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Volition in Prospective Memory: evidence against differences in recalling free and fixed delayed intentions

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Abstract

Human volition can be defined as the extent to which actions are generated by internal states or as a response to externally dictated instructions. Whether actions are voluntary or not influence the cognitive process of action generation and perception of action. The influence of volition on deciding actions at a later point in time is a less explored dimension. A voluntary decision on future **action** requires that the intention must be stored in the prospective memory until the intended action is performed. It is unknown if the distinction between freely chosen actions and externally dictated actions has a cognitive relevance for delayed intentions. In the present study, we compare the difference between voluntarily formed intentions and intentions fixed by external instructions in a prospective memory task. In the task, participants either freely chose a cue or were given a fixed cue by the task instructions which they had to store in memory and recalled when the cue was encountered during an ongoing filler task. We examined if there would be a difference between the free and fixed delayed intention on retrieval of the delayed intention by modelling the task performance and reaction time using a Bayesian hierarchical drift-diffusion model. We then compared if there were differences in diffusion rate, decision threshold, bias, and non-decision time between free and fixed intentions in the prospective memory task, which would signify that free and fixed delayed intentions differentially engage prospective memory. Comparison of the estimated model parameters for the free and fixed intentions showed evidence against differences between free and fixed conditions in the prospective memory task. The results suggest that once the intention is encoded in memory, it no longer makes a cognitive difference at retrieval if it was initially formed freely or was fixed.

Keywords

Volition; Prospective Memory; Intention; Drift-diffusion Model

1 Introduction

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

9 In cognitive terms, voluntary actions are defined as originating as a result of internal processes as their prime
10 cause. Voluntary actions are in contrast to actions that are responses to external stimuli (Schüür & Haggard,
11 2011). There are fundamental behavioural and cognitive differences between self-initiated voluntary actions
12 and passive- or involuntary actions (Jensen et al., 2017; Tsakiris & Haggard, 2005). The external consequences
13 of voluntary actions are, for example, perceived differently than the results of passive actions. One example is
14 the perceptual binding between voluntary actions and the following effects of the action that makes the action
15 and effect appear to be closer together in time compared to passive movements (Haggard et al., 2002). The
16 degree of voluntary choice over what action to perform increase the temporal binding subjective agency over
17 actions (Barlas et al., 2018; Barlas & Obhi, 2013; Beck et al., 2017), and lead to a higher subjective rating of
18 control over the outcome (Wen et al., 2015). Voluntary actions also leave different trances in retrospective
19 memory with responses made as voluntary actions being easier to recall than responses that were the result of
20 involuntary actions (Jensen et al., 2014).

21 Freely chosen movements have been shown to exhibit different movement-related potentials measured with
22 electroencephalography (EEG) compared to actions carried out following fixed instructions both during action
23 preparation and following movement (Keller et al., 2006; Sidarus et al., 2017). Similar, functional magnetic
24 resonance imaging (fMRI) studies have shown that freely chosen action engage different brain areas than fixed
25 actions (Krieghoff et al., 2011; Lau et al., 2004; Passingham et al., 2010).

26 The distinction between free voluntary actions versus externally fixed actions is, however, almost exclusively
27 investigated in paradigms involving immediate decision and execution of the free or fixed action. The picture of
28 free versus fixed actions, therefore, does not capture longer-lasting distal intentions that are formed before
29 the action, stored in memory, and recalled at the appropriate 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 condition to activate the distal intention triggers. Distal intentions are dependent on prospective memory as memories to act upon at a later point in time (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, and finally the realisation of 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 about things or past episodes (Goschke & Kuhl, 1993; Graf & Utzl, 2001). Neuroimaging studies show that prospective memory engages different areas of the brain compared to recalling from retrospective memory (Burgess et al., 2001; Gilbert et al., 2009; Sakai & Passingham, 2002). Similar, distinct neural activity during both encoding and retrieval is distinguishable for prospective memory as opposed to retrospective memory (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 outcome sensory-motor processes involved in the proximal actions. The action-preparatory movement-related potentials have 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 have to be carried out when the right conditional trigger or cue appears while performing a partially unrelated ongoing task. Typical tasks include an ongoing word/non-word discrimination task, 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 out 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)

Forming of the prospective memory can, in principle, be either a freely chosen distal intention or a fixed distal intention similar to how free and fixed intentions have been shown to depend on different cognitive mechanisms in proximal intentions. However, the target in prospective memory tasks is fixed by the instructions at the beginning of a task instead of freely chosen. In the present study, we investigated whether the cognitive processes of retrieving prospective memories depend on whether a delayed intention was

59 formed voluntarily or fixed by the instructions, to explore how volition during the formation of distal intentions
60 influence prospective memory.

