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Volition in prospective Memory: Evidence against differences between free and fixed target events

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ABSTRACT

Volition is the extent to which actions are generated as a result of internal states in contrast to responses to external conditions or dictated by external events. Delayed intentions about future action are stored in prospective memory until the intended action has to be formed at a later point in time. It is unknown how voluntary choice affects prospective memory. We compared the difference between freely chosen and fixed targets on the reaction times and task performance in the ongoing task and for the target stimuli in a prospective memory task. The task performance and the reaction time was modelled using a Bayesian hierarchical drift–diffusion model. The analysis showed no differences between self-chosen and fixed prospective memory cues on task responses. The result suggests that volition in choosing the cue to act upon or given a fixed cue does not make a difference for prospective memory task performance.

1. Introduction

An important aspect of voluntary behaviour is the planning of actions to do in the future. The ability to control one's own actions and plan for future action requires both internally guided processes and adequate integration of the response to external events, e.g., cues in the environment that signal when to perform a previously planned action. Delayed intentions depend on prospective memory to sustain the intention until it is retrieved and carried into action at the appropriate point in time (McDaniel & Einstein, 2000). In the present study, we investigated how volition in choosing the targets of delayed intentions affect the subsequent prospective memory performance when retrieving and acting upon the intention.

In cognitive terms, voluntary actions are defined as being guided by internal processes as their prime cause—in contrast to actions that are responses to or induced by external stimuli (Schüür & Haggard, 2011). There are fundamental behavioural and cognitive differences between self-initiated voluntary actions and externally triggered actions (Jensen et al., 2017; Tsakiris & Haggard, 2005). The external consequences of voluntary actions are, for example, perceived differently than the results of passive actions. One example

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is the perceptual binding between voluntary actions and the following effects of the action that make the action and effect appear closer together in time than passive movements (Haggard et al., 2002). The degree of voluntary choice over what action to perform increase the temporal binding subjective agency over actions (Barlas et al., 2018; Barlas & Obhi, 2013; Beck et al., 2017) and lead to a higher subjective rating of control over the outcome (Wen et al., 2015). Voluntary actions also leave different traces in retrospective memory, with voluntary responses made being easier to recall than responses resulting from involuntary actions (Jensen et al., 2014).

Freely chosen movements have been shown to exhibit different movement-related potentials measured with electroencephalography (EEG) compared to actions carried out following fixed instructions (Keller et al., 2006; Sidarus et al., 2017), and functional magnetic resonance imaging (fMRI) studies have shown that freely chosen action engage different brain areas than fixed actions (Krieghoff et al., 2011; Lau et al., 2004; Passingham et al., 2010). However, the distinction between free voluntary actions versus externally fixed actions is almost exclusively investigated in experimental paradigms involving immediate decision and execution of the free or fixed action. The picture of self-in versus fixed actions does not capture longer-lasting distal intentions that are formed before the action, stored in memory, and subsequently recalled and acted upon at a later point in time when the circumstances are right (Pacherie, 2008; Pacherie & Haggard, 2010). An example hereof is to plan in the morning to pick up groceries on the way home, which one would keep in memory until the afternoon when the right condition triggers the recall of the distal intention. Distal intentions are dependent on prospective memory as memories to act upon later in the future (Ellis, 1996).

There are separate cognitive functions related to the different stages of prospective memory: the encoding of the memory, what to do, and when to do it, the storage of the memory until the condition is met, until realising the delayed intentions by recalling the encoded memory at the appropriate time (McDaniel et al., 2015). Prospective memory is considered a different cognitive process than retrospective memory (Goschke & Kuhl, 1993; Graf & Uttl, 2001). Neuroimaging studies show that prospective memory engages different brain areas than recalling from retrospective memory (Burgess et al., 2001; Gilbert et al., 2009; Sakai & Passingham, 2002). Similarly, the neural activity during both encoding and retrieval is different between prospective memory and retrospective memory tasks (Martin et al., 2007; West & Krompinger, 2005; West & Ross-Munroe, 2002). The distinction between proximal intentions and delayed intentions is associated with a change in the binding of action and effect (Vinding et al., 2013, 2015), showing that distal intentions influence the sensorimotor processes involved in the proximal actions. The action-preparatory movement-related potentials have similarly been shown to differ between proximal intended actions and actions generated from delayed intentions (Vinding et al., 2014).

Prospective memory is investigated in tasks where a set of prospective instructions are given at the beginning of a task, which must be carried out when the right conditional trigger appears while performing a partially unrelated ongoing task. Typical tasks include ongoing word/non-word discrimination tasks with the prospective instruction to give a different type of answer when words begin with a specific letter (Marsh et al., 1998), remembering instructions for action to perform at a later time (Goschke & Kuhl, 1993), or based on identification of perceptual features of the stimuli, e.g. shape, colour, spatial location, (Burgess et al., 2001; Wang et al., 2008).

Intentionality plays a role in prospective memory, although how is still unclear. Prospective memory items have a higher recall rate when the items have to be performed compared to only have to be recalled, e.g. remembering specific instructions to set the table and then setting the table afterwards compared to recalling but only repeating the instructions without action (Goschke & Kuhl, 1993). Knowing that one has to do the remembered action leads to a higher rate of recalled prospective cues and faster reaction times for cues related to actions compared to recall of prospective cues without acting (Chen et al., 2015; Freeman & Ellis, 2003; Schult & Steffens, 2013, 2017). Knowing in advance whether the prospective targets must be associated with an action alters the encoding or retrieval of prospective memory.

