# Interfering with inner speech during action encoding impacts their execution

**Angelo Mattia Gervasi (angelomattia.gervasi@uniroma1.it)**
Sapienza University of Rome, Via dei Marsi 78, 00185 Rome, Italy
Lyon Neuroscience Research Centre, INSERM U1028, 16 av. du Doyen Jean Lépine, 69500 Bron, France

**Claudia Mazzuca (claudia.mazzuca@uniroma1.it)**
Sapienza University of Rome, Via degli Apuli 1, 00185 Rome, Italy

**Anna M. Borghi* (anna.borghi@uniroma1.it)**
Sapienza University of Rome, Via degli Apuli 1, 00185 Rome, Italy
Institute of Cognitive Sciences and Technologies, CNR, Via G. Romagnosi 18A, 00196 Rome, Italy

**Claudio Brozzoli* (claudio.brozzoli@inserm.fr)**
Lyon Neuroscience Research Centre, INSERM U1028, 16 av. du Doyen Jean Lépine, 69500 Bron, France

*shared last authorship

## Abstract

Most of the studies so far overlooked the role of inner speech in action, especially new actions. We conducted a behavioral experiment asking participants to observe videos to acquire two actions. In the experimental group, participants performed an articulatory suppression task, continuously repeating a syllable, so as to interfere with the inner speech. In the control group, participants were requested to continuously tap their middle finger on the table. We hypothesized that, interfering with inner speech, participants could not provide themselves with instructions about how to perform the actions, consequently impacting their ability to acquire them. The results confirmed the hypotheses. Compared to the Dual-task Control Group, the Articulatory Suppression Group is overall more impaired in action acquisition and, in part, in motor performance quality. These results confirm the role of inner speech in cognition, providing new evidence about its function in action learning and execution.

**Keywords:** language; inner speech; action

## Introduction

Most people use inner speech, the "little voice in our head", during their everyday activities – to enhance cognition and regulate emotions. While Piaget considered private speech as a sign of cognitive immaturity due to egocentric behavior, Vygotsky regarded it as a crucial milestone in cognitive development (Piaget, 1926; Vygotsky, 1934/1987). According to Vygotsky, the final step of language development is characterized by a transition from private to inner speech. He described private speech as a cognitive tool used for self-regulation, helping children control their behavior and emotions by verbalizing thoughts and actions - more generally, supporting executive functions. Inner speech, on the other hand, represented the final stage of the developmental process, when this cognitive tool becomes internalized (Vygotsky, 1934/1987). Vygotsky's theory is well-supported by recent evidence. As he suggested, inner speech is involved, among others, in executive functions, emotions regulation, and planning (Kiesel et al., 2010; Koch et al., 2018; Lidstone, Meins & Fernyhough, 2010; Morin, Uttl & Hamper, 2011). While research on inner speech and its varieties has become more widespread in recent years (see reviews in Alderson-Day & Fernyhough, 2015; Fernyhough & Borghi, 2023; Langland-Hassan & Vicente, 2018), the role of inner speech in controlling behavior has been only marginally investigated. Consistently, in their review on interference tasks with inner speech, Nedergaard, Wallentin, and Lupyan (2022), identified only two studies examining the role of covert language in motor control tasks. Both studies addressed the interference of verbal versus visual memory dual tasks on physical performance (Biese et al., 2019; Talarico et al., 2017). Although their results showed greater interference of the verbal compared to the visual memory interference condition, the use of the Stroop Color Word test as a verbal interference task raises questions about the effective role of language in these tasks. In other words, the observed effect could be attributed to the increased cognitive demands elicited by the Stroop task rather than a specific influence of verbal interference. Researchers commonly use the articulatory suppression task to specifically disrupt inner speech (Banks & Connell, 2024; Fini et al., 2022). This method prevents participants from accessing the phonological loop, causally disrupting self-directed speech. In addition, as Emerson and Miyake (2003) suggested, to properly access linguistic interference an alternative dual-task condition—usually a motor suppression task—is preferred. This kind of design allows researchers to infer that any significant difference detected between conditions is strictly due to linguistic interference and not to increased cognitive demand, as might occur when comparing articulatory suppression with a simple control condition without interference.

