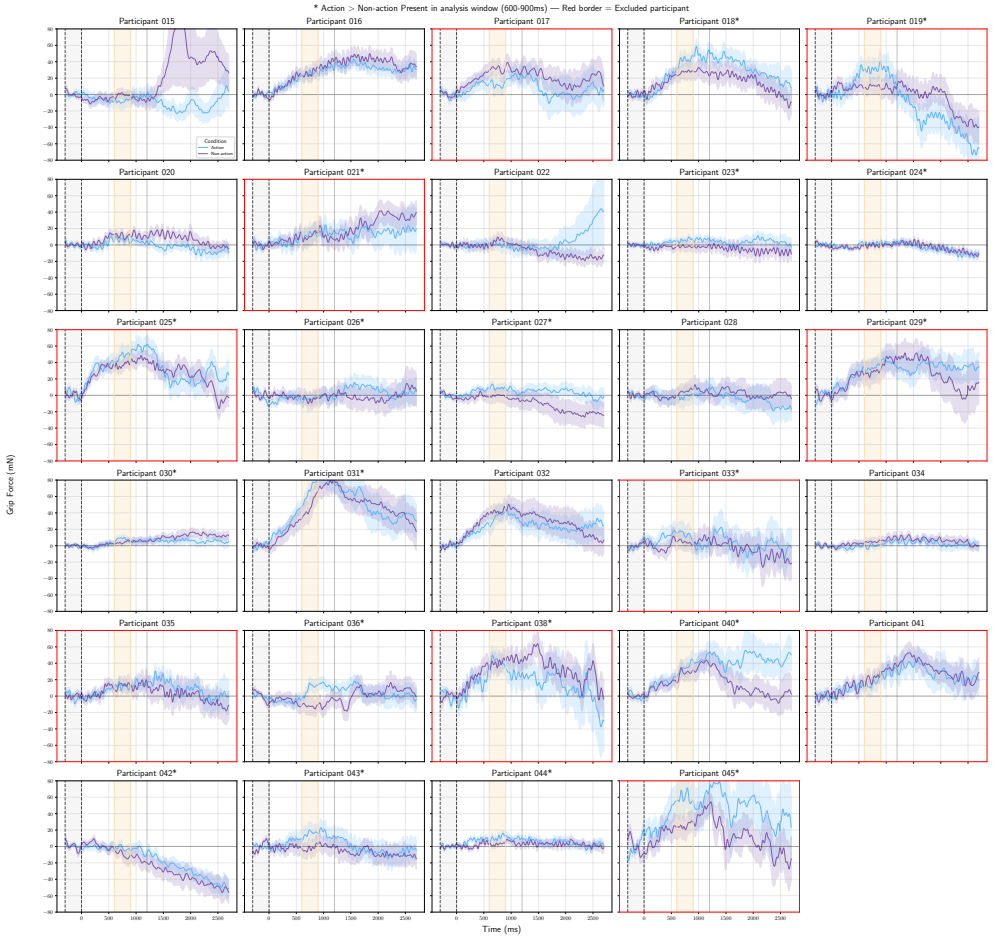



**Fig. D3**: Individual participant grip force trajectories comparing action (blue) and non-action (CNP, purple) conditions in present tense. Each panel shows mean grip force (solid lines) with standard error (shaded regions) for one participant ($N = 29$). Gray shading indicates baseline correction window (−300 to 0 ms). Orange shading highlights the analysis window (600–900 ms) used for statistical comparisons. Asterisks (*) mark participants showing higher mean grip force for action compared to non-action conditions within the analysis window ($n = 19/29$ participants). Red borders indicate excluded participants (n=10) due to high trial rejection rates. Vertical dashed lines indicate baseline start (−300 ms) and verb onset (0 ms). Gray vertical line at 1200 ms marks the end of the primary analysis period.