61 Intentionality plays a role in prospective memory, although how is still unclear. Prospective memory items have
62 a higher recall rate when the items have to be performed compared to only recall, e.g. remembering specific
63 instructions to set the table and then setting the table afterwards compared to just recalling the instructions
64 (Goschke & Kuhl, 1993). This is seen as both higher rate of recalled prospective cues and faster reaction times
65 for cues related to actions that had to be performed than compared to recall of prospective cues without
66 carrying out the recalled action (Chen et al., 2015; Freeman & Ellis, 2003; Schult & Steffens, 2013, 2017).
67 Knowing in advance whether the prospective targets must be associated with an action alters the encoding or
68 retrieval of prospective memory. An explanation for this effect is that information related to future action
69 decays at a slower rate than content not related to actions that have to be performed (Goschke & Kuhl, 1993;
70 Kvavilashvili & Fisher, 2007; Ruthruff et al., 2001).

71 An alternative explanation is that the need to enact a set of instructions leads to a change meta-cognitive
72 allocation of cognitive resources devoted to the task that shifts the task capacity (Hicks et al., 2005; Marsh et
73 al., 2005, 2006). Drift-diffusion modelling of responses in prospective memory tasks (see below) have shown
74 that the presence of the prospective memory instruction increased the boundary threshold, not only for
75 responses to the targets; but also for the responses to the filler trials (Boywitt & Rummel, 2012; Heathcote et
76 al., 2015; Horn & Bayen, 2015). This points to an overall change in the amount of cognitive resources subjects
77 engage during the task rather than a change in the ongoing task. It has also been proposed that the difference
78 in cognitive capacity reflect a difference in the engagement of cognitive control during the ongoing task. This
79 leads to increased response inhibition when the PM task is perceived as more important or when changing the
80 similarity between the ongoing task leading to longer response times due to increased response threshold (Ball
81 & Aschenbrenner, 2018; Strickland et al., 2018).

82 The need to perform a remembered action and the presence of the need to do so engages different cognitive
83 processes and depend on the level of intentionality towards the task. However, the intentionality is
84 manipulated by varying the instructions given by the experimenter to the participant before the task. How
85 volition—the act of forming intentions to act upon versus acting upon fixed instructions—interacts with
86 prospective memory is unknown. If self-generated intentions matter for prospective memory, the increased
87 ownership over the intention formation may change the encoding of the prospective memory. A change in
88 performance of recalling prospective cues could be due to recurrent activation of sensory-motor information

during the encoding phase in the prospective memory task. One mechanism that might explain the influence of distal intention on proximal processes is that the formation of distal intentions involves, at least partially, similar action-preparatory processes as performing the action, based on shared similarity in neural activation of executed movements, planned 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 sensory-motor 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). The role of volition in sensory-motor processing for prospective intentions is reminiscent of the action-superiority account of the role of intentions in prospective memory, which propose that action that the subject know has to be enacted in the future engage a heightened sensory-motor information thereby leading to better recall rate by leaving a stronger trace in prospective memory (Freeman & Ellis, 2003). If volition indeed leads to increased sensory-motor enactment, we hypothesised that free-formed intentions is associated with increased prospective memory task performance compared to fixed instructions.

An alternative hypothesis is that distal intention functions as a higher-order global predictive process that guides the low-level sensory-motor prediction during the actual action execution (Pacherie, 2008). The voluntary aspect of intention formation might change the meta-cognitive engagement of the task. It is possible that increased ownership over the intention, when formed freely, alters the response threshold or degree of response inhibition; similar to how perceived importance of the task or focality have shown to change prospective memory recall (Strickland et al., 2018).

