Analysis of Self and Retrieval Generated Priming in Human Recognition Memory

By

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To my Mother

In no case is an animal activity to be interpreted in terms of higher psychological processes if it can be fairly interpreted in terms of processes which stand lower in the scale of psychological evolution and development.

Morgan's Canon, (Morgan, 1903)

Nevertheless the difference in mind between man and the higher animals, great as it is, certainly is one of degree and not of kind. We have seen that the senses and intuitions, the various emotions and faculties, such as love, memory, attention, curiosity, imitation, reason, etc., of which man boasts, may be found in an incipient, or even sometimes in a well-developed condition, in the lower animals.

(Darwin, 1871)

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Declaration

I hereby declare that this thesis has been composed by myself. In agreement with supervisors, data for Experiment 11 were collected by Ester Lim, Dr Charlotte Bonardi and Dr Jasper Robinson were involved in design of Experiment 11. Otherwise all simulations, data collection and analysis were performed by myself. Experiment 5 reported in Chapter 5 and Experiment 11 reported in Chapter 6 have been published in Nitka, A. W., Bonardi, C., and Robinson, J. (2020). An associative analysis of recognition memory: Relative recency effects in an eye-tracking paradigm. *Journal of Experimental Psychology: Animal Learning and Cognition, 46(3)*, 314-326.

Abstract

In this report, I have documented the development of an eye-tracking procedure able to distinguish between the influence of Self (SGP) and Retrieval Generated Priming (RGP), effects postulated by the Wagner's Sometimes Opponent Process (SOP) model. The procedures of Relative Recency (RR), Object in Place (OIP) and Object in Context (OIC) map onto the two postulated mechanisms and so the primary goal was to exhibit both effects in the human eye-tracking procedure. In the RR procedure, participants have demonstrated to look at stimuli which were pre-exposed earlier in the past when compared with a more recently presented one. In both OIP and OIC, participants engaged more with stimuli which were presented in either a novel spatial arrangement or accompanied by a novel context. Such effects mirror the SOP-derived predictions and demonstrate the involvement of SGP and RGP in the human recognition memory. A key difference between the SGP- and RGP-enabled effects is the influence of time. Hence, the model is evaluated regarding such manipulations applied to RR, OIC and OIP procedures. To that extent, the mathematical tenets of SOP were employed to simulate the experimental procedures, whose predicted results were experimentally tested. Overall, both mechanisms were demonstrated, however, their effects were sensitive to a time-dependent decay. Overall, the experiments reported yield support for the associative account of recognition memory. I argue that the SOP offers a parsimonious, computational, and robust model of recognition memory and that the procedures developed for this thesis offer a more sensitive measure than the procedures currently used for that purpose.

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List of Abbreviations

cm ..... Centimetre(s)

CR ..... Conditioned Response

CS ..... Conditioned Stimulus

cx ..... Context

D2 ..... Discrimination Ratio

$D2_{adj}$ ..... Adjusted D2 Ratio

h ..... Hour(s)

ISI ..... Inter Sample Interval

ITI ..... Inter Trial Interval

m ..... Minute(s)

OIC ..... Object in Context, procedure

OIP ..... Object in Place, procedure

OX ..... Object in Context X, procedure

OY ..... Object in Context Y, procedure

P ..... Pre-exposed, recent or presented in old location test stimulus

P' ..... Presented in a novel location test stimulus

px ..... pixel(s)

Q ..... Novel, less recent test stimulus

RGB ..... Red, Green, Blue, colour model

RGP ..... Retrieval Generated Priming

RI ..... Retention Interval

ROI ..... Region of Interest

RR ..... Relative Recency, procedure

RT ..... Reaction Time

s ..... Second(s)

S1 ..... Sample 1

S2 ..... Sample 2

SGP ..... Self Generated Priming

SOP ..... Standard Operating Procedure

SOR . . . . . Spontaneous Object Recognition, procedure

TR . . . . . Time Ratio

UR . . . . . Unconditioned Response

US . . . . . Unconditioned Stimulus

VPC . . . . . Visual Paired Comparison, procedure

w_2 . . . . . Window 2, 0.5 - 1.0 s of a phase

w_3 . . . . . Window 3, 1.0 - 1.5 s of a phase

List of SOP Terms

$\boldsymbol{A1}$ ..... Primary activation state

$\boldsymbol{A2}$ ..... Secondary activation state

$\boldsymbol{C}$ ..... Constant parameter for the distractor rule

$\boldsymbol{I}$ ..... Inactivity state

$\boldsymbol{L^+}$ ..... Excitatory learning parameter

$\boldsymbol{L^-}$ ..... Inhibitory learning parameter

$\boldsymbol{p1}$ ..... Primary activation parameter

$\boldsymbol{p2}$ ..... Secondary activation parameter

$\boldsymbol{pd1}$ ..... $A1$ to $A2$ decay parameter

$\boldsymbol{pd2}$ ..... $A2$ to I decay parameter

$\boldsymbol{R}$ ..... Response function

$\boldsymbol{r_1}$ ..... $p2$ weight for $A1$

$\boldsymbol{r_2}$ ..... $p2$ weight for $A2$

$\boldsymbol{V}$ ..... Associative strength

$\boldsymbol{V^+}$ ..... Excitatory association

$\boldsymbol{V^-}$ ..... Inhibitory association

$\boldsymbol{we_1}$ ..... Response function weight for $A1$

$\boldsymbol{we_2}$ ..... Response function weight for $A2$

List of Statistical Terms

95% CI ..... 95 % Confidence interval

A' ..... Non-parametric estimate of discriminability

alpha, α ..... Significance criterion

ANOVA ..... Analysis of Variance

BAIN ..... Bayesian Informative hypotheses evaluation

$\boldsymbol{BF}$ ..... Bayes Factor

$\boldsymbol{BF_{01}}$ ..... BF in support of the $\mathcal{H}_0$

$\boldsymbol{BF_{01,U}}$ ..... BF in support of the $\mathcal{H}_0$, corrected for multiple testing

$\boldsymbol{BF_{10}}$ ..... BF in support of the $\mathcal{H}_1$

$\boldsymbol{BF_{10,U}}$ ..... BF in support of the $\mathcal{H}_1$, corrected for multiple testing

$\boldsymbol{BF_{excl}}$ ..... BF for matched models, evidence for the $\mathcal{H}_0$

$\boldsymbol{BF_{incl}}$ ..... BF for matched models, evidence for the $\mathcal{H}_1$

BMA ..... Bayesian Model-Averaged, meta analysis method

Bonferroni .... Bonferroni correction for family-wise error

$\boldsymbol{\chi^2}$ ..... Chi-squared statistic

CR ..... Correct Rejection, signal detection

d ..... Cohen's *d*, measure of effect size

df ..... Degrees of Freedom

DV ..... Dependent Variable

Error ..... Error from the stochastic computation method

F ..... F-test statistic

FA ..... False Alarm, signal detection

H ..... Hit, signal detection

$\boldsymbol{\mathcal{H}_0}$ ..... Null hypothesis

$\boldsymbol{\mathcal{H}_1}$ ..... Experimental or alternative hypothesis

Holm ..... Holm correction for family-wise error

M ..... Mean

M ..... Miss, signal detection

MCMC ..... Markov chain Monte Carlo

MED ..... Median

mu, μ ..... Mean or effect size in BMA meta-analysis

η_p^2 ..... Partial Eta-squared, measure of effect size

p ..... P-test statistic

Posterior ..... Probability of the model after seeing the data

Prior ..... Probability of the model without seeing the data

SD ..... Standard Deviation

SD^2 ..... Variance

SE ..... Standard Error of the Mean

t ..... T-test statistic

T_2 ..... Durbin-Conover pairwise test statistic

$x \sim \mathcal{N}(\mu, \sigma)$. Random x from a normal distribution with *M* of μ and *SD* of σ

$x \sim \mathcal{U}(a, b)$ ... Random x from an uniform distribution between a and b

1 | The SOP Model

In this chapter, I will present Wagner's (Wagner, 1981; Brandon, Vogel, & Wagner, 2003; Uribe, Becerra, Ponce, & Vogel, 2019; Vogel, Ponce, & Wagner, 2019) Standard Operating Procedure (SOP) model of automatic learning and memory together with its computational tenets of self (SGP) and retrieval-generated priming (RGP) mechanisms.

1.1 The Standard Operating Procedure

The Standard Operating Procedure (SOP, sometimes referred to as Sometimes Opponent Process, Wagner, 1981; Brandon et al., 2003; Uribe et al., 2019; Vogel et al., 2019) is a real-time, dynamic model of automatic associative learning, memory and behaviour. It has been described by Bouton (2016 as cited in De Houwer & Hughes, 2020) as "the single most complete account of conditioning and associative learning that is available" (p. 144) which is amongst the "most elegant and influential models in cognitive learning psychology" (p. 102, De Houwer & Hughes, 2020).

The model characterises the memory representation of a stimulus as a node consisting of a limited set of features (representational elements) which map onto the physical characteristics. Nodes are connected in a network-like structure in which representations can affect each other in an inhibitory or excitatory way. On a neural level, nodes can be thought of as systems or assemblies of neurons that code for its low-level features (Wagner & Donegan, 1989). The SOP is sometimes referred to as Standard Operating Procedure which relates to the dual-process

theory of behaviour generation and according to which one stimulus can generate behaviours which primary ($A1$) and secondary ($A2$) elements can either sum or sometimes be in opposition to one another. However, in the context of recognition memory procedures, behaviour generated by both units will sum.

The SOP is an extension of an influential Rescorla-Wagner, RW (Wagner & Rescorla, 1972), model and is a theoretical device whose main aim was to describe the behavioural effects observed within the doctrine of Pavlovian conditioning. The model states that a change in associative strength between the CS and US depends on how well the former predicts the latter. Incremental, trial-by-trial, change in associative strength ($V_{CS:US}$) is formalised as:

$$\Delta V^{n}_{CS:US} = \alpha_{CS}\beta_{US}(\lambda - V^{n-1}_{CS:US}) \tag{1.1}$$

Here, the change in how well CS predicts the US at trial n in the product of CS salience (α) and US (β) scaled by a prediction error term. The prediction error is the difference between the parameter λ denoting a maximal possible associative strength and what has been learned so far ($V^{n-1}_{CS:US}$). Hence, the associative strength can only be modified if the prediction error does not equal to zero, in other words when the external world does not match the internal representation. Despite its robustness and influence (De Houwer & Hughes, 2020) which went beyond the scope of classical conditioning (predictive coding, machine reinforcement learning, artificial neural networks) the RW model could not account for a range of learning phenomena (Miller, Barnet, & Grahame, 1995). Furthermore, the temporal resolution of the model is limited to units of trials, rather than, as in SOP, more discrete

moments.

The SOP follows from Wagner's (Wagner, 1976) theory which defines priming as an activation of a memory representation in short-term memory and has an influence on the response such a representation can produce. Memory representations consist of a finite set of elements (features, characteristics) which define a given stimulus. To explain priming, the basic SOP representation lifecycle principles hold that at any given moment a proportion of representational elements can assume one of two activation states; primary $A1$ or the secondary (primed or refractory) $A2$, the elements which are not in $A1$ or $A2$ remain inactive (I). A parallel can be drawn between this framework and the classical model of memory (Atkinson & Shiffrin, 1968) where $A1$ and $A2$ are respectively, the focal and peripheral working or short-term memory and the Inactivity is the long-term storage. The conceptualisation of memory representation and its real-time dynamics, which the SOP captures in a computational manner, make the model an unique representative amongst the family of learning theory models. Moreover, it provides a framework by which the behaviour can be studied on (but not being limited to) a more granular temporal resolution of moment by moment, within-trial simulations rather than between-trial learning processes.

Each memory representation of a once-experienced stimulus is a node; a set of features which characterise the physical characteristics encoded. Within a node, the features can move around the activation ($A1$ and $A2$) and inactivity states (I). The three key factors which govern this process are: stimulus presentation, time and prior associations. I will first describe the theory behind the non-associative activation dynamics (SGP) and its temporal dependency (together with its mathe-

matical tenets), to then focus on the learning and retrieval aspects of the associative process (RGP).

1.1.1 Self Generated Priming

1.1.1.1 Description

When a stimulus is encountered by an organism, a proportion of its memory representation's features are activated in accordance to the stimulus salience. The process assumed by the SOP can be seen as a low-level attentional selection mechanism by which the physical input is matched against the memory representations and the representations which are comparable to the physical characteristics are activated. In simplified terms, when a red cube is presented the features which constitute the shape, colour and smell will all be activated. Due to a limited capacity of working memory storage (also assumed by the SOP and described later) a process similar to cue competition will occur, and the representation which provides the best match will be activated. In terms of computation, the SOP provides a parameter $p1$ which quantifies the physical salience of the stimulus presented, where a value of 0 denotes the absence of the stimulus and 1 is the maximal possible intensity.

Elements activated by the stimulus enter the $A1$ or primary activation state, which can be described as a focal attention. The SOP assumes that $A1$ and $A2$ activations have "their own behavioural consequences" (p. 162, Wagner & Donegan, 1989); in the context of recognition memory this means that $A1$ produces vigorous and $A2$ reduced exploration of test stimulus which for the sake of simplicity is presented as a single behaviour with varied strength. However, different experimental preparations may yield separate behavioural outcomes enabled by $A1$ and $A2$ ac-

tivity such as drug administration or a foot shock. The $A1$ activation is relatively transient and elements will undergo a rapid decay process by which the elements must transfer to the secondary activation ($A2$). In behavioural terms, as a consequence of the decay, the approaching behaviour will be most vigorous in the early phases of stimulation and will reduce in its potency as a function of time. The capacity, or in other words, how many stimuli can participate in activation is limited, which is in line with the findings from working memory research (Cowan, Saults, & Blume, 2014; Luck & Vogel, 1997, 2013).

Flow of elements between $A1$ and $A2$ is regulated by the decay parameter $pd1$. Being a free parameter, its value is not determined in the literature and should be adjusted to the preparation used (Brandon et al., 2003). However, in no case should the value be less or equal to 0 or exceed 1; a higher decay rate will result in an increased decay speed and shorter temporal window of vigorous responding (orienting). The decay rate is not constant and can be updated in case of consequent new stimulus presentation; the decay will be accelerated each time a new stimulus is presented, which is coherent with the working memory capacity limitation.

The secondary activation ($A2$, also referred to as refractory) can be described as peripheral processing (Cowan et al., 2014). In the context of recognition memory, it still results in approaching behaviour, yet reduced in vigour. The amount of time which elements will assume this state for is governed by the second decay parameter $pd2$. The decay from $A2$ must be into Inactivity (I) and is substantially slower than the $pd1$, often approximated as $^1/_5$th of $pd1$ (Brandon et al., 2003), but earlier literature specifies only that $pd1$ is the higher value of the two (Wagner & Donegan, 1989). This results in a comparatively longer time for elements to de-

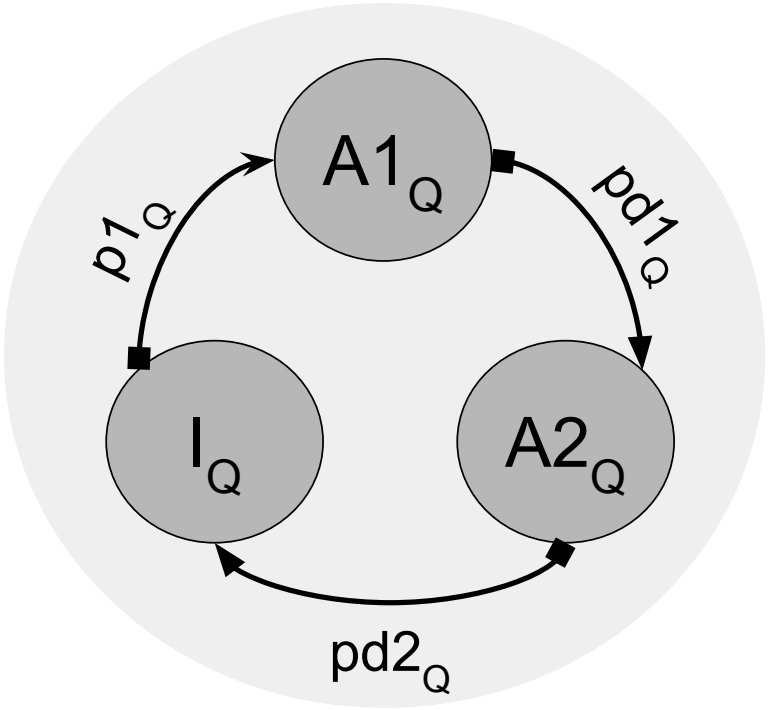


Figure 1.1: Visual representation of a SOP's single memory representation Q. Transition dynamics between the three states $A1$, $A2$ and I are regulated by the activation parameter $p1$ and two decay parameters $pd1$ and $pd2$. Links between the nodes demonstrate the direction of influence: arrow = excitatory influence (increase in proportion of elements at a given state), square = decrease in proportion.

cay from $A2$ than from $A1$ and consequently makes $A2$ of much longer duration. The transition of elements between $A1$ and $A2$ is behaviourally manifested as a reduction in intensity of approaching behaviour. The decay to Inactivity can also be accelerated by a presentation of new stimuli which would accelerate the decay.

A fundamental rule of SOP holds that the elements' activation must follow a certain path: $A1$ activation is followed by $A2$ and then decay into Inactivity. Elements cannot be evoked into primary activation ($A1$) from the primed activation ($A2$) without first being rendered Inactive, Figure 1.1 shows a schematic of a single representational node (memory representation) which, for representation Q, has three stores: $A1$, $A2$ and I. Transfer of elements between the stores is governed by the parameters $p1$, $pd1$ and $pd2$.

Because representational elements can only occupy one state at a time and must follow the decay flow from $A1$ into $A2$ and then into Inactivity (I). If a given stimulus Q is being presented repeatedly with a short interval (ISI), some proportion of its elements will still occupy the refractory state ($A2_Q$), hence reducing the proportion of elements available for recruitment into the primary activation ($A1_Q$); this is illustrated with computer simulation presented in Figure 1.2. This means that the repeated exposure of stimuli will result in a gradual reduction in the response to that stimulus, also known as priming. The SOP can account for it as an effect generated by the stimuli itself and the trace decay process described by the SOP. Such mechanisms, which lead to a reduction of responding to a stimulus as a function of repeated exposure, is referred to as self-generated priming (SGP, Wagner, 1976). However, because such priming depends on decay between all three states it will be an effect which is time dependent; an appropriately long ISI which would enable for a higher decay into the Inactive state would, according to the theory, eliminate the priming effect. In simple terms, the SOP's self-generated mechanisms enable priming because of the information processing cycle in which time plays the central role. Repeated stimulations, which are in close temporal proximity, will produce reduced response whereas those with longer temporal intervals will be more likely to produce a greater response. Hence SOP's SGP is a robust theoretic approach to explain the effects of short term habituation, which, according to Sharpless and Jasper (1956) is "one of the most fundamental properties of animal behaviour" (p. 655). Furthermore, as the SOP allows for the decay to be accelerated if another novel stimulus is presented, it can account for dishabituation, an effect by which a presentation of a novel stimulus reinstates the habituated response (Castellucci,

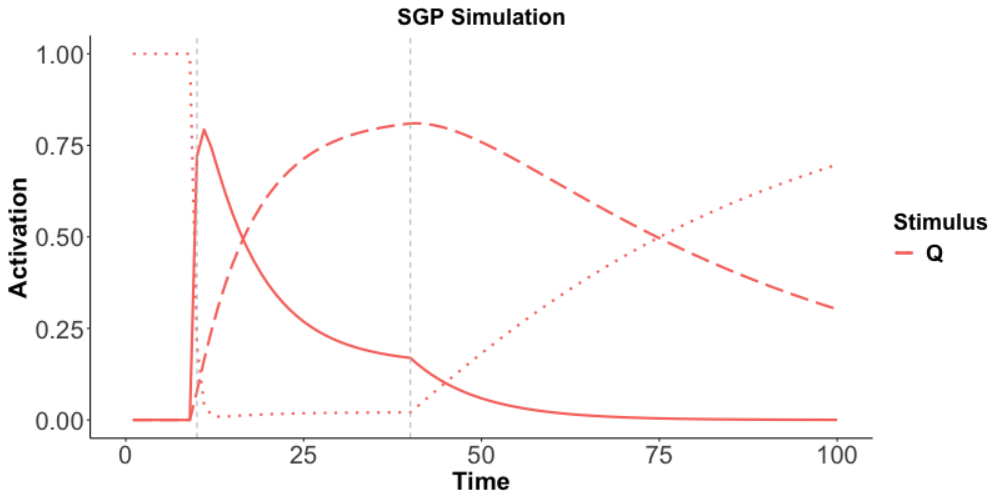


Figure 1.2: Simulation of SOP stimulus processing in SGP, single presentation. Proportion of elements in $A1$ (solid), $A2$ (dashed) and Inactive (dotted) states are plotted as a function of time (x-axis). Stimulus Q was presented between the 10th and 40th moments (vertical grey lines). Before stimulus presentation all elements are in Inactivity; upon the presentation the $A1$ activity increased rapidly reducing the amount of elements in the Inactive state. $A1$ decay is coincident with rise in $A2$ activation which persists after the offset of stimulus, reduction is $A2$ activity is coincident with return of elements to the state of inactivity. Simulation was run with parameters: $p1 = 0.8$, $pd1 = 0.1$, $pd2 = 0.02$.

Pinsker, Kupfermann, & Kandel, 1970).

1.1.1.2 Computation

The SOP provides quantifiable rules which describe the between-state activation dynamics behind the SGP. At any given moment (t), a proportion of elements of a memory representation of a stimulus Q in the $A1_{Q,t}$ (Equation 1.2) is equal to a difference between the elements activated from Inactivity by the parameter $p1_{Q,t}$ (salience of the stimulus Q at time t) and a proportion of elements which has decayed to the $A2_{Q,t-1}$ (according to the parameter $pd1_{Q,t}$). In a similar way, the amount of elements which are in $A2_{Q,t}$ (equation 1.3) is the difference between the amount of elements which have decayed from the $A1_{Q,t-1}$ and proportion which decays to the Inactivity (speed of such decay is regulated by the parameter $pd2_{Q,t}$).

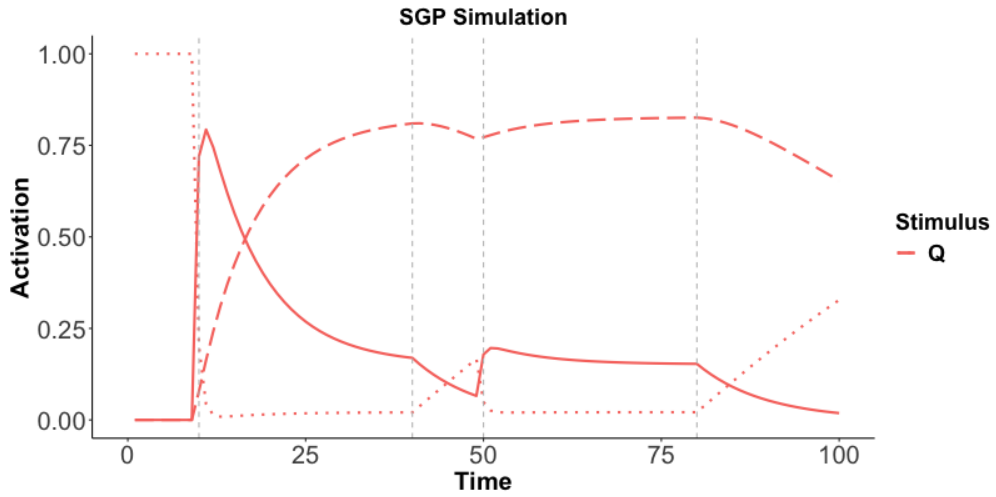


Figure 1.3: Simulation of stimulus processing in SGP, multiple presentations. Proportion of elements in $A1$ (solid), $A2$ (dashed) and Inactive (dotted) states are plotted as a function of time (x-axis). Stimulus Q was presented between the 10th and 40th and then between 50th and 110th moments(vertical grey lines). Prior to the first presentation all elements are in the Inactive state, then, upon stimulus presentation, $A1$ activation becomes the most profound but quickly decays to A2. Upon offset of stimulus (40th moment) the amount of elements in the $A2$ reduces, however as such the process is slow, the second presentation of stimulus at the 50th moment reduces the $A1$ activity. This is because elements which are in $A2$ cannot get into $A1$ without first being rendered Inactive. Simulation run with parameters: $p1 = 0.8$, $pd1 = 0.1$, $pd2 = 0.02$.

Both decay parameters $pd1_{Q,t}$ and $pd2_{Q,t}$ are free and can assume value $0 < x < 1$. As the capacity of $A1_Q$ is smaller than that of $A2_Q$ the decay rates follow the rule of $pd1_Q = 5 * pd2_Q$.

$$A1_{Q,t} = p1_Q I_{Q,t-1} - pd1_{Q,t} A1_{Q,t} \tag{1.2}$$

$$A2_{Q,t} = pd1_{Q,t} A1_{Q,t} - pd2_{Q,t} A2_{Q,t} \tag{1.3}$$

$$I_{Q,t} = pd2_{Q,t} A2_{Q,t} - p1_Q I_{Q,t} \tag{1.4}$$

The SOP assumes that the decay rates ($pd1$ and $pd2$) can be accelerated by a subsequent presentation of stimuli. This is reflected in a distractor rule for both parameters, which hold that (Equations 1.5, 1.6):

$$pd1'_{Q,t} = pd1_{Q,t} + \frac{A1_{X,t}}{C_1} \tag{1.5}$$

$$pd2'_{Q,t} = pd2_{Q,t} + \frac{A2_{X,t}}{C_2} \tag{1.6}$$

Where the decay rates ($pd1_Q$, $pd2_Q$) of representation Q are increased by a quotient of X's (the new stimulus presented) activation in $A1_X$ and $A2_X$ and constants C_1 and C_2. In a recent simulation paper (Uribe et al., 2019) both constants assume values of 2 and 10, respectively, which indicates the $^1/_5$ rule which has also been used to describe the $pd1$ and $pd2$ relationship. Thus, decay is a passive process, however it can be accelerated through interference from other stimuli which is processed concurrently or after the processing of stimulus Q. The SGP mechanism does offer a robust exploratory device which allows us to understand habituation,

however its dynamics are entirely non-associative and as such it would only be able to account for the short-term effects and could not explain the contextual influences on habituation observed by Tomsic, Pedreira, Romano, Hermitte, and Maldonado (1998), who demonstrated that crabs' escape response to a visual stimulus was influenced by change of environment between training and test phases: novel context disrupted habituation acquired during the training in a different context. However, the contextual specificity has been observed in orienting response and lick suppression (Jordan, Strasser, & McHale, 2000), but not in auditory startle response (Marlin & Miller, 1981). Similarly, problematic for the SGP would be the contextual influence on latent inhibition, reported by Hall and Honey (1989) could not be accounted for without reference to an associative mechanism. The SOP captures the associative influences on behaviour with the retrieval-generated priming RGP.

1.1.2 Retrieval Generated Priming

1.1.2.1 Description

In addition to the non-associative learning explained by the SGP, the SOP provides a second mechanism which in turn explains how two mental representations can enter into an associative relationship between one another. As in the case of the SGP, the focal issue here is how a given stimulus becomes primed, in other words, how a memory representation becomes active in the secondary state $A2$. Here such an event is enabled by a learned association between two stimuli, where a presentation of one retrieves the representation of another, hence the name: retrieval-generated priming (RGP). An important distinction is that the associatively primed representational elements will not enter into primary ($A1$) activation but the secondary ($A2$)

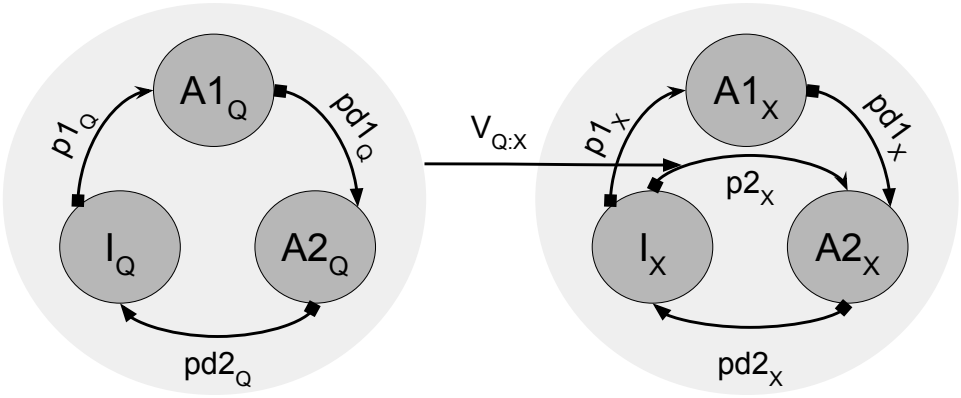


Figure 1.4: Visual representation of two nodes which have entered into an associative relationship whose strength is quantified by the value of $V_{Q:X}$. The retrieval mechanism enables the activation of X from the Inactive state into the secondary activation $A2$ when the stimulus Q is presented. The magnitude of such priming is described by the parameter $p2$. Links between the nodes demonstrate the direction of influence: arrow = excitatory influence (increase in proportion of elements at a given state), square = inhibitory (decrease in proportion).

directly from the Inactivity. Figure 1.4 presents a schematic of two nodes with an associative link.

First, for such retrieval to occur, the association needs to be established. In simple terms, the formation of an association between CS and US is a net difference between the amount of excitatory ($V^{+}_{CS,US}$) and inhibitory ($V^{-}_{CS,US}$) learning. Both types rely on a concurrent activation in the respective nodes, and the excitatory learning is a product of coincident $A1$ activation in both nodes, whereas inhibitory learning is a product of the amount of representative features being activated in $A1_{CS}$ and $A2_{US}$. In other words, when elements of both stimuli are in primary activation ($A1$), an excitatory associative link will be created between the CS and US. However, when one stimulus is in primary activation ($A1_{CS}$) but the other has already been processed and is in secondary activation ($A2_{US}$) then arrangement of representational elements will lead to an inhibitory associative link.

The associative strength ($V_{CS:US}$) quantifies the magnitude of relationship

between the representations of CS and US. This can be thought of as a link between two nodes, which will enable the retrieval process of US when CS is presented. When the net value of $V_{CS,US}$ is positive, then the presentation of the CS will activate elements of US representation. However, the representational elements of US will not be activated into the primary ($A1$), but directly into the secondary activation ($A2$) state, hence the mechanism of priming here will effectively diminish the proportion of representational elements which can be recruited into primary activation ($A1$). The elements will need to first decay into the Inactivity as there is no path between $A2$ and $A1$. A negative $V_{CS,US}$ will operate in the opposite direction, preventing elements from $A2$ activation. After Wagner (1981) action of an inhibitory link is best illustrated when a given US holds an excitatory association with one CS A ($V_{CSA,US} > 0$) and inhibitory with CS B ($V_{CSB,US} < 0$). When combined, both will result in a weaker priming of US, than when CS A is used on its own.

Wagner's formulation of SOP (Brandon et al., 2003; Wagner, 1981) asserts that no learning occurs when both nodes are in their $A2$ or Inactive states. However, this has been challenged by the work of Holland (Holland, 1981; Holland & Forbes, 1982; Holland, 1983; Holland & Sherwood, 2008) and Dwyer (Dwyer, Mackintosh, & Boakes, 1998; Dwyer, 2000).

Holland (1981) first trained animals with two auditory CS (*A* and *B*) with separate sucrose and flavour solutions (*SA* and *SB*), then one previously used auditory CS *A* was presented with a, sickness inducing, lithium chloride (LiCl) injection. The author observed that, in a test phase, animals consumed less of the flavour solution *SA*, despite not having any direct training with this flavour and LiCl. Authors argued that during the administration of LiCl presentation of the auditory CS *A*

primed the representation of *SA* into $A2$. This enabled the representation of *A* to enter into an excitatory association with representation of LiCl ($A1$) resulting in less consumption of flavour A on test. In a followup study Holland and Forbes (1982) used same initial training, however in the second stage both sucrose solutions were paired with LiCl injections. In a following extinction phase the authors presented the auditory CS *A* on its, and after this, tested the animals with the two sucrose solutions, observing that animals consumed more of the solution *SA* over *SB*. Here, authors argued, they demonstrated an indirect extinction of the *SA* and LiCl association through indirect activation of the SA representation by the auditory CS *A*. The results of both experiments has led to a proposed modification of the SOP (Holland, 1983) which argued that when the CS is in $A2$ and US in $A1$ the arrangement will result in a excitatory association.

Dwyer and colleagues (Dwyer et al., 1998; Dwyer, 2000) as well as Aitken and Dickinson (2005) and Dickinson and Burke (1996) argued for a different associative rule modification. In Dwyer et al. (1998) the authors first presented animals with two flavours in two distinct contexts: *CX1* was paired with a peppermint and *CX2* with an almond and sucrose mixture. In a second training phase, the animals were split into two groups; both were given almond flavour, but in group one this was done in *CX1* and *CX2* in the other. At test, both groups were presented with peppermint solution but the animals in group *CX1* demonstrated a greater preference. The behaviour observed at test has been attributed to an excitatory learning between the $A2$ primed representations of peppermint and sucrose in *CX1* group. In this group, the representation of peppermint is activated by an association with *CX1*; concurrently the associative link between the almond flavour and sucrose primes the

Table 1.1: Comparison between the associative rules postulated by Wagner (Wagner, 1981; Brandon et al., 2003), Holland (Holland, 1981; Holland & Forbes, 1982; Holland, 1983) and Dwyer (Dwyer et al., 1998; Dwyer, 2000), Dickinson (Dickinson & Burke, 1996; Aitken & Dickinson, 2005). CS and US columns indicate activation state which either stimulus assumes and remaining three columns show the associative result; excitatory V^+, inhibitory V^- or no learning. * - Holland and Sherwood (2008) and Wheeler et al. (2008) revised their account of $A2$ - $A2$ learning

CS	US	Wagner	Holland	Dwyer & Dickinson
$A1$	$A1$	Excitatory	Excitatory	Excitatory
$A1$	$A2$	Inhibitory	Inhibitory	Inhibitory
$A2$	$A1$	Inhibitory	Excitatory	Inhibitory
$A2$	$A2$	No learning	Inhibitory*	Excitatory

latter into $A2$. The preference for peppermint in group *CX1* is an evidence for $A2$ - $A2$ excitatory learning, argued the authors. In the followup experiment Dwyer (2000) divided animals into six groups, however the results from *P*+ and *P*- groups provided the data of most importance. In both groups, the animals were first given almond solution in the *CX1*, then in second training phase the *P*+ group was given peppermint and sucrose solution in *CX2*, whereas the *P*- group received peppermint and quinine in *CX2*. During the treatment phase both groups were given peppermint solution in *CX1*, however when tested with almond solution the *P*+ group demonstrated the strongest consumption, whereas the *P*- animals consumed least of all groups. The author argued that in the treatment phase representation of the almond was primed by the presentation of *CX1* and the peppermint flavour activated either the sucrose (*P*+) or quinine (*P*-) and that such pattern of activation enabled a excitatory association with almond and sucrose or quinine.

To resolve the evident conflict between the postulated associative rules, summarised in Table 1.1, Holland and Sherwood (2008) obtained evidence supporting the indirect excitatory association resulting from concurrent $A2$ activation

of primed representations. The authors observed that when separate visual CS are paired with tone and sucrose, presentation of both visual CS, which would activate the tone and sucrose representations, will result in behaviour indicative of excitatory learning. Animals demonstrated expectation for food then primed with tone, despite no direct training concurrent tone and sucrose. However, as demonstrated by Wheeler et al. (2008), the authors demonstrated that the temporal arrangement of associates signalling the tone and sucrose may be of crucial importance, the summary of the findings is presented in Table 1.2. When both light CS were presented together or when the signal for the sucrose was presented before the one for the tone the authors observed inhibitory learning, however when the $A2$ representation of the tone was primed first and representation of sucrose followed, the resulting relationship was excitatory. Hence, the evidence shows that excitatory learning can occur between indirectly activated memory representations, but if and only if the order of presentation of their associates (signals) follows the $CS_{A2} \rightarrow US_{A2}$. The most recent description of SOP (Vogel et al., 2019) does not incorporate the $A2$ - $A2$ learning rules and the characteristics of stimulus which enable associations remain a matter for future studies (Holland & Sherwood, 2008).

1.1.2.2 Computation

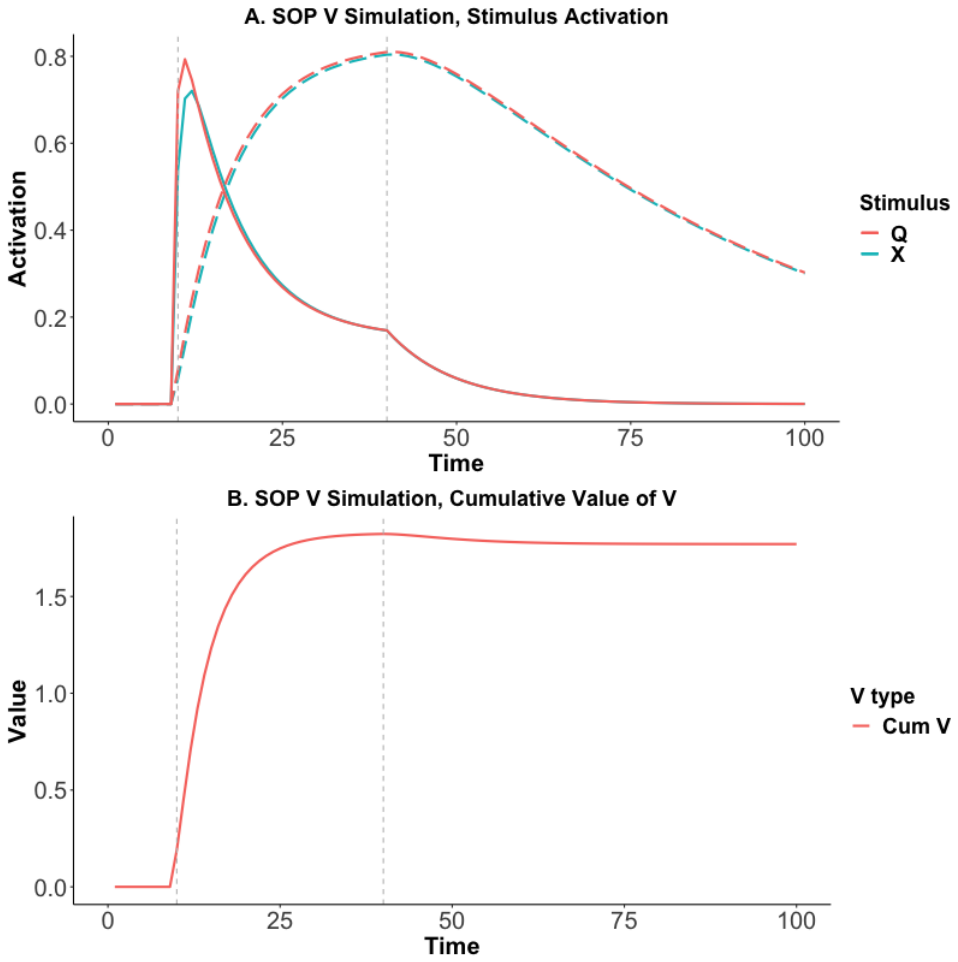
Formally, the process of association between representations is captured by the following Equation 1.7 which demonstrates it in the case where two stimuli Q and X are presented together:

$$V_{Q:X} = (A1_{Q,t}A1_{X,t}L^{+}) - (A1_{Q,t}A2_{X,t}L^{-}) \tag{1.7}$$

Table 1.2: Summary of the key findings from Wheeler et al. (2008) and Holland and Sherwood (2008). In three conditions authors presented animals with the same training in phase 1: visual stimuli P and Q were followed with either tone (T) or sucrose (Su), in the phase 2 the signalling stimulus was either presented as a compound (simultaneous) or in order (forward and backward). The authors demonstrated that when the representations of T and Su were primed at the same time the $A2$ - $A2$ association between the T and Su was inhibitory. Same effect resulted from backward order: when the $A2$ representation of Su preceded that of the T. However, when the T was primed first and Su followed, the T acquired excitatory association with Su.

Condition	Phase 1	Phase 2	$A2$ Order	Effect
Simultaneous		P + Q	T + Su	Inhibitory
Forward	P $\rightarrow$ T / Q $\rightarrow$ Su	P $\rightarrow$ Q	T $\rightarrow$ Su	Excitatory
Backward		Q $\rightarrow$ P	Su $\rightarrow$ T	Inhibitory

Here, at a given time (t), the associative strength between the representation of CS Q and US X ($V_{Q:X}$) is calculated as a difference between two terms: excitatory, $A1_{Q,t}A1_{X,t}L^{+}$, and inhibitory, $A1_{Q,t}A2_{X,t}L^{-}$, learning products. The former is a three-part product of the proportion of elements of Q activated in $A1$, the proportion of activated elements of X in its respective node and an excitatory learning rate parameter (L^{+}). The latter part follows in a similar fashion, but here the amount of $A1$ activation of Q is multiplied by the amount of $A2$ activation of X and the inhibitory learning rate parameter (L^{-}). Whereas both the proportion of elements activated in $A1$ and $A2$ can be calculated from the dynamics of activation described in Equations 1.2, 1.3 and 1.4, both learning constants are set *a priori*. Literature does not elaborate on their nature apart from their relationship in magnitude with the inhibitory (L^{-}) constant being $^{1}/_{5}$th of the excitatory one (L^{+}) (Brandon et al., 2003). The sign of $V_{Q:X}$ indicates the character of the association; 0 means that there is no association between the two, negative values signify an inhibitory relationship and a positive value of $V_{Q:X}$ means that Q will have an excitatory relationship on X. A computational simulation of V is presented in Figure 1.5, where three panels



present the activation and cumulative V at each time point and underlying changes in associative strength.