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Considering the empirical evidence on the role of inner speech, a gap emerges in the literature regarding the link between inner speech and motor control. More specifically, the role of inner speech in relation to action, particularly novel actions, remains unclear. In the only study addressing the link between inner speech and novel actions, in three behavioral experiments, Banks and Connell (2024) explored whether interfering with inner speech during the encoding and recall phases impairs memory for events (complex motor meaningful sequences). In the first experiment, participants had to perform an articulatory suppression task either at encoding (while learning how to construct a wooden birdhouse by observing a video) and recall (when trying to build the birdhouse themselves) or during recall only. Results showed that the recall performance was impacted only in the first case, showing thus a key role of inner speech during the learning phase. Similarly, in the second experiment, authors investigated the role of inner speech in events composed of several motor sequences with different lengths (constructing several Lego models) by asking participants to perform articulatory suppression at either encoding or recall or both. Here, results pointed out that articulatory suppression is specifically effective in the encoding phase but not in the recall phase, possibly supporting encoding through labelling the different sequences. In a third experiment, the authors compared the articulatory suppression with another dual-task condition: an auditory monitoring task. Results confirmed that the memory impairment in study 1 and 2 was not due to the cognitive demand of a dual task, but rather to the specific interference of the articulatory suppression with inner speech.

Similarly to Banks and Connell, our behavioral experiment aims to investigate the role of inner speech in acquiring novel actions. In this case, we employed meaningless motor sequences which are unlikely to become encoded in semantic memory, unlike Banks and Connell, who employed actions associated with meaningful semantic components (e.g. building a birdhouse or Lego models of a boat, a bridge, a fish etc.). In everyday life, individuals encounter this kind of task, for instance, when learning new dance moves. Specifically, we explored whether inner speech acts as a cognitive tool in guiding attentional and sensorimotor resources during action learning. We hypothesized that observing another person executing an action to learn involves more than basic sensorimotor processes, pointing out a role of inner speech in modulating these processes, for instance, providing fine-grained sensorimotor information as well as labelling the motor sequences or even scanning the sequences rhythm. Thus, we speculated that interfering with inner speech during action learning would impair the ability to learn and consequently reproduce the action. As suggested by Emerson and Miyake (2003), to match the cognitive demand between groups, we compared the linguistic interference condition (Articulatory Suppression Group) with another dual-task condition, a finger tapping task. This study is part of a larger and preregistered project (https://osf.io/5dupa/), composed by several behavioral experiments, aiming to explore the role of language in the acquisition of novel actions.

# Method

## Participants

The experiment received ethical approval from the Ethics Committee of the Department of Dynamic and Clinical Psychology, and Health Studies of Sapienza University of Rome. Before beginning the experimental procedure, all participants were asked to fill a consent form containing all the standard terms related to the participation in the experiment, data collection, and the sharing of all anonymized, alpha- numeric data in a public data repository.

To carry out a between-participants design experiment with the group as unique fixed factor, we conducted a power analysis using G*Power (Faul et al., 2007), simulating a t-test between two independent means with 80% of power detecting a medium effect size of .5 at the standard .05 alpha error probability. We thus obtained a total sample size of 102 participants. However, to facilitate the subdivision of participants in the various experimental conditions, the sample size was raised to 104 ($n$ = 52 per group). All participants (58 females; $M$ age 23.41 ± 3.21) were: aged between 18 and 35 years old, right-handed, Italian native speakers, not bilingual from birth and without history of neurological issues. The number of females/males was balanced between groups (29 females and 23 males per group). We ensured the participants' handedness through the Edinburgh Handedness Inventory (Oldfield, 1971).

## Materials

**Experimental Setting and Materials** The experiment took place in a quiet room of the Department of Dynamic and Clinical Psychology, and Health Studies of Sapienza University of Rome. Each participant sat on a chair placed in front of a table measuring 60x120 cm, seated at its shorter side. On the table in front of each participant were the following items: a 19-inch Acer AL1917AS monitor at a fixed distance of 80cm from the table's edge; a yellow horizontal line (along the short side of the table) marked with tape; a yellow square made with paper (75x75 mm), where a wooden cylinder (12 cm tall, 5 cm in diameter) was positioned, as its starting point; and a computer keyboard with the down key marked with yellow tape. The monitor was connected to a laptop MSI Cyborg 15 A12VF.

## Stimuli

**Task 1, Motor Task** Participants were asked to acquire two actions that they were required to observe in a video during the encoding phase through the observation of a video and subsequently perform during the test phase. The actions were composed of the same four motor chunks but differed in the order of the chunks and side of the action execution.