Finally, there is the possibility that through freely chosen intentions and fixed instruction differ in their formation. Free and fixed delayed intentions might be encoded in prospective memory in a similar fashion that does not influence the subsequent recall of the delayed intention and will not influence recall of prospective cues.

The process of retrieving previous intentions when encountering a target cue involves a matching between 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 that the decision threshold either for or against the target is reached leading to a behavioural response (Ratcliff et al., 2016; Ratcliff & Rouder, 1998). The DDM describe the joint distribution of task performance and reaction time as a function of a random walk determined by four parameters as visualised in Figure 1. The drift rate (v) indicates the rate at which evidence accumulates and

119 drifts towards a decision. The decision threshold (a) is the amount of evidence that must accumulate before
 120 committing to a response. The threshold has an upper and lower boundary where the upper edge represents a
 121 correct answer, and the lower edge represents a wrong answer. The accumulating evidence will drift toward
 122 one of the boundaries given the drift rate, resulting in an answer whenever the accumulating evidence crosses
 123 either threshold. The offset of the random walk can have a bias (z) towards either edge. Finally, the non-
 124 decision time interval (t) is the time interval before evidence begins to accumulate, e.g., the time it takes to
 125 perceive the stimuli (Ratcliff & Rouder, 1998). Drift-diffusion modelling of task performance and reaction time
 126 can recreate the characteristic skewed distributions of reaction times.

127

Figure 1: Illustration of a drift-diffusion model (DDM) of reaction times in two-choice tasks. Reaction time distributions and answer (correct or wrong) are determined by underlying random accumulating evidence illustrate by the red and blue traces in the figure. 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 threshold (a) is the amount of evidence needed before committing to a response. The non-decision time (t) right after stimulus onset represents the perceptual processing of stimuli where no evidence accumulates. Finally, the model might contain a bias (z) in the offset towards one of the alternatives.

128 Relevant cognitive difference between free and fixed delayed intentions on prospective memory will show as
 129 differences in one or more parameters of the drift-diffusion model between conditions. Any differences in
 130 model parameters between free or forced targets would support the hypothesis of different cognitive
 131 processes associated with free versus fixed delayed intentions. We hypothesised that a difference between

free and fixed delayed intention would manifest as a difference in either the evidence accumulation drift rate (v), a difference in response threshold (a)—which have shown to increase with increased task demand and cognitive effort (Boywitt & Rummel, 2012; Horn et al., 2013; Strickland et al., 2018), or as an increased bias (z) for the voluntarily formed intentions. Alternatively, if there is no difference in the model, it would support the hypothesis that both free and forced delayed intentions are functionally similarly when retrieved from memory.

Though the non-decision time is taken to reflect perceptual and motor-processes—i.e. processes not related to the decision process—we did not have an initial hypothesis that the distinction between free and fixed intentions would affect non-decision time. We were, however, recommended by reviewers to model non-decision time as a function of task and volition, as previous studies have reported that the non-decision parameter change for the ongoing task due to the PM task-demand (Horn & Bayen, 2015) and have been shown to change with age (Horn et al., 2013). We, therefore, tested if there were an effect of volition on non-decision time.

To explore the role of volition in prospective memory, we used a prospective memory task where the participants freely chose a target or were given one of five targets without the option to choose. The intention has to be retrieved from memory to respond when the target then is encountered at a later time during an ongoing task. Besides from the encoding phase, there was no difference in the ongoing task or the recall phase for the prospective cue.

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.

We planned for 30 participants but looked at data when ten subjects had completed to check data quality. At that time, we increased the number of blocks from 12 to 14 but made an error resulting in 13 blocks per participant. We made no other changes to the task.

2.2 Prospective memory task

The experiment had two conditions: *free* and *fixed*. Both tasks began by showing participants five randomly selected stimuli with one of the figures were randomly highlighted (Figure 2A). In the *free* 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 *fixed* blocks, there was no choice: the PM target was chosen at random and presented to the participant on the screen. The stimulus consisted of one of four shapes (triangle, square, circle, or rhombus) in one of five different colours (yellow, green, blue, red, or white) on a black background. Besides the initial option to choose the PM target or not the task and stimulus presentation was identical for the free and fixed blocks.