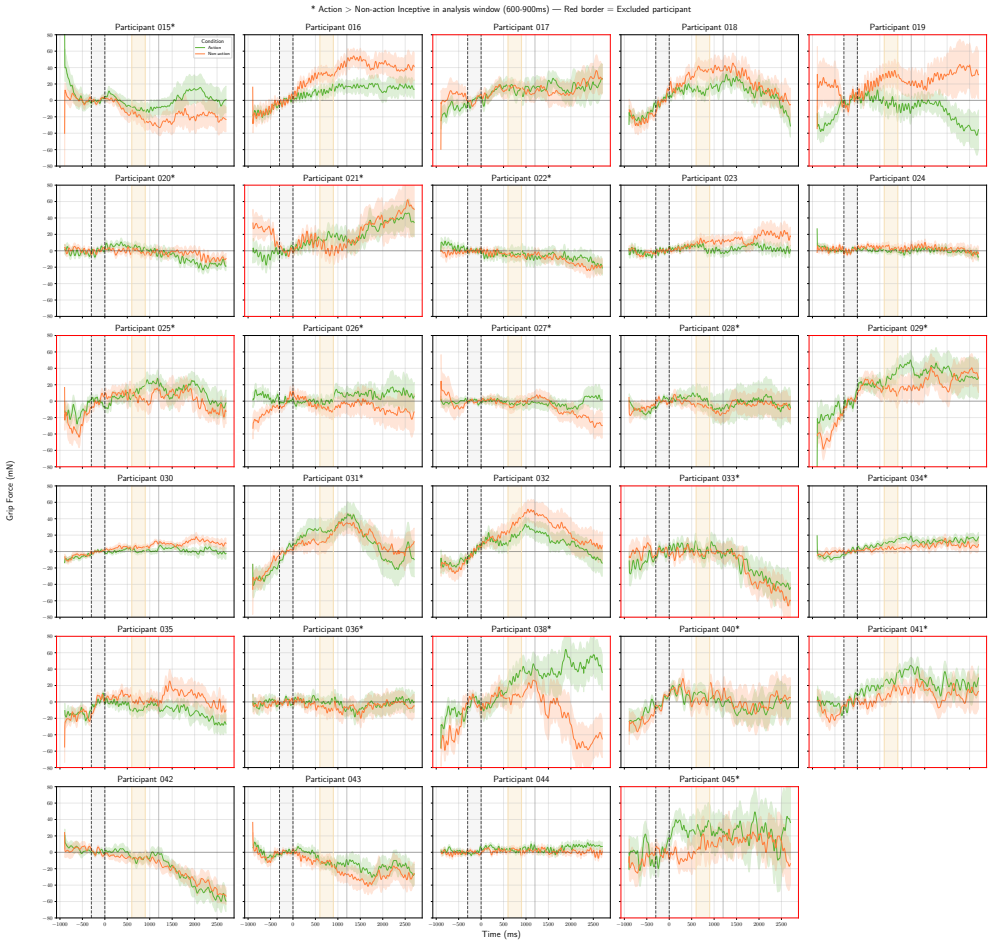



**Fig. D4**: Individual participant grip force trajectories comparing action (CI, green) and non-action (CNI, orange) conditions in inceptive aspect. Each panel shows mean grip force (solid lines) with standard error (shaded regions) for one participant ($N$=29). Gray shading indicates baseline correction window (−300 to 0 ms). Orange shading highlights the analysis window (600–900 ms) used for statistical comparisons. Asterisks (*) mark participants showing higher mean grip force for action compared to non-action conditions within the analysis window ($n$ = 19/29 participants). Vertical dashed lines indicate baseline start (−300 ms) and verb onset (0 ms). Gray vertical line at 1200 ms marks the end of the primary analysis period.