An explanation for this effect could be that information related to future actions decays at a slower rate than content not related to actions that have to be performed (Goschke & Kuhl, 1993; Kvavilashvili & Fisher, 2007; Ruthruff et al., 2001). An alternative explanation is that the need to enact a set of instructions leads to a change in the *meta*-cognitive allocation of cognitive resources devoted to the task that shifts the task capacity (Hicks et al., 2005; Marsh et al., 2005, 2006). Drift-diffusion modelling of responses in prospective memory tasks (explained below) has shown that the presence of the prospective memory instruction increased the decision threshold, not only for responses to the targets but also for the responses to the filler trials (Boywitt & Rummel, 2012; Heathcote et al., 2015; Horn & Bayen, 2015). This points to an overall change in the engagement of cognitive resources during the task rather. It is proposed that the difference in cognitive capacity reflects a difference in cognitive control during the ongoing task. Experimental manipulation that makes the PM task perceived as more important or when changing the similarity between the ongoing task—both conditions that induce a higher degree of cognitive inhibition—leads to longer response times due to an increased response threshold from cognitive inhibition (Ball & Aschenbrenner, 2018; Strickland et al., 2018). In sum, intentionality plays a significant role in prospective memory though the precise mechanisms are unclear and likely involves several stages in the prospective memory process. How volition—the act of internally forming intentions versus acting upon fixed instructions—interacts with prospective memory is unknown.

In the present study, we investigated whether prospective memory performance depends on the degree of volition in choosing the prospective memory target to explore how volition during the formation of distal intentions influence prospective memory. Volition is a multifaceted concept, and volition can potentially affect prospective memory processes in many ways. For example, in the choice of the target during the formation of the intention, in the process of choosing when to realise the intention, and how to act—or even whether one wants to carry out the action at all as often used in inhibition tasks (Brass & Haggard, 2008). The present experiment explicitly investigates the role of volition when choosing the target for the task, while the task instruction on how to act when the target occurred was fixed for both conditions. The intentional action (shift response when the target appears) was constant for both conditions—the only thing that differed between conditions was the process of choosing the target stimuli. The experiment manipulates volition in one dimension in prospective memory among the many dimensions where volition potentially can influence prospective memory.

If this specific aspect of volition matters for prospective memory targets, we hypothesise that the increased ownership over the self-chosen distal intention will change the prospective memory performance. One mechanism might be that the formation of distal intentions involves, at least partially, the same action-preparatory processes as performing the actual action. A change in recalling prospective cues could be due to recurrent activation of sensorimotor information during the encoding phase in the prospective memory task. This could be facilitated by shared neural activation, as shown to apply to executing movements, planning movements, and mental imagery of movements (Jeannerod, 1994; Jeannerod & Decety, 1995). The difference between free and fixed actions for proximal intentions are seen as a function of predictive sensorimotor processes, where the process of forming self-initiated actions generate a predictive model of the immediate action to be performed (Christensen & Grünbaum, 2018; Tsakiris & Haggard, 2005). This could be analogous to the proposition that prospective cues that subjects know must be enacted in the future engage heightened sensorimotor information, thereby leading to increased recall rate by leaving a stronger trace in prospective memory (Freeman & Ellis, 2003). If volition leads to increased sensorimotor enactment, we hypothesised that self-chosen intentions are associated with increased prospective memory task performance compared to fixed instructions.

An alternative hypothesis is that distal intentions work as a higher-order global predictive process that guides the low-level sensorimotor prediction during the actual action execution (Pacherie, 2008). The voluntary aspect of intention formation, in this view, changes the *meta*-cognitive engagement of the task rather than by sensorimotor reactivation. Increased ownership over the intention may alter the response threshold or degree of response inhibition, similarly to how the task's perceived importance has shown to change prospective memory recall (Strickland et al., 2018).

Finally, there is the possibility that self-chosen targets do not differ from fixed targets on how they influence prospective memory. Self-chosen and fixed delayed intentions might be encoded in prospective memory in a similar fashion that does not influence the subsequent prospective memory of the targets.

The process of retrieving previous intentions when encountering a target cue involves matching the perception of the cue and the representations stored in memory that can be modelled as a drift–diffusion process (Horn et al., 2011). The core of a drift–diffusion model (DDM) is the random accumulation of evidence over time until enough evidence has accumulated to reach a decision threshold leading to a behavioural response (Ratcliff et al., 2016; Ratcliff & Rouder, 1998). The DDM describes the joint distribution of task performance and reaction time as a random walk function determined by the four parameters visualised in Fig. 1. The drift rate (*v*) indicates the rate at which evidence accumulates and drifts towards a decision. The decision threshold is the amount of evidence that must accumulate before committing to a response. The threshold has an upper and lower boundary where the upper boundary represents one decision option, and the lower boundary represents an opposing decision option. The decision thresholds are represented as the boundary separation parameter (a), indicating the distance between the upper and lower boundaries. The accumulating evidence will drift toward one of the boundaries given the drift rate, resulting in a response when the accumulating evidence crosses either