The task was to remember the target stimuli and respond when it appeared in the stream of ongoing filler stimuli, similar to the prospective memory task used by Burgess et al. (2001). The task stimuli consisted of a stream of stimuli was presented in one quadrant of a 2 x 2 grid with 1° visual angle between the cells so that all stimuli were presented foveally (Figure 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 of the grid. 20% of the trials were PM-trials, and the remaining 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 that both accuracy and reaction times became meaningful. The next trial was presented immediately after the participant made a response.

Whether left/right or up/down arrow keys were used for targets or fillers were shifted mid-experiment. The starting setting for both free/fixed and arrow keys 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 colour-shape conjunction had been used as a PM target, it was removed as the target choice options in the proceeding blocks to prevent that participants repeated the same target.

Free and fixed blocks alternated through the experiment. There were two practice blocks of 35 trials each 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 block, there was feedback on wrong responses and RTs above 1.5 seconds only. Participants were shown 120 trials per block for 12 or 13 blocks (see

188 “Participants”) with no feedback or time-limits. Two participants were only had 90 trials per block due to an
 189 error, but still generated a total amount of trials to be included in the analysis.
 190 The task was presented using PsychoPy (Peirce, 2008; Peirce et al., 2019). The experiment files, data, and a
 191 video demo are available at https://github.com/mcvinding/PM_volition.

Figure 2: Overview of the behavioural paradigm. Each block started with a screen (bottom row) asking subjects to freely choose a prospective target (PM-cue) amongst five alternatives or presenting a fixed cue, depending on the condition.

Participants watched with an ongoing stream of figures in one of the four corners of a quadrant. The ongoing 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).

2.3 Data analysis

2.3.1 Data cleaning

During the test of one participant, the laboratory had a power cut, and the experiment ended before the participant had completed all the blocks. The participant had completed 1102 trials, which is sufficient to include in the analysis. Ten participants completed had 1440 trials in total, two participants had 1080 trials in total (number of repeated blocks set too low and only discovered afterwards), and 17 participants had 1560 trials in total. The mixed-model regression used to analyse the data is robust to unbalanced data.

Outliers were defined as reaction times below 150 ms or above 2500 ms and removed from the analysis. Between zero 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 of 43962 trials were used to estimate the parameters of the DDM. The number of trials used in the analysis is well above the number of trials to make valid estimations of the parameters and compare differences with DDMs (Stafford et al., 2020; Voss et al., 2010).

2.3.2 Drift-diffusion analysis of reaction times and task performance

We combined the task performance (correct/wrong answer) and reaction-time in a single analysis by modelling both as a function of a hierarchical DDM using the Hierarchical Drift-Diffusion Model (HDDM) package (Wiecki et al., 2013) in Python (v. 3.5). The DDM takes reaction time and answers as a function of a random walk determined by four parameters (a , v , z , and t) as visualised in Figure 1. We modelled the i th response for participant j as a function drift rate (v), decision threshold (a), bias (z), and non-decision time (t). All four parameters were modelled as a linear combination of factors indicating the task k (PM-cue or filler) and volition type l (Free or Fixed) as graphically represented in Figure 3.

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 (Matzke & Wagenmakers, 2009). The priors have proven useful for general DDM analysis of reaction times. The model was sampled by drawing

217 10.000 samples from the posterior distribution by Markov chain Monte Carlo (MCMC) sampling and discarding
 218 the first 2000 samples.

Figure 3: Graphical representation of the parameters in the hierarchical DDM used to analyses reaction times and specification of their prior distributions used to estimate the parameters of the model. See main text for description.

220 From the model, we tested for differences between conditions by comparing the posterior distribution of the
 221 estimated parameters between the free and fixed conditions on all parameters v , a , z , and t . If freely chosen
 222 PM-cues and fixed PM-cues were encoded differently in prospective memory, we expected a difference
 223 between free and fixed conditions in at least one of the four parameters. Alternatively, if freely chosen PM-
 224 targets were encoded in the same manner in prospective memory, we expected no differences in model
 225 parameters between free and fixed conditions.