Specifically, Action 1 consisted of chunk 1: moving the cylinder from the starting position (yellow square) to the right/left side (depending on the condition) of the yellow line; chunk 2: raising the cylinder and replacing it in the same position; chunk 3: flipping the cylinder on the yellow line; chunk 4: placing the cylinder, from the yellow line, back to the starting position. Action 2 consisted of chunk 1: flipping the cylinder on the starting position; chunk 2: moving the cylinder from the starting position (yellow square) to the right/left side (depending on the balancing condition) of the yellow line; chunk 3: raising the cylinder and replacing it in the same position; chunk 4: placing the cylinder back to the starting position. Male participants viewed videos with masculine hands performing the actions, while female participants viewed videos featuring feminine hands. Besides the videos, we used two images as go signals to avoid any linguistic influence on the participants during the practice and the test phase. The images were screenshots from the action videos depicting the beginning of each action. The picture for Action 1 (Figure 1) showed a hand grasping the top of the cylinder before moving it toward the yellow line, while the picture for Action 2 (Figure 2) showed a hand gripping the cylinder in reverse from the left side before flipping it.

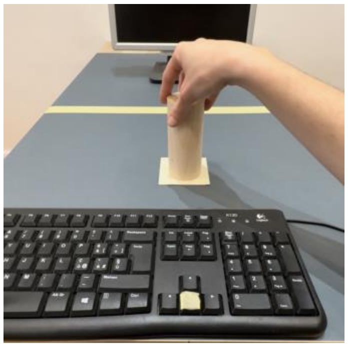

Figure 1: Go signal image Action 1

Figure 2: Go signal image Action 2

**Task 2, visuospatial 2-back** Inspired by Dores et al. (2017), a visuospatial n-back (2-back) task served as working memory control. This task consisted of a single block with 50 stimuli, composed of 10 target stimuli and 40 distractors. Four randomized stimulus lists were created using a Python script, with participants divided into four subgroups, each assigned a unique list. The stimuli were 9-square matrices with one black square presented in varying positions. We used Psychopy to program both this task and the motor task (Peirce et al., 2019).

## Procedure

The experiment lasted approximately 40 minutes, and each participant was randomly assigned to one of the two groups: the Articulatory Suppression Group (ASG) or the Dual-task Control Group (DTCG). Both groups were given instructions to carefully observe the videos and learn the actions presented. In the ASG, participants repeated the syllable “SA” (“knows” in English) twice per second while watching the videos. In line with a recent study (Banks & Connell, 2024), we chose to ask participants to repeat a meaningful word, in this case, an Italian monosyllable without any spatial or motor information. A frequency of two syllables per second was chosen, based on a pilot study, to ensure effective interference. In the DTCG, participants tapped with their right middle finger on a marked area of the table at the same frequency as the ASG. No dual-task was performed during action execution, this was limited to the encoding phase. To help participants maintain the correct rhythm, a metronome set to 120 bpm was used briefly before the video started. Once synchronized, the metronome was turned off and the video was played. Crucially, participants were specifically instructed to try to keep the rhythm during all the videos but to prioritize action learning as the main task. At the same time, the experimenter monitored the correct execution of the secondary task, ensuring there weren’t rhythm changes or pauses. After the video session, participants were asked to perform a practice phase composed of 4 trials (two per action) to familiarize themselves with the procedure. Since this was the first moment participants executed the action, we chose to consider this practice phase as a learning assessment and, thus, measured the motor performance (Action Accuracy and Action Performance Score). The same variables were measured in the test phase as well. In each trial, which was similar for the practice and the test phase, participants were shown a white screen, and the onset of the trial had to be manually triggered by pressing and keeping pressed the down key on the keyboard. All actions had to be performed with the right hand, starting with pressing the down key with the index, thumb, and middle finger together.

While keeping the down key pressed, after a fixation cross (500 ms) the go signal image was shown, suggesting to the participant the action that had to be executed in that trial. Once participants were confident about the action required, they could release the button and perform the action. Keeping the down key pressed was necessary for us to collect Reaction Times (RT), conceived in this case as the amount of time necessary to recall and initiate the action. Once all the actions had been executed, participants could go back to the starting position button and press it to finish the trial. In this case, pressing again the down key was necessary to record the end of the action and, consequently, to measure the Action Execution Time (AET, in milliseconds), from the button release (action onset) to the button press (action end). The AET was informative about how fast participants performed each action. For the purpose of this study, we focused on Accuracy and Motor Performance Score as motor performance measures. Once the four trials of the practice phase had been executed and the procedure was clear, the test phase could begin. The test phase consisted of 50 trials (25 per action) displayed in a randomized order for each participant.