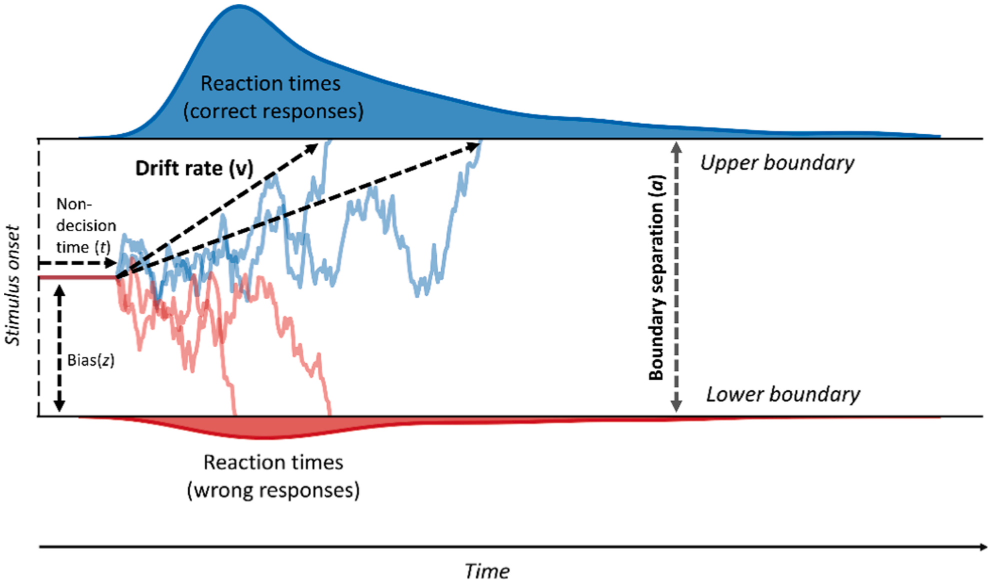


Fig. 1. Illustration of a drift–diffusion model (DDM) of reaction times in two-choice tasks. Reaction time distributions and answer (correct or wrong in this experiment) are determined by underlying random accumulating evidence illustrate by the red and blue traces. The drift rate (v) is the rate at which evidence accumulates. Faster drift rates lead to shorter reaction times, as indicated by the two arrows. The decision boundary (a) are the amount of evidence needed before committing to a response. The non-decision time (t) right after stimulus onset represents the stages where no evidence accumulates. Finally, the model might contain a bias (z) in the offset towards one of the alternatives. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