The RGP is enabled by a prior association between stimuli representations, where a presentation of a given stimulus (Q) indirectly primes representation of another stimulus (X), transferring its representational elements into the $A2$ state. This indirect activation from Inactivity in the $A2$ state is regulated by a parameter

Figure 1.5: SOP Simulation of V between stimuli Q and X. **Panel A** presents the activation (y-axis) of $A1$ (solid) and $A2$ (dashed) for Q (red) and P (blue), time is on the x-axis and concurrent presentation lasted for 30 moments between the 10th and 40th moment (grey vertical lines mark the onset and offset). **Panel B** presents the cumulative value of V (y-axis) at each time point (x-axis). Stimulus intensity of Q was set as $p1 = 0.8$ and for X it was $p1$ = 0.6, both stimuli had the same decay parameters $pd1$ = 0.1 and $pd2$ = 0.02. Excitatory learning parameter was set as L^+ = 0.5 and inhibitory L^- = 0.1.

$p2$ which quantifies the proportion of elements of X which will be activated. For primed stimulus X at a given time (t), $p2$ follows the equation:

$$p2_{X,t} = V_{Q:X}(r_1 A1_{Q,t} + r_2 A2_{Q,t}) \tag{1.8}$$

Here, the amount of elements which will be primed into the $A2$ state depend on the associative strength between the two stimuli; its value scales the remainder of the equation and so if $V_{Q:X} = 0$ there will be no priming. The following term takes the respective proportions of $A1$ and $A2$ activation of the signalling stimulus (Q) which both are weighted by parameters r_1 and r_2. The relationship between the two indicates that the proportion of elements in the primary activation, $A1$, is a stronger force than the $A2$ counterpart, as the size of r_2 is $^1/_5$ of that of r_1. In other words, the number of elements primed by the associative link is dictated by the associative strength between stimuli and the activation of the signalling stimulus, chiefly its primary activation. Recent literature (Uribe et al., 2019; Vogel et al., 2019) proposed a modified $p2$ parameter which removes the weighted $A2$ activation out of this Equation:

$$p2_{X,t} = V_{Q:X} A1_{Q,t} \tag{1.9}$$

In such a formulation, the $A2$ priming only exercises its effect through the $A1$ activation of the signalling stimulus. Weights r_1 and r_2 are also removed from this updated model, but as they are chosen arbitrarily, it can be assumed that $r_1 = 1$ and $r_2 = 0$. Here, there is no priming generated directly from the $A2$ unit of the signalling stimulus and, as is the weight was $^1/_5$ of that of $A1$, on the face of it may appear, that the change is negligible. However, as the $A1$ activity is transient,

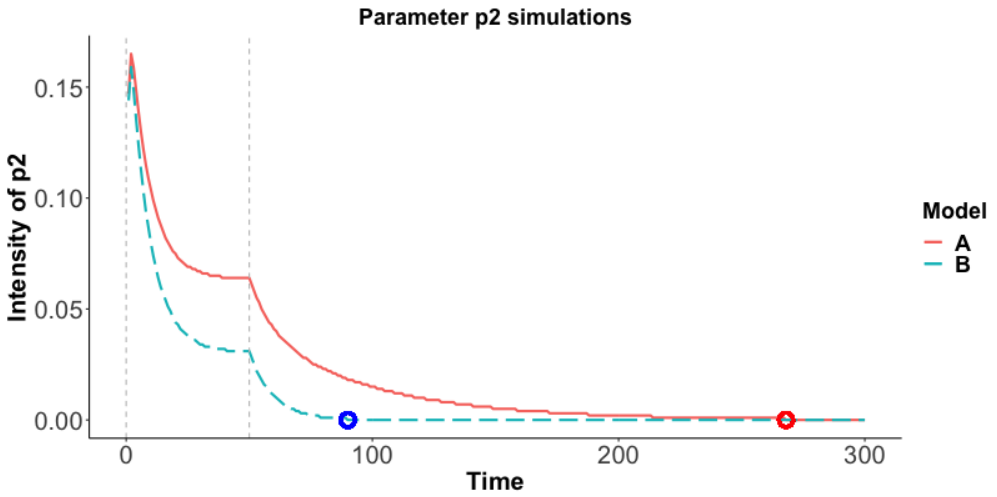


Figure 1.6: Outcomes of computational simulation of two models of the associative priming parameter $p2$. *Model A*, in red solid line, represents the formulation first offered by Wagner and Donegan (1989), *model B*, in blue dashed line, is the formulation by Uribe et al. (2019) and Vogel et al. (2019). Time, in moments, is on the x-axis and value of $p2$ is on the y-axis. Grey dashed line presented the onset (at 0) and offset (at 50) of stimulus Q, blue and red points demarcate the time point at which the $p2$ predicted by *Model A* (red, reaches 0 at time 268) and *B*, (blue, reaches 0 at time 90). All other parameters were set equal for both models and were: $p1 = 0.8$, $pd1 = 0.1$, $pd2 = 0.02$, $V = 0.2$. Weights, r_1 and r_2, for *Model A* were set as 1 and 0.2. Values of $p2$ were rounded to the 3rd decimal point.

the exclusion of $A2$ driven associative priming results in a brief temporal window during which priming can be observed. First, I would like to demonstrate the difference between the original formulation of $p2$ (Wagner & Donegan, 1989), later as *Model A*, and the one offered by Uribe et al. (2019) and Vogel et al. (2019), *Model B*. and to that end I have run a computer simulation of both models and the output is presented in Figure 1.6. Assuming the parameters of $p1_Q = 0.8$, $pd1_Q = 0.1$, $pd2_Q = 0.02$ and a stimulation lasting 50 moments from moment 1 the associative strength $V_{Q:X}$ was set as 0.2 for both models. To keep the priming generated by the $A1$ unit activity the first weight (r_1) of *Model A* was set as 1 and the second (responsible for the scaling of $A2$ activity) as 0.2, because of that the associative priming generated from the $A1$ activity is equal and the models differ only in their respective activity generated from the secondary activity unit ($A2$). As anticipated

the two models resulted in different patterns of $p2$ activation with the Wagner and Donegan (1989) *Model A* offering a stronger and longer lasting priming. The $p2$ generated by the *Model B* reached 0 at 90th moment whereas the one generated by the *Model A* had a much slower decay and maintained its value above zero until the 268th moment of the simulation. Authors (Uribe et al., 2019; Vogel et al., 2019) have not provided any theoretical or empirical justification as to why such a model has been employed, however one justification may lie in the character of their simulations. As they have modelled between-trial effects of habituation, they were not concerned with the much slower acting priming from $A2$ units. In fact, Uribe et al. (2019) explicitly stated, that the only value that has not been reset after each simulated trial was the associative strength V. Perhaps justified, given the design of simulations in Uribe et al. (2019), the $p2$ formulation used there would not be able to account for the effects of priming observed by Whitt, Haselgrove, and Robinson (2012) who reported that a presentation of a context associated with a given stimulus produced reduction of its exploration. Critically, however the context preceded the presentation of test stimuli and under the more recent $p2$ formulation (*Model B*) this effects would be much less likely than under the *Model A* as the magnitude of priming and duration of thereof is stronger and longer after the offset of the signal. Hence, at least in the context of recognition memory, it would be more appropriate to resort to the model which relies on both activation units as described in Wagner and Donegan (1989).

Figure 1.7 presents the RGP activation predicted by both $p2$ formulations. For both, however, the $A1$ activity is substantially reduced for primed stimulus P, the difference in temporal extent of $p2$ priming, longer in Wagner and Donegan

(1989) and presented in panel A, is emphasised with the gradient of $A2$ activation following the stimulus offset. When compared to the unprimed stimulus Q, data in panel A suggests that priming effects persist for much longer after the stimulus offset whereas in panel B the effects of priming are vastly limited to the inhibition of $A1$ activity during the time that stimulus is presented, after the offset the effects are not different than those observed in unprimed $A2$ decay.

In summary, the SOP model of learning, memory, and behaviour provides a computational description of how a stimulus is processed. The key theoretical tenet here is that memory representations can be activated in two ways, primary $A1$ and secondary $A2$, both having different capacities and temporal duration. In some cases both units can produce qualitatively different behaviours, but in the context of recognition memory the difference is quantitative; $A1$ results in transient and vigorous orientation to the stimulus whereas $A2$ causes weaker but longer response. Response to a stimulus can be weakened by either a repetitive or prolonged presentation , where such an effect is self-generated, or indirectly through a presentation of an associated stimulus which retrieves the representation from Inactive to the $A2$ state.

1.1.3 Response Generation

Thus far, all presented mechanisms produce effects which are covert and cannot be directly observed on the level of behaviour without passing through the response function, *R*. According to the SOP theory, the response is a function of weighted $A1$

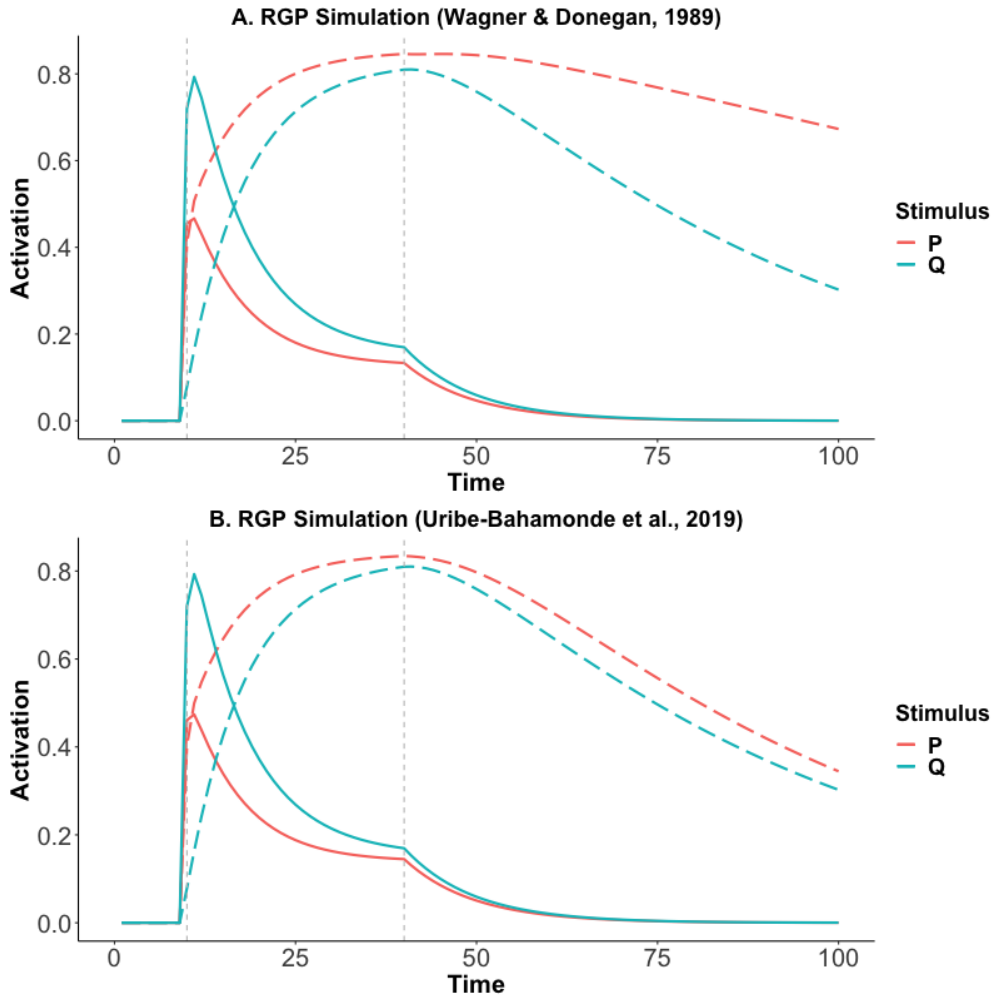


Figure 1.7: Simulations of RGP process in the SOP. **Panel A** presents outcomes from a simulation using $p2$ based on Wagner and Donegan (1989), as in Equation 1.8, and **panel B** data from a simulation using $p2$ from Uribe et al. (2019), as in Equation 1.9. For both stimuli Q (blue) and P (red) and X (not plotted) were presented between the 10th and 40th moments (grey vertical lines). $A1$ activity is plotted in solid and $A2$ in dashed lines for both Q and P. Stimulus P had a prior association with X which was of $V_{X:P} = 0.5$. Q, P and X were entirely inactive before the onset of stimuli, all three were presented with intensity of $p1 = 0.8$ and their decay rates were set as $pd1 = 0.1, pd2 = 0.02$. Because of the prior association the $A1$ activity of P was reduced due to recruitment of representational elements from Inactivity to $A2$ state. For the Wagner and Donegan (1989) simulation in panel A, weights were set as 1 and 0.2 respectively for r_1 and r_2.

and $A2$ activities and response to a stimulus Q is formally presented as:

$$R_Q = f(we_1 A1_Q + we_2 A2_Q) \tag{1.10}$$

The two weighting factors we_1 and we_2 are regulating how much of each activity unit contributes to the behaviour. Whereas we_1 assumes always a positive value, the second weight can assume any value. According to Mazur (2016) this leads to three different behavioural outputs; if the value of we_2 is equal to 0, then the behaviour will be only generated from the primary activity $A1$ with $A2$ output being silent. Here, the response will be transient and limited to only to the stimulation period as $A1$ decay is rapid. Alternatively, we_2 can assume a positive value which, depending on the magnitude of we_2, will result in a response which sums with the one generated from the primary activity. In such a case, the behaviour will be observable after the stimulation, but it will be only different from the one generated from $A1$ in intensity. Finally, if the assumed we_2 is negative the secondary activation will result in a response which will be opposite to the one generated by the primary activity and, as $A2$ follows $A1$, the pattern of behaviour in response to the stimuli will change as a function of time. Hence, the activation process can result in a situation when both $A1$ and $A2$ elements generate behaviour qualitatively similar, one that will reduce in intensity as a function of time or, in some cases, both units will produce different and opposing responses. Hence, the SOP is occasionally referred to as Sometimes Opponent Process. To specify the quantifier *sometimes* Mazur (2016) argued that the difference lies in the structure of the unconditioned response (*UR*). If the unconditioned stimulus Q generates an response

which has only one phase (monophasic response) then the learned, conditioned response (*CR*) will sum with the one generated by Q; however if the response to Q has two phases, then the *CR* will be in the opposite direction. The most common behaviour in which the opponent process can be observed are the responses caused by pharmacological stimuli. Here, the primary response is followed by *compensatory* rebound and presentation of an associated cue can evoke the secondary response, as suggested by SOP (Siegel, 2005).

As such, the activation states and their real-time dynamics must have a latent neuronal correlate but cannot be directly observed as an overt behaviour; however SOP does not aspire to be a biologically plausible model in a sense of neural circuitry. Yet, the model could potentially lend itself to analysis and an attempt has been made by Wagner and Donegan (1989) who have applied the SOP theory to model rabbit's eye blink conditioning. In this preparation, the authors were able to isolate two distinctly different responses which mapped onto $A1$ and $A2$-related processes and certain subcortical structures which could be involved. Despite encouragement from Wagner and Donegan (1989) to the best of my knowledge, no further systematic attempts to map the SOP onto the neural architecture have been made.

1.1.4 Summary

Despite its parsimonious character, the simple tenets of the SOP carry some profound consequences which lead to a complex network of relationships and influences, and a multilayer structure which spans the domains of learning, memory and behaviour generation. Figure 1.8 presents a relationship diagram for the two nodes

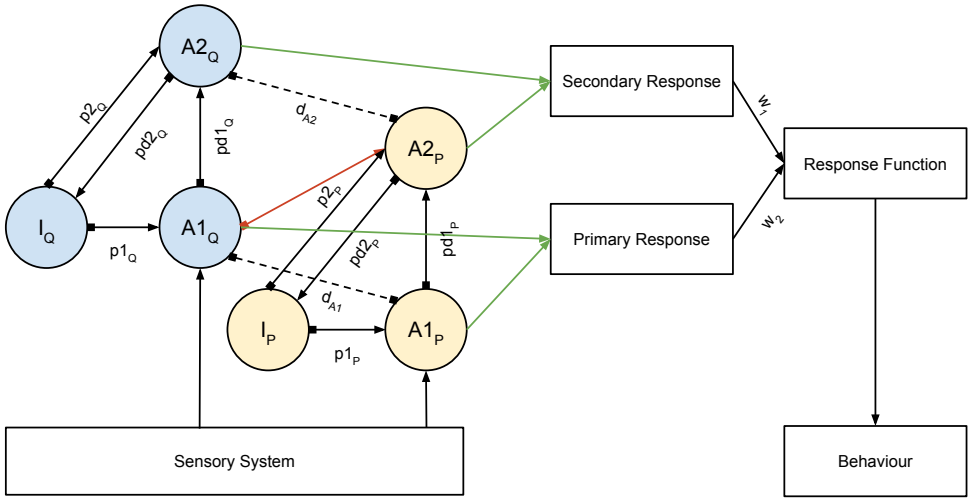


Figure 1.8: SOP as a complex network with two nodes Q (blue) and P (yellow) plotted with their influences. Sensory system stimulates both primary activation nodes $A1$ according to parameter $p1$ and the activation follows the SOP activation life cycle according to parameters $pd1$ and $pd2$. An association between Q and P is plotted as a red path and the response generation contributions as green paths. Inhibitory influence is marked as square and excitatory as an arrow. Inhibitory links which result from the $A1$ and $A2$ capacity are plotted in a dashed line (d_{A1}, d_{A2}). Adapted after: Wagner and Donegan (1989); Vogel et al. (2019).

with their excitatory and inhibitory connections as well as memory and response layers.

The SOP is a computational, real-time abstraction of processes which are involved in learning and memory. It describes how behavioural effects, learning, and memory arise from latent mechanisms of memory representation activation, and associative learning. Memory representation can assume two activation states, $A1$ and $A2$ characterised by different behavioural and learning properties summarised in Table 1.3. Central to the theory is the notion of priming, a process by which a stimulus' representation becomes $A2$ activated. This can occur as a result of prolonged or repetitive stimulus presentation, self-generated SGP, or by prior association with a signalling stimulus, retrieval-generated RGP.

The SOP is a unique theory of learning and memory as it provides com-

Table 1.3: Summary of key features of SOP activation states and their behavioural outputs.

Characteristic	$A1$	$A2$
Duration of activation	Short term	Long term
LTM dependent	Not, only evoked through stimulus presentation	Yes, activation from another representation (indirect), but also through decay from $A1$ following stimulus presentation
Attention	Focal	Peripheral
Storage capacity	Small	Large
Response type	*UR*	*UR*, *CR*
Response contribution	Excitatory behaviour	Excitatory, inhibitory or silent behaviour
Activation onset	Early	Late
Response activated by	*US*	*US*, *CS*
Behaviour in the context of recognition memory	Approach, increased looking time	Habituation, decrease of looking time

putational rules for a number of psychological phenomena and their behavioural consequences. The system encompasses attention, working and long-term memory, learning and behaviour generation, as well as providing quantifiable relationships between them.

The model provides a robust account for the results obtained by Davis (1970). The author observed that previous research has not distinguished between the ISI and RI and that the time plays an important role in habituation of orienting response. To that extent, he tested how varying lengths of both experimental parameters influence the startling reaction (SR) to a loud tone. Davis (1970) first separated two experimental groups of rats; one that will undergo the habituation training with 2 s and one with 16 s ISI. Both groups were first prehabituated with series of tones on 2, 4, 8 and 16 s ISI. In both groups the SR increased as the ISI got longer, conversely shorter ISI resulted in greater habituation. Then, during the habituation training both groups received series of 1000 trials, each group with their respective ISI. The 2 s group demonstrated a greater habituation than the 16 s, a re-

sult consistent with the observation from the prehabituation session. During the test phase (posthabituation) both groups received the same treatment with either the ISI of 2, 4, 8 or 16 s between the tones and with RI set at either 1 min or 24 h. When the RI was at 1 min the group which received training with 2 s ISI demonstrated higher SR at all four ISI, whereas the 16 s group demonstrated a stronger habituation at all ISI levels. At the RI of 24 h similar pattern of results was observed; the 16 s group demonstrated stronger habituation to the tone than the 2 s group.

The behaviour during the prehabituation session and habituation training was consistent with the notion that habituation is greater when the ISI between the stimuli is shorter. The SOP's SGP mechanisms explains such reduction with lack of decay from $A2$ activation. However, the same explanation cannot be used when, after a fixed RI, both groups are subjected to a same test, however the one with 16 s ISI demonstrates a stronger habituation than the one which was trained with 2 s ISI. The SOP's account for this observation, as longer ISIs allowed for more of elements to decay to I to be activated into $A1$ during the next trial. More elements in $A1$ led to a better association between the tone and shock. The result has led the author to the conclusion that the resulting behaviour is caused by two types of learning: one that is short-term and explains the stronger habituation to a more frequent stimulus, and another that is longer lasting and could account for the stronger habituation in animals which have received a training with a longer ISI. The results suggest, that habituation of orienting response relies on two mechanisms: one that is short term and a consequence of repetition in close succession, and one which effects can be observed for longer time. Such mechanisms are precisely captured with SOP's SGP and RGP.

In Lubow and Moore (1959) study, a group of sheep and goats were first presented with visual stimuli without any reinforcement. Then, in a following phase, the same animals were presented with a previously shown stimulus followed by a foot shock and a novel visual stimulus followed by the same intervention. The authors observed that the preexposeure to a stimulus has led to a slower learning of the stimulus - shock association and concluded that the not reinforced preexposure to a stimulus can impair later learning; a process since known as latent inhibition. Here, the SOP offers two explanations; as the ISI was set at 30 - 150 s and the delay between the phases was 2 min, it may be possible that the stimulus representation has not fully decayed into the inactive state when phase 2 was administered. Hence, the novel stimulus had a greater chance of being activated into $A1$, which resulted in stronger association between the novel stimulus and shock. Alternatively, during the phase 1, animal could have associated the context of the stock, in which it was placed, with stimulus. The context then primed the representation of the preexposed stimulus into the $A2$ which reduced its associative ability. Because the novel stimulus had not had such association, its representation could have been evoked into $A1$ yielding stronger association between the novel stimulus and the shock.

Using the spatial learning paradigm Sanderson et al. (2010) tested the dual process account offered by SOP. When two groups of mice, one with training phases separated by 1 min and one with this time being 24 h, were presented with a Y-maze with one arm blocked and then given an opportunity to explore the novel arm at test. When test was performed after 1 min both groups demonstrated a similar magnitude of preference for the novel arm. However, when the RI was set at 24 h, animals which were trained with ISI of 1 min demonstrated low nov-

elty preference, when the ones trained with 24 h ISI still demonstrated a novelty preference. Here, the effects of novelty obtained at the short RI can be attributed to SGP as the representation activated during the last iteration of a training was still A2-activated, however in the long RI the effect can only be attributed to the RGP and follows the SOP predicted facilitated learning with spacing presentations. In a separate experiment, the authors investigated how ISI and training durations influence the novelty preference after 24 h RI. All animals received the same number of training trials with the same ISI, however one group had the duration in the maze set as 2 min while the other had 24 s for each training. Greater novelty was observed with animals which total training time was longer, indicating the duration of exposure training influences the RGP-enabled novelty preference effect. When two, 10 min long, training phases were presented with either a 24 or 216 h ISI the novelty preference was lower than when 10 training phases were administered with 24 h ISI. Hence, both the duration of ISI and presentation time had an influence on habituation to familiar arm and conversely time spent exploring the novel arm of the maze. Thus, the authors have demonstrated that the basic form of learning, habituation, depends on two mechanisms which are well predicted by SOP; short term non-associative SGP and a long-term associative RGP.

Mainstream theories of recognition memory, such as the episodic approach (Yonelinas, 2001; Aggleton & Brown, 1999, 2006) and related dual model of recollection and familiarity (Yonelinas, 2002) are only described in terms of natural language and statistical summary of the data (Yonelinas & Parks, 2007; Yonelinas, 1997), however useful and valid, such models are of limited explanatory power as their purely descriptive character does not answer the question of how certain recog-

nition memory effects are observed. SOP on the other hand, provides rules by which experimental data can be described, but also what mechanisms generate observed behaviours, giving a more complete insight into the problem at hand. Furthermore, the SOP, relying on its credibility as a robust model of classical conditioning, allows for recognition memory to be interpreted within a context of adaptive behaviour, in other words, why certain behaviours are observed and what biological factors enable it. Therefore, the SOP spans across all three levels of model complexity types: it is descriptive, mechanistic and interpretative in nature (Dayan & Abbott, 2001). Perhaps the most profound advantage of the SOP over the mainstream recognition memory theories is its ability to generate novel hypotheses, which being based on numerical simulations, provide quantifiable hypotheses. As any other model (Rosenblueth & Wiener, 1945), the SOP is an abstraction of reality and a hypothesis and its predictions must be experimentally tested, hence it is the aim of this thesis to describe human recognition memory in terms of the SOP, generate derived from the model predictions and to experimentally test those.

2 | Recognition Memory

In this chapter, I will outline the procedures used in animal and human recognition memory research, that human analogues have been developed for the purpose of this thesis. I will then turn to the matter of the associative account of recognition memory and evidence supporting it. Current mainstream theories relating to human recognition and episodic memory are to be described briefly and I will present findings from conceptually related human studies.

2.1 Procedures for Assessment of Recognition Memory in Non-human Animals

Research on recognition memory in animal models, mainly rodents and non-human primates, has largely focused on two experimental methods: Spontaneous Object Recognition (SOR, Ennaceur & Delacour, 1988; Ennaceur, 2010, also known as Novel Object Recognition, NOR, or Object Recognition, OR tests) and Delayed Match to Sample (DMTS, and its modification Delayed Non Match to Sample, DNMTS). Of the two, the latter requires multiple phases of training as an animal is rewarded for selecting a certain stimulus which is either one that is familiar (DMTS) or one that is novel (DNMTS). In both versions of the task, an animal must first learn the rule, which if not acquired, may mimic the performance attributed to recognition (Dix & Aggleton, 1999). On the other hand, the SOR does not require an extensive training period, the stimulus is usually presented once in the sample phase and once at test, and does not involve reward or punishment, so that the target behaviour is

free from reward processing confounds. Furthermore, the SOR can be easily modified; ISI or RI duration can be manipulated as well as the number and contents of presentations. From such manipulations, three are of importance in the context of this thesis (Robinson & Bonardi, 2015), namely the Relative Recency, RR (Mitchell & Laiacona, 1998; Hannesson, Howland, & Phillips, 2004a; Hatakeyama, Sugita, Yamada, & Ichitani, 2018; Hotte, Naudon, & Jay, 2005), Object-in-Place, OIP (Nelson, Cooper, Thur, Marsden, & Cassaday, 2011; Barker, Bird, Alexander, & Warburton, 2007; Good, Barnes, Staal, McGregor, & Honey, 2007; Dere, Huston, & Silva, 2005; Dix & Aggleton, 1999; Langston & Wood, 2010; Tam, Robinson, Jennings, & Bonardi, 2013), and Object-in-Context, OIC (Tam, Bonardi, & Robinson, 2014; Barker & Warburton, 2020; Honey, Marshall, Mcgregor, Futter, & Good, 2007; Langston & Wood, 2010; Dix & Aggleton, 1999; Eacott & Norman, 2004; Honey & Good, 2000; Honey, Good, & Manser, 1998). I will first describe the behavioural paradigms with the theoretical account of SOP presented in the Associative Account of Recognition Memory, section 2.2, below.

2.1.1 Spontaneous Object Recognition

The SOR preparation (Ennaceur & Delacour, 1988; Ennaceur, 2010), in its basic form, involves two phases of stimulus presentation: sample and test separated by an RI, the schematic design is presented in Table 2.1. During the sample phase, an animal is given two identical objects (PP) for free exploration, then an animal is removed from the arena and two objects are replaced with a copy of the familiar object, presented in the sample (P), and a novel one (Q). Animal returns to the arena and is given time to explore the two test objects freely. A typical outcome

Table 2.1: Basic design for the SOR experiment, sample phase during which a pair of stimuli PP is shown is followed by a RI of choice. At test a copy of P is presented together with a novel stimulus Q. A typical response is that an animal will spend more time exploring the novel stimulus Q over the pre-exposed P. Extension of the RI results in reduction of the novelty preference (Tam et al., 2013).

Sample	RI	Test
PP	$\rightarrow$	QP

is that the novel object Q is explored for a longer time than the preexposed one. The effects of SOR were demonstrated to be time dependent, Tam et al. (2013) demonstrated that, when the RI is extended from 5 m to 2 h, the discrimination ratio reduces, suggesting less dwell towards Q. Commonly used as a recognition memory procedure, the SOR has been described as a cross-species memory evaluation tool (Raber, 2015).

2.1.2 Relative Recency

Derived from SOR is the test of Relative Recency, RR (Mitchell & Laiacona, 1998), a procedure in which an animal is first presented with two sample phases, each consisting of free exploration of two objects (QQ then PP), divided by a ISI. Then after RI, copies of each of the sampled objects (PQ) are presented together for test exploration; the schematic of the procedure is presented in Table 2.2. Animals usually explore a more temporally distant object more than the recent one, however, the preferential exploration of the less recent Q is time dependent and manipulation of either the ISI or RI modifies the effects. Tam et al. (2013) demonstrated that extension of the sample-to-sample ISI from 5 m to 2 h extended the amount of preferential exploration of the less recent stimulus Q. Increase in RI, however reduces the preference towards Q, as demonstrated by Mitchell and Laiacona (1998).

Table 2.2: Experimental procedure for the RR. During the first sample a pair of stimuli QQ is presented for free exploration, then after a ISI of choice animal is given a pair of stimuli PP. After a RI a copy of Q and P is presented for the test. A typical outcome is that the animal will spend more time exploring the less recent stimulus Q over the recently presented P. Both extensions of ISI and RI modify the effects obtained at the test. As the time between the two sample phases gets longer so will the preference for Q at test (Tam et al., 2013), longer RIs result in elimination of preference for either of the test stimuli (Mitchell & Laiacona, 1998).

Sample 1	ISI	Sample 2	RI	Test
QQ	$\rightarrow$	PP	$\rightarrow$	PQ

Performance on the RR can be disrupted by interference with the prefrontal cortices (Mitchell & Laiacona, 1998; Hannesson et al., 2004a; Barker et al., 2007) leaving the performance on the SOR spared. Hippocampal manipulation by (Good et al., 2007) indicates a potential involvement of Hippocampus in the effect of recency as lesion of this structure resulted in a reduction of preference towards the less recent stimulus.

2.1.3 Object in Place and Object in Context

Both procedures use modulation of the contextual (spatial or nonspatial) as key independent variables. There are multiple versions of the OIP preparations, but key element of each is the change in the spatial location of test stimulus in relation to sample presentation, Table 2.3 presents an example procedure. Some adaptations of the procedure (Langston & Wood, 2010; Dix & Aggleton, 1999; Nelson et al., 2011; Hotte et al., 2005) first presented a sample consisting of two different objects (PR, where P is on the left and R on the right), then after an RI, two copies of one of the objects are presented for test (P and P', indicating respectively left and right copies of P). Both objects are identical to the objects presented in the sample phase, however, the one presented in a novel location (P') is usually explored more. In an

Table 2.3: Basic design for the OIP experiment, sample phase during which a pair of stimuli PR is shown, P on the left and R on the right side of the screen or arena. Sample is followed by a RI of choice and test phase. At test two copies of stimulus P are presented, one on the left (P) and one on the right (P'). A typical response is that an animal will spend more time exploring the copy P' presented in a novel location over the pre-exposed and presented in the same location (P). Extension of the RI results in reduction of the novelty preference (Tam et al., 2013).

Sample	RI	Test
PR	$\rightarrow$	PP'

alternative version of the OIP (Good et al., 2007; Barker et al., 2007; Tam et al., 2013) an animal is first presented with an array of four different objects ($PQRS$), each in a certain spatial location, for free exploration. Then after an RI, two objects switch their respective locations ($QPRS$) and this manipulation causes an increase in exploration of those objects. Increased exploration of a stimulus presented in a novel location has been demonstrated in rodents (Dix & Aggleton, 1999; Nelson et al., 2011; Tam et al., 2013) and primates (Bachevalier & Nemanic, 2008).

When the OIP involves a spatial/object configuration manipulation, the effects of OIC are based on the co-occurrence of given stimuli during the sample and test phases. A typical preparation (Langston & Wood, 2010; Honey et al., 2007; Tam et al., 2014; Barker & Warburton, 2020; Eacott & Norman, 2004; Honey et al., 1998; Honey & Good, 2000), presented in Table 2.4, involves two sample phases, the first consisting of an object presented in a given context (XQ), then after an ISI another object is presented with a different context (YP), and then after an RI both objects are presented in either the first (XPQ) or the second (YPQ) context. An animal would explore the object which is presented in a context which does not match its sample presentation.

Table 2.4: Basic design for the OIC experiment, sample phase during which stimulus Q is shown in a context X. Sample is followed by an ISI of choice and a second sample during which a novel stimulus P is presented in context Y. Then, following a RI, at test a copy of Q and P are presented, either in context X or Y. A typical response is that an animal will spend more time exploring the stimulus which has been presented in novel context, that is $P < Q$ in Y and $P > Q$ in X.

Sample 1	ISI	Sample 2	RI	Test
XQ	$\rightarrow$	YP	$\rightarrow$	XPQ or YPQ

2.1.4 Neural Correlates of Recognition Memory

The methods described above have been associated with different types of information which depend on different brain structures. Involvement of hippocampus in associative components of recognition memory have found support in the work of Tam et al. (2013). The authors demonstrated that lesions of dorsal hippocampus (dHPC) disrupted performance on a 4-item OIP ($ABCD \xrightarrow{5min/2h} BACD$), however only when the RI was long (2 h) but spared performance on a 5 min RI. In contrast, animals in control group demonstrated significant discrimination at both RIs. Here, the intact performance at the short RI can be attributed to a SGP process, which suggests lack of involvement of hippocampal (HPC) region in non-associative component of recognition memory. Using a similar design Good et al. (2007) demonstrated that HPC damage impaired performance on the 4-item OIP task can be impaired when RI was 2 min. The authors demonstrated that sham operated rats spent more time exploring displaced objects, whereas animals with lesions spent more time on those presented in familiar locations. Based on this evidence, the authors argued that the structure is relevant for an associative recognition memory process. With a more visually complex stimuli and working with primates Bachevalier and Nemanic (2008) demonstrated a similar impairment. Animals were presented with a task involving a

30 s sample of a visual array consisting of five elements ($ABCDE$), then after a 10 s RI, an identical copy of sampled array was presented alongside a copy with two displaced constituents. Animals without the lesions spent more time looking at the array with displaced items, but those with HPC damaged did not demonstrate similar discrimination. Furthermore, authors demonstrated that when a simpler version of OIP, involving a sample of A and test presentation of AA with one of images being presented in novel location, animals with TH/TF lesions (parahippocampus) did not explore the novel location A more than the old one. Damage to such area also impaired performance on the 5-item OIP. On the other hand, perirhinal (PRH) lesions impaired the 5-item OIP and SOR discrimination. In Barker and Warburton (2011) study authors assessed how HPC, medial prefrontal cortex (mPFC) and PRH lesions disrupt performance on SOR, OIP and RR. SOR performance here was only affected by PRH lesions, this echoes the results obtained by Good et al. (2007) as well as Langston and Wood (2010) and Tam et al. (2013) who demonstrated that HPC damage does not disrupt novelty discrimination. Barker and Warburton (2011) demonstrated involvement of HPC in OIP but this task was also affected by lesions to PRH and mPFC. The authors also observed that performance on object in place task can be disrupted by HPC and contrlateral mPFC or PRH damage while ipsilateral damage of those structures preserves performance. The results of (Bachevalier & Nemanic, 2008) and Barker and Warburton (2011) suggests that different aspects of recognition memory are reliant on interconnected structures of medial temporal lobe and that information processing in RR and OIP depends on structural integrity of the MTL-mPFC structures (Aggleton & Brown, 1999).

Hence, the SOR/VPC task does not seem offer a reliable assessment tool

of HPC function. The structure is more sensitive to processing and memory of complex spatial relations such as in OIC and OIP procedures. Furthermore, there is a compelling evidence to suspect that the postulated by Wagner (1981) associative component of recognition maps onto the MTL structures of which the hippocampus plays the key role.

Relatively less attention has been given to the RR discrimination in the context of its underpinning neural correlates. The Mitchell and Laiacona (1998) demonstrated that the prefrontal structures are necessary for discrimination of recency. Similar results were obtained by Hannesson, Howland, and Phillips (2004b) where, using a $QQ \xrightarrow{60min} PP \xrightarrow{45min} QP$ procedure demonstrated selective disruption of recency memory after a bilateral infusion of lidocaine into mPFC. Furthermore, when lidocaine was infused into mPFC no change in novelty (SOR) detection was observed, however same intervention into the PRH disrupted both novelty and recency discrimination. Therefore an evidence suggests, that pre-frontal structures are involved in RR, but not in SOR (Barker et al., 2007). However, evidence also indicates for a role of HPC and suggests that its interaction between PRH and mPFC in each of the lobes enable temporal discrimination (Barker & Warburton, 2011) Overall, in comparison with SOR, both RR and OIP procedures are not only better explained in terms of SOP, but provide a more specific and spatially precise marker of memory impairment caused by localised brain damage.

2.1.5 Summary

In summary, the trio of methods presented above have been widely used in recognition memory research. To account for the performance, a range of theo-

ries have been called for. It has been argued that OIC is an example of an animal analogue of episodic memory (Clayton & Dickinson, 1998; Clayton, Salwiczek, & Dickinson, 2007) or "what-where-when" memory (Suddendorf & Busby, 2003) whereas RR has been interpreted as an example of sequence memory relying on temporal separation (Kesner, Gilbert, & Barua, 2002). Others argued for familiarity and recollection (Aggleton & Brown, 1999) to be the best account of recognition memory. As such, those models offer an interesting account for the data, and often are able to explain complex findings, however, they often do not go beyond the description of the results and are limited to the particular task or behaviour under study. What follows is that new memory types or models are produced to account for results which do not fit the scope of a given model. However, science should seek parsimony, that is, a model should be constructed from the simplest and known tenets and be able to account for a range of phenomena. Furthermore, in line with Morgan's Canon principle (Morgan, 1903) and Darwin (1871), behaviour should be interpreted with reference to the most basic principles, mechanisms which exist in less developed organisms. To that extent, the SOP model of learning and memory offers a parsimonious, yet robust, account of recognition memory (Robinson & Bonardi, 2015). The mechanisms of classical conditioning, in the spirit of which the SOP was developed, have been extensively tested in a range of organisms. Hence, it offers an account according to which recognition memory can be understood under rules of adaptive behaviour demonstrated by much lower-level organisms (Nelson, 1971; Tully & Quinn, 1985; Wagner, 1976) and without reference to much more complex, yet less validated, theories.