At the end of the motor task, after a short break, participants were asked to complete the visuospatial 2-back task. Following the instructions, they were first asked to perform a 10-trial practice phase to familiarize themselves with the procedure. Once the practice phase was concluded and the procedure was clear, participants could perform the test phase. At the beginning of each trial, a fixation cross was presented for 2350ms, followed for 650ms by an image (stimulus). Participants were asked to press the down key if the image presented in that trial was the same one presented two trials before, meaning that the black square's position in the grid matched its location two trials prior.

## Motor Performance Data Pre-Processing

To obtain motor performance results, we manually coded action by action in each participant's video, using ELAN software (Lausberg & Sloetjes, 2009). In this regard, we specifically asked participants for permission to record exclusively their hand, trying to avoid recording their faces, during the task execution. We thus obtained two dependent variables: Action Accuracy (as a binary measure, 0 = error; 1 = correct) and Action Performance Score (from a —potentially infinite—negative value to the maximum positive score of 5, calculated for each action). For Action Accuracy, the following criteria were used:

o Score 1 when the action was correctly executed: all four chunks were executed in the right order, independently of the cylinder grip.

o Score 0 when the action was not correctly executed: the participants didn't perform all four chunks (more chunks or fewer chunks), or they performed them in a different order.

o NA, when a trial was not executed or there were technical issues during the trial.

Besides that, the following coding scheme was used to assign a qualitative performance score to the entire action. This score is the sum of all the chunks that a participant executes in that trial.

- Entire action score:
  - 5: when the action was correctly executed: all four chunks were executed in the right order, and the cylinder was grasped from the right position in each chunk. A 4+1 score was assigned as a reward for the overall correctness of the execution.
  - 0: when the action was executed on the wrong side (right instead of left or vice versa). Independently of the chunks executed, the score was always 0.
- Chunk by chunk score:
  - Each chunk correctly executed (as shown in the videos) was assigned +1, independently of the correct order of execution of that chunk.
  - Each chunk correctly executed was assigned +0.5 if the participant used a different grip compared to what is shown in the videos (e.g., the cylinder was grasped from the side rather than the top).
  - If a participant executed a chunk in a wrong way, invented a new chunk, or repeated a chunk more times than expected, a score of -1 was assigned to that chunk.
  - When a participant unified two chunks into a single movement (for instance: instead of flipping and then moving the cylinder, the participant flipped the cylinder while moving it), a score of +1 was assigned to both chunks (+0.5 per chunk). This was considered as a particular case, not as an error.

As mentioned in the preregistration, participants who did not perform even a correct action, both in the practice and test phase, were considered as outliers, excluded from data analysis about motor performance and included in a specific analysis. We, thus, manually coded videos referring to the practice phase as well. To carry out a specific analysis on Outliers, from this point called "Non-learners", we introduced a new binary dependent variable: "1" means "non-learner" and "0" means "learner". We speculated that the number of Non-learners was higher in the Articulatory Suppression Group.

## Results

Results were analyzed using RStudio (version 2024.12.0+467; R Core Team, 2020). To be sure that any difference detected from the analyses on motor performance was strictly due to the experimental manipulation, we first analyzed data of the visuospatial 2-back task. As a Working Memory Score, for each participant, we calculated the d' (d prime), a measure of the sensitivity index. We calculated it using the following formula: *d_prime = z_hit_rate - z_false_alarm_rate*, where the *hit rate* was calculated as *hits / N_targets* (in this case *x/10*) and the *false_alarm_rate* was calculated as *false_alarm / N_non_targets* (in this case *x/40*). This measure served as dependent variable of a linear model with group as predictor. The model showed no significant differences between the two groups ($b = 0.054$, $SE = 0.205$, $t = 0.264$, $p = 0.792$, see Figure 3).