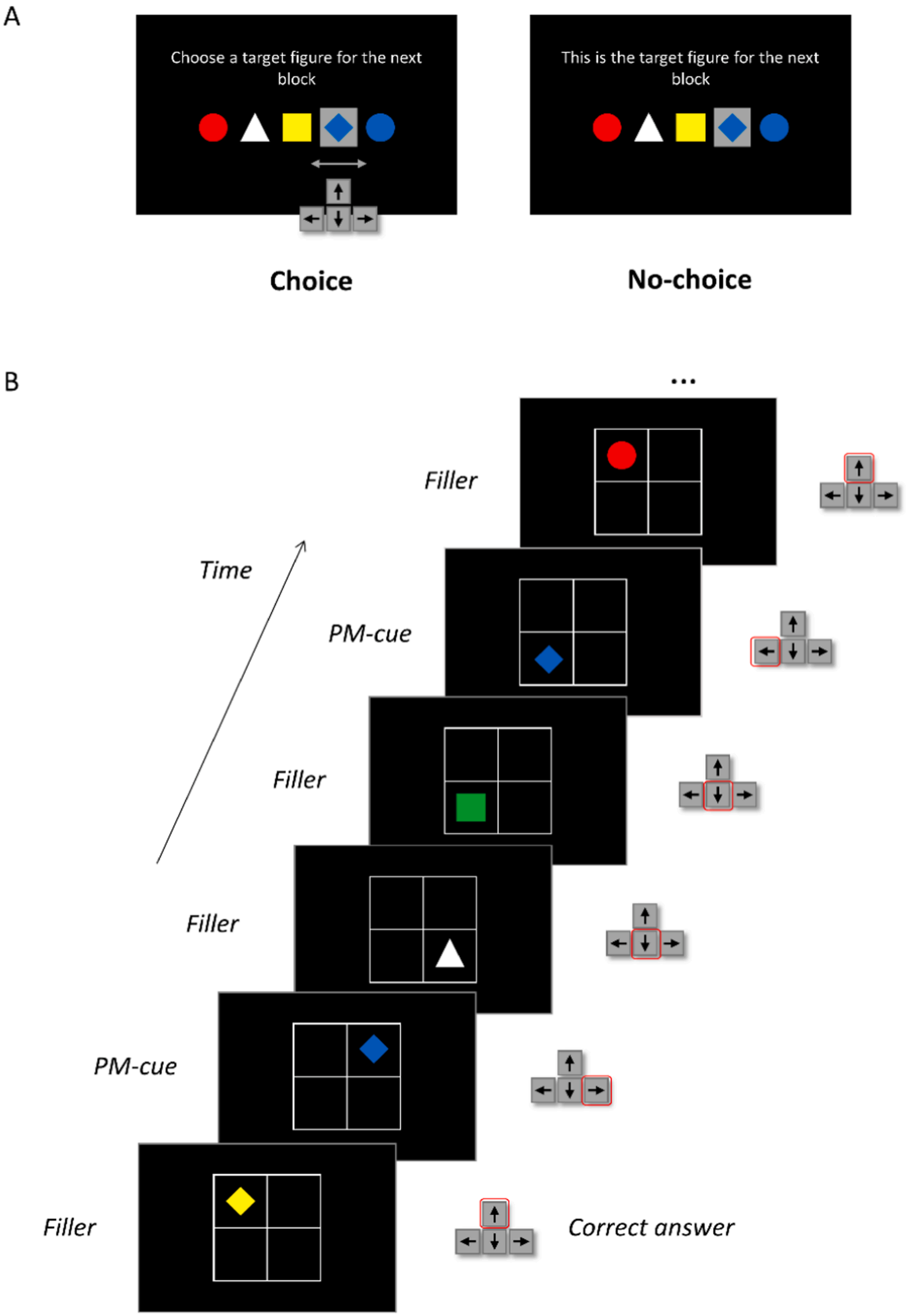


Fig. 2. Overview of the behavioural paradigm. (A) Each block started with a screen asking subjects to freely choose a prospective target (PM cue) amongst five alternatives or presenting a fixed cue depending on the condition. The task would then commence. (B) Participants watched with an ongoing stream of figures in one of the four corners of a quadrant. The task was to answer if the figure were in the top or bottom half of the quadrant by pressing the corresponding arrow key. When the PM cue appears, the task was instead to answer whether the figure was in the left or right half of the quadrant (though response keys were switched halfway through for counterbalance; see main text).

threshold. The offset of the evidence accumulation is usually at the mid-point between the two boundaries but can include a bias (z) towards either boundary. Finally, a part of the reaction time is not related to the cognitive decision-making process—such as the perception of stimuli itself or the automatic sensorimotor processes in giving the behavioural response—this is modelled by the non-decision time (t); depicted in Fig. 1 as a time interval before evidence begins to accumulate (Ratcliff & Rouder, 1998). Drift-diffusion modelling of task performance and reaction time can recreate the characteristic skewed distributions of reaction times.

Relevant cognitive difference between self-chosen and fixed delayed intentions on prospective memory will show differences in the drift–diffusion model parameters between conditions. We hypothesised that a difference between self-chosen and fixed delayed intention would manifest as a difference in either the evidence accumulation drift rate (v) or a difference boundary separation (a)—which have shown to increase with increased task demand and cognitive effort (Boywitt & Rummel, 2012; Horn et al., 2013; Strickland et al., 2018). Alternatively, if there were no differences in the model, it would support the hypothesis that both self-chosen and fixed delayed intentions are functionally similarly when retrieved from memory.

To explore the role of volition in prospective memory, we used a prospective memory task where the participants freely chose one of five targets or were given a fixed target by a computer without the option to choose.

2. Materials and method

2.1. Participants

Thirty healthy subjects (14 female) between age 20–31 (mean age: 22.9) participated in the experiment. All participants gave written informed consent before participating. The experiment was approved by the local ethics committee (The Central Denmark Region Committees on Health Research Ethics) and carried out according to the Declaration of Helsinki.

2.2. Prospective memory task

The experiment had two conditions in a within-subject design: *Choice* and *No-choice*. Both tasks began by showing five randomly selected stimuli, with one of the figures randomly highlighted (Fig. 2A). In the *Choice* blocks, participants had to move the highlight using the arrow keys and select a stimulus to their liking that would be the PM target in the following block. In the *No-choice* blocks, the PM target was chosen randomly and highlighted on the screen.

The stimulus consisted of one of four shapes (triangle, square, circle, or rhombus) in five different colours (yellow, green, blue, red, or white) on a black background. The task and stimulus presentation was identical for the two conditions besides the initial option to choose the PM target.

The task was to remember the target stimulus and respond when it appeared in the steam of ongoing filler stimuli, similar to the prospective memory task used by Burgess et al. (2001). The stimuli were presented in one quadrant of a 2 × 2 grid with a 1° visual angle between the cells (Fig. 2B). In the ongoing task, the participants had to indicate if the stimuli appeared in the top or bottom half of the quadrant using the up/down arrows on the keyboard. When the stimulus matched the PM target, participants instead had to use the left/right arrow keys to indicate whether the figure was presented in the left or right column. 20% of the trials were PM trials, and 80% of the trials were filler trials. There was a minimum of two filler trials between target trials. Participants were instructed to respond as fast and accurately as possible, so both accuracy and reaction times were meaningful. The subsequent trial was presented immediately after the participant made a response.

Whether left/right or up/down arrow keys were used for targets or fillers shifted mid-experiment. The starting setting was counterbalanced between participants to prevent systematic order effects. Shape-colour conjunctions were chosen at random in all parts of the experiment. Stimulus appearance in columns and rows was balanced within-participant. Once a colour-shape conjunction was used as a PM target, it was removed as the target choice options in the proceeding blocks to prevent repeating the same target.

Choice and No-choice blocks alternated through the experiment. Each block consisted of 120 trials. The participants completed two practice blocks of 35 trials before the experiment began. In the first practice block, a text indicating the correct response was present on each trial and warnings were shown for incorrect answers. In the second practice block, there was feedback only on wrong responses and RTs above 1.5 s. There was no feedback in the main experiment.

The experiment consisted of 12 blocks for the first 10 participants and 13 blocks for the remaining 20 participants (after the first ten subjects had participated, we wanted to increase the number of blocks from 12 to 14 but made an error resulting in 13 blocks per participant). The first ten participants each completed 1440 trials, two participants had 1080 trials in total (number of repeated blocks set too low and only discovered afterwards), and 17 participants had 1560 trials. The laboratory had a power cut during one test, and the experiment ended when the participant had completed 1102 trials. The number of trials for all participants is in the range to make valid estimations of the parameters and compare differences with DDMs (Stafford et al., 2020; Voss et al., 2010).

The task was presented using PsychoPy (Peirce, 2008; Peirce et al., 2019). The experiment files, data, and a video demo are available at https://github.com/mcvinding/PM_volition.