2.2 The Associative Account of Recognition Memory

2.2.1 Spontaneous Object Recognition

The SOP theory provides an account for the observed effects of RR, OIP, and OIC based on either the SGP and RGP mechanisms; however, the SOR can be described in terms of both processes. The SGP account of SOR, computer simulation of which is graphically presented in Figure 2.1, holds that when the sample stimulus (P) is presented its memory representation is activated into $A1$ from where it decays into the $A2$. As the decay from $A2$ is relatively slow, when the test stimuli (PQ) are presented part of the P representation cannot be activated to $A1$. Stimulus Q however can be fully activated into the $A1$, resulting in a higher orientation towards it. Supporting this account are the findings of Tam et al. (2013) who demonstrated that extension of RI from 5 minutes to 2 hours reduces the relative orienting towards the novel stimulus. Such a decrease seems to be enabled by the decay of P's representation from $A2$ and I warranted by the longer RI duration, which in turn allows for a higher $A1$ activation of P at test. However, despite the reduction, animals still spend around 40% more time exploring the novel Q than the old P (Tam et al., 2013), suggesting that either the $A2$ to Inactivity decay requires more time or that the effects of novelty observed in the SOR are enabled by the associative mechanisms of RGP. Bearing in mind that learned associations are relatively immune to temporal decay, the long-lasting effects of SOR could potentially be partially enabled by the RGP mechanism. The RGP account of SOR holds that during the sample phase the stimulus P is associated with the context (X) in which it has been presented, such an association will then prime the representation of P into $A2$ when context X is rein-

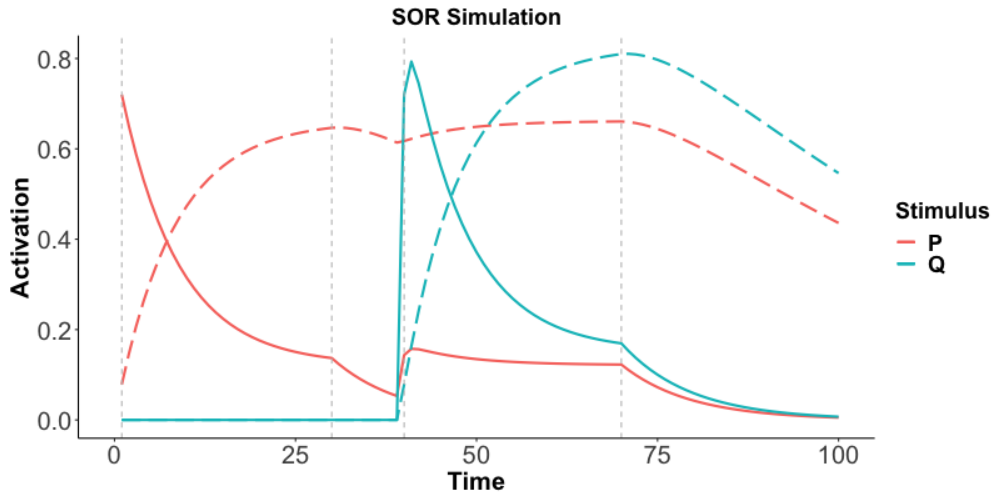


Figure 2.1: Computer simulation of the SOP account of SOR procedure (single trial) with time on the x- and activation on the y-axis. $A1$ is plotted as solid and $A2$ as dashed lines, stimulus P in red and Q in blue. During the sample phase (0 - 30 moments) the stimulus P is presented which results in an $A1$ activation which quickly decays into the $A2$, after the RI (31 - 40 moments) both Q and P are presented. As representation of Q is entirely available to be activated into $A1$ and P's elements are largely in $A2$ the former is able to evoke higher orientation. Simulation performed with $p1 = 0.8$, $pd1 = 0.1$ and $pd2 = 0.02$ set equally for P and Q.

troduced. Because representation of Q is free from association with X, it will not be primed and its elements available to be activated into $A1$, resulting in higher orientation to Q than to P during the test. Furthermore, this effect will not be affected by the RI, but will be reduced through extinction, when X is presented without P which X predicts.

Support for the associative mechanism of SOR comes from Dellu, Fauchey, Le Moal, and Simon (1997) who first presented animals two sample objects (PP) in a Y-maze with contextual cues added, then after 2 h RI, animals returned to the maze for the test phase with object P and novel Q, each in separate arms. When the context matched that of the sample, the animals demonstrated preference in exploring the arm with novel object Q, but when the context changed the novelty preference was not reliable. With reference to SOP, such results are enabled by the

context-stimulus association acquired during the sample phase; at test, the context primed the representation of P, but not Q, which resulted in higher exploration of the unprimed stimulus. When the context was novel, neither stimuli were primed and there was no difference between their exploration.

2.2.2 Relative Recency

The RR procedure demonstrates the involvement of SGP on recognition memory (Robinson & Bonardi, 2015). The SOP accounts for the preferential exploration of the more temporally distal stimulus Q with reference to the differential representation decay states at which the short-term memory of Q and P are at test. Results of a computer simulation are presented in Figure 2.2. During the sample phase, the stimulus Q representation is activated into $A1$, then such activation gives way to the $A2$ state. When P is presented at the sample it also undergoes the same $A1$, then $A2$ activation. However, at test the representation of Q has a higher chance to have decayed into the Inactive state as the time between the offset of stimulus and onset of test is longer for Q than for P. What follows is that Q can render more of its elements into the $A1$ state, which results in a greater orientation to that stimulus at test. Extending the time between the samples, or in other words, giving more time for Q to decay, results in a greater preference for that stimulus at test (Tam et al., 2013). Extending the RI, giving both Q and P time to fully decay, results in a null preference (Mitchell & Laiacona, 1998).

However, the duration at which the recency effect ceases to be reliable is problematic for the SOP account. Mitchell and Laiacona (1998) demonstrated that the preference for Q is still robust at 24 h, but dies out before 72 h. Such a duration

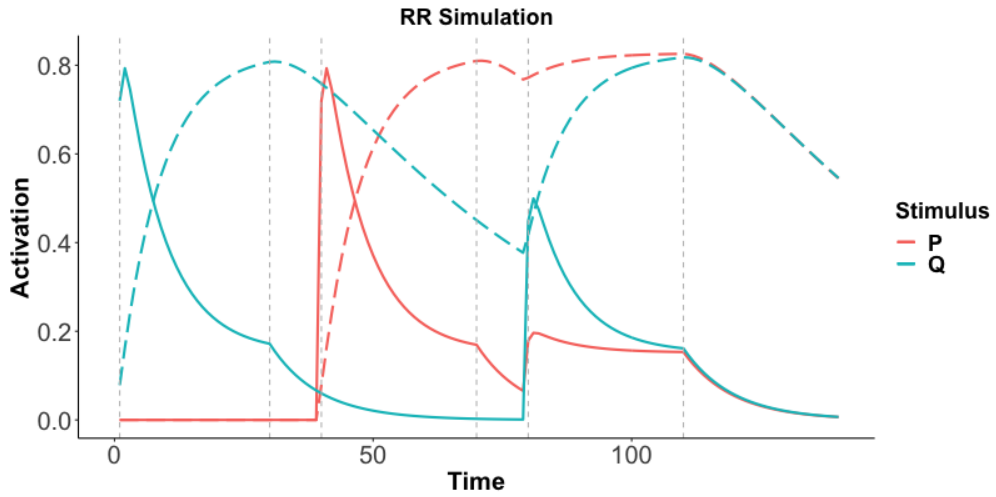


Figure 2.2: Computer simulation of the SOP account of RR procedure. Time is presented on the x- and activation on the y-axis. $A1$ is plotted as solid and $A2$ as dashed lines, stimulus P in red and Q in blue. During the first sample phase (0 - 30 moments) the stimulus Q is presented which results in an $A1$ activation which quickly decays into the $A2$, after the RI (31 - 40 moments) stimulus P is presented for 30 moments resulting in the same pattern of activation. After the RI (10 moments) both Q and P are presented for test exploration, however as representation of Q has had more time between the offset of its sample presentation its representational elements decayed into Inactivity to a greater extent than P's. Because of that Q can activate more of its elements into $A1$ than P can resulting in greater orientation to the former. Simulation performed with $p1 = 0.8$, $pd1 = 0.1$ and $pd2 = 0.02$ set equally for P and Q.

appears to be at odds with the short-term effects of SGP, and as such challenges the SOP as a model of recognition memory. I will investigate the RR in humans and evaluate two potential solutions to the problem in the following Chapters 5 and 6.

2.2.3 Object in Place and Object in Context

The OIP and OIC procedures present an opportunity to investigate the associative in nature RGP mechanism of SOP. During the sample phase, stimulus P enters into association with the context X. Then when such a context X is presented again, the representation of P is primed directly into the $A2$ state, whereas stimulus Q whose representation does not have such association will be entirely available for $A1$ activation. The different exploration of elements available for $A1$ recruitment will

drive the preference for stimulus Q which has not been primed by the context. The RGP effects in OIP and OIC can be explained as resulting from a mismatch with a cognitive map (memory representation) of the environment. During the training an animal forms a representation of stimuli and their relations. Then, if the environment changes and the memory prediction does not match the environment, the displaced stimulus will attract attention. It can be argued, that behaviour on OIC can be attributed to perceptual influences between the stimuli presented at test; that is, stimulus Q is perceived differently in context Q than Y. This interpretation is in line with generalisation decrement which is generally manifested in a partial transfer of CR from one context to another, given similarity between the two (Wheeler, Amundson, & Miller, 2006). In the context of OIC, the effect attributed to contextual dependency does not have to be enabled by the associative but perceptual character of stimulus; memory representation of stimulus Q_X is only partially similar to, presented at test, Q_Y. When the latter is presented, only a part of Q_X's representation will be matched and activated, leaving a proportion of elements to be activated into $A1$. However, Whitt et al. (2012) demonstrated that OIC effects can be obtained when a risk of perceptual influences are removed. The authors first paired context X with stimulus Q and context Y with P, after this either of context (X or Y) were presented (cue) and followed with stimuli Q and P in a novel context Z. Animals preferentially explored the stimulus which had not been previously paired with the cued context. Here, the preference for the unprimed stimulus cannot be explained with perceptual influences, as the context was presented before the test stimuli array, so the effect can be due to the associative priming of the memory representation.

The support for the SOP account has also been provided by Whitt and Robinson (2013) who obtained better novelty preference following a more spaced sample phase. In this study, animals were given multiple presentations of stimulus P in context X which lasted for 30 s. The ISI between the sample presentations was either set as 30 s (Massed) or 4 min (Spaced) and during that time the experimental stimuli were not illuminated. At test both groups were given objects P and Q in context X. Better novelty preference in the spaced group can be explained with a higher association between X and P resulting from concurrent $A1$ activation. Because of the temporal spacing between the sample presentations, both X and P representations had a greater opportunity to be activated into $A1$ resulting in high excitatory association, which translated to stronger priming of P's representation at test.

2.3 Recognition Memory in Humans

It is unclear to what extent findings from animal studies can be extrapolated to humans (Sivakumaran, Mackenzie, Callan, Ainge, & O'Connor, 2018). In particular it is unknown how associative and non-associative mechanisms, RGP and SGP, contribute to novelty discrimination. The following section focuses on eye-tracking procedures used in the study of human recognition memory, which bear a close resemblance to those used in animal procedures.

2.3.1 Visual Paired Comparison

An analogue of SOR: Visual Paired Comparison (VPC, also known as Novel Object Recognition, NOR or Visual Recognition Memory test), has been developed

and successfully applied in developmental (Rose, Feldman, & Jankowski, 2004) and clinical research (Zola, Manzanares, Clopton, Lah, & Levey, 2013; Crutcher et al., 2009). However, as the VPC is a human adaptation of SOR, it suffers from the same shortcomings, namely, it is ambiguous whether the effects of recognition memory observed in the SOR are due to associative or non-associative processes. Nevertheless, the VPC offers a promising tool in the assessment of human recognition memory as it requires no language skills and limited motor control (Richmond, Sowerby, Colombo, & Hayne, 2004) and the procedure is also free from response bias (Sivakumaran et al., 2018), involves simple or no instructions and hence can be used as a procedure applied without modification to all age groups as well as, in tandem with SOR, across the species (Fagan & Haiken-Vasen, 1997). An addition of appropriately designed procedures specific to the human associative (OIC, OIP) and non-associative (RR) mechanisms, which are modifications of SOR/VPC, would allow for a more robust assessment of recognition memory.

The VPC procedure has first been used by Fantz (1964) who, following a study of nonhuman primates, observed that repeated presentation of a stimulus reduces the amount of time an infant spent looking at that stimulus when compared with a novel one. This findings were replicated in Fagan's (1970) study, which coined the name VPC, where infants looked longer at a novel stimulus with the effects of novelty being present in 4 and 5 months old infants for up to 2 days; however when faces were used as stimuli the preference for novel faces was evident after 14 days. The VPC had become a "revolutionary" tool (p. 77, Rose et al., 2004) in developmental memory and attention research showing a rapid development in both systems capabilities in infants' first year of life. Younger (0 - 3 months old)

infants may require a longer sample phase for the novelty effects to demonstrate themselves, whereas such a requirement is reduced as a function of age (Reynolds, 2015). The retention interval after which novelty discrimination is still possible also increases with age; with 4 year-old children being able discriminate the novel object after 6 months (Morgan & Hayne, 2011). Evidence suggests that it is also possible, given the young age (up to 3.5 months old) and a short sample duration, that an infant would demonstrate preference for a familiar stimulus over the novel one (Reynolds, 2015). However important, interpretation of infant studies from the recognition memory perspective is limited by the potential deficits in the visual system (Atkinson, Braddick, & Braddick, 1974) and other factors such as temperament (Weissbluth & Liu, 1983; Vaughan et al., 2003).

Working with the adult population, Ryan, Hannula, and Cohen (2007) demonstrated that when presented alongside pre-exposed faces, novel ones are looked at more; however the novelty preference is reduced when sample time is short, retention interval is longer and context changes between the sample and test (Richmond et al., 2004). Healthy participants demonstrated a reduction of novelty preference when the RI was extended with reliable discrimination at 1 h, but not at longer RIs (Squire & McKee, 1993) suggesting an influence from the SOP's non-associative SGP mechanism. Performance on VPC has also been attributed to the domain of declarative memory as performance on the task correlated with conscious recall (Manns, Stark, & Squire, 2000).

On the other hand, the contextual, associative dimension of the VPC has been demonstrated with the study of Robinson and Pascalis (2004). Here, across two experiments reported, 6, 12, 18 and 24 months-old infants were presented with

a VPC task in which the test stimuli (pictures of toys) were presented in either the sampled or different contexts (background colour). Infants in all age groups demonstrated novelty preference, spending more time looking at the novel stimulus when the test was performed in the same context; however, when the context was changed neither the 6 nor the 12 month old children demonstrated novelty preference, which was still significant for 18 and 24 month olds. However, the results obtained by Jones, Pascalis, Eacott, and Herbert (2011) demonstrated that change in context (testing room) disrupted the novelty preference in 12 and 18 month old infants. In this study the novelty preference was robust for all age groups (6, 9, 12 and 18 months) when the testing room was the same as the one in which an infant was familiarised with the stimulus. Inconsistency between the two studies may be due to the different DVs, Jones et al. (2011) used looking time whereas Robinson and Pascalis (2004) used % of fixations.

It would then appear that the performance on VPC, namely, the preferential looking towards the novel stimulus, is context dependent, although the mechanism enabling this performance may be age-related.

The SOP's RGP mechanism can successfully account for the effects of contextual habituation of a response to the preexposed stimulus. When the stimulus P is presented in context X it enters into an association, then when the context is presented on test the representation of P is primed into $A2$ resulting in a lesser orientation to that stimulus. However, when the context is not present, both test stimuli can be activated into the $A1$ with the same magnitude, resulting in null preference on test. The associative nature of VPC is also supported by the study of Cornell (1980) who demonstrated that a distributed, spaced sample (5 s presentation of P

with 60 s ISI) presented to 5 and 6-month old infants resulted in novelty preference apparent at 60 s RI, whereas when the sample consisted of a less spaced series of presentations (5 s presentation of P with 3 s ISI) the effects were only evident at 5 s RI. The results bear similarity to the results obtained by Whitt and Robinson (2013) who presented rodents with either the spaced or massed stimulus and context trials, showing when pairings are presented in a distributed manner the effects of novelty preference were more robust. Although, in Cornell (1980) study, the context was not an experimental variable, it can be assumed that the experimental conditions nevertheless consisted of a latent contextual stimulus.

Pascalis, Hunkin, Bachevalier, and Mayes (2009) compared SOR performance of patient YR, who suffered bilateral damage to the hippocampus and a group of monkeys who had similar damage. The procedure consisted of stimuli sequence presented on the same ($xQ \xrightarrow{RI} xQP$) or different background ($xQ \xrightarrow{RI} yQP$). The RI for the patient was set at 1 s and 5 s for the animals. The authors observed, that when context was the same, both the YR and animals with hippocampal damage, spent more time looking at the novel stimulus. However, change in the context disrupted novelty discrimination in subjects with the damage. The authors argued that hippocampal damage disrupted an ability form flexible associations between visual information. However, such behaviour can also be attributed to perceptual effects, namely the generalisation decrement and disruption of the hippocampus prevented integration of sensory information.

It is also possible that the effects are due to SGP mechanisms where the pre-exposed stimulus' representation is not fully available for $A1$ recruitment at test resulting in novelty effect at test. Change in context however accelerates the decay

of pre-exposed representation (see Equation 1.6 10) so it can be evoked into $A1$ to a greater extent than when such change should not have taken place. It would then appear that both SGP and RGP can successfully account for the effects of novelty. This assumption is supported with the findings of Richmond et al. (2004) who explored the effects of context and RI manipulation on adult VPC performance. At a RI of 3 minutes both same and changed context conditions demonstrated a significant preference for novel stimulus, albeit the change in context resulted in a lower effect. When the RI was extended to 2 weeks both same and changed context VPC were lower than their 3 min RI analogues. However, a significant preference was only observed in the same context condition. Furthermore, in a separate experiment, the authors demonstrated that extension of a RI from 2 minutes to 1 week reduces the novelty preference, the effects are the most robust at the shortest RI. However, the effect is still present at the longest RI. Here, both the time (which plays a role in SGP) and context change (related to RGP mechanism) have played their parts.

Taken together, it appears that as long as the VPC is concerned, both the SGP and RGP are involved in human recognition memory, however, the procedure is not sufficient to parse out the effects driven by either of those mechanisms alone when the RI is short. Hence, both SOR and VPC procedures are tainted with their inability to distinguish between the associative and non-associative components of memory. However, a modified version of SOR, namely, the RR, OIC, and OIP, are capable of this assessment to be more specific.

To the best of my knowledge, human adaptations of the RR procedure have not been developed (Nitka, Bonardi, & Robinson, 2020). More focus has

been dedicated to either the effects of LTM on visual attention or the preferential looking task, both of which bear a strong similitude to the OIC paradigm. In a series of experiments, Hannula and colleagues (Ryan, Shen, & Liu, 2020; Ryan, Althoff, Whitlow, & Cohen, 2000; Hannula, Ryan, Tranel, & Cohen, 2007; Mahoney, Kapur, Osmon, & Hannula, 2018; Ryan et al., 2007; Hannula & Ranganath, 2009) investigated how the effects of context-stimulus associations, learned during the sample phase, influence eye movements on a subsequent test. Hannula et al. (2007) first presented adult participants with face-context pairings, then presented a selected context with a set of pre-exposed faces of which one face was matching the sample. The results demonstrated that stimulus which matched the sample context was looked at more than the non-matching ones. Same match-preference was obtained by Hannula and Ranganath (2009) and it has been since argued that the effect is obligatory and automatic (Mahoney et al., 2018). Such findings stand in stark contrast to the effects of associative priming observed in animal OIC literature where, given a prior association between the context and stimulus, presentation of the context at test leads to a decreased exploration time of the associated stimulus. It is possible that the preferential looking at the context-matching stimulus results from the experimental procedure employed by Hannula and colleagues. In the experiments reported in Hannula et al. (2007) participants were given different instructions; in experiment 1 this was to identify the matching face with a keyboard, but in experiment 2 participants were asked to study the stimuli arrays for a later test recollection. Contrast between the two experiments is important due to response intention selection (Ryan et al., 2007), an effect by which the to-be-selected stimulus is looked at more, and is an effect of instruction, not memory. However,

the results show that in both versions the time spent looking at stimuli was higher for the context matching one. It can be argued that when following instruction to study the stimuli, participants will modify their looking patterns to perform the task (Holmqvist et al., 2011). The results from Richmond and Nelson (2009) show that 9 months-old infants demonstrated a similar preference for the context-matching stimulus, this time however in absence of any instructions. However, as suggested by Robinson and Pascalis (2004), the contextual influence on infants' VPC is age dependent and may not be as reliable as those observed in adults.

In summary, whereas the SOR's analogue of VPC has been used to study recognition memory, its utility in assessment of associative and non-associative components is limited. A human analogue of RR, that would be sensitive to the non-associative mechanism of SGP, has not been developed to date. Bearing similitude to OIC, human procedures yielded opposite results to those expected from the animal studies and by doing so challenged the SOP interpretation of recognition memory. In this thesis I will address the lack of human RR procedures and reconcile the discrepancy between the contextual effects on animal and human recognition memory.

2.3.2 Episodic memory theory

The classical model of memory holds that it consist of two large sub-systems: declarative and non-declarative (Squire & Zola, 1996; Tulving, 2002). The difference between the two lies in one's ability to consciously access the information stored. The former incorporates knowledge of facts (semantic) and memory for events (episodic) and can be verbalised and consciously recalled. The latter covers

skills, effects of classical conditioning, implicit learning and priming and can only be accessed through behaviour. Episodic memory, recall a specific autobiographical event, is characterised by an ability to distinguish time (when), location (where), and identity of objects (what) involved in a given past event. Moreover, the trio of what-when-where is accompanied by an ability of mental time travel: conscious replay of past events.

Recognition is a process related to episodic memory (Aggleton & Brown, 2006). Within this framework it has been conceptualised as a result of two sources. The most prominent representant of this family of models is the recollection - familiarity (Yonelinas, 2002). According to this account, recognition can rely on either a feeling of previous occurrence (familiarity) or by a detailed memory which can be recollected. The two have separate neural correlates, with recollection being hippocampus-dependent and familiarity relying on perirhinal cortex (Eichenbaum, Yonelinas, & Ranganath, 2007). The two operate in parallel, however familiarity is faster than recollection and is not associative, the slower recollection is characterised by its associative nature. Recognition memory effects are best described with use of signal detection theory receiver operating characteristic (ROC) curves. When false alarms (responding *old* to *new* stimulus) are plotted against hits (correct identification as *old*) the function reflecting familiarity will have a symmetric curvilinear shape, whereas the recollection is characterised by an asymmetrical and flat function (Yonelinas, 2001) with higher hits ratio (Yonelinas, Aly, Wang, & Koen, 2010). When assessed with remember/known (RK) procedure, an experimental paradigm in which a participant has to evaluate whether an item is *old* or *new* and then indicate metamemory basis of such decision; whether one knows or remembers. A

typical result is that remembered items are much less susceptible to false alarms than known items - which is a reflection of a threshold employed to discriminate recollected items. Based on the dependence of hippocampus in recollection, necessity of this structure for conscious recall and relational nature of both recollection and episodic memory the dual process accounts hold, the process of recollecting is contributing to episodic memory retrieval.

Two features of the episodic account are at odds with the associative one described earlier. First is the episodic binding; a process by which relations between events are encapsulated together in a spatiotemporal context (Ranganath, 2010). When the aspects of item-item relations proposed by the episodic account are in line with SOP, the temporal relations between events are not treated as a part of associative structure but a part of trace-decay non-associative mechanism of SGP. Supporting the episodic account here was a study by DeVito and Eichenbaum (2011). The authors gave mice with two sequences of five odours (A to E and L to P), each sequence being repeated three times and with spacing between the two sequences lasting for 3 h. At test, animals were given pairs of odours which were either form the same sequence (eg. AD) or came from different sequences (AN). Based on the RR, animals should demonstrate preference towards the stimulus presented earlier, regardless of the sequence. However, the authors reported that animals recency discrimination was limited to items presented in the same sequence, and when items from two sequences were compared animals demonstrated no preference. Such demonstration is in line with the episodic account, in opinion of the authors, animals bound each sequence as an event and constructed temporal map of events according to which the behavioural outputs are constructed.

Barker, Evuarherhe, and Warburton (2019) further challenged the SGP account of RR, the authors trained animals on a sequence of four stimuli in two sequences: long lag with $A \xrightarrow{10min} B \xrightarrow{160min} C \xrightarrow{10min} D \xrightarrow{60min} BC$ and short lag iwth $A \xrightarrow{85min} B \xrightarrow{10min} C \xrightarrow{85min} D \xrightarrow{60min} BC$. The key difference between the sequences was the ISI between the sampled stimuli B and C. According to SGP, the longer delay between the sample and test the more of elements should decay into the Inactive state and produce more orienting towards the matching stimulus. However, the authors found no difference between the two time lag conditions. Barker et al. (2019) interpreted the null result as supporting the episodic account; as in DeVito and Eichenbaum (2011) study, animals did not rely on a trance decay and the behaviour is better aligned with the episodic view.

Second contrasting finding relates to the role of long-term memory in attention. A large body of evidence have demonstrated, that when an object is associated with a given context, presentation of this context again will habituate attention to the matching item. On the other hand, evidence from human studies have demonstrated the opposite (Kerzel & Andres, 2020; Hannesson et al., 2004a; Hannula & Ranganath, 2009; Mahoney et al., 2018; Chun & Jiang, 1998), memory-matching configuration attract attention in an automatic manner.

3 | Motivation

3.1 Summary

As noted by Tulving (2002), the distinctions between different memory systems are purely speculative with demarcations between them not being represented in the brain. Human behaviour results from intertwined influences from multiple systems across multiple levels of evolutionary hierarchy and parsing out any hypothetical element from that system is impossible. Stopping here however, would render all psychological and neuroscientific experiments futile and would lead us to a form of epistemological nihilism, a view that nothing can be known for certain. Using methods which provide the best sensitivity and, at the same time are free from potential confounds, could yield a better approximation of the true states. To that extent, in the context of recognition memory research, the enquiry should focus on organisms and behaviours which are free from higher level influences. Procedures of SOR, RR and OIP/C are an unbiased, sensitive and parsimonious tools to study recognition memory and their neural correlates. Whereas experimental animals provide a foundation for such study, the end goal of psychology is to inform the understanding of human mind and behaviour as well as their neural underpinnings. Extrapolation of non-human studies to human populations, without an appropriate translational vehicle which would demonstrate an overlap would be problematic (Sivakumaran et al., 2018). Furthermore, being able to distinguish between the contributions of associative and non-associative processes in recognition memory can potentially lead to a development of more sensitive diagnostic tools. Crutcher et al. (2009) demonstrated

that patients with mild cognitive impairment (MCI) cannot discriminated between a preexposed and novel objects at 2 min RI, the pattern of results overlapped with clinical diagnosis suggesting that the task can provide a reliable behavioural index of impairment. Same task can also be used to assess the risk of future conversion from MCI to Alzheimer's disease (Lagun, Manzanares, Zola, Buffalo, & Agichtein, 2011) and from non-pathological presentation to MCI (Zola et al., 2013). Because different clinical presentations correlate with localised impairment of frontal and temporal lobes (Neary, Snowden, Northen, & Goulding, 1988; Kaye et al., 1997; Hodges et al., 1999; Chan et al., 2001) being able to separate the associative and non-associative contributions to recognition memory may make the prediction more specific. For that purpose, here I will first document development and evaluation of an eye-tracking based procedures which are an adaptation of animal procedures used in recognition memory research. Resulting data will be interpreted in term of SOP theory, which offers a robust, parsimonious and reliable model of learning and memory.

3.2 Aims and Objectives

The primary aim of this thesis is to address such a knowledge gap in the context of animal to human translational research. I argue that the procedures of RR, OIP and OIC allow for a high degree of sensitivity, greater than the ones currently used in human recognition memory research. Such procedures are free from confounds of language, motivation, and meta-memory, allowing for recognition memory to be addressed in a more precise and controlled manner. In the first experimental Chapter, 5, I will document the development and evaluation of a human eye-tracking

based procedure which follows the design of SOR, OIP, OIC, and RR.

Development of a close human analogue of an animal recognition memory test comes with difficulties and limitations. Whereas innate inquisitiveness can be expected from animals, the same cannot be said about human participants; the lack of engagement is potentiated by the repetitive nature of human-centred psychological experiments (multiple trials) and less immersive 2D presentations which are limited to the computer display. Therefore, to ensure the quality of data and to arrange conditions which would facilitate participants' attention, a covering task must be employed. Task must fulfil three, specified by Holmqvist et al. (2011), criteria: it should be neutral, so it does not bias participants' eye movements in a way not intended by the experimental design, it should also be engaging, ensuring participation in the experiment, and plausible, so that it minimises the risk of demand characteristics. Experiments in Chapter 5 demonstrate that changes in the cover task do have an influence on the expected effects and, as in the case of human adaptations of OIC procedure, can potentially yield problematic results.

Furthermore, the temporal duration of animal trials, particularly the RIs, is not feasible in human studies, so both retention and presentation time must be scaled down. Here, I mainly relied on 3 s presentations and RIs between 1 and 10 s; the values were selected as there are no guidelines as to what RIs should be used in adult humans VPC tasks. The RI bounds were also selected so the RR procedure can be implemented without potential confounds from other stimulus interference, that would accelerate the decay $A2 \xrightarrow{pd2} I$.

In contrast to animals, humans have much more stimulating daily lives,

which results in two important implications. Firstly, it is difficult to create a novel, never seen, stimulus so it can be assumed that all stimuli presented have been preexposed at some point in the past. Hence, the memory representations are very likely to exist. Second, the existence of memories may result in idiosyncratic associations which may confound the effects observed here. Assuming this, I decided to mitigate it with the use of numerous trials, which is another departure from the paradigms used in animal studies. However, this approach benefits from an improved signal-to-noise ratio, which is particularly important given the high degree of variance observed in animal procedures (Ameen-Ali, Easton, & Eacott, 2015).

Tulving (2002) has pointed out the effect of "proliferation of memories" (p. 8), creation of new memory types which either reflects publication bias or a result of inefficient communication of theory. With the former being self-explanatory, the latter reason may be a result of the formulation of theories in natural language, allowing for multiple interpretations by researchers. Debate on the taxonomy of memory and recognition in the cognitive and episodic circles is lengthy, far from being conclusive and with many horses in the race, and to accurately describe the discourse would not be appropriate to the topic of this thesis. However, my belief is that the self-reflective metaphysical formulation of the dominating human recognition memory theory, which enables recollection and familiarity theorising, may not be the best path of enquiry. In contrast, the research should be laid upon a solid, experimentally validated, objective, and unbiased theory. Moreover, the formulation of theories must incorporate clear and quantitative tenets, with a set falsification capability. To that extent, I argue for a departure from the currently dominant approach and for a novel one, which in my judgement offers a better alternative. I

assert that the associative account of recognition memory offers a parsimonious, robust, tentatively confirmed, and mathematically sound model of human recognition memory.

Therefore, the second, yet equally important, aim is to examine whether the associative learning theory, which has been successfully applied to animal recognition memory, can also account for human recognition. The foundation of the associative account of recognition memory, the theory of Pavlovian conditioning, has been extensively validated in a number of learning phenomena. Amongst the set of theories which have been developed to understand and predict behaviour, the SOP is best suited to explain the recognition memory. This is due to its temporal character, previous success in accounting for other learning phenomena, computational character, and ability to model recognition in animals. To that extent, the experiments presented in this thesis have been designed to examine the applicability of human eye tracking analogues of SOR, RR, OIP, and OIC to the study of recognition memory. And the results obtained are interpreted with reference to the SOP, a proxy for the associative account of recognition memory (Robinson & Bonardi, 2015). In Chapter 6, I will evaluate the SOP-derived predictions concerning the influence of time (RI and to a lesser extent ISI) on the SGP and RGP enabled recognition memory effects in RR and OIP/OIC. The evaluation of SOP in this context will also incorporate experimental tests of, postulated by McLaren (personal communication) and Sanderson (2016), explanations of the long-lasting effects of RR observed by Mitchell and Laiacona (1998).

Finally, I will address some findings which are problematic for the SOP account of RGP effects observed in OIC. Analysis of the literature suggests that

there is a discrepancy between animal and human studies concerning the effects of associative priming on the orienting response. Rodent studies demonstrated that when an animal is presented with a sample where context X was presented alongside Q and, on a separate presentation, Y was presented with P, the animal spends more time exploring the stimulus which was then presented in a context which does not match the sample pair, $Q > P$ in context Y. (Whitt et al., 2012; Barker & Warburton, 2020; Tam et al., 2014; Honey et al., 2007; Honey & Good, 2000; Dix & Aggleton, 1999). In the area of human studies, recognition effects have been demonstrated to be of opposite polarity: participants spent more time looking at stimuli in a familiar configuration, $Q < P$ in context Y (Ryan et al., 2007; Hannula et al., 2007; Hannula & Ranganath, 2009; Mahoney et al., 2018; Ryan et al., 2000, 2020). I will address this matter in experiments spanning both experimental Chapters 5 (Experiment 5) and 6 (Experiment 10 and Experiment 11).

3.3 Thesis Outline

The remainder of this report is organised as follows:

Chapter 5 Documents the development of eye-tracking paradigms sensitive to SGP and RGP recognition memory mechanisms. Demonstrates the involvement of both mechanisms through the procedures of RR and OIC and reconciles the differing results from animal and human OIC procedures.

Chapter 6 Presents the evaluation of SOP-derived predictions concerning the influence of time (RI and ISI) on the associative and non-associative mechanisms involved in recognition memory. Evaluation of two associative mech-

anisms of RR aiming to account for results of Mitchell and Laiacona (1998) which are problematic for the associative account.

Chapter 7 Summarises the results from the preceding chapters in a meta-analytic Bayesian method. Interprets the findings with reference to the previous studies and theory.

Chapter 8 Reflective report from the Professional Internship for PhD Students (PIPS) placement at Lehigh University.

4 | General Methods

In this chapter I will describe some common methodological practices and assumptions for the experiments reported in the following chapters.

4.0.1 Participants

All participants recruited for the experiments reported here have only taken part in a single experiment, hence all were naive to the purpose of the test. All participants were recruited via an internet advert (callforparticipants.com), posters placed around the University of Nottingham UK campuses and SOMA system. On-line and poster recruitment included only very general information about the experiment's purpose being to understand memory and did not reveal its theoretical background or explicit hypotheses. No participants had participated in other experiments reported in this thesis and were assumed to be naive with respect to the images that I used. All participants reported normal or corrected-normal vision. Informed consent was obtained in accordance with the University of Nottingham School of Psychology Ethics Committee.

4.0.2 Apparatus

Eye movements in all experiments were recorded with the Tobii TX300 eye tracker (Tobii Technology, Stockholm, Sweden) sampling gaze from both eyes at either 60 Hz (Experiment 1 and Experiment 2) or 300 Hz (the remaining experiments). Participants sat in front of a 23-inch diameter liquid crystal display (51.0 cm wide $\times$ 28.5 cm high) and a computer keyboard. Distance from the screen was approximately

50-60 cm and whenever specified a chin rest was used. The display's resolution was 1920 $\times$ 1080 px and its refresh rate was 60 Hz. Image presentation and data collection was controlled by a Windows 8.01 Pro Dell machine running PsychoPy (1.82.02; Peirce & MacAskill, 2018) and Tobii Studio (version 3.4.8.1348).

4.0.3 Stimuli

All experiments used stimuli from the combined Bank of Standardized Stimuli (BOSS©, Brodeur, Dionne-Dostie, Montreuil, & Lepage, 2010; Brodeur, Guerard, & Bouras, 2014). The images depicted objects such as animals, vehicles, tools, and domestic items. These depicted objects, but not the particular images, were familiar to the experimenters and were nameable. The images were matched for luminance to reduce the effects of low-level visual features using the SHINE toolbox (Willenbockel et al., 2010) and MATLAB (MathWorks, 2019). Images were resized to 350 $\times$ 350 px and were randomly without replacement for each participant and presented on a grey (PsychoPy colour space RGB: 0, 0, 0) background. Selected examples of BOSS stimuli are presented in Figure 4.1.

Where specified, BOSS stimuli were accompanied with salient, colourful flags which were taken from a set of 38 images of maritime flags (Wikipedia, International Code of Signals letters and NATO number flags combined, Public Domain) and 5 created manually in graphical software (43 in total). Selected examples of flags are presented in Figure 4.2.

Figure 4.1: Selected stimuli from the combined Bank of Standardized Stimuli (BOSS©, Brodeur et al., 2010, 2014). The images were matched in luminance to reduce the effects of low-level visual features using the SHINE toolbox (Willenbockel et al., 2010) and MATLAB (MathWorks, 2019).

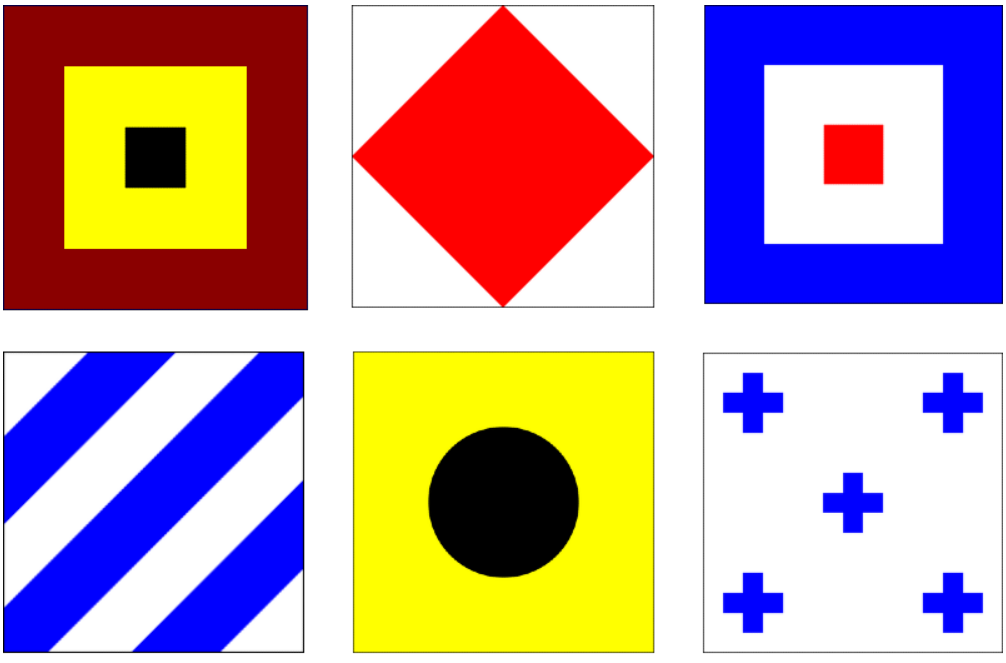


Figure 4.2: Selected stimuli from the combined set of maritime flags (sourced from Wikipedia, International Code of Signals letters and NATO number flags, Public Domain) and manually created in graphical software

.

4.0.4 Data Treatment

In most analyses performed, we have used dwell time as the main data of interest. This measure should be understood as the number of eye tracker's samples during which the gaze location was located within a given Region of Interest (ROI). Unless specified otherwise, a ROI was specified as a rectangle enveloping the stimulus location. For all experiments reported, the duration of stimulus presentation at sample and test was 3 s. For Experiment 1 and Experiment 2 (Chapter 5) reported the data acquisition frequency (the number of data points the eye tracker device can produce for 1 s) was 60 Hz, the remainder of experiments is reported with 300 Hz frequency. This disparity is due to a more robust method being developed and implemented. The 60 Hz method produced dwell time as a total number of refresh frames a participant looked at a given ROI, without access to the tracker raw data. The data collection frequency was determined by the screen refresh rate. The 300 Hz on the other hand allowed for the data to be accessed and analysed within a specific temporal window of the sample or test phase. When raw dwell time is reported, it is in samples but depending on the method implemented in a given experiment, this time can be converted to seconds by dividing the dwell time by 60 or 300 and so for a 3 s stimulus presentation the 60 Hz method yielded around 180 data points, whereas for the 300 Hz, this was around 900. It was not uncommon for the device to return fewer data points than expected, mostly between 178-179 for the 60 Hz and 896-899 for the 300 Hz for a 3 s recording period. This was due to the operating frequency of the tracker not being synced to the computer time and due to computer background processes which sometimes interfered with the transfer of data from the tracker to the hard drive of the computer. However, such problems were always minimal and

data were sense checked for any excessive losses. On a very rare occasion, particularly in the 60 Hz version, it was also possible for the tracker to record over 180 samples in a 3 s time window. The overcounting was always by a low margin of 1 sample and was due to the computational method used in the 60 Hz version.

The lower frequency sampling method was developed in a way where the dwell time is calculated online (during the experiment) and involved an inefficient process where the computer must, on each screen refresh, draw a fully transparent polygon around the ROI. This was necessary to determine whether there is an overlap in both drawn items and if so, the dwell time in that ROI was increased by 1. Because drawing even an invisible polygon is a computationally taxing action and that process is performed on the same processor core as all other processes engaged, the experiment could run into a backlog. What follows is that a small number of data points could have been recorded with false time leading to sometimes increased overall sample count. Because the backlog was never large and the delay in recording was in the range of milliseconds, the risk of substantial error was small. The 300 Hz method eliminated such problems, as during the experiment, the gaze location data were only collected and the dwell time was calculated later. Furthermore, the 300 Hz method has shifted the eye tracking data collection to another processor core which can perform operations in a more computationally efficient way.

The main DV is all experiments, the discrimination ratio D2, can be calculated for the entire temporal window of a given test phase or for a specified window of that time. Both of formulations are used in this thesis.

In its basic form, D2 is calculated according to the formula in equation

4.1:

$$D2 = \frac{Q - P}{Q + P} \tag{4.1}$$

where Q refers to the dwell time on the test stimulus which, according to the hypothesised effects, should be explored more, that is, for SOR: novel, RR: less recently preexposed, OIP: in novel location and OIC: in a novel context. P denotes the stimulus which has been pre-exposed, presented in same context or same location. A positive value of D2, $0 \ll D2 \leq 1$, should be then interpreted as reflective of expected higher dwell towards Q, and a negative, $-1 \leq D2 \ll 0$, as higher dwell towards P. Values of 0 are indicative of no preference, with both stimuli being explored for an equal amount of time. D2 allows for experiment-to-experiment comparison; however, it is not sensitive to the overall change in dwell time, hence it will be complemented with a raw dwell time to Q, P analysis.