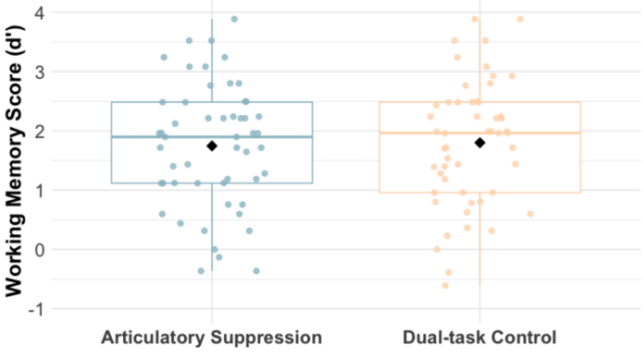

Figure 3: Distribution of Working Memory Score (d') across the two groups. In the boxplots, black dots indicate mean values, black bold horizontal lines the median, and vertical extremes of the boxplots represent minimum and maximum values in the data. The boxes' length shows the interquartile range, with the upper side representing the 75th percentile and the bottom side the 25th percentile.

Thus, we proceeded with analyses on motor performance (Action Accuracy and Action Performance Score) and conducted a generalized linear mixed effect model on Action Accuracy, with Group as fixed factor and participants as random intercepts, using "lme4" R's package (Bates et al., 2015). The results show that the Articulatory Suppression Group performed more incorrect actions compared to the Dual-task Control Group. However, this result didn't reach statistical significance (*b* = 0.850, *SE* = 0.714, *z* = 1.191, *p* = .234, see Figure 4).

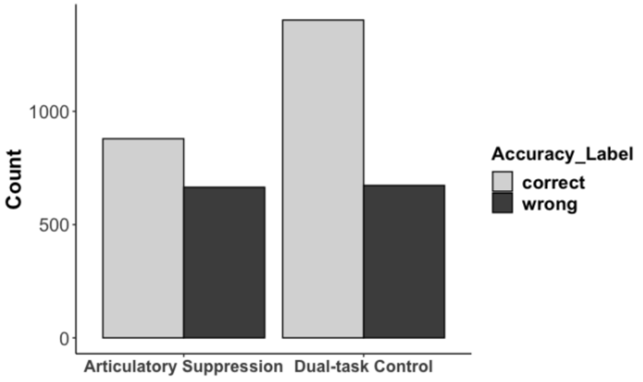

Figure 4: Number of correct and wrong actions performed by each group.

We then performed a linear mixed effect model on Action Performance Score with Group as fixed factor and participants and trials as random intercepts, using again the "lme4" R's package (Bates et al., 2015). The model showed that the quality of the action execution was slightly higher for the Dual-task Control Group (*M* = 3.57, *SD* = 1.73) compared to the Articulatory Suppression Group (*M* = 3.34, *SD* = 1.90, see Figure 5), but this difference did not reach statistical significance , (*b* = 0.249, *SE* = 0.329, *t* = 0.758, *p* = .451, see Figure 5). However, considering the highly asymmetric distribution of Action Performance Scores, we conducted an explorative analysis on the median. The Wilcox rank-sum test on the Action Performance Score with Group as fixed factor revealed a significant effect, with the Articulatory Suppression Group showing lower median compared to the Dual-Task Control Group (W = 1,508,694, *p* = .001.)

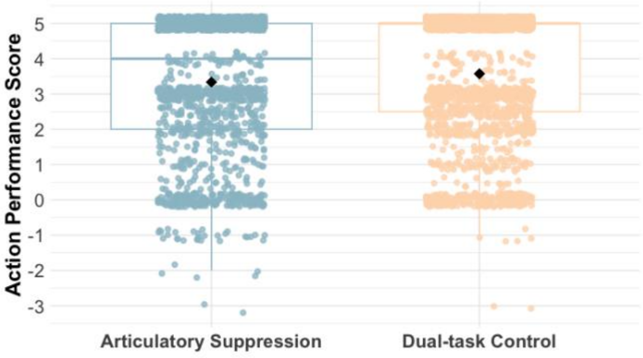

Figure 5: Distribution of Action Score across the two groups (scale between -x and 5)

Finally, the generalized linear model on Non-learners, with Group as fixed factor, showed that the number of participants who did not perform even one correct action was significantly higher for the Articulatory Suppression Group (*b* = -1.094, *SE* = 0.464, *z* = -2.356, *p* = 0.019, see Figure 6).