226 We tested the hypotheses by calculating the difference between the posterior distributions and from the
 227 difference between the posterior distributions calculate the percentile that contains zero. The resulting test
 228 statistic is the probability P ranging from 0 to 1. As opposed to classical p -values, (capital) P is a parametric
 229 measure of evidence for or against the hypothesis of a difference between conditions. P close to 0 is evidence
 230 for a difference between conditions, whereas P close to 1 provide evidence against a difference. The
 231 proportion was multiplied by two to accommodate two-tailed hypotheses.

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. Figure 4 shows a summary of reaction times and performance across conditions for the 29 participants used in the analysis.

The group-level average reaction time on the PM-trials was 693 ms (range 604-812 ms) to the free targets and 696 ms (range 597-798 ms) to the fixed targets. The group-level average reaction time for the filler trials was 696 ms (range 597-798 ms) to the fixed targets. The group-level average reaction time for the filler trials was 548 ms (range 461-674 ms) in the free condition and 552 ms (range: 468-670) in the fixed condition.

Figure 4: (A) Summary of reaction times. Each dot represents the median reaction time per subject. (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-percentiles of the population-level data.

The performance in the *free* PM-trials was between 80.7-97.9% correct responses (average: 92.8% correct) and between 72.9-99.3% correct (average: 91.5% correct) in the *fixed* PM-trials. The performance was overall higher in the filler trials than in the PM-trials as expected. The performance for the filler trials ranged between

245 92.2-99.3% correct (average: 96.6% correct) in the free conditions and between 90.9-99.1% correct (average:
 246 96.5% correct) in the fixed condition.

247 3.2 Drift-diffusion model

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

251 There was substantial overlap between the posterior distribution for decision threshold (a) and drift rate (v) for
 252 the free and fixed PM-cues, as can be seen in Figure 5A. The comparison showed no difference in the decision
 253 threshold (a) for the free and fixed PM-cues ($P = 0.71$). The comparison of the posterior distributions for the
 254 drift rate (v) also favoured that the fixed and free PM-cue responses came from overlapping distributions ($P =$
 255 0.75). The bias (z) in the PM condition were marginally larger in the free condition compared to the fixed
 256 condition but not a significant difference ($P = 0.41$). The non-decision time showed the largest degree of
 257 overlapping distributions ($P = 0.78$) for free and fixed PM cues. Comparison of the posterior distributions
 258 between free and fixed conditions on filler tasks also showed evidence for no difference in decision threshold
 259 ($P = 0.86$), drift rates ($P = 0.83$), bias ($P = 0.77$), and non-decision time ($P = 0.59$). The difference in the posterior
 260 distributions of the model paraments between the free and fixed conditions is shown in Figure 6A-B.

261 Figure 6C-D shows the difference in the posterior distributions between the PM cues and filler trials. There
 262 were, as expected, differences between the PM trials and filler trials on drift rate (free: $P = 0.002$; fixed: $P <$
 263 0.001), and a more substantial bias for the filler trials than the PM trials ($P < 0.001$ for both free and fixed
 264 conditions). The decision thresholds for PM- and filler trials had only partially overlap but not different enough
 265 to conclude a significant difference (free: $P = 0.28$; fixed: $P = 0.09$). Finally, the model gave a difference in the
 266 non-decision time between PM- and filler trials ($P < 0.001$ for both free and fixed conditions).

Table 1: Population-level (fixed) effects of the drift-diffusion model (DDM). The columns show the estimated coefficients of the decision threshold (a), drift rate (v), bias (z), and non-decision time (t) with highest density intervals (HDI) of the posterior distributions. $\hat{R} \approx 1$ indicates convergence across independent MCMC chains.