Apart from Experiments 1, 2 in Chapter 5 the D2 ratio was calculated from consecutive temporal windows of the test phase: six windows, each lasting 0.5 s, for which D2 based on the respective dwell time to Q and P was calculated as per Equation 4.2 where w_x refers to temporal windows, from w_1 to w_6, specifics of which are described in Table 4.1:

$$D2_{wx} = \frac{Q_{wx} - P_{wx}}{Q_{wx} + P_{wx}} \tag{4.2}$$

As a saccade reaction takes at least 0.2 s (Carpenter, 1988) and, as will be demonstrated in Chapter 5, the most sensitive window of interest corresponds to 0.5 - 1.5 s of the test phase: windows w_2 and w_3. An adjusted, $D2_{adj}$, Equation 4.5, ratio will be calculated based on adjusted Q_{adj}, Equation 4.3, and P_{adj}, Equation

Table 4.1: Temporal windows involved in dwell analysis. Windows from w_1 to w_6 are specified with their respective start and end times in both, tracker data samples and real time.

Window	Time in tracker samples	Time in seconds
w_1	1 – 150	0 – 0.5
w_2	151 – 300	0.5 – 1.0
w_3	301 – 450	1.0 – 1.5
w_4	451 – 600	1.5 – 2.0
w_5	601 - 750	2.0 – 2.5
w_6	751 – 900	2.5 – 3.0

4.4:

$$Q_{adj} = \frac{Q_{w2} + Q_{w3}}{2} \tag{4.3}$$

$$P_{adj} = \frac{P_{w2} + P_{w3}}{2} \tag{4.4}$$

$$D2_{adj} = \frac{Q_{adj} - P_{adj}}{Q_{adj} + P_{adj}} \tag{4.5}$$

Here, Q_{adj} and P_{adj} are an average dwell to a given stimulus in a specified time window (Table 4.1) Preference quantified by the $D2_{adj}$ can be interpreted in the same way as D2.

If a participant demonstrated a consistent low engagement with experimental stimuli - on average spent less than 10% of the time stimuli was displayed to look at it - then the entire data associated with the participant was removed from further analysis.

Statistical analysis was performed using Jamovi (Jamovi Project, 2020) and JASP (JASP Team, 2020) software. For frequentialists ANOVA, I reported η_p^2 effect and checked for sphericity violations using Mauchly's test. If the assumption

was violated, Greenhouse-Geisser correction and, as suggested by Field (2019), *post hoc* test yielding from Greenhouse-Geisser corrected main effects of interactions were corrected with Bonferroni method. Holm correction was used for family-wise error mitigation in all other *post hoc* tests. Effect sizes are interpreted it in line with Cohen (1988) and Wetzels et al. (2011).

Classical frequentist inferential tests are supplemented with their Bayesian counterparts. Bayesian methods do not require data to be normally distributed, they can also interpret the null effect in a more robust way (Dienes, 2014). Most importantly, this approach allows for the strength of support for a given statistical model to be quantified, this can be done for either the experimental hypothesis $\mathcal{H}_1$ and for the null $\mathcal{H}_0$ with the Bayes Factor (BF) statistic. For $\mathcal{H}_1$ support I will use BF_{10}, $BF_{10,U}$ and BF_{incl} which respectively refer to test statistics, *post hoc* tests yielded by a significant main effects and interactions. For the $\mathcal{H}_0$ support same will be reported as BF_{01}, $BF_{01,U}$ and BF_{excl}. Interpretation rules are presented in Table 4.2 and are in line with Wagenmakers, Love, et al. (2018), Dienes (2014), Wagenmakers, Marsman, et al. (2018) and Wetzels et al. (2011)[1]. Both BF_{10} and BF_{01} are inversely proportional to each other and can be converted as $BF10 = \frac{1}{BF01}$ and $BF_{01} = \frac{1}{BF_{10}}$, I will report the value which is larger (provides stronger evidence), but in some cases, such as when frequentist test yields different results than Bayesian, both values will be reported.

For not significant results, $p > 0.05$, I will only report the *p*-value and BF_{01} (for interactions: BF_{excl} and *post hoc* tests:$BF_{01,U}$) values. As Bayesian

[1]Jeffreys (1961, as cited in Wetzels et al., 2011) interprets *BF* > 100 as *decisive*, Wagenmakers, Love, et al. (2018) however refers to such values as *extreme* evidence. I will use both terms as synonymous.

Table 4.2: Interpretation of BF values, after Wagenmakers, Love, et al. (2018). BF_{10} refers to support for the $\mathcal{H}_1$ and BF_{01} for $\mathcal{H}_0$.

BF	Interpretation
>1	No evidence
1 - 3	Anecdotal
3 - 10	Moderate
10 - 30	Strong
30 - 100	Very Strong
100 <	Decisive or Extreme

analysis is based on a stochastic method (Markov chain Monte Carlo, *MCMC*) its results may not exactly replicate when the test is re-run. This will particularly be the case when the error is substantial, therefore in cases where the error >1% it will be reported alongside the test statistic.

The preparation of data was performed in RStudio with R programming language (R Core Team, 2020; RStudio Team, 2020) aided by a range of packages. For the data importing xlsx (Dragulescu & Arendt, 2020) and hdf5r (Hoefling & Annau, 2020) packages were used, dplyr (Wickham, Francois, Henry, & Muller, 2020) was used for data manipulation and wrangling and some auxiliary plotting was performed with ggplot2 (Wickham, 2009) and jtools (Long, 2020). Responses were analysed with psycho package (Makowski, 2018). MBESS (Kelley, 2020) package was used for *95% CI* for η_p^2 calculation. Shiny environment was used for SOP simulations (Chang, Cheng, Allaire, Xie, & McPherson, 2020), Prism (GraphPad, 2020) for published plots and LaTeX for typesetting and document preparation.

5 | Development of Human Recognition Memory Procedure

5.1 General Introduction

The main purpose of the experiments reported in this chapter is to document the development and testing of a robust, nonreinforced, and eye-tracking based recognition memory procedure which would parallel the procedures used in nonhuman research. Secondly, but of equal importance, I want to evaluate whether the associative learning theory, specifically the SOP model (Wagner, 1981; Brandon et al., 2003; Vogel et al., 2019) provides a parsimonious, yet robust theoretical foundation to understand human recognition memory. I argue that the associative account of recognition memory offers a compelling path of inquiry that will not only contribute to a greater understanding of the processes involved in human recognition memory, but could potentially enable development of a clinical assessment tool which would be more specific than the current, VPC-based, procedure (Crutcher et al., 2009; Zola et al., 2013).

To a large extent, an analogue of Spontaneous Object Recognition (SOR) has been implemented as an experimental approach and used in the context of infant cognition (Colombo, Mitchell, & Horowitz, 1988; Colombo & Mitchell, 2009; Oakes, Kovack-Lesh, & Horst, 2009), dementia (Crutcher et al., 2009; Lagun et al., 2011; Zola et al., 2013; Seligman & Giovannetti, 2015) and amnesia research (Hannula et al., 2010; Pascalis, Hunkin, Holdstock, Isaac, & Mayes, 2004; Smith

& Squire, 2008). However, the mechanism behind the novelty discrimination observed in SOR remains unclear and ambiguous in terms of SOP theory (Robinson & Bonardi, 2015). From the associative account (Wagner, 1976; Robinson & Bonardi, 2015), SOR relies on two mechanisms: short-term non-associative Self-Generated Priming (SGP) and long-term associative Retrieval Generated Priming (RGP). The latter is enabled by a learned association between stimuli, whereas the former depends on the processing of a single stimulus and it is argued that both have different neural correlates in the medial temporal lobe (Robinson & Bonardi, 2015). SOR cannot be taken as a procedure which assesses either the SGP or RGP in isolation, but a synergy of the two mechanisms. To address that, I assert that the Relative Recency (RR) and Object in Context / Place (OIC, OIP) methods allow for SGP and RGP to be parsed out from the behavioural recognition effects.

In the RR procedure (Mitchell & Laiacona, 1998; Tam et al., 2013; Barker et al., 2007; Good et al., 2007; Hotte et al., 2005; Nelson et al., 2011; Hannesson et al., 2004a), an animal is first presented with a pair of two objects (QQ) for free exploration, then after a short interval an animal returns to the enclosure with a different two objects (PP). After a retention interval (RI), a single copy of the first sample's (S1) object Q and a copy from the second sample (S2) P are presented for exploration. A typical outcome is that an animal will explore the object which has been presented earlier: Q, conversely spending less time re-exploring the more recent P. The relative reduction in exploration of object P is accounted for by SOP's activation dynamics. Because more time has passed between the sample and test presentations of Q, its memory representation has a higher proportion of representational elements which have decayed into the Inactive state. On the other

hand, the more recently presented P's representation elements will be more likely to occupy the $A2$ state. The difference in exploration time relies on the number of representational elements which can be activated in the $A1$ state on test, and because Q's elements have more elements in the Inactive state than P, it will drive the higher approach to Q. The effect of RR has been attributed to the SGP mechanism as the exploratory preference towards Q diminishes as a function of RI duration; when the time between the S2 and test increases, the two stimuli are explored equally (Mitchell & Laiacona, 1998). Furthermore, the SOP theory predicts that if the ISI between the S1 and S2 is increased the preference for Q should be more robust, and this has been experimentally demonstrated by Tam et al. (2013). However, the RR procedure has only been applied in animal procedures and to date there was no adaptation of the procedure that would explore human behaviour, particularly using the eye tracking methods. In this Chapter I demonstrate, for the first time, the effects of RR in human subjects, whereas in the following Chapter I explore this phenomenon further and address results of Mitchell and Laiacona (1998) which are challenging for the SOP theory.

While the RR is underpinned by the SGP mechanism, the OIC and OIP are enabled by Retrieval Generated Priming (RGP). In a commonly used version of the OIP, the animal is presented with two copies of the stimulus PP, then on test one copy of P changes its location (Dix & Aggleton, 1999; Hotte et al., 2005; Nelson et al., 2011; Barker et al., 2007). In an altered version of the OIP (Langston & Wood, 2010; Eacott & Norman, 2004) an animal is presented with two objects (PP) for free exploration, then after an RI two copies of PP' are presented again, however one of the objects, P' is presented in a novel location to that from the test.

A typical outcome is that an animal would spend more time exploring the object in a novel location.

In a related manner, the OIC procedure (Honey et al., 1998; Eacott & Norman, 2004; Barker & Warburton, 2020; Tam et al., 2014; Langston & Wood, 2010; Honey et al., 2007; Honey & Good, 2000; Dix & Aggleton, 1999) involves a presentation of a stimulus Q in a given context X for a free exploration, then after a delay, an animal returns to the enclosure with a different stimulus P, but also a different context Y. After a retention interval, the animal is given both Q and P but this can happen in either context X (XQP) or Y (YQP). The animal typically explores the stimulus presented in a context which does not match the one from the sample, that is, Q will be explored more in Y and P will be explored more in X.

In this chapter, I will document the development and tests of a novel recognition memory procedure which mirrors the animal procedures. By doing so, I explore whether human recognition memory can be conceptualised within the classical conditioning framework. I focus on the SOP model of learning and memory and assess its explanatory capabilities in accounting for performance on human versions of SOR, RR, OIP, and OIC. In Experiment 1 (p. 81) I investigate whether the adaptation of the dot probe procedure provides a suitable method to study recognition memory, then discuss the results in the context of the SOP. Experiment 2 (p. 99) looks at the versions of SOR and RR procedures which utilise a target detection, yet without interference with the effects of SOR and RR observed in Experiment 1. Experiment 3 (p. 110) follows from the previous with an addition of OIP as an experimental condition, which fails to be demonstrated in this procedure. I discuss this problem with relation to the SOP theory. Experiment 4 (p. 131) attempts to

replicate the previous one, however using a task which enables greater engagement with the experimental stimuli. Then, drawing on the information gained from previous experiments, the last Experiment 5 (p. 143) explores OIC and its interactions with RR. Results of this Experiment, reported in Nitka et al. (2020), to the best of my knowledge, are the first to demonstrate the effects of RR in humans. I discuss the results in the context of the rodent analogue (Tam et al., 2014) and SOP theory.

5.2 Experiment 1

5.2.1 Introduction

A key characteristic of the SOR procedure is a lack of reinforcement; the animal is not rewarded or punished for selecting a certain stimulus from the array. Curiosity and exploratory behaviour are not directed and the behaviour is a result of prior memory. In contrast to this are the methods commonly used in human recognition memory, such as the Remember-Known (RK, Tulving, 1985) procedure where participants are asked to first memorise a set of stimuli for a later test where they select old or new item and judge their subjective sense of memory quality. This approach is biased towards the dual (recollection and familiarity) model of recognition memory and is problematic in interpretation of its results (Migo, Mayes, & Montaldi, 2012). There is an ongoing theoretical debate as to whether the split between recollection and familiarity is qualitative (Yonelinas, 2002) or whether it depends on a signal strength (Dunn, 2004). The method itself also carries some methodological drawbacks, it is unclear as to whether the memory tested is in fact episodic or declarative which may be a result of experimental design. Participants are given

an explicit study set knowing that they will be later tested on that set, hence it is possible that they could memorise the set as a list of items (declarative) rather than as experiences (episodic).

Thus the use of SOR derived methods may offer a more sensitive and mechanism (associative, non-associative) specific way of assessing recognition memory. Furthermore, I argue that using a non-explicit test of memory, free from instructions to memorise and interpret one's memories, offers a more sensitive test of true signal strength (Sivakumaran et al., 2018). Since the SOR (VPC) is ambiguous in terms of the mechanisms which enable it, tasks which are able to parse and capture the effects of non-associative SGP and associative RGP should be used. In this document I aim to investigate whether the procedures sensitive to both components can be used in human research.

To this extent, the method developed for assessing the effects observed in SOR and RR in the animal population draws inspiration from the area of attention research in cognitive psychology and neuroscience, in particular the dot probe (MacLeod, Mathews, & Tata, 1986) and Posner procedures (Posner, 1980). I will first describe the two methods, regarding the biased competition framework (Desimone & Duncan, 1995), then compare and contrast it to the one used in Experiment 1. The Posner procedure (Posner, 1980) is a widely used procedure which assesses the influence of visual cues on target detection latency. In the exogenous cueing version of the task, participants are presented with two bilaterally located squares, then at some point one of the squares becomes visually salient for a brief moment. The cue is followed by a short ISI and the target array which consists of a single target stimulus located either in the same location as the cue (valid) or in

the other location (invalid cue). The typical finding is that valid cues facilitate the RT due to the attentional shift to the location of the incoming target. Furthermore, the experiment is structured in a way where the cue is valid 80% of the time, so the subject is able to learn the importance of the cue.

In the dot-probe procedure (MacLeod et al., 1986), an experimental design used to measure attentional allocation following a stimulus preexposure, a pair of stimuli is presented bilaterally for a short period of time (cue), then after a short delay, a target stimulus (dot) is presented in a location previously occupied by one of the stimuli. The task was mainly applied in the research involving processing of an affective or substance-related (Ehrman et al., 2002) stimulus, where one is threatening (angry face) or related to the substance (ashtray).

The reliability of dot-probe tasks has been reevaluated (Schmukle, 2005; Waechter, Nelson, Wright, Hyatt, & Oakman, 2014) in recent years, questioning the use of RT or early eye movements as a measure of attentional bias. However, a total dwell time calculated over a longer period was deemed to be a more sensitive measure, showing that the influence of a stimulus may be delayed in time.

According to the biased competition attentional framework (Desimone & Duncan, 1995), external signals compete for limited information processing resources with certain stimulus types which are either visually salient or relevant to the task goals prioritised; as in visual search task, where features of an object which are similar to target draw attention. In the context of the Posner task the attention can be captured by a brief, salient cue which precedes the target array. The salient flash causes an automatic orientation towards the cue location and because the ef-

fect is driven purely by visual features the process is deemed to be a bottom-up. To add to that, the participants learn the association between the cue and target lateralisation as cues are 80% valid (indicating the same location as targets). In the dot probe task the cue relies on long-term associations; cue signals a biologically significant target. This means that a certain stimulus will be attended first given its prior recognition and identification as a relevant signal.

However, in the context of the dot probe task, the process of recognition has not been identified as a precursor to the attention biasing effect, but the recognition memory process must be involved even prior to the effects of attentional bias. Experiment 1 aims to address that knowledge gap by investigating the attentional effects of prior associative (SOR) and non-associative (RR) learning on attentional deployment. Here I want to assess whether the effects of exploratory preference observed in experimental animals can be observed in humans using an adaptation of SOR and RR procedures to a dot probe task. The SOR and RR procedures demonstrate that in the absence of reinforcement, rodents' orientation to a stimulus is driven by novelty and decay of memory representation (time since last exposure). Animals spend more time exploring a novel or less recent stimulus when it was presented alongside previously seen or recently seen one. In other words, more overt attention is given to novel or less recent items in an array. It is possible, that the process of preferential looking at a novel or less recent stimulus is driven by attentional capture, by which the stimulus which does not match the working memory template will attract more overt attention. If so, then it is of interest whether the effects of novelty and recency can result in a process similar to that in Posner's task - where novelty and recency effects would act alike an automatic attentional cue.

It is expected that when the target appears embedded in a novel or less recent stimulus participants will have less problems detecting it. This will translate into facilitation of RT to that target. It is also hypothesised, that participants will spend more time exploring novel and less recent stimulus Q than (recently) preexposed P, this means that D2 in both conditions will be positive and different from 0.

5.2.2 Methods

5.2.2.1 Participants

9 female and 3 male University of Nottingham students and staff participated, either earning course credits or an inconvenience allowance of £5, *M* age = 23.2 years (*SD* = 2.9, range 18-27).

5.2.2.2 Apparatus

Eye movements were recorded with the Tobii TX300 eye tracker (Tobii Technology, Stockholm, Sweden) sampling gaze from both eyes at 60 Hz. Participants sat in front of a 23-inch diameter liquid crystal display (51.0 cm wide $\times$ 28.5 cm high) and a computer keyboard. Distance from the screen was approximately 50-60 cm and participants were free to move. The display's resolution was 1920 $\times$ 1080 px and its refresh rate was 60 Hz. Image presentation and data collection was controlled by a Windows 8.01 Pro Dell machine running PsychoPy (1.82.02; Peirce & MacAskill, 2018) and Tobii Studio (version 3.4.8.1348).

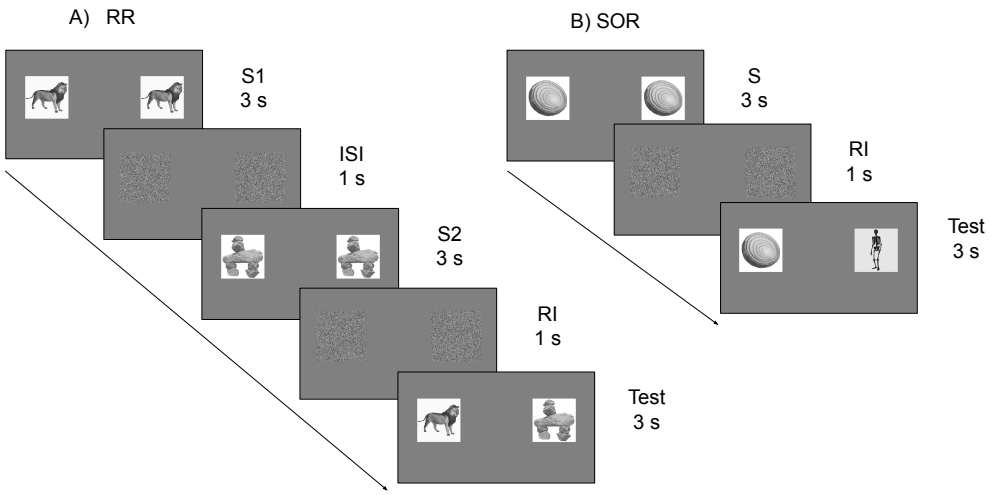


Figure 5.1: Experiment 1, demonstration of procedure for RR (panel A) and SOR (panel B). Each stimuli array was displayed for 3 s with 1 s ISI and RI of the same length during which a random visual noise was presented.

5.2.2.3 Stimuli

A set of 930 images was created from the combined Bank of Standardized Stimuli (BOSS©, Brodeur et al., 2010, 2014). The images depicted objects such as animals, vehicles, tools, and domestic items. These depicted objects, but not the particular images, were familiar to the experimenters and were nameable. The images were matched for luminance to reduce the effects of low-level visual features using the SHINE toolbox (Willenbockel et al., 2010) and MATLAB (MathWorks, 2019). Images were resized to 350 $\times$ 350 px and were preselected randomly without replacement for each participant using R script and presented on a grey (PsychoPy colour space RGB: 0, 0, 0) background. The target was a grey (PsychoPy colour space RGB: 0, 0, 0) dot (12 px diameter) that could appear during the test phase of each trial superimposed on a given image. An illustration of a stimulus with a target is presented in Figure 5.2.

Figure 5.2: Experiment 1, demonstration of a stimulus with a target.

Table 5.1: Design of Experiment 1. In two conditions: SOR and RR participants were presented with either one (SOR) or two (RR) sample stimulus. Each presentation lasted for 3 s and all ISI, RI and ITI were 1 s.

Condition	Sample	RI	Test
SOR	PP	1 s	PQ
RR	$QQ \xrightarrow{1s} PP$		PQ

5.2.2.4 Procedure

All participants completed a 5-point calibration procedure to ensure that the apparatus provided accurate gaze coordinates, and they were then provided on-screen and verbal instructions.

Table 5.1 presents the design of the Experiment. A total of 252 trials consisted of 84 trials without a dot target (42 per each trial type: SOR and RR) and 168 trials with targets present (84 SOR and 84 RR). Trials which consisted of a target presentation were equally split into three levels (28 trials each) of target onset which could have been either 0, 1, or 2 s. Trials were selected pseudo-randomly by the experimental software and presented with 1 s ITI. A demonstration of the stimulus sequences are presented in Figure 5.1. Each trial began with a first sample (S1) phase: a bilateral presentation of two identical images (size 350 $\times$ 350 px), one on the left (centre aligned to -685, 100 px accordingly along the x- and y-axis) and the right (685, 100 px). Images remained on the screen for 3 s and at their offset, they were followed by a visual noise mask (see below) which lasted the entire duration of ISI, 1 s. In RR trials, S1 was followed by a second sample (S2) phase during which another two identical images were presented in the same locations and for the same duration; the SOR trials did not have a S1 phase. The RI lasted 1 s, after which the test phase was presented for 3 s. In SOR condition, one image was identical to S1, whereas the other was novel and not previously shown. In the RR test phase, both images were identical to those presented in the sample phase; one from S1 and one from S2. Another trial followed immediately after. Participants were not asked to remember the stimuli but to pay attention to the screen and to

press the space bar as soon as possible each time they saw a target - a grey dot which appeared embedded onto an image.

The location of the target was determined by design and was equally distributed between the left and right as well as stimulus type (novel / pre-exposed in SOR and less / more recent in RR), however, the precise location within the image bounds was pseudo-randomly calculated on each trial by adding a pseudo-random spatial jitter which on each trial was drawn from an uniform distribution as $x_j, y_j \sim \mathcal{U}(-125, 125)$ by the presentation software. The x_j and y_j were then added to the x,y-location of the target (left or right: -685, 100 px or 685, 100 px) which ensured that the location of a target was within the image bounds but not in the same place. Target onset and duration (for how long the target remained on the screen) depended on onset time specified by the experimental design (either 0, 1 or 2 s after the onset of a given test phase) and a temporal jitter pseudo-randomly drawn from a normal distribution as $o_j \sim \mathcal{N}(0, 0.1)$ that was added to the onset time except for the onset time of 0 where the absolute value of jitter was used to avoid the target appearing before the image array. Target was displayed on the screen for the remainder of 3 s; and until the stimulus was displayed. Participants were given an opportunity to take a break after each 31 trials were completed.

The visual noise mask, which followed each image presentation and lasted for 1 s, was constructed from 2000 white and 2000 black dots (each 2 px in diameter). Dots were moving randomly (coherence factor was set as 0) with the speed of 0.1 px/frame (display was set to 60 frames per s). There were two areas in which the noise was displayed, both overlapping with the locations used for the experimental stimuli.

5.2.2.5 Data Treatment

Behavioural Measures: RT and Accuracy. Response times (RT) were collected during the test phase of each target-containing trial and collected with experimental software. Accuracy was calculated based on the number of detected targets over the number of all target trials.

Eye Tracking. The eye tracker collected data during the entire sample and test phases and recorded the total time spent looking at the ROI, of which there were two: one with its centre aligned to the left (-685, 100 px on x- and y-axis) and right (685, 100 px) locations. The ROI was of 450 $\times$ 450 px dimensions and was larger than the stimulus presented by an additional 50 px in each direction.

Discrimination ratio, D2, was calculated as per Equation 4.1 on p. 72.

5.2.3 Results, Behavioural

5.2.3.1 Target Trials Reaction Time

It was hypothesised that the stimulus Q will receive more attention and will be looked at for a longer time, this will result in a higher probability of the target being detected and, consequently, a shorter RT. Furthermore, this effect will be evident in the early stages of the test as the SOP model predicts that $A1$ activation is the most pronounced in early temporal windows. To test that hypothesis, I have entered RT data into the 2 $\times$ 2 $\times$ 3 repeated-measures ANOVA with factors of Condition (SOR and RR), Target Type (Q, P) and Target Onset (0, 1, and 2 s) and dependent variable of RT (s).

The summary statistics are presented in Figure 5.3 panel B. The main

effect of Condition was not significant ($F(1, 11) = 3.226$, $p = 0.1$, $BF_{01} = 3.470$, *Error* = 1.3%) nor was the main effect of Target Type ($F(1, 11) = 0.226$, $p = 0.644$, $BF_{01} = 5.437$, *Error* = 1.26%). The main effect of Target Onset was significant with $F(2, 22) = 66.634$, $p < 0.001$, $\eta_p^2 = 0.858$, *95% CI* $\eta_p^2 = [0.694, 0.905]$, $BF_{10} = 4.026 \times 10^{27}$. Smallest p in Condition $\times$ Target Type $\times$ Target Onset: $F(2, 22) = 2.861$, $p = 0.079$, $BF_{excl} = 2.638$. *Post hoc* (Holm corrected) paired sample t-tests in the factor of Onset yielded significant differences between the RTs at 0 and 1 s Onsets: $t(22) = 3.863$, $p < 0.001$, as well as between 1 and 2 s: $t(22) = 7.49$, $p < 0.001$ and between 0 and 2 s: $t(22) = 11.353$, $p < 0.001$. The statistical test received decisive support from the Bayesian analysis, $BF_{10,U} = 238.302$, $BF_{10,U} = 1.659 \times 10^{12}$, $BF_{10,U} = 9.995 \times 10^{17}$ respectively.

5.2.3.2 Accuracy

Accuracy was analysed to determine a potential influence of novelty and recency. The summary statistics are presented in Figure 5.3, panel A. Accuracy data were analysed with repeated-measures 2 $\times$ 2 $\times$ 3 ANOVA (factors as in RT analysis).The main effects of Condition: $F(1, 11) = 0.089$, $p = 0.771$, $BF_{01} = 5.499$, *Error* = 1.98%; and Target Type: $F(1, 11) = 1.432$, $p = 0.257$, $BF_{01} = 3.771$, *Error* = 1.21% were not significant. The main effect of Target Onset was significant, $F(2, 22) = 138.383$, $p < 0.001$, $\eta_p^2 = 0.926$, *95% CI* $\eta_p^2 = [0.836, 0.95]$, $BF_{10} = 9.875 \times 10^{24}$. None of the interactions as significant with smallest $F(1, 11) = 2.939$, $p = 0.114$, $BF_{excl} = 2.334$. *Post hoc* demonstrated differences between the Target Onsets of 0 s and 1 s: $t(22) = 1.357$, $p < 0.001$, $BF_{10,U} = 0.646$. This might have been due to ceiling effect as the Accuracy was highest in the 0 s onset. The difference between

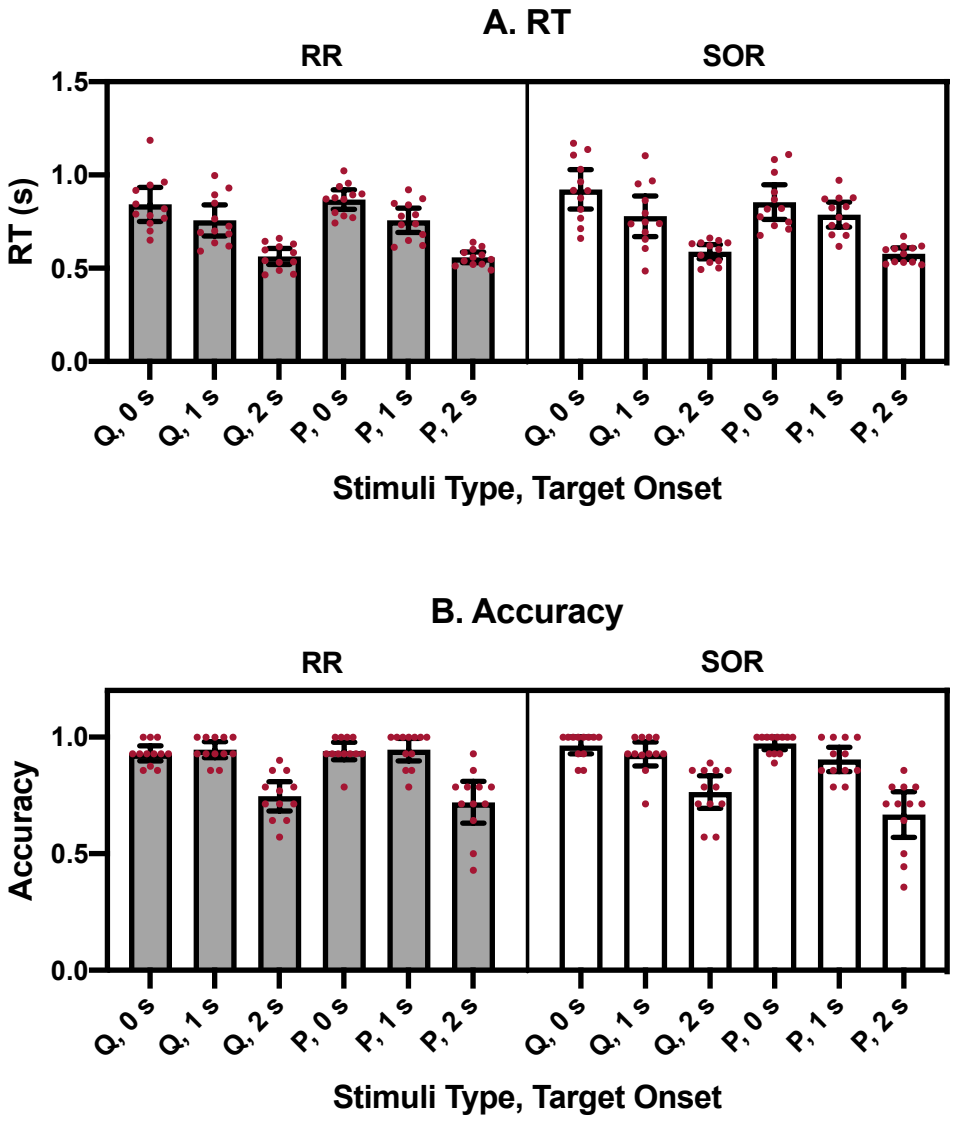


Figure 5.3: Experiment 1, Reaction Time, **panel A**, and Accuracy, **panel B**, data for RR (grey) and SOR (white) conditions collected during the test phases of target (dot detection task) containing trials. On the x-axis in both panels Stimuli Type (Q, P) and Target Onset in a given trial are plotted. In figure A RTs (in s) are plotted on the y-axis. In figure B, Accuracy on the y-axis, calculated as a ratio between targets participants pressed the button for, over the number of all target trials. Means are presented with *95% CI* and individual observations as points.

the 1 and 2 s Onsets was significant with $t(22) = 13.681$, $p < 0.001$, $BF_{10,U} = 1.857 \times 10^{10}$. Same was true for the 0 and 2 s difference: $t(22) = 15.038$, $p < 0.001$ also supported by a decisive evidence in favour of *H1*, $BF_{10,U} = 3.728 \times 10^{12}$.

5.2.4 Results, Eye Tracking

5.2.4.1 Sample Dwell

Because participants were not aware whether a given trial would have a target, until they were presented with the target phase array, the sample data are collapsed down into Condition factor only. Summary of the data is presented in Figure 5.4 (panel A) and indicates a bi-modal distribution, and so the data violated the assumption of normality and neither the *log10*, nor the square root transformation could normalise its distribution. Therefore the nonparametric Friedman test was, which was $\chi^2 = 8.0$, $p = 0.018$ with pairwise comparison indicating towards a significant difference between the SOR S1, *MED* = 158.706, *95% CI MED* = [140.275, 159.786], and RR S2, *MED* = 158.175, *95% CI MED* = [143.182, 162.048], with Durbin-Conover pairwise test of $T_2 = 2.872$, $p = 0.009$. There was also a significant difference between the RR S1, *MED* = 157.718, *95% CI MED* = [139.422, 159.706], and RR S2 with $T_2 = 2.872$, $p = 0.009$. There was no difference between the SOR S1 and RR S1, $p = 1$. The elevated dwell in the S2 of RR, apparent from the graph and supported by the test, may be attributed to either the expectation of a stimulus characteristic to a SOR's test phase but also to a presentation of two novel items in that sample phase.

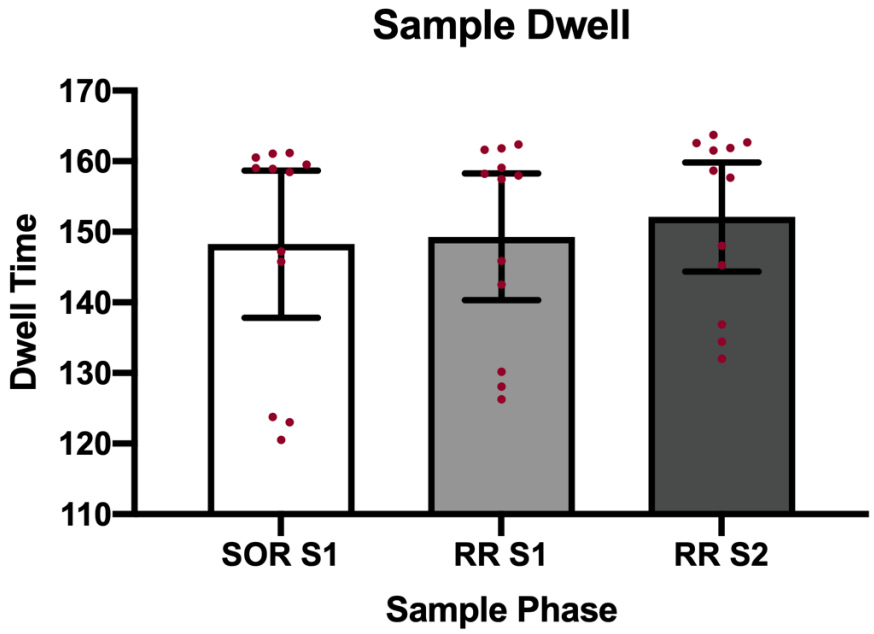


Figure 5.4: Experiment 1, sample dwell times. Plot presents dwell time for sample phases in SOR and RR conditions, each sample phase is on the x-axis and dwell time on y (units of eye tracker samples at 60Hz). All means are presented with *95% CI* of the mean and individual means as points.

5.2.4.2 Test Dwell

Data were entered into a 2 x 2 repeated measures ANOVA with factors of Condition and Target and DV of D2, summary data are presented in Figure 5.5. The main effect of Condition was not significant with $F(1, 11) = 2.365$, $p = 0.152$, $BF_{01} = 0.717$. So was the main effect of Target: $F(1, 11) = 0.304$, $p = 0.592$, $BF_{01} = 3.133$. Both main effects interacted; $F(1, 11) = 21.832$, $p < 0.001$, $\eta_p^2 = 0.665$, *95% CI* $\eta_p^2 = [0.212, 0.807]$, $BF_{incl} = 4.127$. *Post hoc* analysis performed with paired sample *t*-test (Holm) demonstrated that for trials with target present D2 in SOR was higher than in RR; $t(11) = 3.166$, $p = 0.04$, all remaining paired test were not significant (smallest $p = 0.087$). When all four D2s were compared with $\mu = 0$, only the D2 in SOR with target present demonstrated significant difference; $t(11) = 3.09$, $p = 0.01$, $d = 0892$, *95% CI* = [0.309, 1.442], $BF_{10} = 5.78$. All other tests have not reached

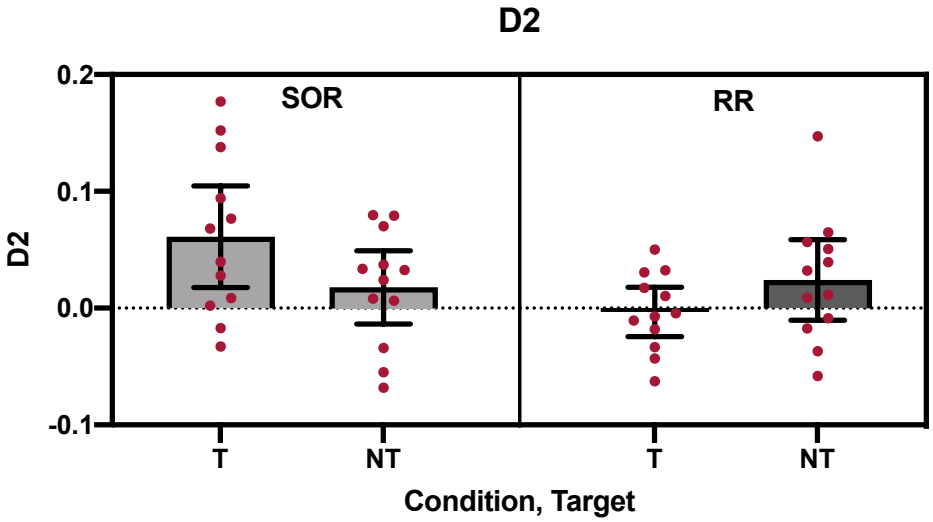


Figure 5.5: Experiment 1, Test D2, SOR on the left and RR on the right. Target factor plotted on the x- and D2 on the y-axis. Individual observations as points with *95% CI* as error.

the significance criterion, smallest $p = 0.153$.

A supplementary analysis was performed with repeated measures ANOVA with factors of Condition, Stimulus Type and Target and DV of raw dwell time, summary of the data is presented in Figure 5.6. The main effect of Condition was not significant with $F(1, 11) = 1.04$, $p = 0.33$, $BF_{01} = 3.549$, *Error* = 1.119%. The main effect of Stimulus Type reached significance, $F(1, 11) = 7.37$, $p = 0.02$ $\eta_p^2 = 0.401$, *95% CI* $\eta_p^2 = [0.008, 0.651]$, $BF_{10} = 31.184$. There was no influence of the Target, $F(1, 11) = 0.116$, $p = 0.739$, $BF_{01} = 4.544$, *Error* = 2.346%. Only the three-way interaction was significant; $F(1, 11) = 12.606$, $p = 0.005$, $\eta_p^2 = 0.534$, *95% CI* $\eta_p^2 = [0.078, 0.731]$, $BF_{incl} = 3.024$. All other interactions were not significant; smallest $F(1, 11) = 2.163$, $p = 0.169$. *Post hoc* analysis exploring the significant interaction demonstrated a significant difference between dwell to Q and P in SOR's when accompanied by the target; $t(11) = 3.532$, $p = 0.034$ (Holm). Significant difference was also observed between SOR's dwell to P with Target present and RR's Q with

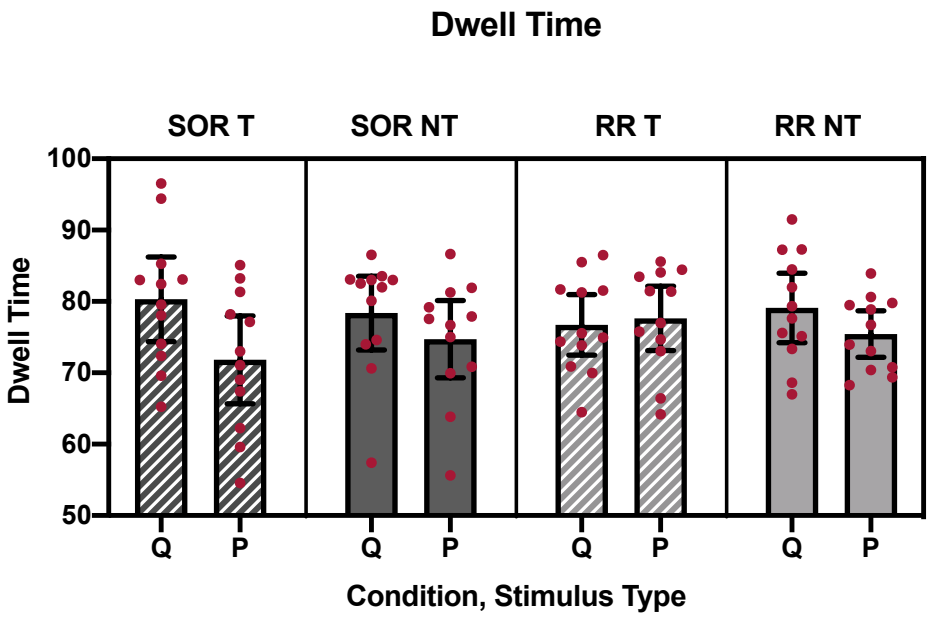


Figure 5.6: Experiment 1, Test dwell to QP. In facets from the left SOR with and without target, RR with and without target. Stimulus Type factor plotted on the x- and dwell time on the y-axis. Individual observations as points with *95% CI* as error.

no target; $t(11) = -3.72$, $p = 0.021$. All other tests were not significant, smallest $p = 0.242$.