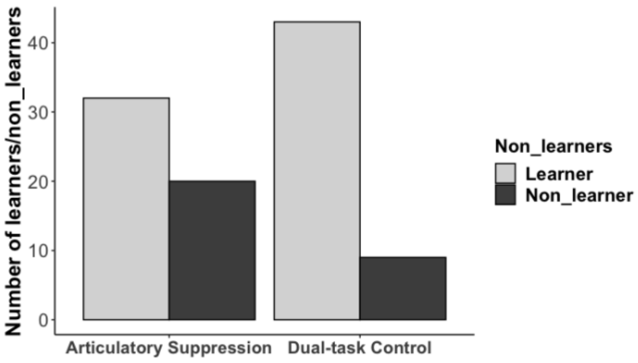

Figure 6: Number of Learners and Non-Learners in each group.

## Discussion

In this study, we investigated the role of inner speech in an action acquisition and execution task. We hypothesized that, when observing someone else performing an action we need to learn, we rely on inner speech to drive and consolidate sensorimotor processes rather than merely relying on visuomotor learning processes. To examine the role of inner speech, we interfered with it through an articulatory suppression task during action encoding. Articulatory suppression is one of the most frequently employed tasks in studying inner speech, due to its effectiveness in causally disrupting the phonological loop and preventing participants from engaging in covert self-talk. We compared this condition with a robust dual-task control condition: performing a finger tapping task with the same effector involved in the actions shown in the videos. To be sure that participants of the articulatory suppression group were not impaired in the action acquisition because of a different fatigue amount between conditions, we conducted an explorative bin analysis (not reported in this work), which showed no significant differences between groups in terms of Reaction Time and Action Execution Time during the course of the experiment. If differences in the amount of cognitive fatigue had occurred, the Articulatory Suppression Group would have shown slower RT and AET.

Our results show that inner speech generally facilitates action acquisition so that, when individuals are not able to rely on it, their ability to acquire novel actions could be completely impaired; moreover, descriptive statistics suggested that the availability of inner speech is also associated with slightly better quality in motor performance. To our knowledge, we provided evidence in this direction for the first time. According to previous studies, the effect of language on actions appears well-established. Several studies showed a semantic modulation of motor performance: presenting action verbs, nouns, and adjectives before action onset influences reaction times and motor trajectories (Gentilucci & Gangitano, 1998; Nazir et al., 2008). Furthermore, pronouncing words related to the movement to execute enhances motor performance through priming effects (Fargier et al., 2012; Rabahi et al., 2013). Conversely, the role of inner speech in action execution and action learning has not yet been thoroughly investigated, except for Banks and Connell's study (2024), who examined the link between inner speech and memory for events. Unlike the previous paradigm, we intended to test the role of language in the case of actions that do not have a goal that becomes established in semantic memory, but that can be rearranged on the fly. To make an example: the first time you learn the action of kicking a ball, you combine various action components to form a complex action, which then becomes rather established in long term memory and possibly associated with a verbal label. A different case is when you learn actions including various components, and having an overall goal, but that will not necessarily be encoded in semantic memory and associated with verbal label. The rationale behind this choice was to explore whether, in a condition as the one just reported, inner speech is used (consciously or automatically) in association with each motor sequence composing the action to support and enhance visual information. Our results on Non-learners suggest that inner speech might have played this role, facilitating the action sequences recall during action acquisition. These findings can be considered an extension of the literature highlighting the well-established role of mirror circuits in learning new motor sequences through observation (De Stefani et al., 2013; Iacoboni, 2009). Along this line, De Stefani and colleagues (2020) demonstrated that an observative-imitative method is more efficient than a descriptive-directive method. In other words, their findings suggest that learning new actions is more efficient when individuals are allowed to observe the action model rather than receiving verbal instructions. In our work, we integrated both models, highlighting the potential advantage of using verbal instructions in conjunction with observing the action model. What remains unclear from this study is the precise function inner speech might play. Participants may have employed various inner speech strategies, such as focusing on the motor sequences composing the action, naming or numbering them, marking the rhythm, or using inner verbalization as a support for visuomotor memory. In conclusion, to better understand the effective role of inner speech in action learning, it will be necessary to take into account individual differences. When learning novel actions, some individuals might rely more on inner speech compared to other individuals who rely more on visuomotor strategies. In this line, investigations in this direction are currently underway (Gervasi et al., submitted).

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