Decision threshold (a)				
Condition		Estimate (β)	97% HDI lower bound	97% HDI upper bound
PM-cue	Fixed	1.70	1.60	1.80
	Free	1.67	1.58	1.77

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Filler	Fixed	1.60	1.51	1.69
	Free	1.61	1.51	1.69
Drift rate (v)				
Condition		Estimate (β)	97% HDI lower bound	97% HDI upper bound
PM-cue	Fixed	3.14	2.90	3.37
	Free	3.10	2.87	3.33
Filler	Fixed	2.60	2.39	2.81
	Free	2.63	2.42	2.84
Bias (z)				
Condition		Estimate (β)	97% HDI lower bound	97% HDI upper bound
PM-cue	Fixed	0.27	0.24	0.29
	Free	0.28	0.26	0.30
Filler	Fixed	0.45	0.42	0.48
	Free	0.45	0.42	0.47
Non-decision time (t)				
Condition		Estimate (β)	97% HDI lower bound	97% HDI upper bound
PM-cue	Fixed	0.38	0.35	0.40
	Free	0.37	0.35	0.40
Filler	Fixed	0.30	0.28	0.33
	Free	0.29	0.27	0.32

267

Figure 5: Posterior distribution densities for the estimated parameters in the DDM: (A) the decision threshold, (B) the drift rate, (C) the bias in response offset, and (D) non-decision time.

Figure 6: The difference in posterior distributions between decision threshold, drift rate, bias, and non-decision time between (A) the PM cues for the Free and Fixed conditions, (B) the filler trials for the Free and Fixed conditions, (C) the PM cues and filler trials in the Free conditions, and (D) between the PM cues and filler trials in the Fixed conditions. The dashed

vertical lines in denotes zero to assess the proportion of the distribution that is above or below zero. The thick black bar indicates the 97% HDI of the difference distribution.

4 Discussion

We hypothesised that a difference in the cognitive function of free or fixed delayed intentions would be present as differences in the DDM parameters. We tested if the difference between free and fixed delayed intentions showed differences in either the drift towards the decision threshold, a change in the decision threshold, an increased bias, or a shift in non-decision time. The comparison of model parameters between free and fixed conditions did not show differences in any of the model parameters between free and fixed delayed intention in the responses to the PM-cues or the filler trials. There was no evidence to support a difference between free and fixed delayed intentions on neither PM-targets nor filler trials.

The comparison of DDM parameters did, as expected, show differences between PD cues and filler trials confirming the shift in cognitive processing for the PM trials compared to the ongoing task. The difference showed a change in drift-rate associated with slower evidence accumulation when the PM cues appeared. There were, however, not evidence to conclude that the decision boundary differed between PM cues and filler trials as has otherwise been reported and ascribed to increased cognitive demand in the PM task (Ball & Aschenbrenner, 2018; Boywitt & Rummel, 2012; Heathcote et al., 2015; Strickland et al., 2018). The analysis revealed a longer non-decision time for the PM cues associated with non-decision related processes (Ratcliff & McKoon, 2008; Voss et al., 2010), which is expected as participants had to alter their motor responses slightly between the ongoing task and the PM targets. Comparison of the posterior distributions also confirmed that there was bias as expected due to the filler trials being more prevalent than PM trials. While this confirms the engagement of prospective memory between PM cues and filler trials, there was no modulation of the performance in the prospective memory task between free or fixed intentions for neither the filler trials nor the PM cues. The analysis shows provide evidence that recalling free formed or fixed delayed intention does not dependent on different cognitive mechanisms in the task we present 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 free or fixed intention did not occur in immediate relation to the performed action. The behavioural and perceptual difference between proximal voluntary actions and involuntary actions may be

296 dependent on mechanics directly tied to generating the motoric outputs. A crucial part of this system is the
297 matching of afferent signals with internal predictive signals generated at the initiation of the action
298 (Blakemore, Wolpert, et al., 2000; Christensen & Grünbaum, 2018; Synofzik et al., 2013). We hypothesised that
299 internal predictive signals during the formation of self-generated intentions might lead to an intention-
300 superiority effect on prospective memory if it engages a heightened sensory-motor information and thereby
301 leading to better recall rate by leaving a stronger trace in prospective memory (Goschke & Kuhl, 1993; Maylor
302 et al., 2000). The results did not support that freely chosen delayed intentions lead to a superiority effect on
303 prospective memory. However, our prospective memory task did not involve an overt task to be carried out by
304 the end of the experiment but based on recall of perceptual cues. Tasks that involve an overt sensory-motor
305 component might show a difference between free and fixed sensory-motor tasks, e.g. carrying out a set of
306 tasks rather than responding to a perceptual cue. This would be in line with findings that preventing enactment
307 during encoding of prospective memory, thereby preventing activating sensory-motor representation of the
308 action to be enacted, diminishes the intention-superiority effect in prospective memory (Freeman & Ellis,
309 2003).