5.2.5 Discussion

Hypothesised facilitation of RT by novelty or recency effects could not be confirmed, Target Onset had a sole influence on how quickly participants responded. Same was observed for accuracy. Data from D2 indicates difference between SOR and RR discrimination, but only in Target trials. One-sample analysis of D2 data demonstrated one significant difference, that the effect of novelty could only be observed in trials with target present. In summary, discrimination was observed only in SOR trials with target. Results from raw dwell time analysis echo those of D2.

Here, I investigated whether an adaptation of a dot probe task can be used as a reliable measure of human recognition memory. Of main interest were the

results from the eye tracking data. Counter to my expectations, participants have not demonstrated a reliable pattern of results that would support both effects, SOR and RR. D2 analysis did support the effects of novelty (SOR), however limited only to target trials, and there was no evidence for recency discrimination (RR). Participants engaged more with the target stimulus, indicating that the visual search in the dot probe task was an important factor guiding covert attention. Removal of target trials from the analysis provided no evidence to support the hypothesised effects.

Based on evidence, predicted influence of priming on RT cannot be confirmed. The hypothesis that an increase in looking time due to experimental manipulation will result in RT facilitation, finds no support. The observed robust effect of Target Onset can be explained in two ways. Firstly, it can be argued that despite being told to respond as quickly as possible upon seeing the target, the participants learned that if the target appears early, they have more time to respond to it. During the trials with 2 s Target Onset they had less time to respond, which facilitated the RT. The behaviour might have been motivated by the fact that the target was small and it could have been difficult to be detected as both the stimulus and the target were in various shades of grey. Therefore, the participants, knowing that they have more time to process the stimulus, responded slower when they had a longer time window to do so. Alternatively, it can be argued that the increased RT to the target which had its onset in the early stages of the test may be due to the processing load. As the process described by the SOP is automatic and the $A1$ activation is most intense during the early stages of the stimulation, it is possible that regardless of the task demands (target detection), the SOP processing occurs and takes up some cognitive capacity that otherwise would be dedicated to target detection. As repre-

sentative elements move from $A1$ to $A2$ the cognitive resources are freed up and the cognitive process involved in the task at hand can take more of the resources and so the RT can be quicker at later onsets. Effectively, the SOP processing slows down the concurrent target detection and response process resulting in slower RT, but as $A1$ activity decays into $A2$ (processed state), the RT can be quicker. To the best of my knowledge, the SOP has not been tested in the context of human RT, and so the support for this account is speculative at this stage.

Results from the accuracy analysis complement those of RT, the main effect of influence is the Target Onset. The pattern of RT and Accuracy results fits well with the speed-accuracy trade-off (Ollman, 1966; Reed, 1973; Wickelgren, 1977) hypothesis. It asserts that accuracy and RTs are associated with each other; participants can increase the accuracy of response, but it will also increase the RT. On the other hand, when RT is decreased, the participants are more likely to make mistakes. In line with the speed-accuracy trade-off, I have observed a decrease in accuracy when the target is presented late in the test. This corresponds to increased RT to that target. Taken together, it appears that the participants have indeed developed a strategy where they have responded more slowly but more accurately when they expected more time available for a response. Conversely, they made more errors, but were quicker when they were constrained by an expectation of a short response window. As such, the argued above SOP-based explanation of the effect observed in RT analysis is still plausible in light of the accuracy analysis.

Taken together, the results indicate that the dot probe task is not a reliable device to study recognition memory in humans. Despite some evidence in favour of hypothesised effects of novelty, the RT measurement did not contribute to the

understanding of the mechanisms in question. Moreover, the task demands imposed by the visual search may confound the effects of recognition memory as participants adapt a certain strategy which guides the eye movements. The behaviour is in line with findings from the visual search procedure (Yarbus, 1967; DeAngelus & Pelz, 2009). However, when two processes, namely target search and object recognition, compete with each other, the former has a greater influence on eye movements.

5.3 Experiment 2

5.3.1 Introduction

In Experiment 1 I concluded that when participants are told to search for a target the eye movements will be influenced by a cover task. Indeed, the analogue animal procedures are free from reinforcement and the exploration is driven solely by the animals' curiosity. Human participants do not always share similar characteristics and lack of any cover task may lead to a lack of engagement with the experiment, especially with sessions lasting around 30 m. This means that some form of a task that would ensure engagement with the stimuli is vital. However, the task must not interfere with the eye tracking (Holmqvist et al., 2011). For the purpose of the current Experiment I modified the cover task, so that the target detection was less frequent and does not interfere with the presentation of experimental stimuli. Participants were shown sequences of stimuli, as in Experiment 1, with two conditions, SOR and RR. In the former they were presented with a pair of stimuli (PP), then after a short RI a copy of P and a novel stimulus Q were presented. In the RR condition, each sample phase consisted of a pair of stimuli, QQ, then PP, followed

by a test where Q and P were presented. To prevent interference from the visual search on the recognition memory, targets could only appear during the time when the stimuli were not on the screen; targets appeared during the ISI. In this pilot experiment, the hypothesis is that participants spend more time looking at the novel (SOR) or less recent (RR) stimulus Q over the recently pre-exposed P.

5.3.2 Methods

5.3.2.1 Participants

Identical to that in Experiment 1 with the exception of sample size: 3 females and 3 males took part. The mean age was 22.167 years (*SD* = 3.896, range 18 - 29).

5.3.2.2 Apparatus

Identical to that in Experiment 1.

5.3.2.3 Stimuli

Identical to that in Experiment 1.

5.3.2.4 Procedure

Each participant completed a 9-point calibration procedure to ensure that the apparatus provides accurate gaze coordinates, they were then provided on-screen and verbal instructions. Participants were not asked to remember the stimuli but to pay attention to the screen and to press the space bar as soon as possible each time they saw a specified target (see below).

Experimental design is presented in Table 5.2 and Figure 5.7 visualises

Table 5.2: Design of the Experiment 2. In two conditions: SOR and RR participants were presented with either one (SOR) or two (RR) sample phases. Each presentation lasted for 3 s and all ISI, RI and ITI were 1 s.

Condition	Sample	RI	Test
SOR	PP	1 s	PQ
RR	$QQ \xrightarrow{1s} PP$		

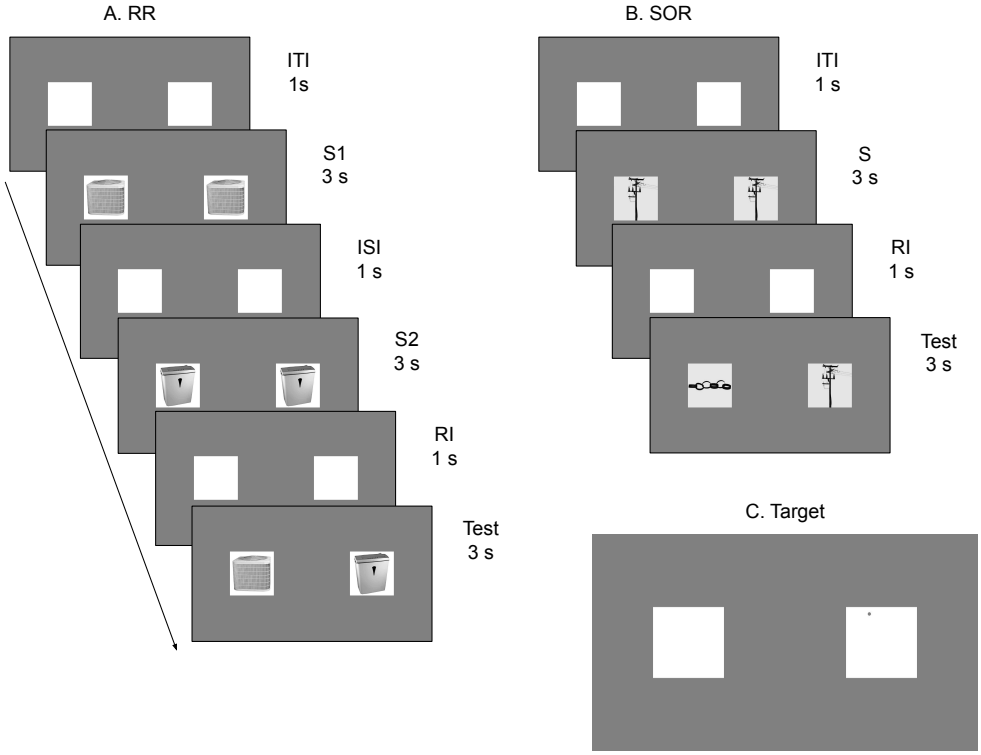


Figure 5.7: Experiment 2 Demonstration of experimental sequences. **Panel A** - RR: each trial begun with a 1 s followed by two sample phases S1 and S2, each lasting for 3 s and separated by a 1 s ISI. Pairs of stimuli QQ and PP were displayed during S1 and S2. After a 1 s RI a copy of each sampled stimuli QP were displayed for 3 s. **Panel B** - SOR: after the IT a pair a PP pair was displayed for 3 seconds and after a RI of 1s a preexposed copy of stimulus P was paired with novel stimulus Q for 3 seconds test. **Panel C** - Target: during the ITI, ISI or RI a small target could have appeared in the area of white polygons presented in the locations of stimuli.

the experimental procedure. A total of 256 trials consisted of 128 RR and 128 SOR trials, each number including 16 target trials. Trials were selected pseudo-randomly by the experimental software and presented with 1 s ITI. All stimuli were presented bilaterally: one on the left (centre aligned to -685, 100 px alongside x- and y-axis respectively) and one right (685, 100 px) and was of size 350 $\times$ 350 px. In SOR trials, the sample phase (S2), during which a pair of stimuli, PP was presented for 3 s, was then followed by a RI (1 s, during which two white squares remained in the location of the images) and test, during which two images were displayed: one image was novel, Q, and the other, P, was identical to the one presented in the S1; both were displayed bilaterally and presented for 3 s. Location of both test stimuli was counterbalanced between the trials. Each RR trial began with a first sample (S1) phase: a bilateral presentation of two identical images, QQ. Images remained on the screen for 3 s and after an offset, they were followed by a 1 s ISI. During the ISI, two white squares remained in the location of the images. The S1 phase was followed by a second sample phase (S2), during which two other images were shown, PP. This was followed by a test, during which one image from S1 and one from S2 PQ, were displayed for 3 s. Participants were allowed to take self-regulated breaks after completion of a multiple of 16 trials.

Participants were advised to respond to targets; the task was used for the sole purpose of ensuring engagement with the experiment. In contrast with Experiment 1 and due to its results which indicated that the task demands have a major influence on human eye movements, the targets were less frequent and appeared only during the ISI/RI/ITI phases (Figure 5.7, panel C). On pre-selected trials, a grey dot (12 px in diameter) could appear during the time when the stimulus was

not displayed. The location of the target was equally split between the left and right location, but the exact location of target was determined by adding a jitter in both x- and y-axis. The jitter, j, was randomly drawn from an uniform distribution as $x_j, y_j \sim \mathcal{U}(-125, 125)$ by the presentation software and added to the x, y coordinate. The onset of the target was determined pseudo-randomly and on each trial it was drawn from an uniform distribution as $o \sim \mathcal{U}(0, 0.5)$. After the onset the target remained on the screen till the end of the ISI/RI/ITI phase, even if a response was made. The periods during which the target could have appeared were pre-selected in the design; out of 16 targets in the SOR condition 8 appeared during the RI period (after the S1 phase) and 8 during the ITI phase (after the test phase). Similarly, in the RR condition, the targets were equally distributed amongst the ISI (after the S1), RI (after the S2) and the ITI (after the test), each with 6 trials. In contrast with Experiment 1, if a target was missed, or a false alarm was caused, participants were presented with visual and auditory feedback, no feedback was given after hits or correct rejections. Feedback was introduced to increase engagement with the task.

5.3.2.5 Data Treatment

Identical to that in Experiment 1 with an exception of a nonparametric estimate of discriminability *A'* which was computed based on the number of hits (*H*), false alarms (*FA*), correct rejections (*CR*) and misses (*M*) using the R's psycho package (Makowski, 2018). There were no *FA*s and on average participants correctly responded to the target on 78.65% of target trials (*SD* = 8.71%); the estimate of discriminability was high with *A'* = 0.947 (*SD* = 0.022). Participants responded quickly with *M* = 0.556 s, *SD* = 0.033, which indicates that participants have appropriately

engaged with the cover task.

Because targets appeared only during the ISI or ITI and did not appear during the tracking period, both target and nontarget trials have been included in the analysis. To verify whether dwell differed due to Trial Type, a 2 (Stimuli: Q, P) by 2 (Trial Type: Target, No Target) repeated measures ANOVA with DV of dwell time was used. It had a not reliable main effect of Trial Type (p = 0.109), the evidence in support of the $\mathcal{H}_0$ was anecdotal, BF_{01} = 2.727, however all trials were kept in the analysis.

Discrimination ratio D2, Equation 4.1, on p. 72, was calculated for test phase data, as a difference between the time spent looking at the stimulus Q and P, divided by the sum of both.

5.3.3 Results

5.3.3.1 Sample Dwell

Descriptive statistics for dwell time during the sample phases are presented in Figure 5.8, panel A; values are sums of left and right ROIs. Dwell duration appears to be lower in the S1 of SOR condition; however the repeated-measures ANOVA with factors of Sample Phase (S1 SOR, S1 RR and S2 RR) was not reliable (F(1.01, 5.06) = 1.98, p = 0.218). Bayesian analogue of the analysis yielded evidence for the $\mathcal{H}_0$ anecdotal, BF_{01} = 1.315, Error = 1.02%, however there was no support to the $\mathcal{H}_1$ hypothesis. Therefore, it can be assumed that participants engaged with the sample stimuli in similar ways, regardless of the sample phase.

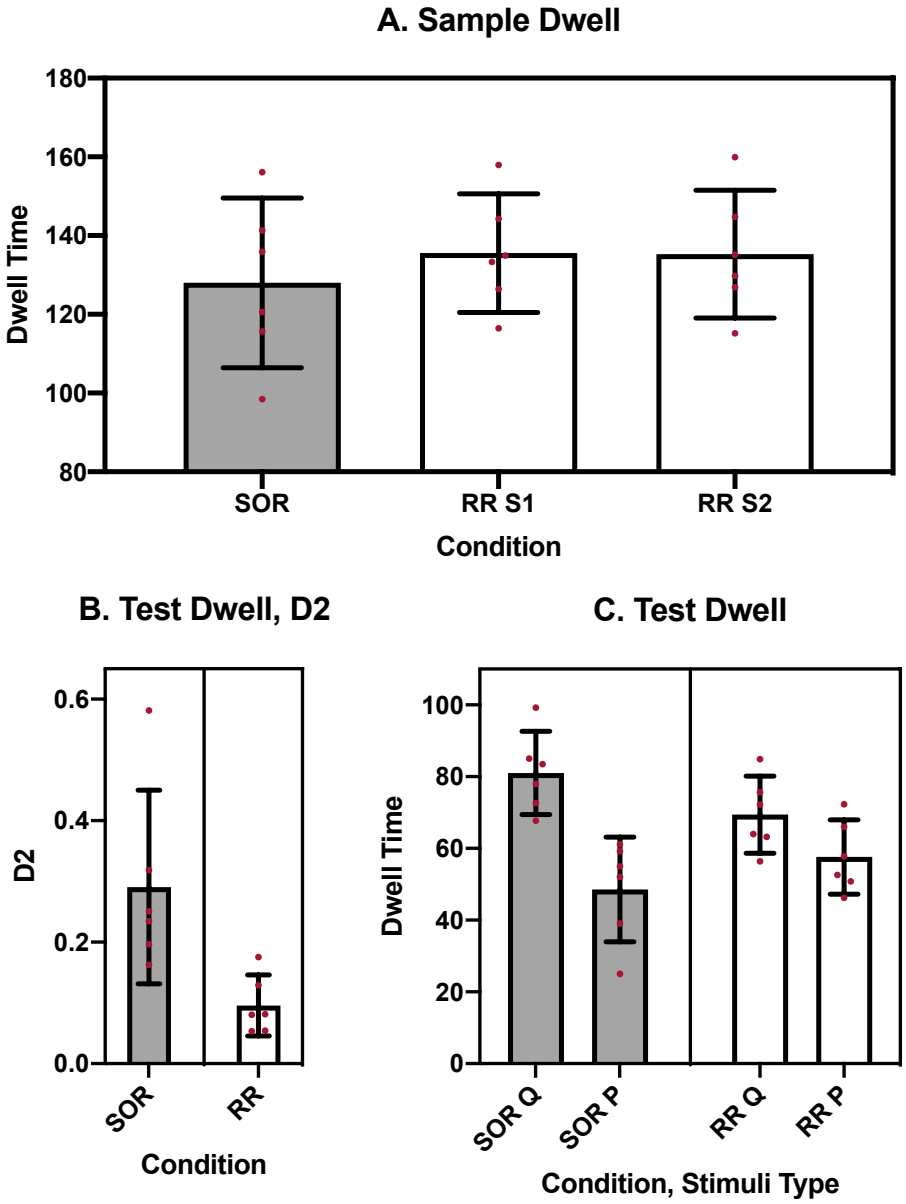


Figure 5.8: Experiment 2, dwell time data for the sample (panel A) and test phases: D2 in panel B and raw dwell in panel C. In **panel A**, sample phase's values for the SOR and RR are plotted on x- with dwell values on y-axis (units of eye tracker samples at 60Hz). In **panel B**, test data are split into condition: SOR in grey, RR in white, with D2 on the y-axis. In **panel C** raw dwell time is presented in the y-axis (units of eye tracker samples at 60Hz) and stimuli type for each condition on the x-axis. All data are plotted with mean and *95% CI* of the mean as error, individual observations are plotted as scattered points.

5.3.3.2 Test Dwell

The data of main interest came from the test phases of each trial. The DV of D2 was entered into a repeated measures ANOVA with a main effect of Condition. Summary of the data is presented in Figure 5.8, panel B. The main effect of Condition was significant with $F(1, 5) = 15.901$, $p = 0.01$, medium to large effect size $\eta_p^2 = 0.761$, *95% CI* $\eta_p^2 = [0.085, 0.876]$ and a strong support in favour of the $\mathcal{H}_1$, $BF_{10} = 13.226$. Both SOR, $t(5) = 4.691$, $p = 0.005$, $d = 1.915$, *95% CI* $d = [0.49, 3.291]$, $BF_{10} = 11.024$, and RR, $t(5) = 4.907$, $p = 0.004$, $d = 2.003$, *95% CI* $d = [0.535, 3.424]$, $BF_{10} = 12.745$, were significantly different from 0. Upon inspection of the means, it could be counterintuitive to accept that both differences were supported by an equal amount of evidence, especially that the D2 SOR $M = 0.291$ and D2 RR $M = 0.096$. Both tests fulfilled the requirement for the assumption of normality, however, the D2 SOR had a much larger variance ($SD^2 = 0.023$) than D2 RR ($SD^2 = 0.002$) which may be due to a relatively small sample size. In effect, this could have been the reason why the much larger mean difference of D2 SOR did not correlate with a higher BF_{10}.

Supplementary analysis was performed on DV of raw dwell time recorded during the test phase of each trial. The data were entered into a repeated measures ANOVA with factors of Condition (SOR, RR) and Stimulus Type (Q, P), Figure 5.8, panel C summarises the data. The main effect of Stimulus Type was of particular interest here and inspection of the data appears to demonstrate an effect with elevated dwell towards the novel or less recent stimulus Q. Inferential test yielded the main effect of Stimulus Type significant with $F(1, 5) = 118.909$, $p < 0.001$, η_p^2

Table 5.3: Experiment 2, results of post hoc analysis enabled by significant Condition x Stimulus Type interaction. Paired sample t-test were performed for each of the stimuli pairs, Cohen's *d* is reported with 95% CI.

Measure 1	Measure 2	*t*-test, *df* = 5	BF_{10}
SOR Q	SOR P	t = 9.16, p <.001, d = 3.74, [1.359, 6.111]	113.873
RR Q	RR P	t = 7.503, p <.001, d = 3.063, [1.05, 5.053]	54.847
SOR Q	RR Q	t = 10.932, p <.001, d = 4.463, [1.679, 7.251]	221.149
SOR P	RR P	t = -2.98, p = 0.031, d = -1.217, [-2.271, -0.102]	2.98

= 0.96, *95% CI* η_p^2 = [0.706, 0.978], BF_{10} = 12571.075. The second main effect of Condition has not met the criterion of significance (F(1, 5) = 0.923, p = 0.381), but the evidence for the $\mathcal{H}_0$ was anecdotal BF_{01} = 2.645, *Error* = 3.45%. The interaction between the main effects was significant with F(1, 5) = 31.394, p = 0.003 and a large effect size η_p^2 = 0.863, *95% CI* η_p^2 = [0.283, 0.927] and this result was supported by a decisive evidence, BF_{incl} = 291.716. The interaction was further investigated with a series (Holm) paired sample *t*-tests, presented in Table 5.3.

5.3.4 Discussion

Here, I tested whether the human adaptations of SOR and RR can replicate the results observed in animal studies. Results from both analyses indicate that participants demonstrated significant discrimination for both novel and less recent stimulus with a decisive level of evidence in support.This suggests that the RR can be observed in humans and that the method used is adequate in demonstrating the behaviour of interest without any noticeable interference from the cover task. Despite the lack of main effect of Condition the interaction indicates that the looking time was affected by the Stimuli Type, but this influence was modulated by the Condition; namely, the novelty and recency effect are quantitatively different in SOR and RR Conditions. The difference in dwell time between the novel stimulus (Q SOR)

and less recent (Q RR), with the former being looked at more, is accounted for by the model.

To demonstrate this, a computer simulation of RR and SOR (Figures 5.9 and 5.10) was performed. The results of the simulation demonstrate that the maximal $A1$ activation for the Q in SOR was 0.793 but for the same stimulus in RR this was 0.499. This is caused by a lesser $A2 \xrightarrow{pd2} I$ decay of Q in the RR than in SOR, illustrated by the green dashed line at around the 80th moment. In the RR, a proportion of both Q and P elements are in the $A2$ at the moment preceding the test, whereas in SOR Q is completely in I. What follows is that the representation of Q in SOR can produce much stronger orienting as it is proportional to the strength of $A1$ activation. Hence, the SOP model can account for the difference in D2 between the two conditions. However, the model cannot account for the difference between the Ps in RR and SOR, as both achieved the same $A1$ activation. However, the difference may caused by the design of the task, that is, looking at the stimulus Q will decrease the time spent looking at P.

Results from this experiment must be taken with reservation, as small sample size reduces the power of inferential test. However, being able to demonstrate the RR effect in humans means that the underpinning SOP's mechanism of self-generated priming (SGP) and the model itself provides, at least partly, a sound theoretical explanation of recognition memory. Because it is unclear whether the effects of novelty in SOR are due to SGP or the retrieval mechanism (RGP). The following experiment attempts to replicate the findings obtained here, as well as investigate the associations in recognition memory using the Object-in-Place (OIP) procedure.

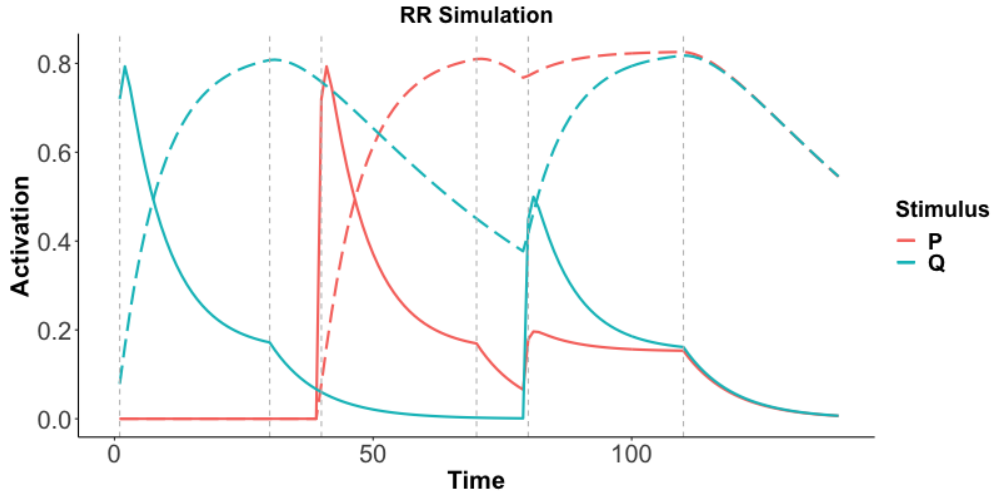


Figure 5.9: SOP simulation for the RR. Each simulated phase where stimuli were presented lasted for 30 moments with 10 moments ISI and RI. Design followed RR's standard of $Q \xrightarrow{ISI} P \xrightarrow{RI} QP$ in S1 (1 - 30 moments), S2 (40 - 70 moments) and test (80 - 110 moments) phases. Time is presented on x-axis and proportion of activated elements on the y-axis. Simulation run with parameters: $p1$ = 0.8, $pd1$ = 0.1 and $pd2$ = 0.02. $A1$ and $A2$ are plotted in solid and dashed lines respectively, Q in blue and P in red. Both Q in S1 and P in S2 were able to achieve similar maximal $A1$ activation of around 0.793, however on test (80 - 110 moment) $A1$ activation for Q was 0.499 and for P 0.196.

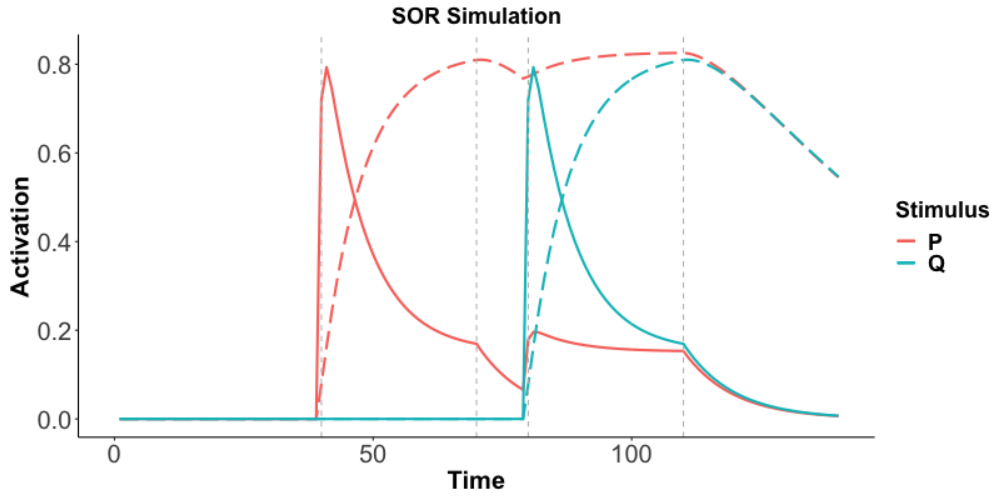


Figure 5.10: SOP simulation for the SOR. Each simulated phase where stimuli were presented lasted for 30 moments with 10 moments RI. Design followed SOR's standard of $P \xrightarrow{RI} QP$ in S1 (40 - 70 moments) and test (80 - 110 moments) phases. Time is presented on x-axis and proportion of activated elements on the y-axis. Simulation run with parameters: $p1$ = 0.8, $pd1$ = 0.1 and $pd2$ = 0.02. $A1$ and $A2$ are plotted in solid and dashed lines respectively, Q in blue and P in red. Q in S1 was able to achieve maximal $A1$ activation of around 0.793, however on test (80 - 110 moment) $A1$ activation for Q was 0.793 and for P 0.196.

5.4 Experiment 3

5.4.1 Introduction

The SOP model asserts that there are two mechanisms which govern the activation of memory representations: one non-associative and transient Self Generated Priming (SGP) and the second associative and long-term Retrieval Generated Priming (RGP). The focal idea of both is to explain how a given representation becomes primed. The former mechanism achieves the primed state through the consecutive or prolonged exposure of a stimulus, the latter operates through an association where the signal (context) primes what it is signalling (associated stimulus). In Experiment 2 I have demonstrated the effects of RR in humans using eye tracking methods and to the best of my knowledge such effects have not been previously demonstrated in humans. Existence of RR implies the SGP mechanism, postulated by Wagner (1976) and that the SOP can, in at least to the extent of SGP, account for human recognition memory. As it is unclear to what extent the effects of novelty observed in the SOR are due to associative or non-associative mechanisms, I will investigate the potential effects of RGP using a version of the Object-in-Place (OIP) procedure (Langston & Wood, 2010) alongside the SOR and RR used previously. In the OIP procedure, animals typically present greater attention towards an object which, in comparison to the sample, is presented in a novel location. The trial consists of a sample phase where the animal is presented with two different stimuli PR, then after the RI two copies of one of P are presented, one in a novel location, P', previously occupied by R. Because stimulus has been preexposed, and both PP' are identical, the preference can only be explained by the factor of novel place and

location configuration. According to the SOP theory, a recently pre-exposed representation remains in $A2$, so only some of its elements will be available for $A1$ activation, however the copy of P presented in a novel location will only partially match the cognitive map. There should then be a difference between the amount of $A1$ activity, caused by the object in novel location P' being able to recruit more elements, consequently the stimulus will receive more attention. An improvement in comparison with previous experiments reported in this chapter is the use of a tracking method with higher temporal resolution (300 Hz), which allows for the eye tracking data to be analysed at any given temporal window of interest. In practical terms, the DV of dwell time in previous experiments was calculated over the entire 3 s presentation, whereas the novel method used here enables the dwell calculation to be performed on any given time interval. This is relevant to the evaluation of the SOP account of recognition memory, as the $A1$ activation is transient and time limited to early moments after the visual array onset, whereas the $A2$ activation is longer-lasting, but reaches its peak after the $A1$. Simulated dynamics for a single presentation of a stimulus are presented in Figure 5.11. For a presentation of 300 moments, the $A1$ activation peaks very early and is marked by a quick decay into the $A2$ state. Moreover, the differences between the test dwell time on SOR and RR, postulated by the SOP, are due to the differential $A1$ activation of Q and P representations. The temporal dynamics could not have been observed in previous experiments as the dwell value averaged over the entire stimulus presentation time.

It is hypothesised that novel, less recent and presented in a novel location stimuli will be looked at more than preexposed. This will manifest itself in a positive and significant D2. Furthermore, it is expected that the effect will be most profound

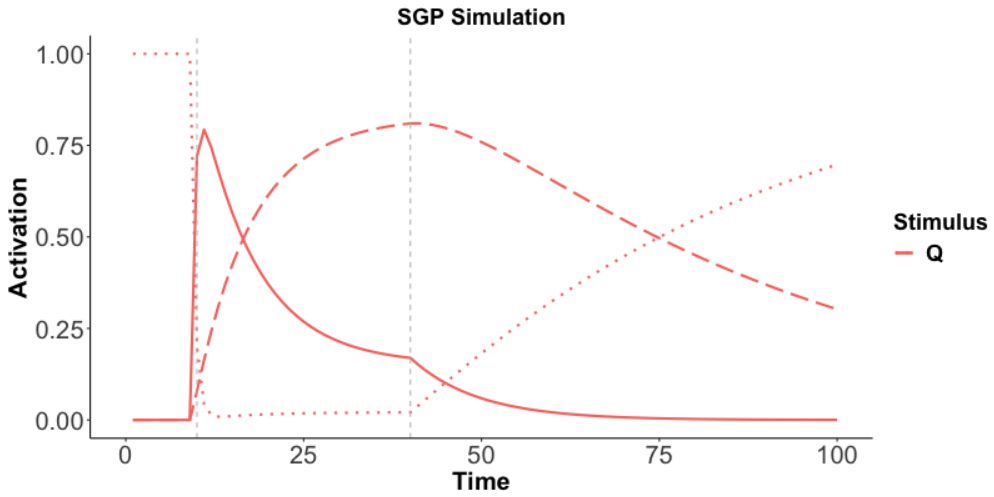


Figure 5.11: Simulation of a single stimulus process in SOP with time in moments on x- and activation on y-axis. Single presentation of stimulus Q (10 - 40 moments) resulting in strong early $A1$ (solid line) activation which quickly gives way to more lasting $A2$ (dashed line). After the stimulus offset (40th moment) the $A2$ activation slowly decays into inactivity (dotted line).

in the early windows of the test array.

5.4.2 Methods

5.4.2.1 Participants

Identical to that in Experiment 1 with the exception of sample size: 20 female and 5 male adults participated in this experiment. The mean age was 22.16 years (*SD* = 3.17, range 18 - 29).

5.4.2.2 Apparatus

Identical to that in Experiment 1 with the exception of the sampling frequency which was set to 300Hz.

5.4.2.3 Stimuli

Identical to that in Experiment 1.

Table 5.4: Design of the Experiment 3. In three conditions: SOR, OIP and RR participants were presented with either one (SOR and OIP) or two (RR) sample phases. Each presentation lasted for 3 s and all ISI, RI and ITI were 1 s. In the OIP's sample 2 two stimuli are presented (PR) of which one (P') is in a novel location, hence for the purpose of data analysis $P' = Q$.

Condition	Sample	RI	Test
SOR	PP		PQ
OIP	PR	1 s	PP'
RR	$QQ \xrightarrow{1s} PP$		PQ

5.4.2.4 Procedure

Eye tracker calibration and instructions given were as in Experiment 2. An OIP condition was added in this procedures which is the only difference from the Experiment 2. Experimental design is presented in Table 5.4. A total of 138 trials consisted of 46 RR, 46 OIP, and 46 SOR trials, each number including 6 target trials. The SOR and RR conditions mirror those of Experiment 2 and their sequence visualisations are presented in Figure 5.7. In the OIP condition, visualised in Figure 5.12, S1 included two different images, PR. In the test phase, both images presented were identical to one of the images presented before, however one was in a novel (in comparison to the S1) location: PP'. Participants were allowed to take self-regulated breaks after completion of each 23 trials. The cover task were as in Experiment 2.

5.4.2.5 Data Treatment

Locations of ROIs were as in Experiment 2 but their size was 350 $\times$ 350 px and overlapped with the experimental stimuli. Discrimination ratios were calculated in line with Equation 4.2 on p. 72, were Q/P' were treated as Q. An adjusted discrimination ratio $D2_{adj}$, was calculated according to Equation 4.5 on p. 73.

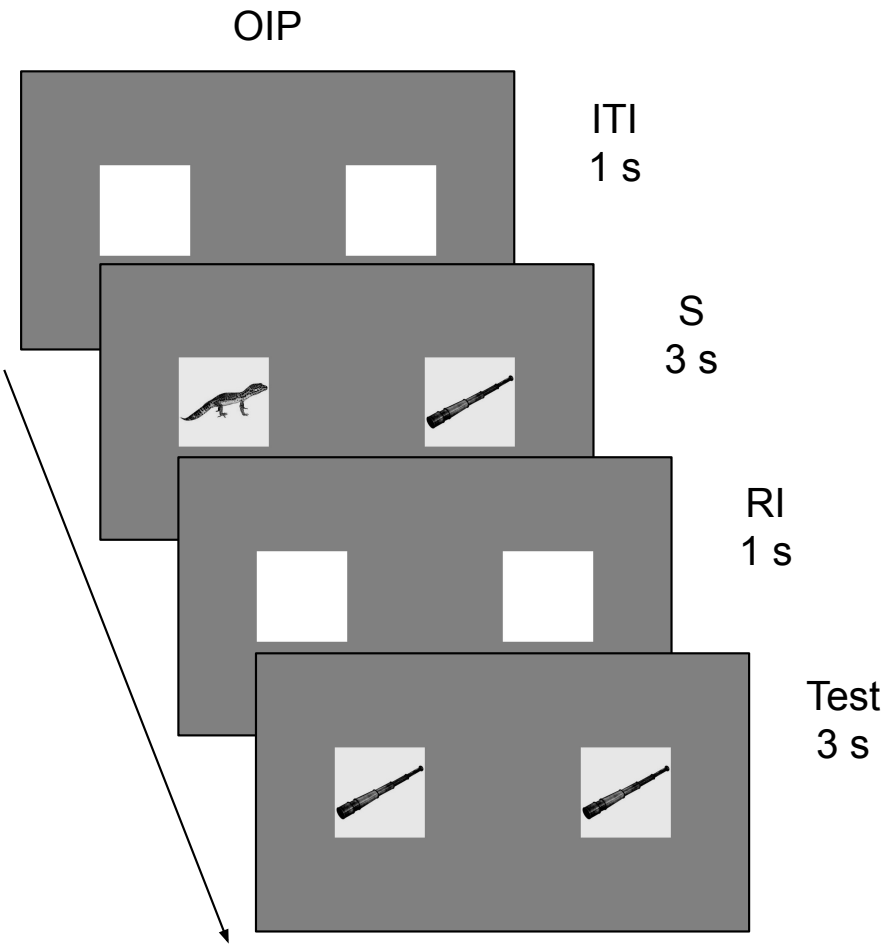


Figure 5.12: Experiment 3, sequence demonstration for the OIP procedure. The SOR and RR sequences were presented in Figure 5.7. The procedure involved a single sample phase during which two novel stimuli PR were presented for 3 s, then after a 1 s RI, two copies of the preexposed stimulus PP' were presented for 3 s.

One participant was removed from the analysis due to lack of engagement with the task (see Figure A.1 in Appendix A, p. 267), as she/he spent only 8.5% of the time exploring stimuli during the sample phases (M = 34.8%). Accuracy in the engagement task was high; there were no FAs and there were only 1.96 Misses per participant (SD = 1.837, range = 0-7); this resulted in a high mean A' = 0.98 (SD = 0.013). Participants responded quickly with RT M = 0.677s, SD = 0.057s.

5.4.3 Results

5.4.3.1 Sample Dwell

Dwell time data recorded during the sample phase were entered into 2 x 6 repeated measures ANOVA with factors of Sample Phase and Window (6 levels each corresponding to 0.5 s or 150 samples long windows of a 3 s long sample). Figure 5.13, summarises the data, with each panel showing the dwell time split into six temporal consecutive (0.5 s) windows. The main effect of Sample Phase was not significant with $F(1.9, 43.59) = 1.864$,$p = 0.169$ and the evidence for the *null* being strong, $BF_{01} = 20.908$, $Error = 2.424\%$. The main effect of Window was significant with $F(1.788, 40.892) = 6.428$, $p = 0.005$, $\eta_p^2 = 0.218$, *95% CI* $\eta_p^2 = [0.025, 0.398]$, and decisive evidence in support of the model ($BF_{10} = 4.002 \times 10^{16}$). The interaction between the two main effects has not met the criterion for significance ($F(5.39, 13.57) = 0.398$, $p = 0.93$) and can be ruled out as plausible due to decisive evidence for lack thereof, $BF_{excl} = 2072.084$. Taken together, there are no reasons to assume that engagement with stimulus during the sample phases depended on experimental condition, however the engagement changed as a function of time. Further inspection of data presented in Figure 5.13 indicates that the effect is chiefly due to the

shorter dwell time in the first temporal window (w_1) as a series of (Bonferroni-corrected) paired sample *t*-test yielded significant only when w_1 was paired with other windows (*p* range: < 0.001 to 0.03), this found its support in extreme level of evidence range ($BF_{10,U}$ between 3036.543 and 601578.463). All other tests were statistically not reliable (all with Bonferroni corrected p = 1), however Bayesian *post hoc* comparison supported the $\mathcal{H}_0$ model only in some of the comparisons (all with moderate evidence, range $BF_{01,U}$ = 3.652 to 8.801). Counter to the frequentist analysis, Bayesian test indicated for a anecdotal difference between the w_2 and w_6, $BF_{10,U}$ = 2.533, moderate difference between the w_3 and w_5, $BF_{10,U}$ = 4.011, strong difference between the w_4 and w_6, $BF_{10,U}$ = 16.382 and very strong difference between the last two windows: w_5 and w_6, $BF_{10,U}$ = 33.038. Reduction in dwell time during the early window is most likely due to time needed to orient the gaze to stimulus upon its presentation (Carpenter, 1988). Indicated by the Bayesian analysis difference in later parts of the stimulus presentation may be due to habituation of response and corresponding $A1 \xrightarrow{pd2} A2$ decay, however the effect is not apparent when looking at the data.