2.3. Data analysis

2.3.1. Data cleaning

Outliers were defined as reaction times below 150 ms or above 2500 ms and removed from the analysis. Between 0 and 11 trials were removed per participant (median: 2 trials). For the analysis, all participants had between 1002 and 1560 trials (median: 1551 trials). A total number of 43,962 trials were used to estimate the parameters of the DDM.

2.3.2. *Drift-diffusion analysis of reaction times and task performance*

We combined the task performance (correct or incorrect answer) and reaction-time in a single analysis by modelling responses as a hierarchical DDM using the Hierarchical Drift-Diffusion Model (HDDM) package (Wiecki et al., 2013) in Python (v. 3.5). The hierarchical DDM modelled the *i*th response (reaction time and answer) for participant *j* as a random walk function determined by the parameters visualised in Fig. 1. The drift rate (*v*) was modelled as a linear combination of factors *k*—indicating the task (PM cue or filler)—and volition type *l* (Choice or No-choice) as graphically represented in Fig. 3. The boundary separation parameter was allowed to vary between volition types. The onset was fixed to the midpoint of the boundary separation ($a/2$), and the model did not include a bias parameter. As it is unknown at the trial's onset whether the trial would be a filler or PM trial, the non-decision time was modelled as a pooled intercept for all conditions.

To estimate the parameters in the model, we used the default priors for DDMs in the HDDM toolbox, based on a review of previous literature analysing reaction times with DDMs that have proven to work for general DDM analysis of reaction times (Matzke & Wagenmakers, 2009). The model was sampled by drawing 10.000 samples from the posterior distribution by Markov chain Monte Carlo (MCMC) sampling and discarding the first 2000 samples. The posterior predictive checks to assess the model fit are documented in the Supplementary Material.

We tested for differences between conditions by comparing the posterior distribution of the estimated parameters between the *Choice* and *No-choice* conditions. If the self-chosen PM cues and fixed PM cues were associated with different prospective memory performance or response time, we expected a difference between Choice and No-choice conditions in at least one parameter. Alternatively, if self-chosen and fixed PM targets are functionally indistinguishable in prospective memory, we expected no differences in model parameters between Choice and No-choice conditions.

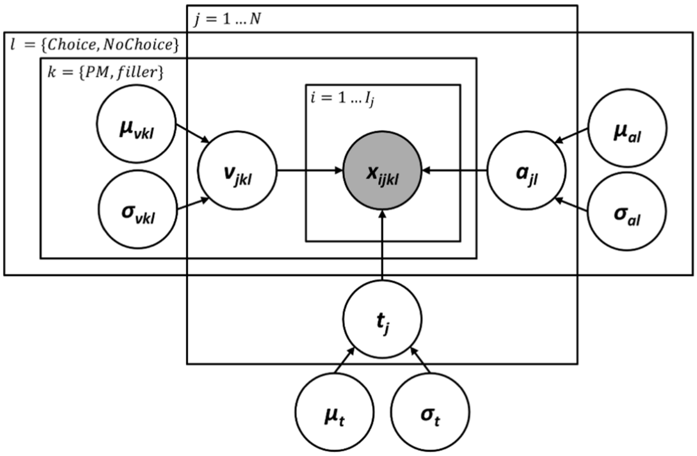
We tested the hypotheses by calculating the difference between the posterior distributions and finding the smallest proportion of the difference-distribution that was either above or below zero as the test statistic *P*. The proportion was multiplied by two to accommodate two-tailed hypotheses. *P* close to zero is evidence for a difference between conditions. In contrast, *P* close to one provide evidence for the null hypothesis that the parameters come from the same distribution. We used a cut-off of $P < 0.05$ as indicating "significant" differences between the estimated parameters. As opposed to classical *p*-values, *P* is a parametric measure of evidence for or against the null hypothesis.

3. Results

3.1. *Reaction time and performance*

One participant had a performance around the chance level, scoring only 45.7% and 59.9% correct in the two PM conditions. The participant seemed to have misunderstood the task-switching requirement, and data from this participant was excluded from the analysis. Fig. 4 shows the reaction times and performance across conditions.

The group-level average reaction time on the PM trials was 693 ms (range 604–812 ms) to the self-chosen targets and 696 ms (range 597–798 ms) to the non-chosen targets. The group-level average reaction time for the filler trials was 548 ms (range 461–674 ms) in the



$$x_{ijkl} \sim F(v_{jkl}, a_{jl}, z_{jl}, t_j)$$

$$v_{jkl} \sim \text{Normal}(\mu_{vkl}, \sigma_{Vkl})$$
$$a_{jl} \sim \text{Gamma}(\mu_{al}, \sigma_{al})$$
$$t_j \sim \text{Gamma}(\mu_t, \sigma_t)$$

$$\mu_{vkl} \sim \text{Normal}(2,3)$$
$$\mu_{al} \sim \text{Gamma}(1.5, 0.75)$$
$$\mu_t \sim \text{Gamma}(0.4, 0.2)$$

$$\sigma_{vkl} \sim \text{Half-Normal}(2)$$
$$\sigma_{al} \sim \text{Half-Normal}(0.1)$$
$$\sigma_t \sim \text{Half-Normal}(1)$$

$$z_{jl} = a_{jl} / 2$$

Fig. 3. Graphical representation of the prior parameters in the hierarchical DDM used to analyses reaction times and specification of their prior distributions used to estimate the model parameters. The response was modelled as a function of drift rate (v), boundary separation (a), and non-decision time (t), where x_{ijkl} is the combined reaction time and response for the ith trial for all trials from 1 to I_j number of trials for the jth subject in either the Choice or No-Choice condition (l) belonging to either filler or PM target trials (k). The parameter for non-decision time could vary between subjects. The drift rate and boundary separation parameters varied between the lth task (Choice or No-choice condition). Drift rate additionally varied between the kth trial type (PM or filler trials).