310 Similarly, the perceptual matching task we used in the present experiment involves a high degree of vigilance in
311 monitoring the perceptual cues and thereby higher demand for keeping the delayed intention in mind for
312 constant matching with the ongoing stimuli. It has been proposed that tasks, where the prospective memory
313 cues are encountered only very rare, engage different aspects of prospective memory (Graf & Uttl, 2001). Since
314 the present study required high vigilance in the monitoring of stimuli and matching to the PM cues, we cannot
315 make claims if low-vigilance tasks, e.g. by having an unrelated ongoing task, could be affected by the degree of
316 volition during intention formation.

317 That volition does not seem to play a role for the realisation of delayed intention might hint that volition is
318 more complicated than distinguishing between “me” or “not me.” It has been proposed that volition is a
319 layered or hierarchical structure rather than a singular dimension going from voluntary to involuntary
320 (Pacherie, 2008). Intentions in direct relation to action execution might be primarily related to cognitive control
321 of the ongoing action and thus relying on the primary incoming and outgoing signals related to bodily
322 movements to reach the intended goal. In contrast, delayed intentions might be detached from the sensory-
323 motor signals involved in action control and more related to the target or conditions under which the intention
324 has to be realised. The complexity of how different levels of volition extend beyond the two dimensions
325 discussed here: free or fixed and proximal versus delayed. Our finding provides evidence that volition does not

326 affect prospective memory as such. Further studies should explore to what extent volition more specifically
327 influence sensory-motor related information and non-motor cognitive information or differences between high
328 or low levels of vigilance.

329 Prospective memory involved many different cognitive subprocesses that involve and is influenced by other
330 cognitive processes (McDaniel et al., 2015; McDaniel & Einstein, 2000). We explored how volition in the
331 formation of intention in the form of freely chosen PM targets during the encoding influenced the subsequent
332 prospective memory task when recalling prospective cue in a perceptual matching task. Another dimension
333 might be the valence or value associated with the intention. One study used a prospective memory task similar
334 to the present study, in which the prospective target cue was either given as a neutral instruction or was
335 assigned a subjective value in the form of points. The study found both differences between value targets and
336 non-value targets in behavioural performance and differences in cortical activity measured with fMRI (Gilbert
337 et al., 2009). While volition itself, i.e., whether the intention is free or fixed is not associated with a change in
338 cognitive function when it comes to recalling delayed intentions, the valence associated with the intention
339 might be. Future research could also explore how self-made decision associated with rewards could lead to a
340 change in prospective memory task performance as findings have shown that task importance alters
341 prospective memory performance (Boywitt & Rummel, 2012; Strickland et al., 2018).

342 There is still much to learn about the cognitive architecture of human volition. Uncovering the cognitive
343 functions of volition can help understand disturbances in cognitive control and sense of agency, e.g., as is a
344 common symptom of schizophrenia. Schizophrenia patients are characterised by disruptions in the prediction
345 of incoming sensory signals (Blakemore, Smith, et al., 2000) and show worse performance in prospective
346 memory tasks compared to healthy controls (Chen et al., 2015; Wang et al., 2008, 2009). Uncovering the role of
347 volition in cognitive control can help understand the origin of disturbances in the sense of self and agency in
348 schizophrenia.

349 In the present study, we show that freely chosen or externally fixed delayed intentions to act have the same
350 effect on the intended action on an ongoing perceptual matching prospective memory task. The results provide
351 evidence that volition during prospective memory encoding does not influence the behavioural performance
352 when the intentions are recalled. Once the intention is formed, recall performance elicited by delayed
353 intentions is independent of whether it was formed freely or forced.

Acknowledgements

This study was supported by The Sino-Danish Center for Education and Research.

Author Contributions

MCV, YX, RCKC, and TAS formed the idea for the study. The design of the study was conceived by MCV, JL, YX, TAS, and implemented in PsychoPy by JL. YX, MCV, and two assistants collected data. MCV and JL analysed data. MCV created the first draft of the manuscript. All authors approved the final draft.

Open science statement

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

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