5.4.3.2 Test Dwell

The data of primary interest came from the test phase of each trial with the DV of the discrimination ratio D2. The Data were analysed in a Condition (with levels of SOR, OIP, and RR) and Window (w_1 to w_6) repeated measures ANOVA. Inspection of the data, summarised in Figure 5.14, demonstrates that discrimination differed between the Conditions. Inferential analysis supports this description and the main effect of Condition was reliable with $F(2, 44) = 12.647$, $p < 0.001$, $\eta_p^2 = 0.365$, *95%*

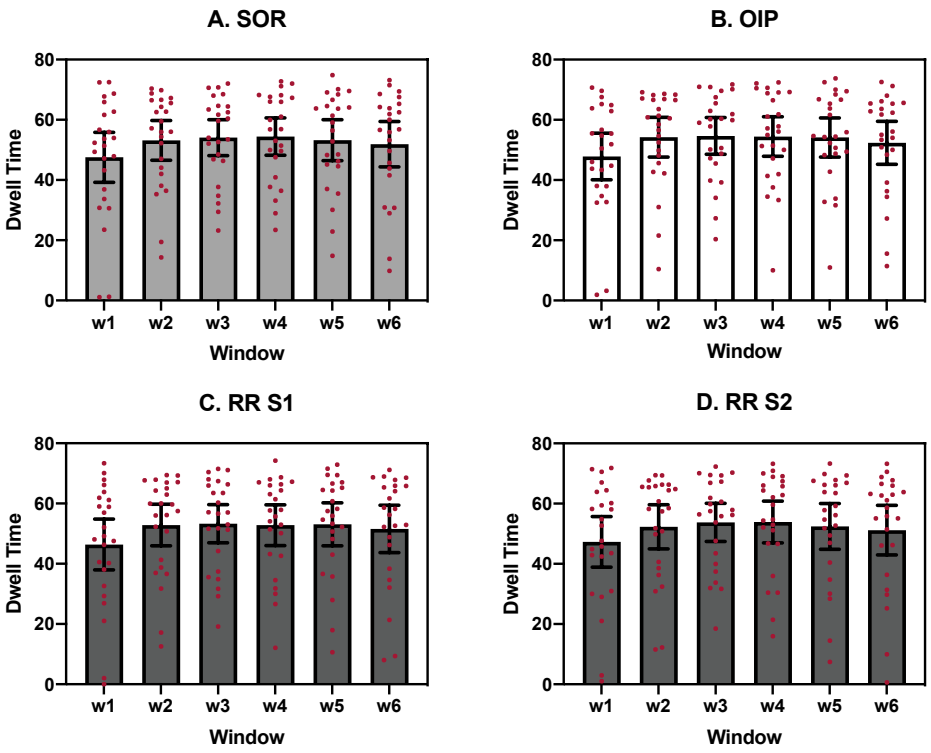


Figure 5.13: Experiment 3, sample phase dwell for the experimental conditions of SOR (panel A), OIP (panel B) and RR (panels C and D). Temporal window of the phase, $w1$ to $w6$ are plotted on the x-axis and dwell time on the y-axis (units of eye tracker samples at 300Hz). Means are presented with error bars of *95% CI*, all observations as points.

Table 5.5: Experiment 3, selected *post hoc* test enabled by the Condition and Window interaction. Conditions are compared at each window.

Window	SOR v OIP	SOR v RR	OIP v RR
w_1	t = -1.954, p = 1	t =-1.466, p =1	t =0.488, p =1
w_2	t = 3.747, p = 0.034	t =2.264, p =1	t =-1.482, p =1
w_3	t = 5.777, p <.001	t =4.07, p =0.01	t =-1.707, p =1
w_4	t = 4.059, p = 0.01	t =3.885, p =0.02	t =-0.174, p =1
w_5	t = 1.93, p = 1	t =1.45, p =1	t =-0.48, p =1
w_6	t = -0.196, p = 1	t =-1.469, p =1	t =-1.273, p =1

CI η_p^2 = [0.129, 0.521], there was a decisive evidence in support of the $\mathcal{H}_1$, BF_{10} = 2.326 $\times$ 10^8. Both the main effect of Window, F(2.312, 50.869) = 3.678, p = 0.027, η_p^2 = 0.143, *95% CI* η_p^2 = [0, 0.296], and the interaction between Condition $\times$ Window, F(5.983, 131.627) = 5.282, p < 0.001, η_p^2 = 0.194, *95% CI* η_p^2 = [0.058, 0.278], were significant and the support for $\mathcal{H}_1$ was strong and decisive for both, BF_{10} = 12.508 and BF_{incl} = 4532.596.

Significant interaction between the main effects of Condition and Window resulted a over 100 *post hoc* test being performed. For brevity, I only selected the tests which compared each Condition at each of the Window which are presented in Table 5.5.

Condition $\times$ Window interaction waas explored further, focusing on three windows: w_2, w_3 and w_4 in both RR and SOR which were tested using one-sample *t*-test. Because the assumption of sphericity was violated, α was corrected with Bonferroni method (9 tests) resulting in α_B = 0.006. In the SOR conditions all three windows were significantly different from 0; w_2, t(23) = 7.783, p < 0.001, d = 1.589, *95% CI* d = [0.974, 2.188], BF_{10} = 213757.189; w_3, t(23) = 8.241, p < 0.001, d = 1.682, *95% CI* d = [1.047, 2.302], BF_{10} = 533038.207; w_4, t(23) = 4.216, p < 0.001, d = 0.861, *95% CI* d = [0.384, 1.324], BF_{10} = 93.685. In the RR condition only the

D2 at w_2 has reached the corrected significance criterion, $t(23) = 5.3$, $p < 0.001$, $d = 1.082$, *95% CI* $d = [0.568, 1.581]$, $BF_{10} = 1049.529$; w_3, $t(23) = 2.474$, $p = 0.021$, $d = 0.505$, *95% CI* $d = [0.075, 0.926]$, $BF_{10} = 2.597$; w_4, $p = 0.447$, $BF_{01} = 3.554$. After correction neither of the windows of OIP demonstrated a reliable D2 with w_2, $t(23) = 2.761$, $p = 0.011$, $d = 0.564$, *95% CI* $d = [0.127, 0.99]$, but with a moderate in support of the $\mathcal{H}_1$, $BF_{10} = 4.43$, w_2, $p = 0.978$, $BF_{01} = 4.657$ w_3, $p = 0.391$, $BF_{01} = 3.302$. In summary, the results indicate that the effects of novelty (SOR) are strong and robust between 0.5 s and 2.0 s, on the other hand, the influence of recency, RR, is less temporally robust and is limited to the window between 0.5 s and 1.0 s, however, relying on Bayes analysis it can be argued, that the effects are also observable during the 3rd window (1.0 s to 1.5 s). OIP demonstrated the least effect with moderate evidence for the effect in w_2, 0.5 - 1.0 s.

Supplementary analysis was performed on raw dwell time values for stimuli Q/P' and P. The data were entered into 3 (Condition) by 2 (Stimuli Type), by 6 (Window) repeated-measures ANOVA with DV of raw dwell time. Summaries of the data are presented in Figure 5.15 with each panel corresponding to the experimental condition. The main effect of Condition was not significant, $F(2, 46) = 2.062$, $p = 0.139$, $BF_{01} = 33.891$. The main effect of Stimuli Type was significant, $F(1, 23) = 44.51$, $p < 0.001$ and $\eta_p^2 = 0.659$, *95% CI* $\eta_p^2 = [0.377, 0.779]$, $BF_{10} = 3.576 \times 10^{25}$, *Error* = 1.701%. There was also a significant main effect of Window, $F(1.714, 39.423) = 5.951$, $p = 0.008$, $\eta_p^2 = 0.206$, *95% CI* $\eta_p^2 = [0.017, 0.388]$, $BF_{10} = 11.589$. From all interactions, only one has not met the α: Condition $\times$ Window, $F(10, 230) = 1.578$, $p = 0.148$, $BF_{excl} = 2118.467$. Condition influenced dwell time for different Stimuli Types, as demonstrated by a significant interaction, $F(2, 46) =$

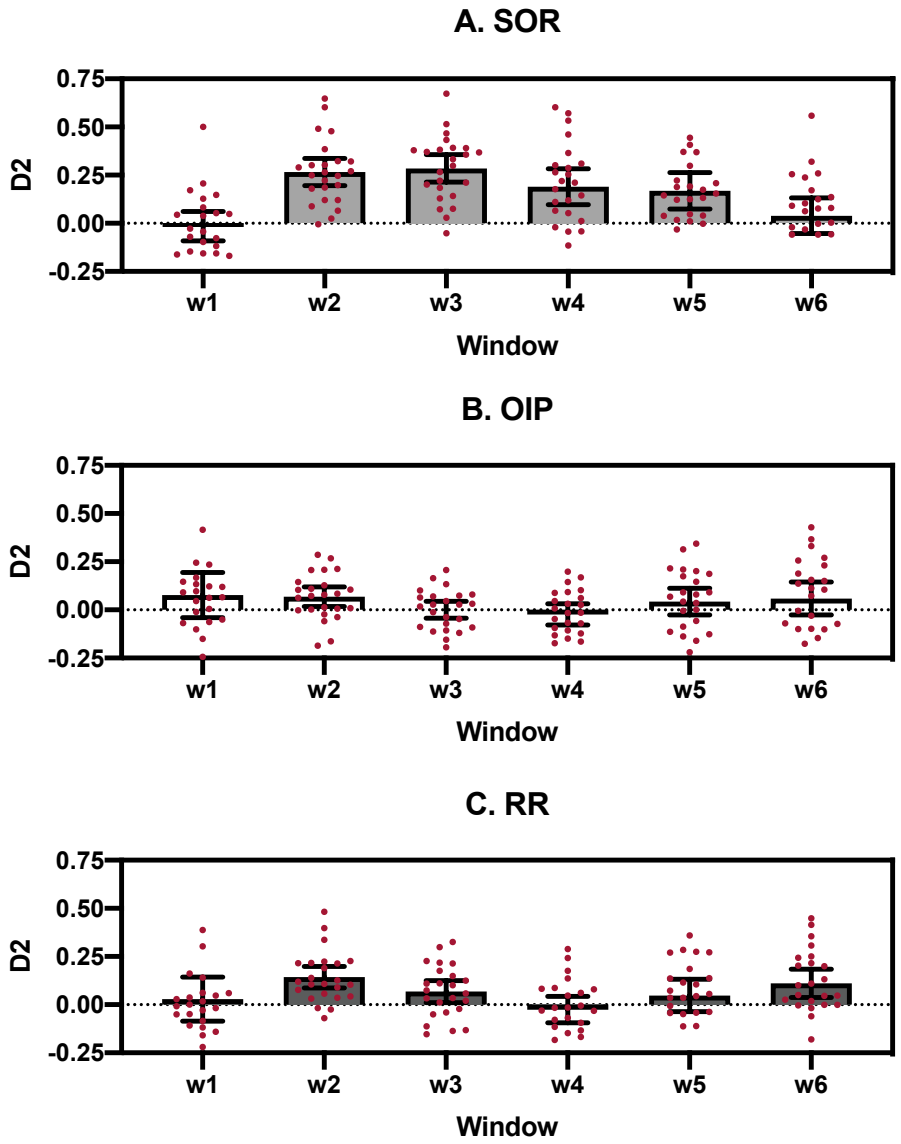


Figure 5.14: Experiment 3, results of the Condition $\times$ Window analysis with DV of discrimination ratio D2, panels A, B and C present data from three experimental conditions with temporal Window on the x- and D2 ratio on the y-axis. Means are plotted with the *95% CI* of the mean and observations with D2 [-0.25, 0.75] as points. Data in **panel A** present the robust effect of SOR, during the windows w_2 - w_4, whereas **panel C**, the effect of recency, which is limited to early windows of the test (w_2). The OIP, in **panel B**, presented only a moderate support for reliable discrimination in window w_2.

Table 5.6: Experiment 3, *post hoc* test results in Condition × Stimuli Type × Window interaction, data for the **SOR** trials only. Selected test comparing raw dwell time to novel Q and pre-exposed P at each Window. All *t*-test had a common *df* = 23 and are reported with corresponding effect size *d* and BF_{10}.

Window	*t*-test	Cohen's *d*, *95% CI*	BF_{10}
w_1	*t* = -1.906, *p* = 0.069	*d* = -0.389, [-0.801, 0.03]	1.01
w_2	*t* = 9.111, *p* < 0.001	*d* = 1.86, [1.185, 2.519]	2.827×10^6
w_3	*t* = 7.769, *p* < 0.001	*d* = 1.586, [0.972, 2.184]	207698.988
w_4	*t* = 4.691, *p* < 0.001	*d* = 0.958, [0.465, 1.436]	269.586
w_5	*t* = 2.801, *p* = 0.01	*d* = 0.572, [0.134, 0.999]	4.784
w_6	*t* = 0.807, *p* = 0.428	*d* = 0.165, [-0.24, 0.566]	0.288

Table 5.7: Experiment 3, *post hoc* test results in Condition × Stimuli Type × Window interaction, data for the **OIP** trials only. Selected test comparing raw dwell time to presented in a novel location P' and pre-exposed P at each Window. All *t*-test had a common *df* = 23 and are reported with corresponding effect size *d* and BF_{10}.

Window	*t*-test	Cohen's *d*, *95% CI*	BF_{10}
w_1	*t* = 0.875, *p* = 0.39	*d* = 0.179, [-0.227, 0.58]	0.303
w_2	*t* = 3.504, *p* = 0.002	*d* = 0.715, [0.259, 1.159]	19.959
w_3	*t* = 0.489, *p* = 0.629	*d* = 0.1, [-0.302, 0.5]	0.239
w_4	*t* = -0.602, *p* = 0.553	*d* = -0.123, [-0.523, 0.28]	0.253
w_5	*t* = 1.642, *p* = 0.114	*d* = 0.335, [-0.08, 0.743]	0.691
w_6	*t* = 1.342, *p* = 0.193	*d* = 0.274, [-0.137, 0.679]	0.476

12.586, $p < 0.001$, $\eta_p^2 = 0.354$, *95% CI* $\eta_p^2 = [0.124, 0.509]$, $BF_{incl} = 2.551 \times 10^8$). A significant interaction between the effects of Stimuli Type and Window, $F(3.707, 85.262) = 8.072$, $p < 0.001$, $\eta_p^2 = 0.26$, *95% CI* $\eta_p^2 = [0.09, 0.377]$, $BF_{incl} = 7.680 \times 10^6$. The three-way interaction between the Condition, Stimuli Type and Window was significant with $F(5.838, 134.268) = 6.676$, $p < 0.001$, $\eta_p^2 = 0.225$, *95% CI* $\eta_p^2 = [0.085, 0.312]$, $BF_{incl} = 1.556 \times 10^{10}$. *Post hoc* tests, results are summarised in Tables: 5.6 for SOR, 5.7 for OIP and in 5.8 for RR.

Specifying the temporal window at which the effects of recency and novelty can be observed (0.5 s to 1.5 s) allows for a more sensitive test of these effects. To reduce the dimensionality of the data, the D2 ratio was calculated based on the

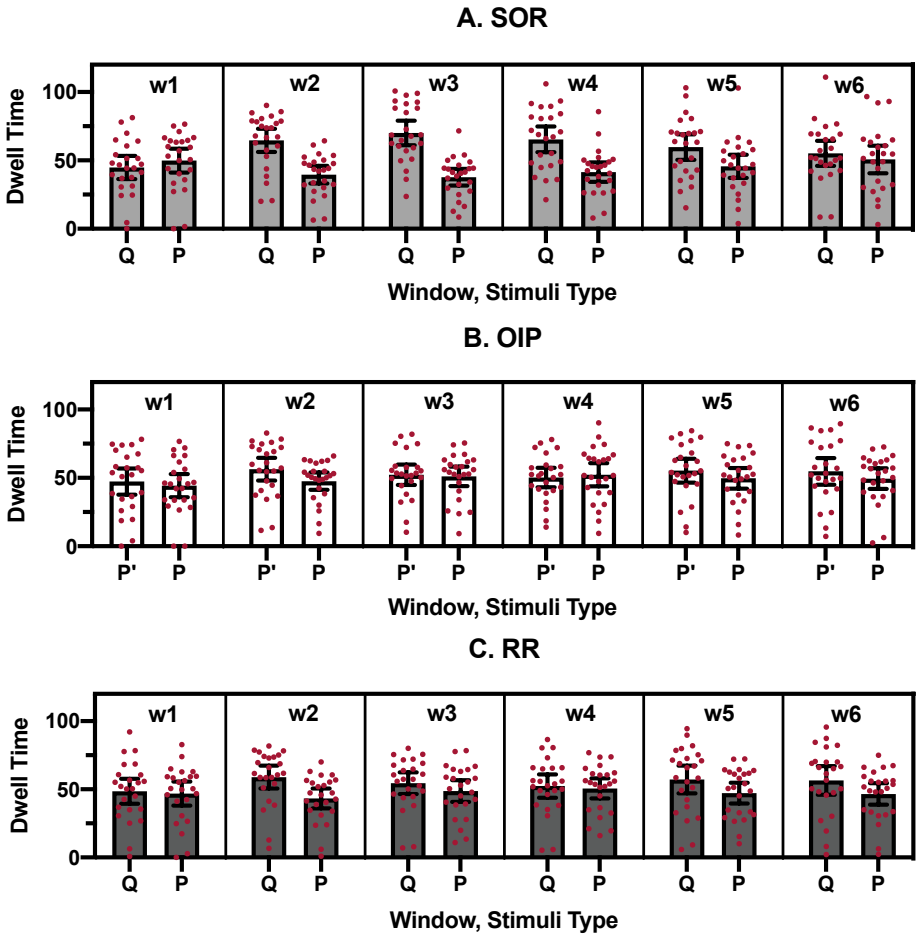


Figure 5.15: Experiment 3, results of the Condition × Stimuli Type × Window analysis with DV of dwell time collected during the test phase. Panels A, B and C present the data for three experimental conditions with dwell time plotted on the y-axis (units of eye tracker samples at 300Hz) and Stimuli Type: novel or less recent, Q, and (recently) pre-exposed P for RR and SOR; for OIP P' is the stimulus in novel location and P is the *old* location. data are sorted by Window on the x-axis. Means are presented with *95% CI* of the mean with all observations plotted as points.

Table 5.8: Experiment 3, *post hoc* test results in Condition × Stimuli Type × Window interaction, data for the **RR** trials only. Selected test comparing raw dwell time to less recent Q and recent P at each Window. All *t*-test had a common *df* = 23 and are reported with corresponding effect size *d* and BF_{10}.

Window	*t*-test	Cohen's *d*, *95% CI*	BF_{10}
w_1	$t = 0.595$, $p = 0.558$	$d = 0.121$, [-0.281, 0.522]	0.252
w_2	$t = 7.113$, $p < 0.001$	$d = 1.452$, [0.866, 2.022]	53842.24
w_3	$t = 1.961$, $p = 0.062$	$d = 0.4$, [-0.02, 0.813]	1.098
w_4	$t = 0.622$, $p = 0.54$	$d = 0.127$, [-0.276, 0.527]	0.256
w_5	$t = 2.556$, $p = 0.018$	$d = 0.522$, [0.089, 0.944]	3.014
w_6	$t = 2.458$, $p = 0.022$	$d = 0.502$, [0.072, 0.922]	2.525

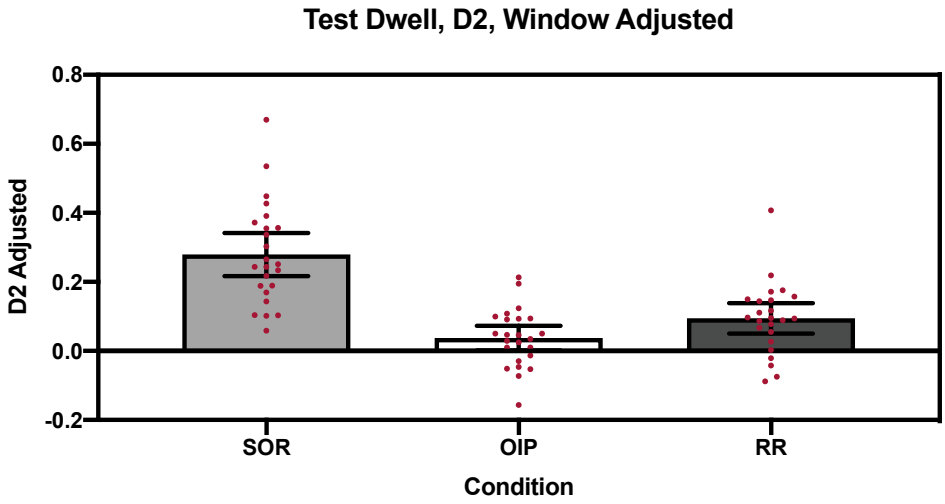


Figure 5.16: Experiment 3, test dwell data with $D2_{adj}$ as DV. Condition on the x- and $D2_{adj}$ on the y-axis. Means presented with *95% CI* and observations as points.

mean values of windows 2 and 3 (w_2, w_3), $D2_{adj}$, and entered into a repeated-measures ANOVA with the main effect of Condition. Data of main interest is presented in Figure 5.16, panel A.

Post hoc analysis, enabled by the significant main effect of Condition: $F(2, 46) = 27.836$, $p < 0.001$ $\eta_p^2 = 0.548$, *95% CI* $\eta_p^2 = [0.326, 0.665]$, $BF_{10} = 8.705 \times 10^7$ (*Error* = 2.072%), yielded significant difference between the $D2_{adj}$ in SOR and OIP, $t(23) = 7.136$, $p < 0.001$ (Holm), $d = 1.457$, $BF_{10,U} = 1077820.812$, as well as between the SOR and RR, $t(23) = 5.456$, $p < 0.001$, $d = 1.114$, $BF_{10,U} = 225.245$. Difference between the OIP and RR has not met the significance criterion with $p = 0.1$, however this could not be concluded with $BF_{01,U} = 0.875$. All three $D2_{adj}$ were then entered into one-sample *t*-test with *p*-value corrected with Bonferroni method (corrected $\alpha_B = 0.009$). Both SOR and RR were significantly different from $\mu = 0$; SOR: $t(23) = 9.252$, $p < 0.001$, $d = 1.889$, *95% CI* $d = [1.207, 2.555]$, $BF_{10} = 3.679 \times 10^6$; RR: $t(23) = 4.45$, $p < 0.001$, $d = 0.908$, *95% CI* $d = [0.424, 1.379]$, $BF_{10} = 157.329$ and the $D2_{adj}$ in OIP condition has not met the corrected α_B: $p = 0.04$, $d =$

0.443, *95% CI d* = [0.019, 0.859], however BF_{10} = 1.541 suggest that the analysis is inconclusive here.

5.4.4 Discussion

Three analyses were performed for the purposes of detecting the effects of interest and to specify the time window at which the effects can be best captured. The D2 analysis which took all windows under consideration demonstrated that the most robust differences between the conditions can be captured in windows $w2$ to $w4$. When reliability of discrimination was investigated, with a means of one-sample *t*-test, SOR was reliable in all windows, RR only at w_2 and there was no reliable effect in OIP. Analysis of the raw dwell time has mirrored this of D2. When the data were analysed with DV of $D2_{adj}$, both SOR and RR demonstrated a significant discrimination as well as a difference between the two. There was no effect of OIP that could be conclusive. Hence, the adjusted discrimination measure $D2_{adj}$ provides a more precise measure of interest. Hence, the following experiments will only rely on the DV of $D2_{adj}$ for the test data analysis. Both effects of hypothesised effects of SOR and RR were confirmed with statistical analysis, however the OIP could not. In line with hypothesis, the effects were mainly limited to early windows of the test, however the SOR effect was less transient than the OIP.

The SOP can subsume the effect of recency, and partly the effect of novelty, under the activation-decay cycles, lack of associative in nature, novel object/place effect could also be discussed in terms of this theory. When stimulus is presented for the first time, all of its representational elements are available for recruitment to the primary activation state ($A1$) from the long-term storage (I). The

$A1$ activation is relatively transient, and activated elements will begin its decay to the secondary state of activation (primed state, $A2$). The key difference between the two activation states is the vigour of response they result in; primary activation will produce a strong response whereas the secondary state will result in its decrement. The path between $A1 \xrightarrow{pd1} A2$ is unidirectional, once activated the representational elements must complete the whole cycle: $A1 \xrightarrow{pd1} A2 \xrightarrow{pd2} I$ to be available for the $A1$ activation again. This applied to the context of experiment at hand accounts for the results of novelty (SOR) in a way where the representational elements of pre-exposed P are activated and follow $A1 \xrightarrow{pd1} A2$. A proportion of elements will remain in $A2$ upon presentation of the test stimuli Q and P. Because of this, they cannot be re-activated into $\xrightarrow{p1} A1$ without completing the decay, hence the amount of P's representational elements available for recruitment into $A1$ is limited. This limitation does not apply to the representation of Q whose representational elements are entirely available for activation. The number of elements present at a given moment in $A1$ drives the approach to the stimulus which matches the representation and so novel Q is looked at more than P. In a similar way, when both Q and P are presented in their separate samples, $Q \xrightarrow{ISI} P$, both are activated into the $\xrightarrow{p1} A1$. However, as Q was presented earlier, its representation has more time to decay to inactivity than the more recent P. At test, only a certain proportion of elements of the respective representations will be available for primary activation, however Q is able to generate comparably more orienting as there is a greater probability that a proportion of its representation has decayed to the I state. A significant difference between the novelty effect observed in SOR and the recency effect observed in RR can be accounted for by the same principle, as the decay of Q in RR is only

proportional and Q in SOR has no elements in either active state. The process by which stimulus processing in SOR and RR is described is solely driven by the non-associative short-term memory mechanism: self-generated priming (SGP). Effects of novelty observed in the SOR are potentially only partly due to SGP and an involvement of an associative process has been argued for (Robinson & Bonardi, 2015). The novel stimulus can be explored because of its memory representation being in Inactivity, whereas the representation of the preexposed stimulus is still in the $A2$ (SGP mechanism). Alternatively, during the sample phase, the preexposed stimulus is associated with the context in which it has been presented, which then primes the preexposed stimulus' representation into $A2$ when the context is reintroduced during the test. More of the novel stimulus' elements are then able to be activated into the $A1$ which results in higher orienting (RGP mechanism). However, in the procedure used in this experiment, this account could not be tested, for the sake of parsimony and brevity but also due to the fact that I cannot rule out nor confirm this explanation, SOR is described in terms of a non-associative, SGP, only.

I hypothesised that the effects of location will be observed (OIP) on the basis of an associative process, enabled by a retrieval of memory through an associative link. In brief, assuming that an association V_{XP} exists and in the context of experimental procedure used here, X is the spatial location (configuration) of PR during the sample phase. During the test, one copy of P is presented at the same location and a second copy P' is presented in a novel one. Because of the novelty of the location, it was expected that P' will be attended more than presented in old location P. The expected effect was warranted by the theoretical priming factor which, given the context X, activates the elements of P directly into the $\xrightarrow{p2}$ $A2$.

Because the stimulus P' is not presented in the same location, the associative link $V_{XP'}$ is not reliable and does not prime its representation into the $A2$ and hence, more of its representational elements should be activated into the $A1$. I could not reliably observe an effect as there was no compelling evidence to reject the $\mathcal{H}_0$ model. There are potential, not mutually exclusive, explanations for the *null* result and the lack of OIP effect observed.

However, the theoretical tenets of SOP can explain the outcome observed in the OIP. The $I \xrightarrow{p2} A2$ priming operates on the basis of parameter $p2$, which was formally described in Equation 1.8 on p. 19. The amount of elements primed from the $I \xrightarrow{p2} A2$ depends on the associative strength between X and P (V_{XP}) and activation of X's representation in $A1$ and $A2$, respectively scaled by parameters r_1, r_2. Assuming, for the sake of simplicity, that X (in this case the spatial location or environmental arrangement) can be treated as another stimulus, and that the value of V_{XP} as well as parameter r_1 are equal to 1. Then, following the commonly used rule of the thumb that $r_2 = {}^1\!/_5, r_1 = 0.2$, one can model $p2$ as a function of X's activation.

To that purpose, the Figure 5.17 presents the outcomes of two simulations of parameter $p2_P$ operating as a function of $p1_X$ and given an association V_{XP}. Models 1 and 2 were programmed, first with initial value of $p1_{X,M1}$ = 0.1 (panel A) and second with higher salience of $p1_{X,M2}$ = 0.8 (panel B). The Figure shows how stimulus salience affects the associative retrieval link $p2_P$, when stimulus is of low salience ($p1_{X,M1}$) even with a maximum possible association strength (V_{XP} = 1) the priming mechanism is not able to work effectively. Hence, it can be argued that the location or spatial arrangement, which on every trial was occupied by a

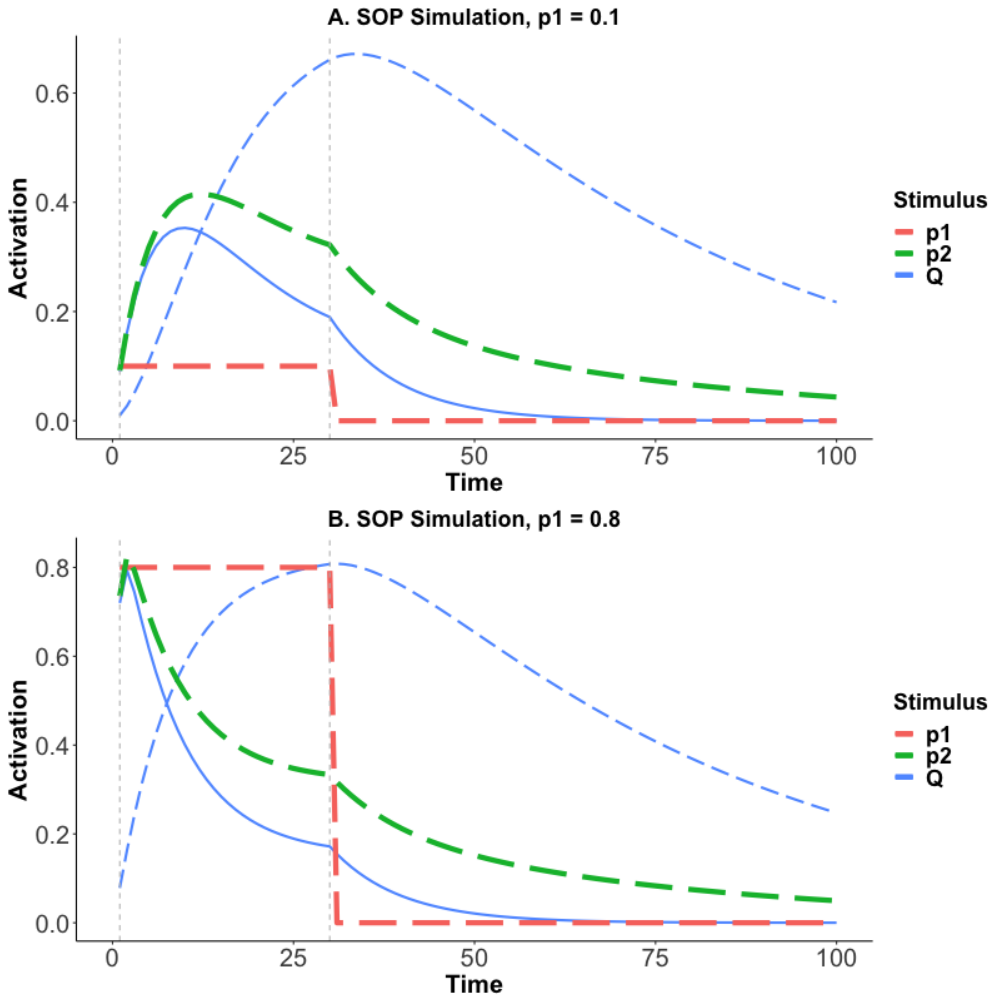


Figure 5.17: Outcomes of two simulations of the SOP model with time in moments on the x- and activation on the y-axis: **panel A** present results of Model 1 ($p1_{X,M1}$ = 0.01) and **panel B** present Model 2 ($p1_{X,M2}$ = 0.8). Simulations assume an associative link between the representation of Q (blue, $A1$ in solid, $A2$ in dashed line) and another stimulus with strength of this association set as $V = 1$. Upon presentation of Q (1 - 30 moments) with strength of $p1$ the another stimulus' representation will be primed in accordance with parameter $p2_P$ (green dashed). The maximal value of $p2$ resulting from the $p1_{X,M1}$ = 0.1 was $p2_{P,M2}$ = 0.415, whereas when $p1_{X,M2}$ = 0.8 the $p2_{P,M2}$ = 0.826 demonstrating the relationship between the salience of the signal Q and strength of associative priming. Apart from $p1$ all parameters were set as equal for both models: $pd1$ = 0.1, $pd2$ = 0.02, we_1 = 1, we_2 = 0.2 and or each moment the priming parameter $p2$ was calculated as per Equation 1.8

certain stimulus, was not salient enough to produce a robust priming to vouch for the expected associative results. It should be noted, that the assumed high value of V_{XP} is unlikely to be achieved given one presentation during the sample, however it makes the results of a simulation more comprehensible. Furthermore, it must be noted that, in the context of OIP, a proportion of elements of displaced stimulus P' most certainly will be active in $A2$ due to pre-exposure of P. However, a proportion of elements will decay into I and be available for activation at test; then, such elements can be either activated by $I \xrightarrow{p1_{P'}} A1$ or by a $I \xrightarrow{p2_{P'}} A2$. In consequence, stronger the signal X which evokes the association V_{XP}, the stronger the $p2_P$ parameter which translates to stronger $I \xrightarrow{p2_P} A2$ priming. Increase in $A2$ activation is then effectively reducing the proportion of elements available for $p1_P$ activation.

Alternatively, but also in a similar vein, the salience of a stimulus in the procedure could have been affected by the cover task implemented in the experiment. Participants were asked to detect a dot target which was displayed during the time when the experimental stimulus was not on the screen and the instructions did not explicitly state to follow it. This means that the stimulus could have been entirely ignored because it was not required for the task of target detection. This problem can be understood as the lower salience of the experimental stimulus and could have resulted in an impaired V_{XP} association. To demonstrate the effect, a simulation of VXP associative strength was performed with two models: *Vph* in which salience for both X and P was set as $p1_X$ = 0.6 and $p1_P$ = 0.8 and model *Vpl* which run with $p1_X$ = 0.05 and $p1_P$ = 0.1. Results of this simulation are presented in Figure 5.18.

The simulation demonstrates that when the salience of context X and

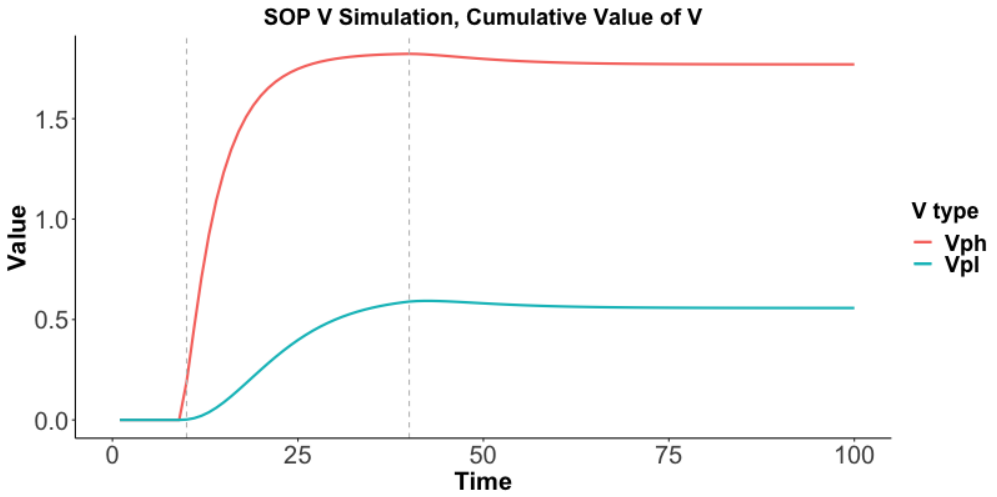


Figure 5.18: Simulation of two models of associative strength V_{XP} based on stimuli strengths: ***Vph*** with $p1_X$ = 0.6 and $p1_P$ = 0.8 and ***Vpl*** with $p1_X$ = 0.05 and $p1_P$ = 0.1. Stimuli were presented between the 10th and 40th moment (time on x-axis) and resulted in $A1$ and $A2$ activation (not shown) in accordance with respective $p1$ parameters and $pd1$ = 0.1 and $pd2$ = 0.02, learning parameters were set at L^+ = 0.5 and L^- = 0.1.

stimulus P is low, as in model *Vpl*, the maximal associative strength was V_{XP} = 0.593. When stimuli and context were of much higher salience, as in model *Vph* the association was stronger with V_{XP} = 1.823. This and the previous simulations show that the salience of stimulus, $p1$, is important for the formation of V_{XP} association as well as for the activation of $I \xrightarrow{p2} A2$ on test.

While it is imperative not to lead participants or give any suggestions that could affect their behaviour (Holmqvist et al., 2011), it is also crucial to develop a procedure that would be engaging, requiring processing of the stimulus, yet free from implicit or explicit suggestions to avoid demand characteristics. Pinto, Papesh, and Hout (2020) demonstrated that participants' ability to encode stimuli when engagement with an experimental task is higher. Hence, in the following Experiment 4, I aimed to investigate whether an increase in engagement with the experimental stimulus can yield better test discrimination. In the SOP-terms, the next experiment

aims to increase $p1$ through an engagement with the experimental stimuli.

In summary, Experiment 3 yielded robust effects of novelty, as participants looked at a novel Q over the pre-exposed P, in line with the animal studies and SOP predictions. The effect of recency was also evident, however it was limited to the early temporal window of the test phase, and this pattern of results is suggested by SOP as vigorous orienting follows the $A1$ activation, which is brief and occurs shortly after the array onset. Hence, both non-associative effects were supported by the evidence however it was problematic to find evidence supporting an associative process as the influence of a novel location has not produced a reliable and robust result. Certain methodological issues should be addressed to explore a possibility of low stimulus salience, and Experiment 4 addresses those.

5.5 Experiment 4

5.5.1 Introduction

Thus far, the experiments reported in this chapter have demonstrated the existence of SOR and RR in humans, of which the latter is a novel finding (Nitka et al., 2020). However, I was not able to reliably demonstrate the effects of associative learning on recognition memory with the OIP procedure. Being able to demonstrate the effects of this mechanism is critical for the associative account of recognition memory, and the lack of effect would significantly reduce SOP's ability to model recognition in humans. In line with SOP theory, it is suspected that the failure to achieve the associative learning effect was due to the low engagement (resulting in low perceived salience) of experimental stimuli. Suggested here, inhibition of stimulus engage-

ment during the sample can be parallel with shallow encoding (Sivakumaran et al., 2018) which is contrasted with the deep suggested in the human recognition memory literature (Marzi & Viggiano, 2010). Furthermore, it has been demonstrated that increased engagement with stimuli can lead to better encoding (Pinto et al., 2020).

To that extent, to increase the contact with stimulus, in Experiment 4, a novel cover task was employed. The current experiment keeps the exposure structure of SOR, RR and OIP with participants staying naive to the purpose of the task; no instructions to remember the stimuli were given. Participants were asked to look at stimuli and respond every time they saw an image which depicts an item of clothing. Target trials were rare (around 19%) and were not included in the analysis due to the influence of target detection on eye movements demonstrated in the Experiment 1.

As in the previous Experiment 3, it is hypothesised that novelty, recency and stimuli/location effects will manifest itself with positive and significant D2. In comparison with Experiment 3, it is also expected that a change in cover task will result in significant improvement in discrimination.

5.5.2 Methods

5.5.2.1 Participants

Identical to that in Experiment 1 with the exception of sample size: 16 females and 6 males participated in this experiment. Their *M* age was 24.09 years (*SD* = 4.1, range 19-39).

5.5.2.2 Apparatus

Identical to that in Experiment 1 with the exception of the sampling frequency which was 300 Hz and use of chin rest which was used to fix the distance from the screen at 50-55 cm. All but one participant used the chin rest.

5.5.2.3 Stimuli

From the combined Bank of Standardized Stimuli (BOSS©, Brodeur et al., 2010, 2014) images were selected and assigned to either a target or stimulus set. A total of 35 target images were selected based on their category (clothing) and agreement score (>0.9) specified by the norms provided by the authors of the set. The mean agreement was of M = 0.955, SD = 0.034. From the remaining stimuli 529 further images were selected based on their agreement (>0.9) score with M = 0.963, SD = 0.031, these were set as stimuli images (Q/P', P and R). During the experiment both stimuli and target images were selected randomly without a replacement by the experimental software (PsychoPy). All images were presented on a grey (PsychoPy colour space RGB: 0, 0, 0) background. All other characteristics were as specified in Experiment 1.

5.5.2.4 Procedure

Eye tracker calibration and instructions given were as in Experiment 3. In contrast with previous experiments participants were given a cover task: they were asked to pay attention to the screen and to press the space bar as soon as and each time they saw a target stimulus (an item of clothing). This experiment follows the design of Experiment 3 with an exception of cover task and presentations during ISI. Experi-

Table 5.9: Design of Experiment 4. Q, P, P' and R denote the experimental stimulus presented to the participants. On each trial the stimulus was novel. Each trial consisted of sample and test phases, SOR and OIP had only one sample phase whereas the RR had two. In the SOR sample involved presentation of PP followed by a test QP where Q was novel. In the OIP sample was PR where both were novel, test was with P', which was in a novel location and P which was identical to P' but in an old location. In the RR condition there were two sample phases each with QQ and PP which was followed by a test where a copy from each sample was presented.