Choice condition and 552 ms (range: 468–670 ms) in the No-choice condition.

The performance in the Choice PM trials was between 80.7 and 97.9% correct responses (average: 92.8% correct) and between 72.9 and 99.3% correct (average: 91.5% correct) in the No-choice PM trials. The performance was overall higher in the filler trials than in the PM trials. The performance for the filler trials ranged between 92.2 and 99.3% correct (average: 96.6% correct) in the Choice conditions and between 90.9 and 99.1% correct (average: 96.5% correct) in the No-choice condition.

3.2. Drift-diffusion model

The parameters of the DDM are summarised in Table 1, and the posterior parameters shown in Fig. 5. Model-converge with Gelman-Rubin $\hat{R}$ (Gelman & Rubin, 1992) confirmed convergence of the model parameters (all $\hat{R}=1$, to at least the third decimal).

There was substantial overlap between the posterior distribution for decision boundary (a) and drift rate (v) for the chosen and fixed PM cues, as seen in Fig. 5. Comparing the posterior distributions for the drift rate (v) favoured the null hypothesis that the chosen and non-chosen PM cue responses came from overlapping distributions ($P = 0.851$). Comparing the posterior distributions of drift rates between the Choice and No-choice conditions on filler tasks also favoured the null hypothesis ($P = 0.986$). Comparing the boundary separation (a) between the Choice and No-choice conditions also favoured the null hypothesis ($P = 0.801$). Fig. 6 shows the difference in the distributions of the posterior parameters between the Choice and No-choice conditions.

There were, as expected, differences between the PM trials and filler trials on drift rate both in the Choice condition ($P < 0.001$) and the No-choice condition ($P < 0.001$).

A supplementary analysis where we slacked on the theoretical assumptions of the DDM and allowed all parameters to vary by condition and trial type is presented in the Supplementary Material. The overall results did not differ from the results presented in the main text.

4. Discussion

We hypothesised that a difference between self-chosen and externally fixed targets in delayed intentions on prospective memory would be present as differences in the DDM parameters and associated with different cognitive functions. We tested if the difference between self-chosen delayed intentions and delayed intentions fixed by external instructions showed differences in either the drift rate or a change in the boundary separation. The comparison of model parameters did not yield evidence for differences in any model parameters between self-chosen and fixed targets in delayed intention. The analysis provides evidence that self-chosen delayed intentions do not affect prospective memory differently from delayed intention fixed by external instructions—at least when it comes to the type of prospective memory task we presented here.

That self-initiated voluntary actions differ from non-voluntary actions has been established in several behavioural paradigms (Haggard, 2019). They do, however, have in common that the voluntary aspect of the task is in immediate relation to the execution of the intended action. The difference in the present study was that the formation of the intention to act did not occur in immediate relation to the performed action. A crucial part of this system is matching afferent signals with internal predictive signals generated at

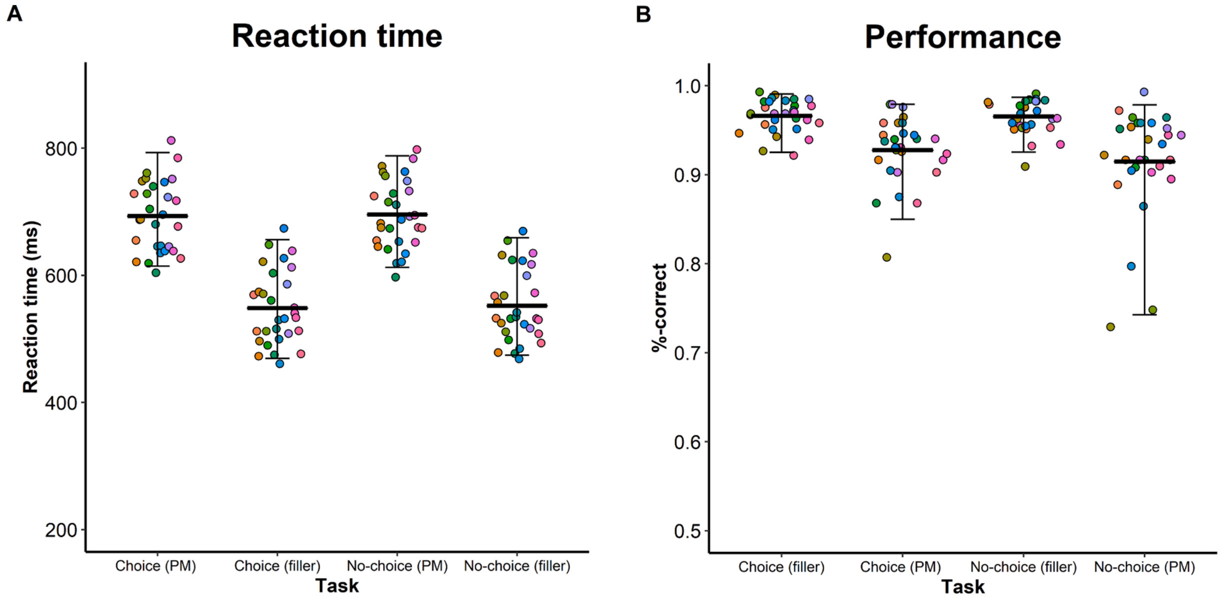


Fig. 4. (A) Summary of reaction times. Each coloured dot represents the median reaction time per subject across conditions. (B) Performance across the four tasks measured as the percentage of correct answers. The dots show the performance of each participant. The thick horizontal bars are the group averages. Whiskers indicate the 95% HDI of the population-level data.