# Appendix E Individual Participant Data from Experiment 2 (Aphantasia Group)

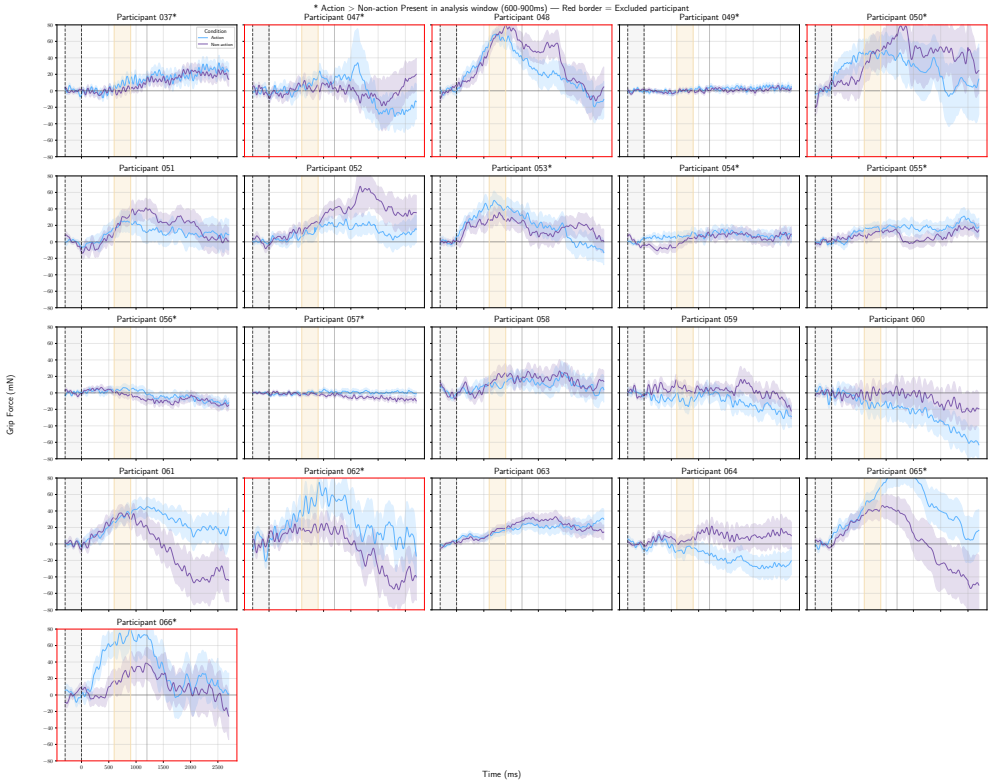



**Fig. E5**: Individual participant grip force trajectories comparing action (blue) and non-action (CNP, purple) conditions in present tense. Each panel shows mean grip force (solid lines) with standard error (shaded regions) for one participant ($N = 21$). Gray shading indicates baseline correction window (−300 to 0 ms). Orange shading highlights the analysis window (600–900 ms) used for statistical comparisons. Asterisks (*) mark participants showing higher mean grip force for action compared to non-action conditions within the analysis window ($n = 12/21$ participants). Red borders indicate excluded participants (n=5) due to high trial rejection rates. Vertical dashed lines indicate baseline start (−300 ms) and verb onset (0 ms). Gray vertical line at 1200 ms marks the end of the primary analysis period.

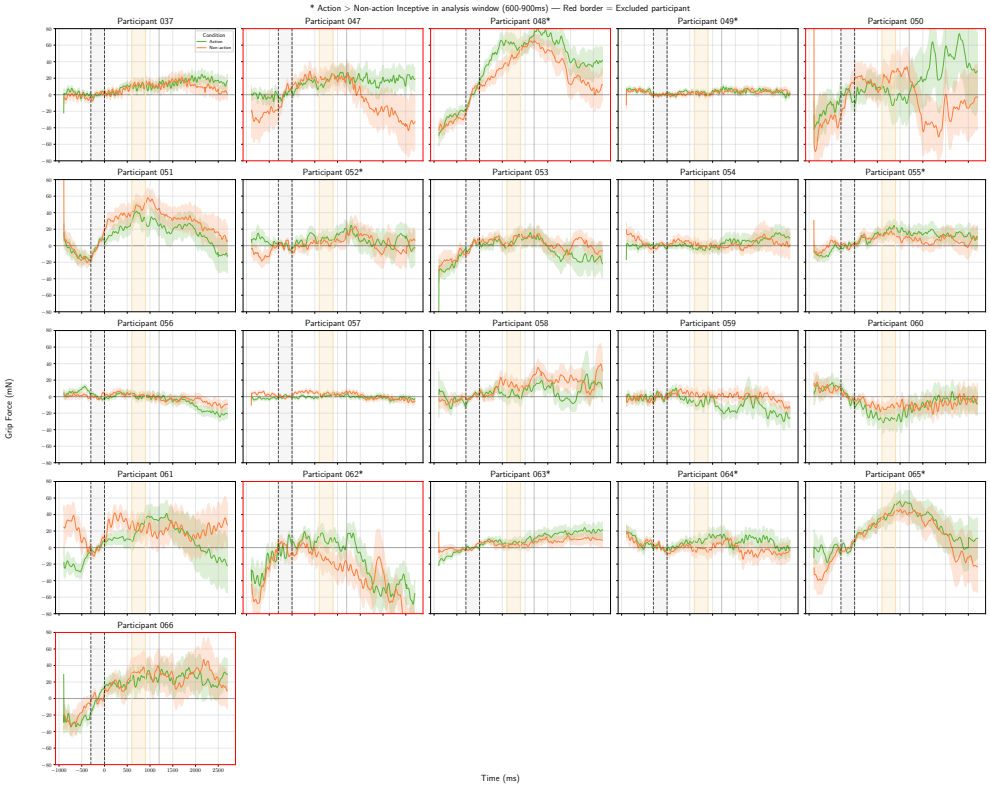



**Fig. E6**: Individual participant grip force trajectories comparing action (blue) and non-action (CNP, purple) conditions in present tense. Each panel shows mean grip force (solid lines) with standard error (shaded regions) for one participant ($N = 21$). Gray shading indicates baseline correction window (−300 to 0 ms). Orange shading highlights the analysis window (600–900 ms) used for statistical comparisons. Asterisks (*) mark participants showing higher mean grip force for action compared to non-action conditions within the analysis window ($n = 8/21$ participants). Vertical dashed lines indicate baseline start (−300 ms) and verb onset (0 ms). Gray vertical line at 1200 ms marks the end of the primary analysis period.