Condition	Sample	RI	Test
SOR	PP		QP
OIP	PR	1 s	$P'P$
RR	$QQ \xrightarrow{1s} PP$		QP

mental design is presented in Table 5.9 and Figure 5.19 demonstrates the sequences presented. A total of 148 trials consisted of 40 trials in each SOR, RR, and OIP conditions and 28 target trials. In contrast to Experiment 3, a solid grey background was displayed during the ISI. There was also no target displayed during that time. The target trials were presented for fulfilment of the cover task which was employed to ensure engagement with the experiment. Participants were instructed to press a space bar each time they saw an image depicting an item of clothing. Trials mimicked the three conditions with a distinction that one stimulus was replaced with a novel image that belonged to the target category. There were eight of such trials that followed the sequence of SOR and eight that followed the OIP, and there were twelve RR-like trials. Target trials were presented in a semirandom order alongside the experimental trials. Participants were able to take a break after the 23rd, 46th, 69th, 92nd and 115th trials.

5.5.2.5 Data Treatment

Identical to that in Experiment 3.

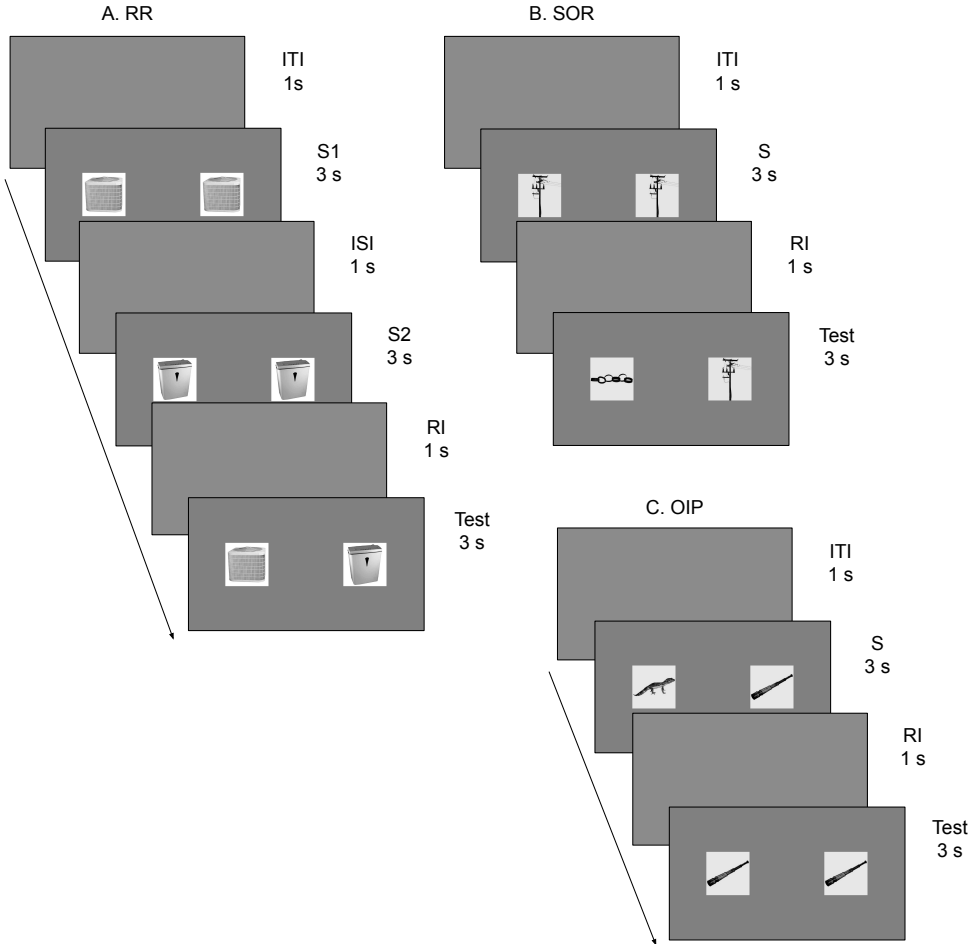


Figure 5.19: Experiment 4, sequence demonstration for the SOR, RR, and OIP procedures. **Panel A** - RR: each trial begun with a 1 s followed by two sample phases S1 and S2, each lasting for 3 s and separated by a 1 s ISI. Pairs of stimuli QQ and PP were displayed during S1 and S2. After a 1 s RI a copy of each sampled stimuli QP were displayed for 3 s. **Panel B** - SOR: after the IT a pair a PP pair was displayed for 3 seconds and after a RI of 1s a preexposed copy of stimulus P was paired with novel stimulus Q for 3 seconds test.**Panel C** - OIP: procedure involved a single sample phase during which two novel stimuli PR were presented for 3 s, then after a 1 s RI, two copies of the preexposed stimulus PP' were presented for 3 s.

No participants were removed and engagement with stimuli on S1 and S2 was high. Accuracy in the cover task was high with an average missed responses *M* = 1.136 (*SD* = 0.889) and average *FA M* = 2.636 (*SD* = 2.321), resulting in *A'* = 0.988, *SD* = 0.009. Trials with *FA* and targets trials were removed from the analysis to avoid the confound of target processing observed in the Experiment 1 as well as to minimise the response-related artefacts caused by the movement of the tracker while the space bar was pressed (both the keyboard and tracker were placed on the same surface).

5.5.3 Results

5.5.3.1 Sample Dwell

Eye tracking data of interest here were collected during the sample phases of each trial. Figure 5.20 presents a summary of the data. Sample data were entered into 4 (Phase: SOR S1, OIP S1, RR S1 and RR S2) $\times$ 6 (Window) repeated measures ANOVA. The main effect of Phase was significant with $F(3, 63) = 5.206$, $\eta_p^2 = 0.199$, *95% CI* $\eta_p^2 = [0.03, 0.335]$ and a moderate support for the model, $BF_{10} = 9.323$. The dwell appears to be influenced by the Window and the second main effect was also significant with $F(1.952, 40.984) = 3.585$, $p = 0.038$, $\eta_p^2 = 0.146$, *95% CI* $\eta_p^2 = [0, 0.319]$ and decisive level of support ($BF_{10} = 2.696 \times 10^6$). There was also a significant interaction between the two main effects $F(5.498, 115.412) = 2.31$, $p = 0.043$, $\eta_p^2 = 0.099$, *95% CI* $\eta_p^2 = [0, 0.173]$, however the analysis of effects indicates towards the $\mathcal{H}_0$ with a decisive level of support ($BF_{excl} = 114.314$).

Post hoc analysis indicates that OIP S1 level was different from all other levels: SOR S1, $t(63) = -3.544$, $p = 0.004$, $BF_{10,U} = 35421.225$; RR S1, $t(63) =$

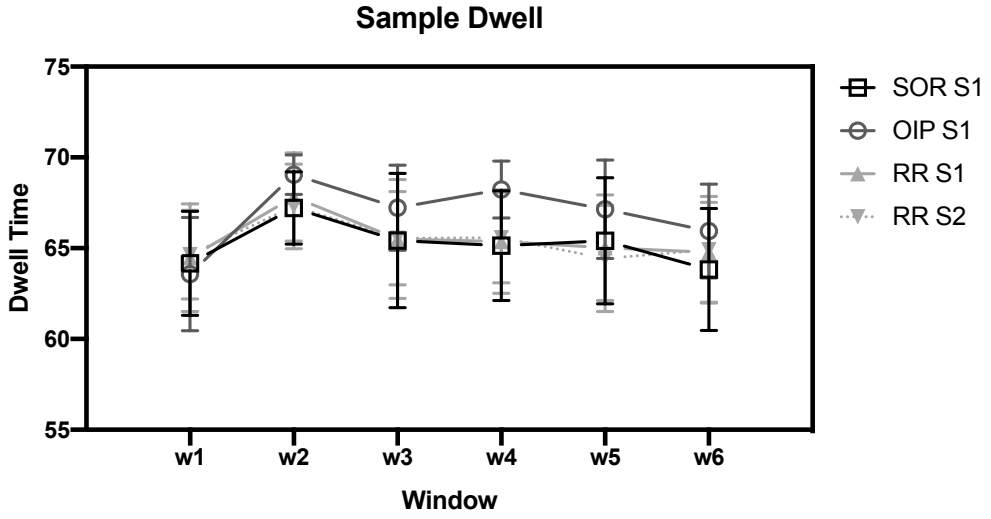


Figure 5.20: Experiment 4, sample phase dwell time with Window on the x- and dwell time on the y-axis (units of eye tracker samples at 300Hz). Mean dwell for each temporal bin is plotted with *95% CI* of the *M*, each sample phase in separate colour and point type.

2.902, $p = 0.02$, $BF_{10,U} = 873.965$; RR S2, $t(63) = 3.1$, $p = 0.014$, $BF_{10,U} = 954.789$, yet the remaining levels did not differ from each other, all $p = 1$, $BF_{01,U}$ between 5.967 and 9.896. The difference in sample dwell time in the OIP condition was most likely caused by the fact that, unlike all other levels, both stimuli on the OIP S1 phase were different and participants needed to explore both which might have caused an elevated response. *Post hoc* results of the Window factor, in particular the differences between the consecutive windows demonstrated significant difference between the w_1 and w_2, $t(105) = -3.91$, $p = 0.002$, $BF_{10,U} = 3446.74$ with all other comparisons being not reliable (all $p = 1$). Similar pattern of results emerges with *post hoc* Phase $\times$ Window analysis. Inspection of the data in Figure 5.20 indicates that the differences would present a similar pattern to those in the main effect of Phase, with OIP dwell time being increased throughout the test phase duration. Overall, dwell in the OIP phase was elevated in comparison to other sample phases, but the difference was most likely caused by a presentation of two novel stimuli in

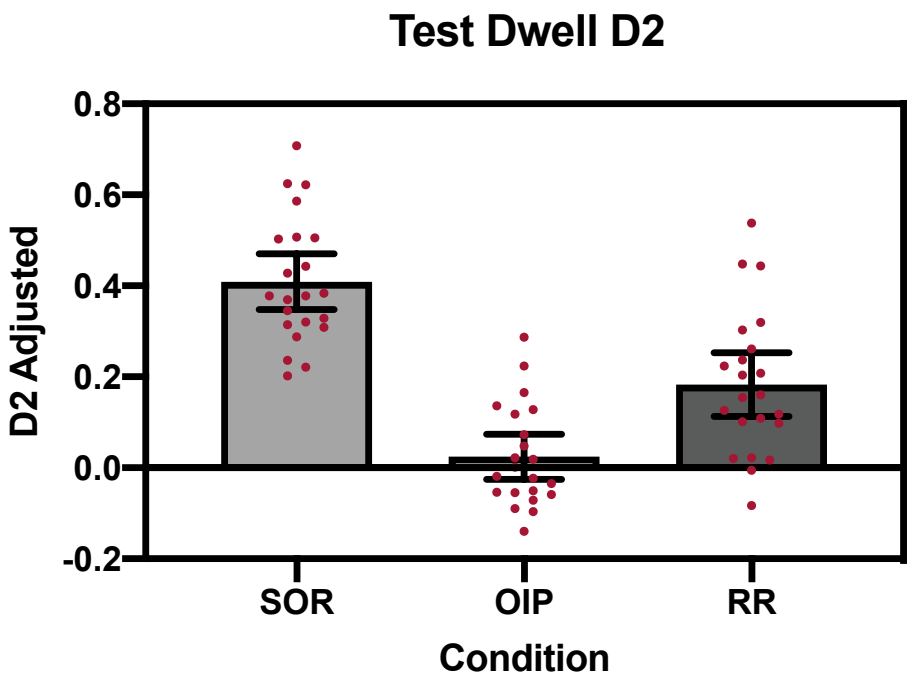


Figure 5.21: Experiment 4, test dwell data presented as adjusted discrimination ratio. $D2_{adj}$ are on y- and test condition on the x-axis. Observations plotted as points and error as *95% CI* of the means.

that phase.

5.5.3.2 Test Dwell

The data of main interest come from the test phase of each trial.An adjusted D2 discrimination ratio, $D2_{adj}$, was calculated based on Q/P' and P dwell times from windows w_2 and w_3. This was done in line with Equations 4.3, 4.4 and 4.5 on p. 73. The data were analysed using a repeated measures ANOVA with the main effect of Condition and the summary of data are presented in Figure 5.21, panel A. The main effect of Condition was significant, $F(2, 42) = 71.617$, $p < 0.001$, $\eta_p^2 = 0.776$, *95% CI* $\eta_p^2 = [0.625, 0.836]$ with significant differences between the $D2_{adj}$ in SOR and OIP: $t(21) = 11.272$, $p < 0.001$, $d = 2.403$, *95% CI* $d = [1.562, 3.23]$, $BF_{10} = 4.348 \times 10^7$, as well as between SOR and RR: $t(21) = 7.666$, $p < 0.001$, $d = 1.634$, *95% CI* $d = [0.981, 2.271]$, $BF_{10} = 95984.046$. The difference between the $D2_{adj}$

in RR and OIP was also significant, $t(21) = 4.884$, $p < 0.001$, $d = 1.041$, *95% CI d* = [0.511, 1.555], $BF_{10} = 339.713$. When the three conditions' $D2_{adj}$ were compared with $\mu = 0$ only the SOR, $t(21) = 13.804$, $p < 0.001$, $d = 2.943$, *95% CI d* = [1.959, 3.913], $BF_{10} = 1.505 \times 10^9$, and RR, $t(21) = 5.434$, $p < 0.001$, $d = 1.158$, *95% CI d* = [0.606, 1.694], $BF_{10} = 1085.019$, were reliable. Lack of effect in OIP, $p = 0.318$, was supported by an anecdotal evidence $BF_{01} = 2.819$.

Overall, the effects of novelty manifested with a significant and positive discrimination ratio, demonstrated by a higher dwell towards the stimulus Q in SOR, and recency, demonstrated by a higher dwell towards the stimulus Q in the RR, were robust and supported with decisive evidence.

5.5.4 Experiment 3 and Experiment 4 Compared

In Experiment 3 and Experiment 4, procedures were very similar except for the engagement (cover) task involved. In Experiment 3 participants were told to press the space bar each time they saw a dot target appearing in a specified area on the screen, the targets were sporadic and could only appear during the time when the experimental stimuli were not on the screen. The hypothesis used to account for the *null* results in the Experiment 3 OIP was that because the cover task did not involve the experimental stimuli, the salience was low which might have led to the *null* preference in the OIP condition and could have also led to a less robust result in other conditions. To address that, Experiment 4 involved different cover tasks in which participants had to engage and process the experimental stimuli. On some rare occasions, the presented stimulus would involve an object which belonged to a clothing category and participants were instructed to press the space bar every time

they saw an image of clothing. The contrast between the two experiments can be described as a juxtaposition of shallow versus deep encoding strategies (Sivakumaran et al., 2018).

The cover task has been changed between the experiments, all else being equal, hence the data from the two can be entered in a between-subject ANOVA to investigate whether the change had any influence on the effects of novelty, recency and novel location. To reduce the dimensionality of the data, the Stimuli Type factor was dropped in favour of the discrimination ratio $D2_{adj}$ which is calculated from the levels of this factor. As the effects of novelty and recency were the most robust between 0.5 and 1.5 seconds, the dependent variable was constructed as an average of w_2 and w_3. Equations 4.3, 4.4 and 4.5 on p. 73 describe the calculation.

The data were entered in a between-subject ANOVA with within-subject factor of Condition (3 levels of SOR, OIP, and RR) and the between-subject factor of Experiment which had two levels (E3, E4) and DV of $D2_{adj}$. Summary of the data are presented in Figure 5.22.

Inspection of the data indicates that discrimination differed between the Conditions and the inferential statistics support this observation as the main effect of Condition was reliable, $F(2, 88) = 92.225$, $p < 0.001$, $\eta_p^2 = 0.677$, *95% CI* η_p^2 = [0.558, 0.746] the main effect was supported by a decisive level of evidence, $BF_{10} = 3.362 \times 10^{20}$. The between-subject factor of Experiment was significant, $F(1, 44) = 7.126$, $p = 0.011$, $\eta_p^2 = 0.139$, *95% CI* η_p^2 = [0.008, 0.324] but there was only an anecdotal support for the model ($BF_{10} = 1.026$). The interaction between the two main effects was also significant with $F(2, 88) = 4.914$, $p = 0.009$, the

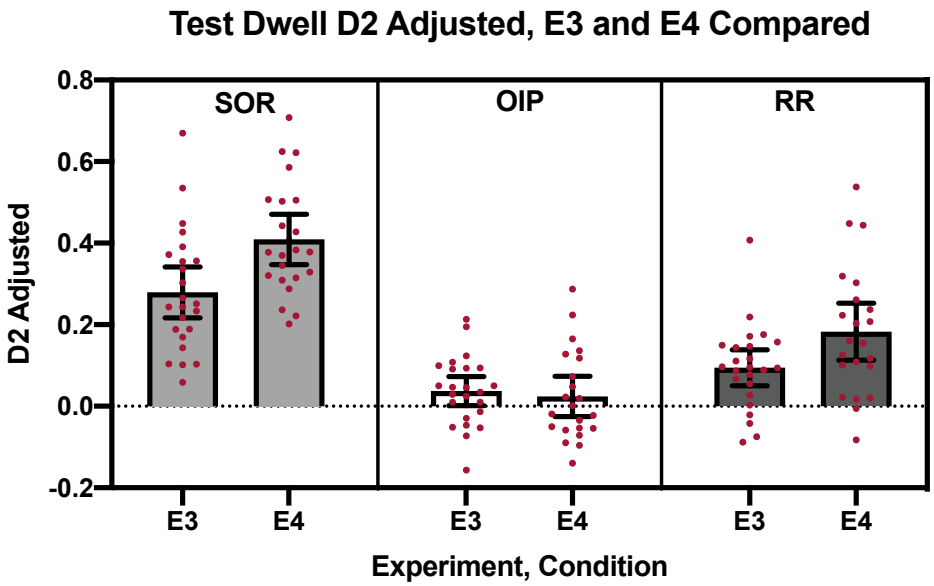


Figure 5.22: Experiments 3 (E3) and 4 (E4) Compared. Presented are adjusted test phase $D2_{adj}$ ratios (with *95% CI* of the mean) on the x-axis and Condition (SOR, OIP and RR) across the two experiments on the y-axis.

effect size was small η_p^2 = 0.1, *95% CI* η_p^2 = [0.007, 0.217] and the support was of moderate size (BF_{incl} = 5.705). Of main interest were the differences between the $D2_{adj}$ values yielded by matched Conditions across two Experiments, which were analysed with *post hoc* independent sample tests which yielded significant for the differences between respective SOR $D2_{adj}$ in E3 and E4, t(44) = -3.057, p = 0.004, d = -0.902, *95% CI* d = [-1.528, -0.26], BF_{10} = 10.496. The difference between the RR $D2_{adj}$ of E3 and E4 was significant, t(35.835) = -2.224, p = 0.033, d = -0.662, *95% CI* d = [-1.271, -0.052], BF_{10} = 2.201. Critically, however there was no difference between the OIP $D2_{adj}$ in E3 and E4, p = 0.652, with moderate support for the $\mathcal{H}_0$, BF_{01} = 3.143.

5.5.5 Discussion

Results demonstrated a significant and supported by decisive evidence effects of novelty in SOR and RR, both effects were also decisively different from each other.

An anecdotal evidence in support of the *null* was reported in OIP. When the effects observed in Experiment 3 and 4 where compared, better discrimination was observed in SOR and RR, but not in OIP. The difference in SOR was strong, in RR anecdotal and in OIP there was a moderate support for the *null*. The hypothesised effects of novelty recency and novel location/objects can only be supported for the first two. It was expected that a change in cover task will result in a better discrimination and this can only be supported in SOR and RR, while in OIP there was no evidence to confirm either an improvement nor existence of discrimination. The results of this experiment are in line with hypothesis and results from Experiments 2 and 3. It is difficult to attribute the *null* effect of OIP to a particular fault in the design. Certain animal versions of the task (Dix & Aggleton, 1999; Nelson et al., 2011; Barker & Warburton, 2015) employed more then two spatial locations. During the test phase stimuli appeared in locations in which nothing was presented during the sample phase. The manipulation could interfere with cognitive map constructed during the sample phase in a more profound way than the spatial arrangement used in this experiment. Furthermore, human analogues of the tasks used here have some differences when compared to the animal counterparts; here the stimulus is presented on the computer screen, where in animal procedures animals are presented with much more immersing and real environment. Due to too many unknowns and multiple possible causes, in the following experiment, I will attempt to investigate the associative component of recognition memory in a more explicit and salient context, namely, an adaptation of the OIC procedure (Langston & Wood, 2010; Honey et al., 2007; Tam et al., 2014; Barker & Warburton, 2020; Eacott & Norman, 2004; Honey et al., 1998; Honey & Good, 2000).

5.6 Experiment 5

5.6.1 Introduction

The experiments reported so far demonstrated robust effects of SOR and quantitatively smaller, yet reliable, effects of RR. Both effects, as well as the difference in magnitude, are well accounted for by the SOP model (Wagner, 1981; Brandon et al., 2003; Vogel et al., 2019). I was also able to demonstrate that the temporal dynamics of $A1$ activation, a critical tenet of the model, are reflected in the behavioural data. However, Experiment 3 and Experiment 4 failed to replicate the OIP effects observed in animal studies. To examine whether the *null* result could be attributed to a true lack of effect or to a lack of sensitivity in procedure in the OIP, here I focus on an alternative associative recognition procedure, which in animal procedures was capable of isolating the behavioural correlates of RGP and demonstrate associative learning in recognition memory. Whereas in the OIP an association is learned between the stimulus and context in which it appears, such as environmental arrangement, the OIC (Langston & Wood, 2010; Honey et al., 2007; Tam et al., 2014; Barker & Warburton, 2020; Eacott & Norman, 2004; Honey et al., 1998; Honey & Good, 2000) is an experimental procedure (see Table 2.4 on p. 38) in which sampled stimuli are first presented with certain salient contexts. Then, during test, copies of stimuli are presented in either matching or non matching contexts. Formally, the design follows: $XQ \xrightarrow{ISI} YP \xrightarrow{RI} XQP$ or YQP, where X and Y are both contexts and Q, P are experimental stimuli.

Associative recognition effects have previously been demonstrated in ro-

dents by Dix and Aggleton (1999), who showed that when stimuli are first paired with a certain context (respectively QX and PY) and then tested with QP in either the context X or Y the exploration was increased to the object which did not match with the sampled context. That is, exploration was higher for Q than P when presented in context Y. However, it is possible to argue (Lovibond, Preston, & Mackintosh, 1984) that a presentation of stimuli in one context modifies the perception of the object presented in it. Then, when the context changes, so does the perception of an object. As such, the SOP could still account for this effect, however not under the associative mechanism. Whitt et al. (2012) demonstrated that the associative influence on recognition can be demonstrated when the context is not presented at the same time as the test stimuli. These authors first presented pairs of stimuli in separate visual contexts (QX and PY); then, rats were presented with a context stimulus X and then a pair of stimuli PQ in a novel context Z. The results demonstrated that when the test was preceded with presentation of the context X, which has been associated with Q, exploration of this object was reduced. According to SOP the effect is driven by the associative activation of the memory representation of Q by the presentation of X. The indirectly activated representation of Q is primed to the refractive state $\xrightarrow{p2} A2$ which blocks its ability to be activated into $\xrightarrow{p1} A1$, effectively habituating the orienting response to that stimulus. Finally, Tam et al. (2014) demonstrated an effect of associative recognition in rats and how the effects of SGP and RGP postulated by the SOP interact with each other. The authors first presented animals with sample $XQ \xrightarrow{5min} YP$, after an RI of 5 min, one group was tested with XQP and the other with YQP. In the YQP group, P is primed by recency, but also by the presentation of the associated context Y. However, in the

other group stimulus P is primed by the SGP but Q is also primed, by the associated X. Hence, Q in XQP has a higher probability of being activated into $A1$. This is what the authors have observed; discrimination was higher in the YQP, where the priming operated on the same stimulus Y.

In the context of experiments involving human population Hannula and Ranganath (2009) tested how prior associations between context and stimuli (human faces) drive eye movements. Authors first presented participants with a series of context - face pairings, then in the test phase participants were given a cue (context) followed by an array of three faces, only one of which matched the sample pairings. Their interpretation of the results led these authors to the conclusion that context-driven retrieval of previous associations resulted in a higher dwell time on the matching face stimulus. Similar results, preferential exploration of the context-matching stimulus, have been demonstrated in related eye-tracking studies (Ryan et al., 2020, 2000; Hannula et al., 2007; Mahoney et al., 2018; Ryan et al., 2007; Hannula & Ranganath, 2009). Hence, results from animal and human studies are conflicting, with the former indicating habituation of dwell time by context retrieval and the latter suggesting an increase in exploration time towards the primed stimulus.

Since the RR effects have been established in prior experiments reported in this chapter. The primary objective of this experiment is to demonstrate the influence of associative priming on recognition memory. Previous studies reported in this chapter have not been been able to demonstrate a reliable effect of OIP. However, an introduction of a more salient context may support a more robust association.

To that extent, it is hypothesised that, in line with Tam et al. (2014) and SOP-predicted pattern of results, participants will spend less time looking at the stimulus Q in OX, then Q is presented with sample-matching context$X$, than in Q in OY, when it is presented with non-matching context. This effect shall also be demonstrated with the D2 ratio being greater in OY than in OX. Considering the effect of SGP in isolation, it is expected that the dwell time will be higher for the less recent Q, over the recent P and the effect should be present in all three experimental conditions: RR, RR with context X (OX) and RR with context Y (OY). However, the effects of SGP are expected to be modified by the effect of RGP. In the OY Condition, the associative mechanism is expected to prime the test P, which is also primed by the SGP, hence both priming mechanisms operate in the same direction. In contrast, the test in OX involves two mechanisms working in opposite directions, with RGP priming the less recent Q. Hence, it follows that the summation of the two priming forces (OY) would result in a higher dwell to Q in OY over the Q in RR, as well as reduction in dwell time to Q in OX when compared to Q in RR. This differences also suggest that the difference between Qs in OX and OY should be significant.

Furthermore, a secondary objective is to reconcile the conflict between the rodent and human experiments by using a close human adaptation of rodent OIC. Manipulation of spacing temporal intervals between the samples and between sample and test was employed for two reasons: first, was to pinpoint the temporal parameter yielding the best RR and OIC effects. The second was to investigate how time delay influences the effects of RR and OIC with the former depending on time-sensitive SGP and the latter is resistant to time-based decay.

The experimental hypothesis is that in condition OY, where SGP and RGP prime the same stimulus, discrimination will be higher than in the OX, where both mechanisms prime different stimuli. This effect could also be different from RR where only the recent stimuli is primed.

5.6.2 Methods

5.6.2.1 Participants

Identical to that in Experiment 1 with the exception of sample size: 26 female and 9 male University of Nottingham students and staff participated. Their *M* age was 22.9 years (*SD* = 4.869, range 18-36).

5.6.2.2 Apparatus

Identical to that in Experiment 1 with the exception of the sampling frequency which was 300 Hz and use of chin rest which was used to fix the distance from the screen at 50-55 cm.

5.6.2.3 Stimuli

BOSS stimuli were selected, split into target and experimental sets, and processed for salience equalisation as in Experiment 4. In addition to that, a third context (X, Y), set was created with 38 images of maritime flags sourced from Wikipedia (International Code of Signals letters and NATO number flags combined, only square versions, Public Domain) and 5 created manually in graphical software (43 in total). During the experiment, both stimuli and target images were selected randomly without replacement by the experimental software (PsychoPy), images from the context

Table 5.10: Design of Experiment 5. Q and P denote the experimental stimuli presented to the participants, In OX and OY conditions the stimuli was accompanied with context, denoted as X and Y. In the RR condition participants were first shown Q, then followed by a ISI of either 0.5, 1.0 or 2.0 s they were presented with P. Test followed after a RI, which was equal to the ISI for that trial, with a concurrent presentation of Q and P. Both OX and OY were similar to the RR, but the Q was presented with context X and P with Y during the respective sample phases. Test in the OX consisted of presentations of Q, P and context X, whereas in the OY both Q and P were presented with context Y. The SGP and RGP columns specify the difference in dwell time according to the theoretical predictions of the SOP and prior evidence. Table adapted from Tam et al. (2014) and Nitka et al. (2020).

Condition	Sample 1	ISI	Sample 2	RI	Test	SGP	RGP
RR	Q	0.5 /	P	0.5 /	QP	$Q > P$	–
OX	XQ	1.0 /	PY	1.0 /	XQP	$Q > P$	$Q < P$
OY		2.0 s		2.0 s	YQP	$Q > P$	$Q > P$

set were sampled randomly without replacement until the set was exhausted, after that, it was reinstated to its full availability and the process was continued. All images were presented on a grey (PsychoPy colour space RGB: 0, 0, 0) background and could assume one of the four positions on the screen: top left, top right, bottom left, or bottom right. In a 2D Cartesian coordinate system (with origin being the centre of the screen), the image centre was aligned to: top left (-275, 275), top right (275, 275), bottom left (-275, -275) or bottom right (275, -275).

5.6.2.4 Procedure

Calibration and instructions were as in Experiment 4.

The design is presented in Table 5.10 and visualisation of the experimental sequences in Figure 5.23. A total of 90 trials consisted of 36 trials for each of RR, OX, and OY and 18 target trials. Trials were presented semirandomly in the order determined by the experimental software. Each trial began with a 1 s ITI during which a fixation cross was displayed in the centre of the screen (Arial, black, 100

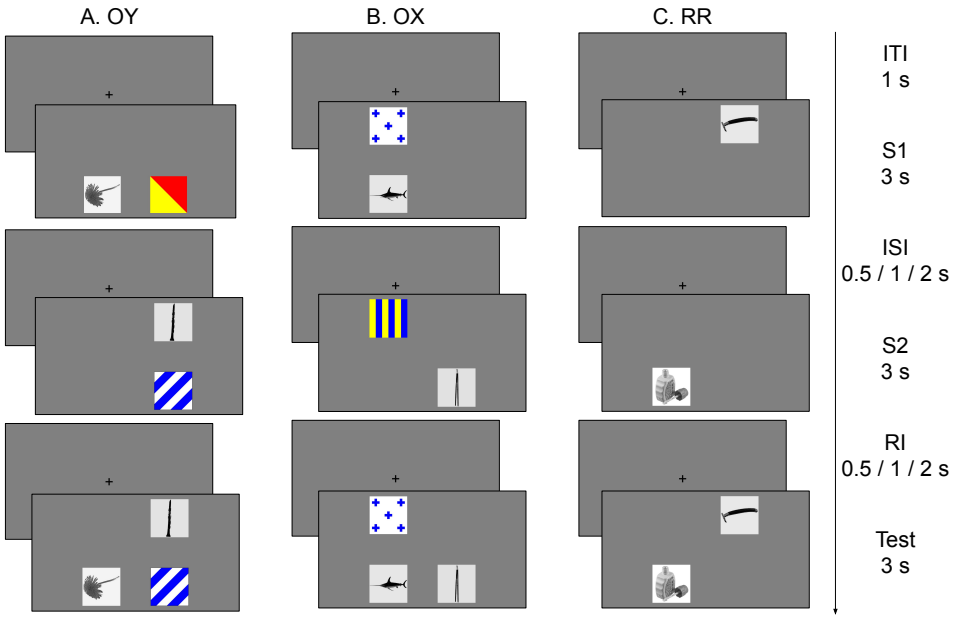


Figure 5.23: Experiment 5, sequence demonstration. **Panel A** - OY: after S1 consisting of stimulus Q and context X and S2 with P and context Y participants were presented with an array of QP with context Y. **Panel B** - OX: sample phases were as in OY, but the Test phase consisted of stimuli pair QP and context X. **Panel C** - RR: on each sample phase a single stimulus was presented; Q in S1 and P in S2, on Test QP were presented. All stimuli presentations lasted for 3s and the ITI was set at 1 s. One each trial, both ISI and RI were set at either 0.5, 1, or 2 s.

px). This was followed by two sample presentations of stimuli (S1, S2); in the RR condition, one image: Q in S1 and P in S2, was presented per phase, in the OX and OY each stimulus was presented with a context: XQ in S1 and YP in S2. Location of Q was determined by the design and was presented in each of four locations equal amount of times, locations for the P and X/Y were determined in a pseudo-stochastic way using an algorithm (see Appendix A.2 on p. 267) in which P was presented contralaterally to Q. All locations maintained their positions between S1, S2 and test phases.

Durations of ISI and RI were determined by the factor of Spacing and were set at three levels: 0.5, 1.0, and 2.0 s, during which a fixation cross was displayed. Sample phases were followed by a test; in the RR this involved the presentation of Q and P, whereas in the OX and OY conditions Q and P were presented together with context X and Y respectively. Test presentation lasted for 3 s and was followed by the next trial. Target trials followed the same structure (9 for each condition with an equal split for each spacing level) with one distinction: either Q or P (selected pseudo-randomly) on such trials was replaced with a stimulus from the target set. Auditory and visual feedback were given for all H and M and FA, but not for CR responses. Participants were given an opportunity to take a break after the 22nd, 43rd, 64th, 85th and 106th trial.

5.6.2.5 Data Treatment

There were four predefined ROIs, with their centres aligned to location: top left (-275, 275), top right (275, 275), bottom left (-275, -275) or bottom right (275, -275). Each ROI was of 350 $\times$ 350 px dimensions and overlapped with the experimental

stimuli.

The main dependent variables were as in Experiment 4.

All target trials as well as false alarms were removed from further analysis. The accuracy of responses in the cover task was high with mean *A'* = 0.991, *SD* = 0.008. No participants were removed and engagement with stimuli on S1 and S2 was high.

5.6.3 Results

5.6.3.1 Sample Dwell

Data of interest comes from the sample phases of each trial; summary statistics are presented in Figure 5.24, with each panel referring to conditions' S1 (left, red) and S2 (right, green) with split into separate spacing levels. The data were entered into a 3 (Condition) $\times$ 2 (Sample Phase) $\times$ 3 (Spacing) repeated measures ANOVA with the dependent variable of total dwell time to sampled stimuli. The main effect of Condition was significant, $F(1.631, 55.45) = 157.212$, $p < 0.001$, $\eta_p^2 = 0.822$, *95% CI* $\eta_p^2 = [0.726, 0.868]$, $BF_{10} = 2.801 \times 10^{104}$. There was a significant main effect of Sample Phase, $F(1, 34) = 13.697$, $p < 0.001$, $\eta_p^2 = 0.287$, *95% CI* $\eta_p^2 = [0.061, 0.485]$, but was not supported by evidence $BF_{10} = 0.648$. The main effect of Spacing was not reliable, $p = 0.302$, $BF_{01} = 34.956$. None of the interactions have reached significance with lowest $F(1.587, 53.967) = 2.718$, $p = 0.073$ (Condition $\times$ Sample Phase). *Post hoc* analysis (Holm-corrected) revealed true difference between the RR and OX, $t(68) = 15.458$, $p < 0.001$, $d = 2.613$, $BF_{10,U} = 2.043 \times 10^{58}$, as well as between RR and OY, $t(68) = 15.252$, $p < 0.001$, $d = 2.578$, $BF_{10,U} = 6.057 \times 10^{49}$,

but not between OX and OY, p = 0.837, $BF_{01,U}$ = 12.207. *Post hoc* comparison between the levels of S1 and S2 was significant, $t(34)$ = -3.701, $p < 0.001$, d = -0.626, $BF_{10,U}$ = 40.184.

The difference between the dwell time in RR and OX, OY conditions can be attributed to the number of stimuli concurrently displayed on the screen, in the RR there was one during each sample when in both OX and OY the stimuli were accompanied with context. To test that suspicion, the dwell data for OX and OY for each sample was calculated as a sum of dwell to stimulus and context. Data were entered into a repeated measures ANOVA with the same main effects. The main effect of Condition remained significant, $F(2, 68)$ = 15.051, $p < 0.001$, η_p^2 = 0.307, *95% CI* η_p^2 = [0.125, 0.446], BF_{10} = 1.632 $\times$ 10^8. The main effect of Spacing was not reliable, $F(2, 68)$ = 0.986, p = 0.378, BF_{01} = 23.465, and so were the interactions; smallest $F(4, 136)$ = 1.319, p = 0.266. *Post hoc* analysing in the factor or Condition yielded dwell in RR to be significantly higher than in OX, $t(68)$ = 4.971, $p < 0.001$, d = 0.84, $BF_{10,U}$ = 973281.015, and than in OY, $t(68)$ = 4.496, $p < 0.001$, d = 0.76, $BF_{10,U}$ = 24589.337. There was no difference between the OX and OY, p = 0.637, $BF_{01,U}$ = 10.606. The data indicate that despite accounting for the time spent looking at context, the dwell time in RR was higher than the one in OX and OY, which had similar dwell time. A potential explanation for this is that dwell time was lost due to increased fixation numbers in the OX and OY, and the increase could have been caused by the presentation of three, instead of two, stimuli.

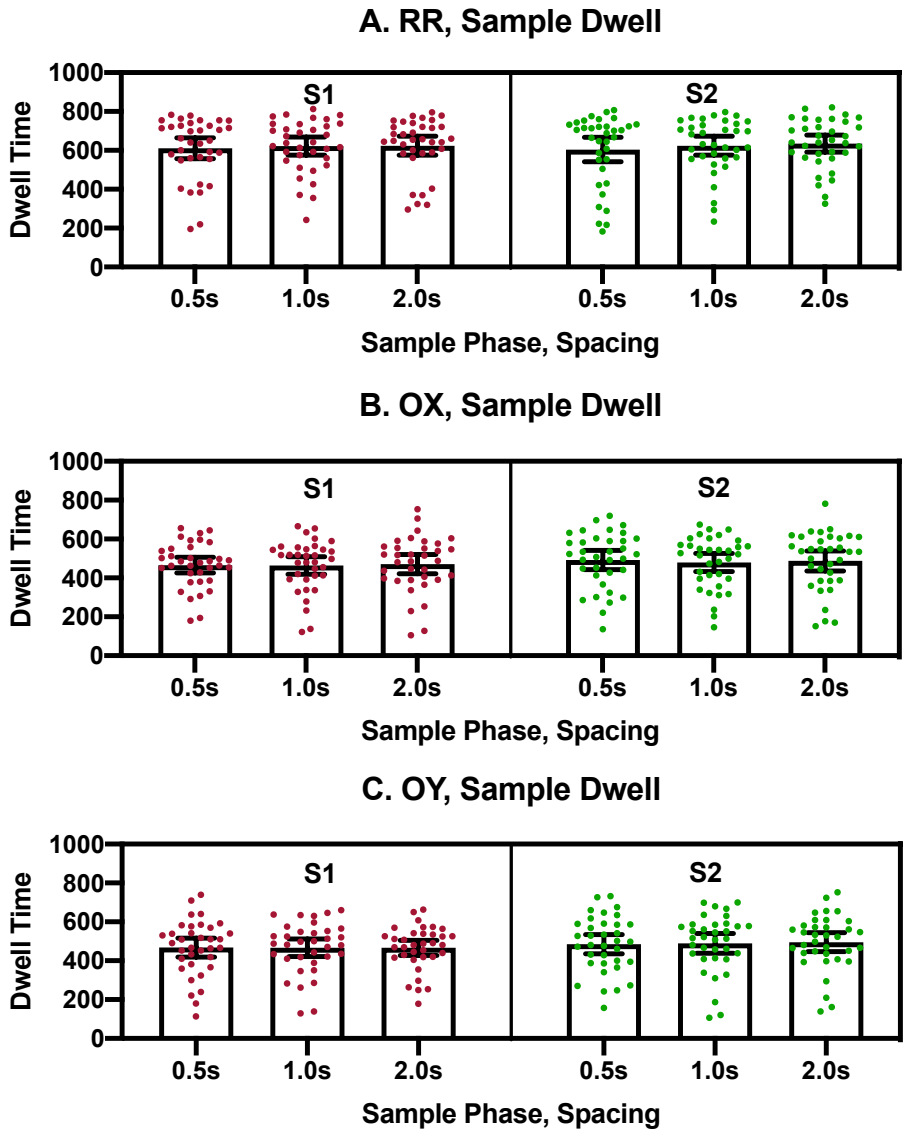


Figure 5.24: Experiment 5, dwell time for sample phases split by condition, sample phase and spacing. Data come from the entire duration of the sample phase, means plotted with *95% CI* and subject-level observations as points. Dwell time on the y-axis (units of eye tracker samples at 300Hz) and sample phases S1 (left, red) and S2 (right, green) with levels of spacing on the x-axis. Analysis of variance revealed a significant main effect of condition with dwell in RR being higher than in OX and OY.