Table 1
Population-level (fixed) effects of the drift–diffusion model (DDM). The columns show the mean of the posterior estimates of the drift rate (v), boundary separation (a), and non-decision time (t) with the highest density intervals (HDI) of the posterior distributions. $\hat{R}\approx1$ indicates convergence across independent MCMC chains.

Drift rate (*v*)					
Condition		**Mean**	**97% HDI lower bound**	**97% HDI upper bound**	**$\hat{R}$**
PM cue	No-choice	1.679	1.538	1.826	1.000
	Choice	1.698	1.555	1.842	1.000
Filler	No-choice	2.549	2.413	2.692	1.000
	Choice	2.552	2.414	2.692	1.000
Boundary separation (*a*)					
Condition		**Mean**	**97% HDI lower bound**	**97% HDI upper bound**	
No-choice		1.797	1.678	1.919	1.000
Choice		1.779	1.661	1.895	1.000
Non-decision time (*t*)					
Condition		**Mean**	**97% HDI lower bound**	**97% HDI upper bound**	
Intercept		0.284	0.259	0.313	1.000

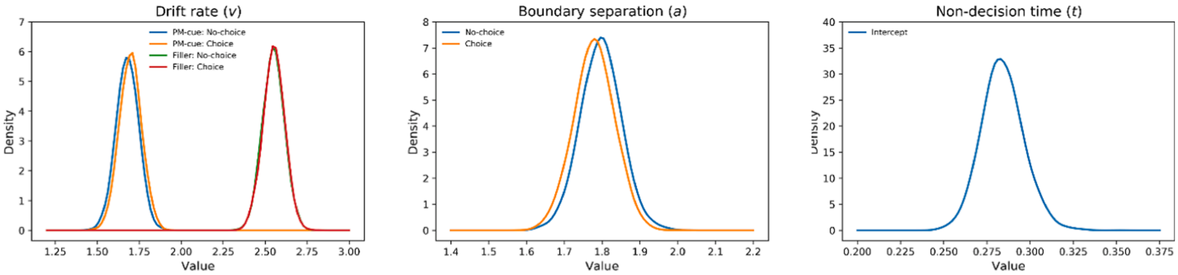


Fig. 5. Posterior distribution densities for the estimated parameters of the drift rate, the boundary separation, and the non-decision time in the DDM.

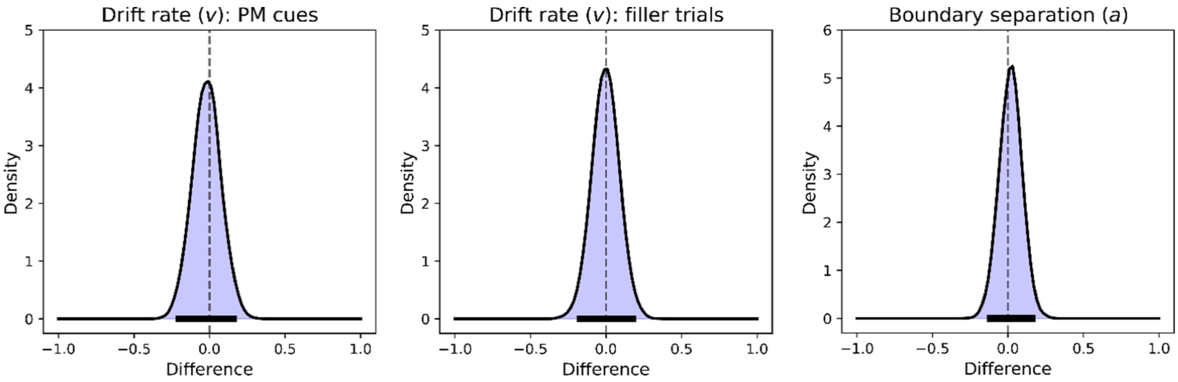


Fig. 6. The difference in posterior distributions between the Choice and No-choice conditions drift rate for PM cues, drift rate for filler trials and boundary separation. The dashed vertical lines indicate zero. The thick black bar indicates the 97% HDI of the differences.

the initiation of the action (Blakemore et al., 2000; Christensen & Grünbaum, 2018; Synofzik et al., 2013). We initially hypothesised that predictive signals during the formation of self-generated intentions might lead to an intention-superiority effect on prospective memory if it engages heightened sensorimotor information, thereby leading to better recall rate or faster responses by leaving a stronger trace in prospective memory (Goschke & Kuhl, 1993; Maylor et al., 2000). However, the results did not support that freely chosen targets lead to a superiority effect in our prospective memory task.

It has been proposed that volition is a layered or hierarchical structure rather than a singular dimension going from voluntary to involuntary (Pacherie, 2008). The cognitive function of proximal intentions is proposed to depend on the sensorimotor information of the bodily movements to reach the intended goal. In contrast, delayed intentions might be detached from the sensorimotor signals involved in action control and related to the target or conditions under which the intention has to be realised.

Volition is a multifaceted concept that encompasses different cognitive processes. The complexity of how different aspects of volition potentially influence the cognitive architecture of prospective memory extends beyond the distinguishing between *choice* and *no choice* used in the present study. In the present study, we operationalised one aspect of volition as choosing the target in a prospective memory task. The experimental manipulation does not capture all aspects of volition. For example, a potential relevant dimension of volition might be the valence or value associated with the intention (Gallagher, 2000). The task used here only varied when choosing the PM target, which meant that choosing the PM target was not of any further significance for the participants, i.e. it was not associated with any additional outcome or reward. The goal was to test if introducing a voluntary aspect in selecting the target was associated with a difference in the PM task. It is possible that manipulating valence associated with the self-chosen target—e.g. introducing a reward—might alter the role of volition when choosing targets in the prospective memory task.

Further studies on the role of volition on prospective memory should explore how valence and choice might interact and influence prospective memory. One study used a prospective memory task similar to the present study, in which the prospective target cue either was given as a neutral instruction or was assigned a subjective value in the form of points. The study found both differences between value targets and non-value targets in behavioural performance and differences in cortical activity measured with fMRI (Gilbert et al., 2009). Future research could also explore how self-made decision associated with rewards could lead to a change in prospective memory task performance as findings have shown that task importance alters prospective memory performance (Boywitt & Rummel, 2012; Strickland et al., 2018).

A related limitation of our study is that the experimental setup did not involve instructions to carry out any overt task by the end of the experiment other than a quick response based on recall of perceptual cues. The minimal engagement of more advanced prospective memory demand might have led to a situation similar to the proposition that preventing enactment during encoding of prospective memory prevents activating sensorimotor representation of the action to be enacted and diminishes the intention-superiority effect in prospective memory (Freeman & Ellis, 2003). Tasks that involve an overt sensorimotor component might show a difference between free and fixed sensorimotor tasks, e.g. carrying out a set of tasks rather than responding to a perceptual cue (Goschke & Kuhl, 1993). We find it likely that varying the task complexity could lead to a difference in task performance between self-chosen targets and externally fixed instruction.

The voluntary aspect of the task manipulated in the experiment was in the initial decision on the target. Choice in prospective memory tasks could, in addition, also be introduced at other stages of the process. For example, choosing what action to carry out when the PM cue is encountered in the ongoing task—or even let the participant choose if they want to act at all. Such a choice would potentially shift the voluntary aspect close to a proximal intention and thus probably be associated with differences in the prospective memory performance.

Similarly, the perceptual matching task we used in the present experiment involves a high degree of vigilance in monitoring the perceptual cues and thereby elicits a higher demand for keeping the delayed intention in mind to match the ongoing stimuli. It has been proposed that tasks where the prospective memory cues are encountered sparsely engage different aspects of prospective memory compared to a task that induces vigilance (Graf & Uttl, 2001). Since the present study required high vigilance in monitoring ongoing stimuli and match the PM cues, we cannot claim that low-vigilance tasks—e.g. by having an unrelated ongoing task—might affect the degree of volition during intention formation. It must also be mentioned that the relatively high frequency that the PM targets occurred in our task (20%) is in contrast to many other studies that model response from prospective memory tasks using DDM where the occurrence of PM targets might be around 1–5% (Ball & Aschenbrenner, 2018; Boywitt & Rummel, 2012; Kvavilashvili & Fisher, 2007). Focused has been on how the additional cognitive demand in the PM task affects performance in the ongoing-task performance compared to the absence of a PM task. In contrast, our current study's focus was comparing two different PM conditions since the hypothesis was not about the increased cognitive load on performance in general but on the specific role of choice on prospective memory performance. However, the comparison of the filler trials also showed no difference between the choice and no-choice conditions.

There is still much to learn about the cognitive architecture of human volition. Prospective memory involved many different cognitive sub-processes that involve and is influenced by other cognitive processes (McDaniel et al., 2015; McDaniel & Einstein, 2000). We explored how volition—in the form of self-chosen PM targets—influenced the subsequent prospective memory performance in a prospective memory task based on perceptual matching. Uncovering the cognitive functions of volition can help understand disturbances in cognitive control and sense of agency, e.g., a common symptom of schizophrenia who show worse performance in prospective memory tasks compared to healthy controls (Chen et al., 2015; Wang et al., 2008, 2009). Uncovering the role of volition in cognitive control can help understand the origin of disturbances in the sense of self and agency in schizophrenia.

The present study shows that distinguishing between freely chosen or externally fixed targets for delayed intentions did not affect the performance on a perceptual matching prospective memory task. The results provide evidence that volition—defined here as the choice of target versus externally fixed target—does not influence behavioural performance. How the target is selected when forming the intention does not make a difference in prospective memory performance independent of whether it is externally fixed or freely chosen. However, there is a need to explore further how volition might affect other cognitive aspects of prospective memory.

Declaration of Competing Interest

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

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CRediT authorship contribution statement

Mikkel C. Vinding: Conceptualization, Methodology, Formal analysis, Writing - original draft, Writing - review & editing. **Jonas Kristoffer Lindeløv:** Software, Methodology, Formal analysis, Writing - review & editing. **Yahui Xiao:** Conceptualization, Methodology, Writing - review & editing. **Raymond C.K. Chan:** Conceptualization, Writing - review & editing. **Thomas Alrik Sørensen:** Conceptualization, Methodology, Writing - review & editing.

Open science statement

Scripts for running the experimental paradigm, data from the study, and scripts for running the data analysis presented in the paper are available at https://github.com/mcvinding/PM_volition.

Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.concog.2021.103175.

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