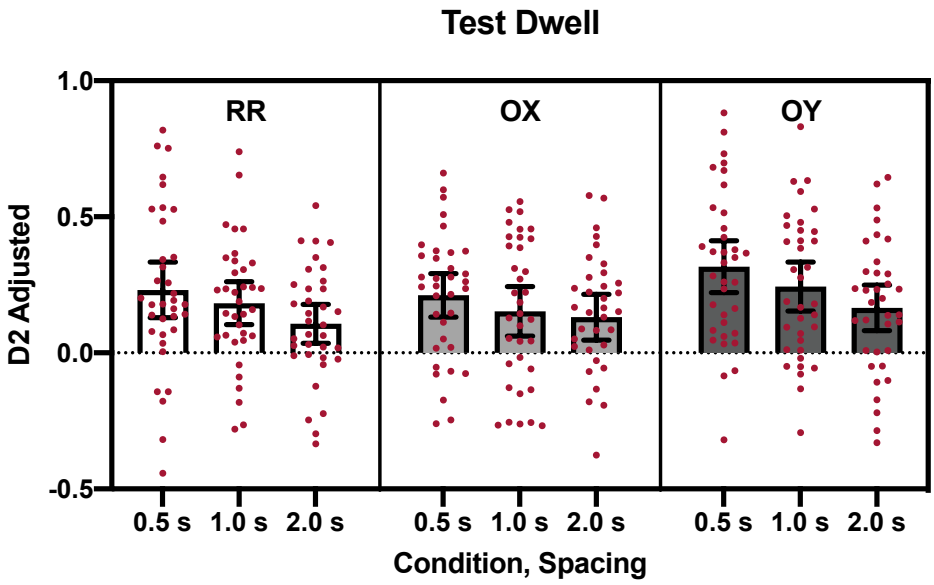


Figure 5.25: Experiment 5 test $D2_{adj}$ values in each experimental condition (separate panels) split into bins based on levels of Spacing (x-axis). On the y-axis mean $D2_{adj}$ with *95% CI* as error and individual observations as points.

5.6.3.2 Test Dwell

Analysis of the main interest involved the DV of $D2_{adj}$ which has been analysed with repeated measures ANOVA with factors of Condition and Spacing. Summary of the data are presented in Figure 5.25.

Inspection of the data indicates that $D2_{adj}$ differs between Conditions and inferential statistics confirm this with a reliable main effect, $F(2, 68) = 3.973$, $p = 0.023$, $\eta_p^2 = 0.105$, *95% CI* $\eta_p^2 = [0.001, 0.236]$, but the $\mathcal{H}_1$ could not be supported with evidence $BF_{10} = 0.757$, *Error* = 1.186%. The main effect of Spacing was significant, $F(1.607, 54.631) = 7.814$, $p = 0.002$, $\eta_p^2 = 0.187$, *95% CI* $\eta_p^2 = [0.029, 0.348]$, $BF_{10} = 24.385$, *Error* = 24.461%. Interaction between the two main effects was not reliable, $F(4,136) = 0.237$, $p = 0.917$, $BF_{excl} = 35.501$. *Post hoc* analysis in the factor of Condition yielded, critical for the hypothesised effects of associative priming, difference between the $D2_{adj}$ in OX and OY significant with $t(34)$ = -

2.571, p = 0.037 (Holm), d = -0.435 supported with anecdotal evidence $BF_{10,U}$ = 1.259. There was no difference between the $D2_{adj}$ in OX and RR, p = 0.777, $BF_{01,U}$ = 8.914 and between OY and RR, p = 0.051, $BF_{01,U}$ = 1.131. *Post hoc*, Bonferroni corrected, *t*-tests yielded reliable difference between the 0.5 and 2.0 s spacing reliable with $t(56)$ = 3.953, $p < 0.001$, d = 0.668, $BF_{10,U}$ = 61.017. No reliable difference was detected between the 0.5 and 1.0 s, p = 0.149, $BF_{01,U}$ = 1.991 and between 1.0 and 2.0 s, p = 0.164, $BF_{01,U}$ = 1.781.

5.6.4 Discussion

Obtained significant difference between the OX and OY was anecdotal, yet significant. No difference was observed between discrimination in OX and RR - moderate support for the *null* - and between OY and RR - anecdotal support. Effects of spacing shown a significant reduction in discrimination between 0.5 s and 2.0 s spacing and was supported very strongly.

The results suggest that participants demonstrated discrimination in all three conditions. Moreover, there was a difference between the OX and OY $D2_{adj}$ which was in line with expected effects. Results indicate that when RGP and SGP mechanisms prime the same stimulus P (OY), participants will spend more time exploring Q, than when the RGP and SGP prime different test stimuli (OX). Effect of spacing was also observed, however it did not interact with Condition. Contributions to the current knowledge provided by the current experiment are two-fold. Firstly, the results replicate the effects of RR obtained in previous experiments reported in this chapter. This demonstration is novel in the human population (Nitka et al., 2020). Secondly, the results provide evidence in support of an associative

account of recognition memory and for the first time demonstrate the effects of both RGP and SGP in human eye-tracking studies.

Furthermore, the results from the current study stand in opposition to those of Hannula and colleagues (Ryan et al., 2020, 2000; Hannula et al., 2007; Mahoney et al., 2018; Ryan et al., 2007; Hannula & Ranganath, 2009), which demonstrated the facilitation of dwell time to a stimulus by a previously associated context. Here, in line with animal studies (Langston & Wood, 2010; Honey et al., 2007; Tam et al., 2014; Barker & Warburton, 2020; Eacott & Norman, 2004; Honey et al., 1998; Honey & Good, 2000), I have demonstrated that the presentation of context which has been previously associated with the stimulus habituates dwell time. The discrepancy between the findings from animal and human research could have been caused by the differential methodologies used to study recognition. Hannula and colleagues used an explicit test of recognition which followed the eye-tracking array. Participants were asked to indicate which face was matching the sample array. As demonstrated, in Experiment 1 in this Chapter, overt instructions severely interfere with eye movements of interest, participants will look at targets to follow the task (Holmqvist et al., 2011). This is echoed with findings of Richmond, Colombo, and Hayne (2007) who, using VPC, observed that when no instructions nor an explicit memory test were administered effects of novelty were observed; however when participants were asked to make an explicit recognition, the results demonstrated familiarity preference. Hence, it is likely that the behaviour authors have observed does not reflect recognition, but target selection. The interpretation is plausible in light of evidence from visual search studies. Chun and Jiang (1998) reported that repeated presentation of a complex search array facilities the response

time to target. Participants learned the spatial arrangement of an array which facilitated RT and accuracy. Similar results were obtained by Summerfield, Lepsien, Gitelman, Mesulam, and Nobre (2006), who demonstrated that prior associations between the items of a given visual search array facilitated RT and the influence of memory resulted in quicker RT than a salient visual cue. In both experiments the attention was guided by a long-term memory representation. According to Chun and Nakayama (2000) memory is, alongside the stimulus salience and goal orientation, a key factor guiding human attention. Memory of a scene enables more efficient information extraction and processing of the most relevant stimuli. The SOP is not at odds here, as the $A2$ activation which results from either a repeated presentation or a long-term memory priming could result in a quicker response time as the representation is in a processed state. Being in $A2$ state could mean that the stimulus does not require the same amount of appreciation or encoding and response can be made quicker than when the processing is in primary activation ($A1$). In support of that Smith and Squire (2017) demonstrated that long-term memory of a scene resulted in fewer but longer fixations which spanned a smaller area of a scene which could be a marker of a processed state ($A2$). To that extent and in the context of Hannula and colleagues' studies, when participants were given an indication that a given task involves a classification of stimuli as old or novel, they will perform the task and gaze will reflect this process. An experimental test of long-term memory-guided visual search which would test the SOP on that field would be of interest here and help in further validating SOP as a general model of behaviour (Robinson & Bonardi, 2015).

5.7 Conclusion

The key aim of the experiments presented in the chapter was to develop a robust eye-tracking procedure which would be able to demonstrate both associative (RGP) and non-associative (SGP) learning mechanisms able to examine an associative account of recognition memory in humans. In Experiment 1 I applied the dot probe to the SOR and RR procedures. Although the effects of novelty and recency were observable, the expected influence of the experimental manipulation had no effect on RT expected, suggesting that the dot probe task may not be methodologically suited to investigate the effects of novelty and recency (SOR and RR). In Experiment 2, I examined SOR and RR using a method which allowed for stimuli to be explored freely and the procedure yielded a robust effect for both SOR and RR. In order to observe clear effects of RGP, in Experiment 3 OIP was added to the SOR and RR. Both latter effects were replicated, however the OIP could not be supported with evidence. Working with the hypothesis that failure could have been due to lack of engagement with stimuli, Experiment 4 used a method which demanded a greater degree of visual investigation of stimuli. Although there was some degree of change in time spent looking at stimuli, the effects of OIP failed to be supported with a satisfactory degree of evidence. On the other hand the effects of RR were replicated in Experiment 2, Experiment 3 and Experiment 4. Finally, Experiment 5 offered evidence in support of both SGP and RGP, where the latter was achieved through an adaptation of the OIC procedure used in Tam et al. (2014).

Results from Experiment 5 demonstrate the existence of an associative component of human recognition memory and that the influence of prior associa-

tions demonstrates effects which are closely aligned with those from animal studies, namely, participants spend more time looking at stimuli which appeared in a context which it has not been previously paired with. As such, these results are in contrast with findings from Hannula and others (Ryan et al., 2020, 2000; Hannula et al., 2007; Mahoney et al., 2018; Ryan et al., 2007; Hannula & Ranganath, 2009) who argued that more attention is given to stimuli matching the prior association. I assert that the familiarity preference observed can be attributed to the explicit task demands involved in the experiments and that participants demonstrated behaviour more akin to visual search, with gaze location being guided by task goals (Chun & Jiang, 1998; Summerfield et al., 2006). This yields an interesting question which should be addressed in future research, how can SOP account for the facilitation of RT in human studies; does secondary activation ($A2$) facilitate response time and what are the temporal dynamics of that potential process.

Results from Experiment 3, Experiment 4 and Experiment 5 demonstrate that temporal specificity of $A1$ response, demonstrated in computational models presented in this Chapter, is supported by the data. When D2 was split into six consecutive temporal windows, the discrimination was most robust in the earlier part (0.5 - 1.5 s) of the test phase. Earlier demonstration (Sivakumaran et al., 2018) and results presented here are comparable in terms of temporal dynamics; however here the effects have been demonstrated for RR and OIC. Using $D2_{adj}$ was the most successful in detecting the effects of interest and it appears; that using the most simple statistical models yields the best results.

Therefore, the evidence presented supports the assertion that, using SOR-derived methods of RR and OIC, human recognition memory can be modelled as an

associative process. Furthermore, the SOP provides a robust and reliable account for the data observed here. In the following chapter, I will further test the SOP account. This will be mainly done by applying RI and ISI manipulation and comparison of the results predicted by the model with experimental data.

6 | Influence of Time on the SGP and RGP

6.1 General Introduction

In this Chapter I further explore the effects of associative and non-associative influences on human recognition memory, namely, the SOP's self (SGP) and retrieval-generated priming (RGP) mechanisms. In Chapter 5 I documented the development of a human adaptation of animal recognition memory procedures and demonstrated that eye-tracking tasks are capable of obtaining the effects of SOR, RR, and OIC. In this chapter, this effects are explored further with a particular focus on their temporal dimension, namely, the manipulation of RI and ISI duration. In particular, in Experiment 6, I will first explore the effects of RI on the SOR, RR and OIP effects to then experimentally test (Experiment 7, Experiment 8) two explanations for the long-lasting effects of RR observed by Mitchell and Laiacona (1998). This is of particular importance as these are problematic for SOP's account. Going further into the assessment of temporal influences on RR, In Experiment 9, I also attempt to explore the effects of sample-to-sample (ISI) duration manipulation on the RR and how those can be subsumed by the SOP theory. In Experiment 10 and Experiment 11 I assess how the two mechanisms, SGP and RGP captured by the procedures of RR, OIC, and OIP, are influenced by the duration of RI.

The SGP and RGP mechanisms differ in their susceptibility to time. The former mechanism and its behavioural effects are time dependent and transient, decaying as representations move from $A1$ to $A2$ states. The latter, however, does not possess this quality; once formed, the associations are resistant to time-dependent

decay and can only be extinguished. This suggests that in the context of recognition memory procedures, the extension of the RI will result in a differential effect of the manipulation on the behaviours enabled by the SGP and RGP.

In the Mitchell and Laiacona (1998) authors investigated memory for the order of presented stimuli and what role does the medial prefrontal cortex (mPRF) play in this process. Using a sample of eight rats and a repeated measures design the authors first presented an animal with a pair of objects QQ which animals could explore freely for 5 min. Then, after an ISI of 1 h, animals returned to the arena and were given two novel objects PP for the same duration. Five RIs were used to test the duration of the effect, preference to explore the object Q when presented alongside P at test. This preference was significant when RI was set at 1, 6, and 24 h and no significant preference was observed at longer RIs of 72 and 158 h. After bilateral mPFC lesion, animals could not demonstrate the same preference as pre-surgery, however were still able to discriminate novel from a pre-exposed (SOR) objects.

As stressed in Mitchell and Laiacona (1998), the RR procedure tests the memory of previously presented stimuli. Effects of RR were also observed when the ISI and RI were set at relatively short 2 min, as observed by Good et al. (2007) or when the ISI was 1 h and the RI was 15 min as in Nelson et al. (2011). This findings were also echoed by Hannesson et al. (2004a) with the RI being set at 45 min. Barker et al. (2007) demonstrated that discrimination was indeed still significant at an RI of 3 h; however Hotte et al. (2005) reported a *null* result at 4 h RI. A recent investigation of RR, which looked at multiple ISI and RI configurations (Hatakeyama et al., 2018), failed to demonstrate an effect of recency when the ISI

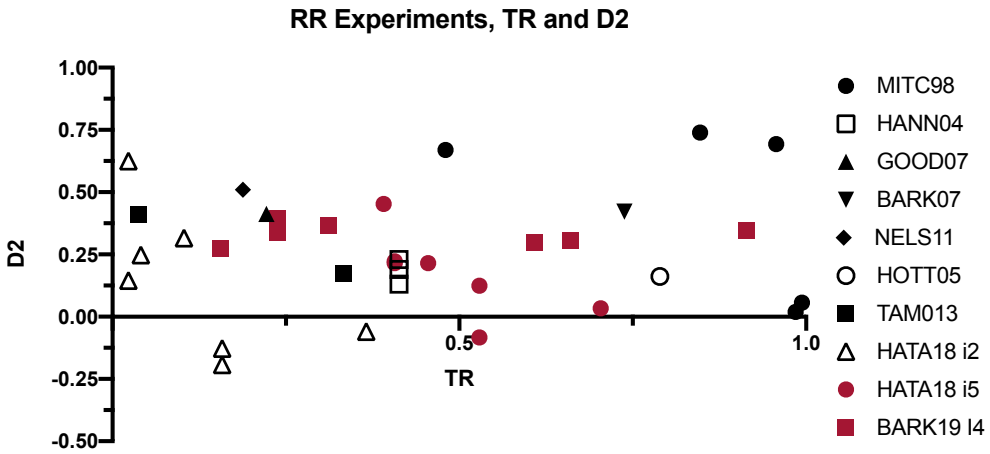


Figure 6.1: Comparison of RR rodent studies with TR on the x- and D2 on y-axis. Outcomes from each study are plotted with different points, studies involving two sample phases are in black and in red denote those with four or five phases.

was set at 11 and RI at 2 min (Experiment 1 in Hatakeyama et al., 2018) and when replicated with RI of 3 min (Experiment 3.2 in Hatakeyama et al., 2018) the resulting D2 was different from 0 but indicated that animals spent more time exploring the familiar stimulus P. The same study obtained a significant discrimination when ISI was 125 and RI 15 min, but did not see any preference in exploration at a RI of 75 min (Experiment 3.1 in in Hatakeyama et al., 2018). Manipulation of ISI on the other hand demonstrated that, with RI set at 3 min, increase from 65 to 125 min resulted in an increase in mean D2 from 0.248 to 0.625 and that both effects were significant at their respective ISIs. The results echo those reported by Tam et al. (2013) who demonstrated that an increase in ISI, from 5 min to 2 h, yielded an increase in D2. This is predicted by the SOP extending the time between the sample allows for a higher probability of the first sample stimulus' representation to decay completely.

Using the discrimination ratio D2, all similar experiments can be compared, Figure 6.1 present the summary of the selected procedures. All data come

from the sham conditions of experiments which used RR procedure with objects and did not involve any explicit context manipulation. It, must be noted, that the experiments differed in many ways; their ISI, RI, stimuli presentation durations and other variables could have influenced DVs. However, such complexity cannot be fully captured and the below review does not constitute a robust analysis or meta-analysis. Because the RR experiments reported in this chapter rely on RI and ISI manipulations the data is interpreted with regards to this two parameters only. Where D2 was not given, it has been calculated as in Equation 4.1 on p. 72, where Q was the dwell time towards the stimulus presented earlier in the sample and P was the recent stimulus, if no data were provided it has been extracted from the plot using the WebPlotDigitizer tool (Rohatgi, 2020). Time Ratio (TR, Hatakeyama et al., 2018) was used to allow for a better comparison between studies, as was calculated as:

$$TR = \frac{t_P}{t_Q} \tag{6.1}$$

where t_P is the time from the end of sample P till the beginning of the test phase and time t_Q is the duration from the offset of sample Q till the onset of the test array. Low TR values indicate that both samples were presented in close temporal proximity, whereas values approaching 1 mean that there was a longer temporal lag between the two sample phases. This is of interest in light of, demonstrated by Tam et al. (2013), effects of ISI extension. Longer ISI duration has resulted in an increased preference for the presented earlier stimulus Q. Most of the experiments cited used 2 sample versions of the task, however two recent studies which were of

particular importance (Hatakeyama et al., 2018; Barker et al., 2019) and used 4 or 5 sample phases were also added. ISI and RI data from the studies were recalculated so that the time t_Q and t_P duration depend on the sample position of the tested stimuli, for example in a design where $AA \xrightarrow{ISI} BB \xrightarrow{ISI} CC \xrightarrow{ISI} DD \xrightarrow{ISI} EE \xrightarrow{RI} BD$ the time t_Q was the time from the offset of BB sample (including the ISI, interleaving stimuli presentations and RI), time t_P was the delay between the offset of sample DD and test array onset, here the ISIs, RIs and stimuli presentation duration (for EE, in t_P and for CC, DD, EE for t_Q) were summed

The SOP predicts that when two sample stimuli are presented in close temporal proximity, their test explorations should be similar and D2 should be approaching 0, this means that TR and D2 should be negatively correlated. Inspection of the data in Figure 6.1 does not suggest this and the results of a Pearson correlation confirm that the observation as the test was not reliable, r = 0.033, *95% CI* r = [-0.299, 0.358], p = 0.848, BF_{01} = 4.736. However, the TR does not take RI under full consideration, for example TR of 0.9 can be both achieved with t_P and t_Q of 9 min and 10 min but also when values are 90 and 100 min. The D2 in both cases should be approaching 0, however it is unclear as to whether this is due to the equal $A1$ activation because both representations have fully decayed or due to similar proportion of elements in respective $A2$ states.

To supplement the above analysis Figure 6.2 presents data from selected 2-sample experiments with similar ISI duration split into groups: >60 min in green, 60 min in red and 60 min < in black. Time, after *log10* transformation, is presented on the x- and D2 on the y-axis. Inspection of the data indicates that results from the selected experiments only partly fit with expected decay. An extension of RI

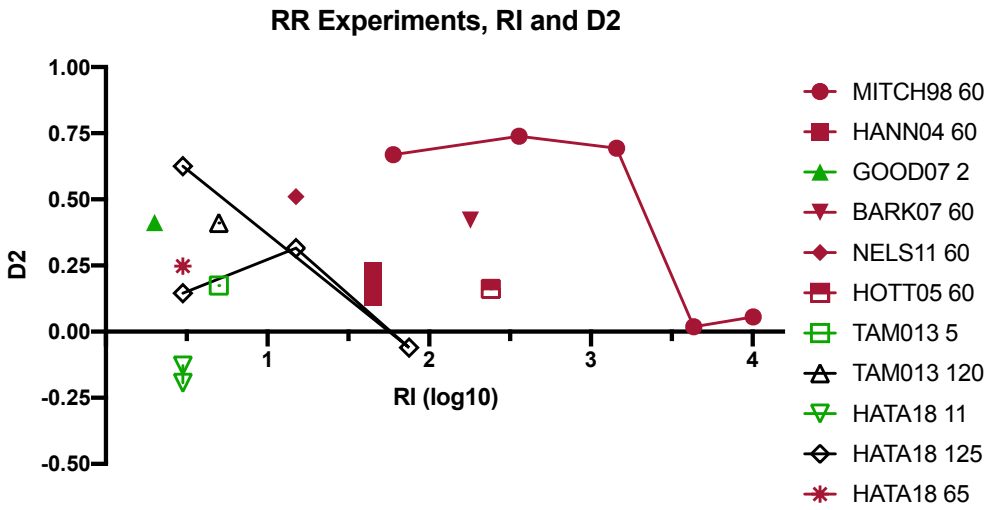


Figure 6.2: Comparison between the 2-sample RR studies, *log10* of RI is on the x- and D2 on the y-axis. Data were divided into three, colour coded, groups based on the ISI: >60 min in green, 60 min in red and 60 min < in black. Number after the study shorthand in the legend specifies the ISI (minutes).

should result in reduction of preference towards the older stimulus Q, hence D2 should be reduced. Here, no relationship is evident and inferential test confirms that observation, r = -0.028, *95% CI* r = [-0.476, 0.432], p = 0.91, BF_{01} = 3.503.

Analysis indicates that, when taken together, past 2-sample studies do not indicate a clear relationship between the sample temporal separation (TR) and RI. Figure 6.3 presents the pattern of results when TR, RI, and D2 are put together. According to SOP, low TR (larger sample temporal separation) and shorter RIs should yield reliable RR discrimination, and observations fall into the lower left quadrant of Figure 6.3. The results are mixed with Hatakeyama et al. (2018) reporting contradicting results. On the other hand the short temporal separation between the samples and long RIs represented on the plot in the upper top quadrant of Figure 6.3 should not yield reliable D2. Here, the results of Mitchell and Laiacona (1998) appear to be inconsistent with the prediction of SOP.

Taken together, the summarised evidence does not provide a robust sup-

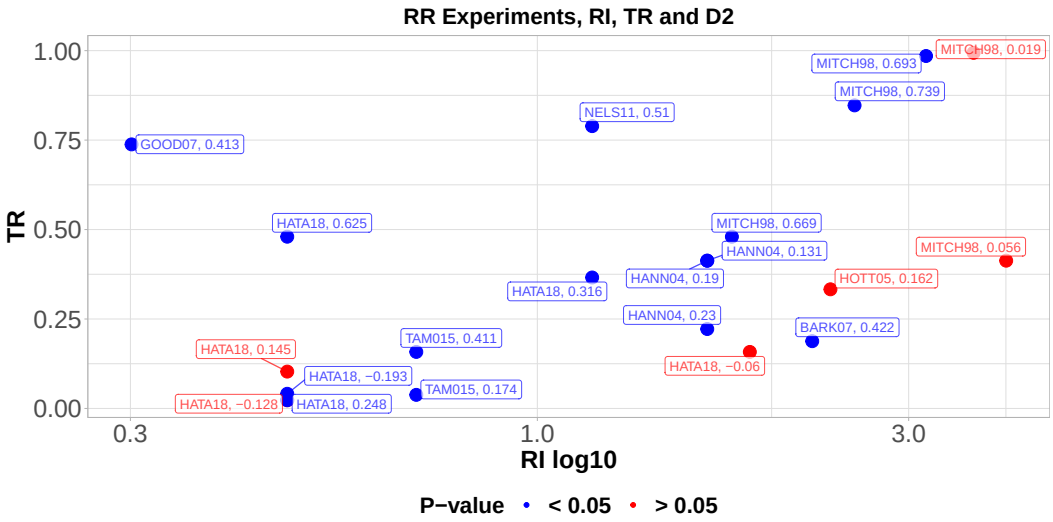


Figure 6.3: Comparison between selected, 2-sample, RR experiments with the duration of RI (*log10*) on the x- and TR on the y-axis. Each experiment is labelled with a shorthand code, and D2 reported or calculated for the study, colour indicates whether the results were reliable, in case where the D2 was not reported the significance reflects the reported statistical test.

port for the SGP account of RR. The SOP predicts that the D2 in RR should be the most robust when the RI is short and the separation between the samples is longer (lower left quadrant in Figure 6.3), the evidence here confirms that prediction, albeit Hatakeyama et al. (2018) reported contradicting results across a series of experiments the authors have conducted. The past results also indicate that when the RI is relatively short and sample phases are presented in closer temporal proximity (upper left quadrant) the temporal discrimination is still reliable. Furthermore, longer temporal distance between the samples can enable the reliable RR effects even when the RI is longer as the bulk of results in the lower right quadrant is significant. The most problematic results are those of Mitchell and Laiacona (1998) which demonstrated a significant RR even though the RI was long and sample separation was short.

A recent examination of SOP SGP as a mechanism behind the RR reported by Barker et al. (2019) used a 5-sample procedure which tested SOP predictions by manipulating the ISI and RIs. The authors demonstrated that even when the

temporal separation between the two sample phases was short the results were still reliable and there was no difference when compared to the condition in which separation was longer. However, when the two conditions were compared the evidence supporting lack of the difference was anecdotal - moderate and as such should be taken with caution. Nevertheless, Barker et al. (2019) adds to the list of concerns around the applicability of SGP to RR.

In this chapter, I will explore the temporal influence on the SGP and RGP. Furthermore, I will also test the two associative accounts of RR proposed by McLaren (personal communication) and Sanderson (2016) (Experiment 7, p. 178, and Experiment 8, p. 191). Because the RR is also affected by the sample separation manipulation, effects of ISI extension are also to be tested in Experiment 9 (p. 201). In the last two Experiment 10 (p. 213) and Experiment 11 (p. 223) reported here, I will explore the predicted by the SOP temporal stability of associative and non-associative components of RR, OIP and OIC.

6.2 Experiment 6

6.2.1 Introduction

The influence of retention interval (RI) on the effects of recognition memory is a key difference between the one enabled by non-associative SGP and associative RGP. In the OIC procedure, the associations acquired are time independent, that is, they do not change due to time, but can only be extinguished. However, in the example of the RR procedure, enabled by the SGP, the extension of RI leads to a reduction of preferential exploration of stimuli which have been presented earlier in the sample.

This, in line with SOP, is explained by the decay of representational elements from the secondary activity to the inactive state. Given the sufficient time, the elements can fully return to the inactive state and the representation in its entirety is available for primary activation during the subsequent test. All other things being equal, both stimuli representations can be activated with the same intensity a *null* preference. An SOP simulation demonstrating the effects of RI on recognition memory in the RR procedure is presented in Figure 6.4. It demonstrates that as RI gets longer the difference between the $A1$ activation of both representations diminishes; the reduction indicates that, when RI gets longer, the preference between the two stimuli should approach *null*.

The effects of RR and how its effects can be influenced by an extension of RI were demonstrated by Mitchell and Laiacona (1998). These authors first presented rats with two objects QQ, then after a short ISI two other objects PP were given to rats for a free exploration, after an RI of either 1, 6, 24, 72 or 168 hours a copy of each object PQ were presented for test. Animals demonstrated a reliable preference in exploration of the less recent object Q after 24 h but not at longer RIs. Furthermore, Tam et al. (2013) demonstrated that an extension of ISI between the samples leads to a better discrimination between the two preexposed stimuli. This effect is also predicted by the SOP's SGP account of RR where the amount of representational elements of Q which had decayed into the Inactive state. The more elements decayed, the more exploration of the stimulus that matches the representation. In other words, the earlier presented stimulus will have more time to be partially or fully forgotten, whereas the more recent one will still be remembered. Hence, the forgotten stimulus will be explored more.

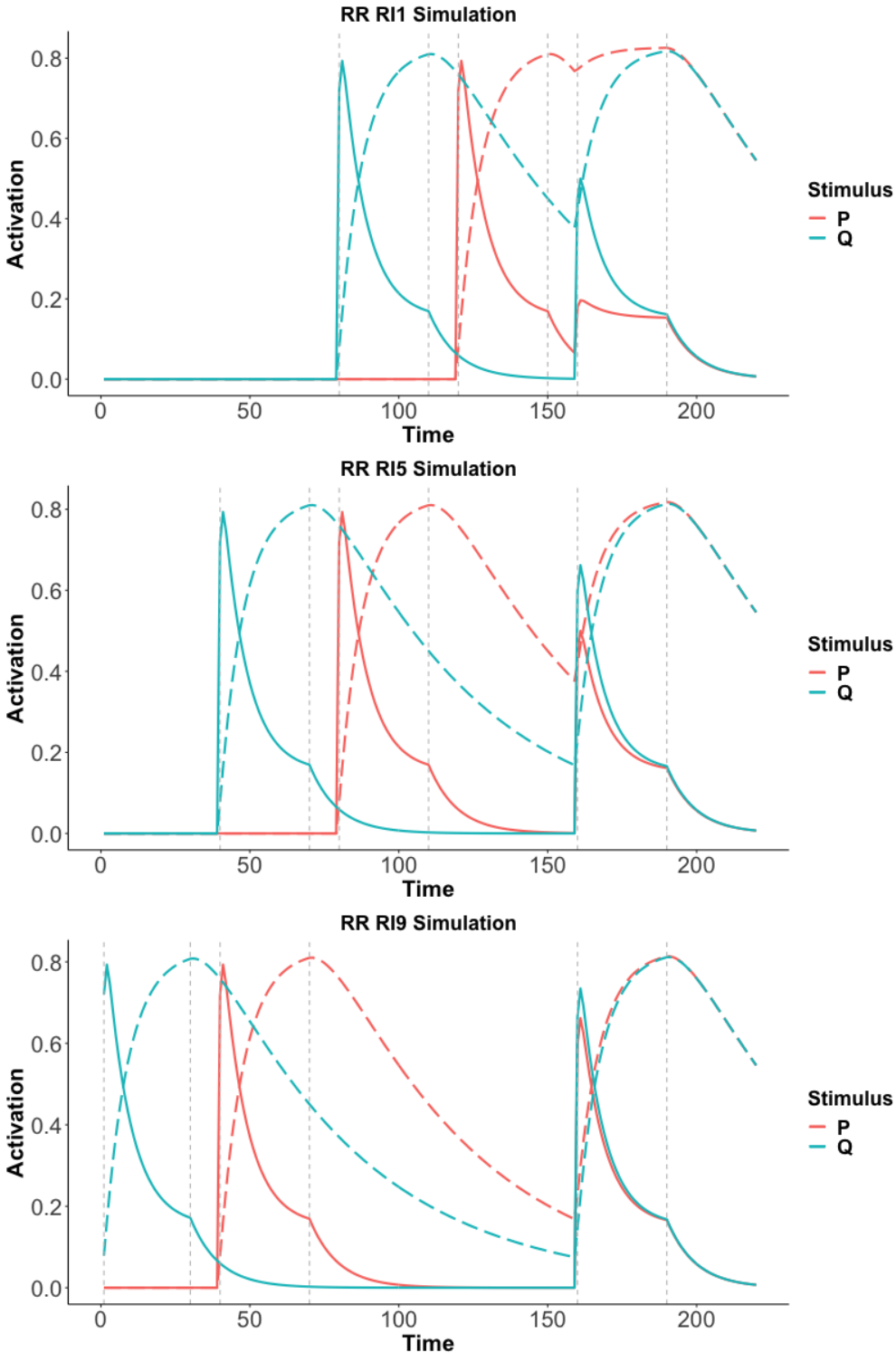

RR RI1 Simulation
Activation
0.0
0.2
0.4
0.6
0.8
0
50
100
150
200
Time
Stimulus
P
Q
RR RI5 Simulation
Activation
0.0
0.2
0.4
0.6
0.8
0
50
100
150
200
Time
Stimulus
P
Q
RR RI9 Simulation
Activation
0.0
0.2
0.4
0.6
0.8
0
50
100
150
200
Time
Stimulus
P
Q

Figure 6.4: Results from a SOP simulation in a RR procedure with time in moments on the x- and activation on the y-axis. $A1$ activation is plotted in solid and $A2$ in dashed lines for Q (blue) and P (red) stimuli representations. Each stimuli presentation lasted 30 moments and onsets and offsets of each phase are marked with grey dotted vertical lines. The real times were converted to moments as 1 s = 10 moments and so the RR with 1 s RI (top panel) had a S1 phase lasting from 80th to 110th moment, followed by 10 moments ISI. S2 lasted from 120th to 150th moment and was followed with 10 moments RI and test phase between 160th and 190th moments. In the RI 5s (middle) and RI 9s (bottom) the test phase was fixed between 160th and 190th moment, but the duration of RI increased to 50 and 90 moments effectively shifting the onsets of both of the sample phases. All parameters were set as: $p1$ = 0.8, $pd1$ = 0.1, $pd2$ = 0.02.

On the other hand, the effects of OIP, which are enabled by the RGP mechanism, will not be influenced by the temporal decay. This is because, in the case of associative priming, the exploration time depends on the stimulus-stimulus signalling: the context (spatial location) primes the representation of the stimulus and, if prediction matches the environment, the external stimulus will be explored less than when the prediction is at odds with the real world state. A critical difference between the SGP and RGP enabled effects for this experiment demonstrated with RR and OIP procedures, is that the former depends on time: its effects are short lived. The latter does not undergo such a process and the enabling association must be extinguished to reduce in magnitude. It is then hypothesised that the effects of RR will be most robust at the shortest RI, but effects will be reduced at a longer RIs. On the other hand, the effects of OIP will maintain its magnitude at all three RIs. Because the commonly used SOR procedure can be accounted for by both: associative RGP and non-associative SGP mechanisms, hence its temporal stability cannot be clearly predicted. If the observed effects are presented and reliable at all three RIs, then the results would yield support to the RGP account. However, if a temporal decay is observed, the case for SGP involvement in the SOR will be

strengthened.

The experimental hypothesis here is that an expected effects of SGP in RR will manifest itself with significant and positive discrimination D2 at the shortest RI. The magnitude of D2 will reduce as a function of RI extension. Effects of RGP should be manifested with significant and positive discrimination in OIP but this effect should not reduce as RI get longer. As SOR is hypothesised to be enabled by both mechanisms, its pattern may reduce with RI extension, but not to the same extent as in RR.

6.2.2 Methods

6.2.2.1 Participants

Identical to that in Experiment 1 with the exception of sample size: 19 female and 7 male University of Nottingham students and staff participated. Their *M* age was 22.5 years (*SD* = 4.02, range 18-32).

6.2.2.2 Apparatus

Identical to that in Experiment 1 with the exception of the sampling frequency which was 300 Hz and use of chin rest which was used to fix the distance from the screen at 50-55 cm.

6.2.2.3 Stimuli

Identical to that in Experiment 3.

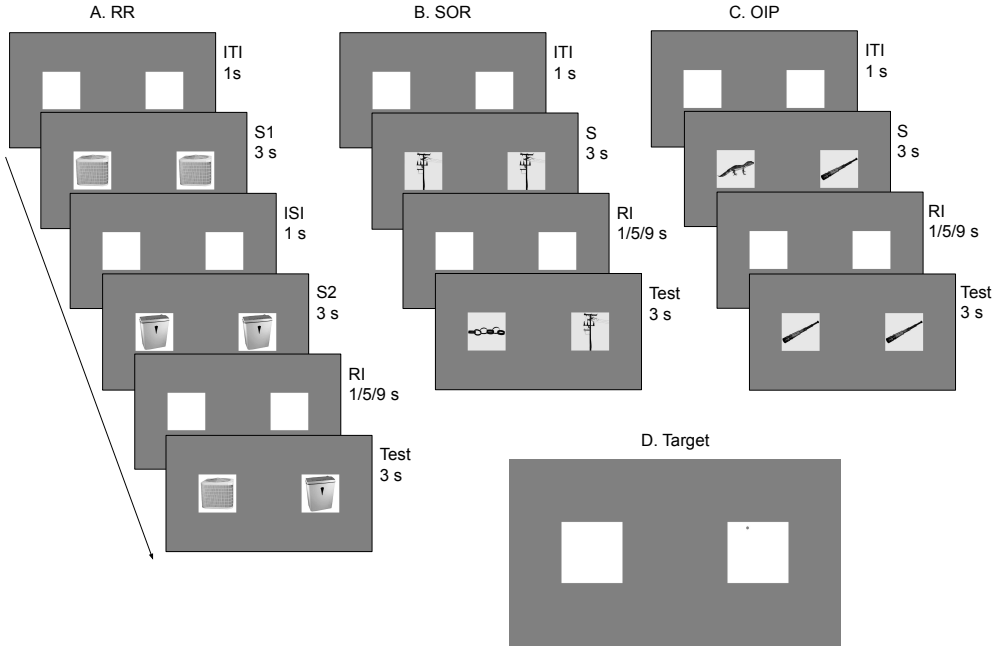


Figure 6.5: Experiment 6, sequence demonstration. **Panel A** - RR: during S1 a pair of stimuli QQ was presented, then after the ISI a second pair PP was presented for free exploration. After the RI both Q and P were presented for Test. **Panel B** - SOR: sample phase consisted of PP presentation, followed by RI and test presentation with novel stimulus Q and preexposed P. **Panel C** - OIP: in the sample phase two novel stimuli PR were presented, then after the RI, two copies of a preexposed stimulus were presented bilaterally PP'. **Panel D** - Target: on some trials, during the ITI, ISI, or RI a grey dot appeared in the area of two polygons which overlapped with the location of stimuli.

6.2.2.4 Procedure

Calibration and instructions were as in Experiment 3. Experimental design followed that of Experiment 4 with an exception of RI which has been set at three levels of 1, 5 or 9 s. Summary of design is presented in Table 6.1 and visualisation of the sequences is shown in Figure 6.5.

Target stimulus was a grey dot (12 px in diameter, PsychoPy colour space RGB: 0, 0, 0), it was presented only during the RI, and its onset was determined by the length of the RI period. For 1 s RI the onset was at the beginning of RI and lasted for 1 s, for 5 s RI the onset was random and between 0 and 4s and lasted till

Table 6.1: Design of the Experiment 6. In three Conditions: SOR, OIP and RR participants were presented with either one (SOR and OIP) or two (RR) sample phases (1 s ISI), each presentation lasted for 3 s. In the OIP's sample two stimuli are presented (PR) of which a copy of P, P', is later presented in a novel location. In RR the first sample consisted of presentation of a pair of stimuli QQ then the second sample contained two stimuli PP on test copies of both Q and P were displayed concurrently. In SOR participants were first shown sample stimuli PP, then at test novel stimulus Q was shown with the pre-exposed P. RI between sample and test phases was set at three levels of either 1, 5 or 9 s.

Condition	Sample	RI	Test
SOR	PP		PQ
OIP	PR	1 / 5 / 9s	PP'
RR	$QQ \xrightarrow{1s} PP$		PQ

the end of RI, the same was done for 9 s RI with random onset between 0 and 7 s. Target lateralisation was selected randomly, and the precise location of the target was determined by adding a jitter in both x- and y-axis. The jitter, j, was randomly drawn from an uniform distribution as $x_j, y_j \sim \mathcal{U}(-125, 125)$ by the presentation software.

6.2.2.5 Data Treatment

Catch trials were removed from the analysis (12.5% of all trials). The main dependent variables were $D2_{adj}$ and raw dwell time as in Experiment 3. The *A'* could not be calculated because the target detection data were incomplete due to a programming error.

6.2.3 Results

6.2.3.1 Sample Dwell

Data of interest here comes from the sample phases of each trial and is summarised in Figure 6.6, panel A. The sample dwell was analysed with repeated measures

ANOVA with factors of Sample Phase, consisting of levels SOR S1, OIP S1, RR S1 and RR S2. The main effect was significant: $F(3, 75) = 3.905$, $p = 0.01$, $\eta_p^2 = 0.135$, *95% CI* $\eta_p^2 = [0.007, 0.256]$, $BF_{10} = 3.424$. The *post hoc* *t*-test (Holm) yielded a significant difference between the OIP S1 and RR S1, $t(25) = 3.119$, $p = 0.015$, $d = 0.612$, $BF_{10,U} = 8.853$. None of the other comparisons between OIP S1, RR S1, RR S2 or SOR S1 were significant (smallest $p = 0.127$, $BF_{01,U} = [0.573, 3.458]$). Elevated dwell time in OIP could potentially be caused by the presentation of two novel stimuli in that phase, whereas in the other sample phase the two stimuli presented were novel but identical.

6.2.3.2 Test Dwell

The DV of adjusted $D2_{adj}$ was entered into a 3 x 3 repeated measures ANOVA, with factors of Condition and RI. Data of interest are summarised in Figure 6.6, panel B. There was a significant main effect of Condition, $F(2, 50) = 2.355$, $p < 0.001$, $\eta_p^2 = 0.342$, *95% CI* $\eta_p^2 = [0, 0.232]$, $BF_{10} = 204084.913$ (*Error* = 1.11%). Second main effect was not significant $F(2, 50) = 2.355$, $p = 0.105$, $BF_{01} = 3.389$ neither was the interaction, $F(4, 100) = 1.603$, $p = 0.179$, $BF_{excl} = 4.685$. *Post hoc* analysis of the Condition levels yielded a significant differences between the SOR and OIP, $t(25) = 4.717$, $p < 0.001$ (Holm), $d = 0.925$, $BF_{10,U} = 23134.14$, as well as between the SOR and RR, $t(25) = 4.042$, $p < 0.001$, $d = 0.793$, $BF_{10,U} = 741.366$ while the OIP and RR difference was not reliable ($p = 0.503$, $BF_{01,U} = 5.971$). The effects of SOR observed in the analysis were of much larger magnitude than those of RR and OIP, which was reflected in the significant main effect of Condition. When a one-way model was run only on RR data at three RIs the main effect was significant, $F(2,$

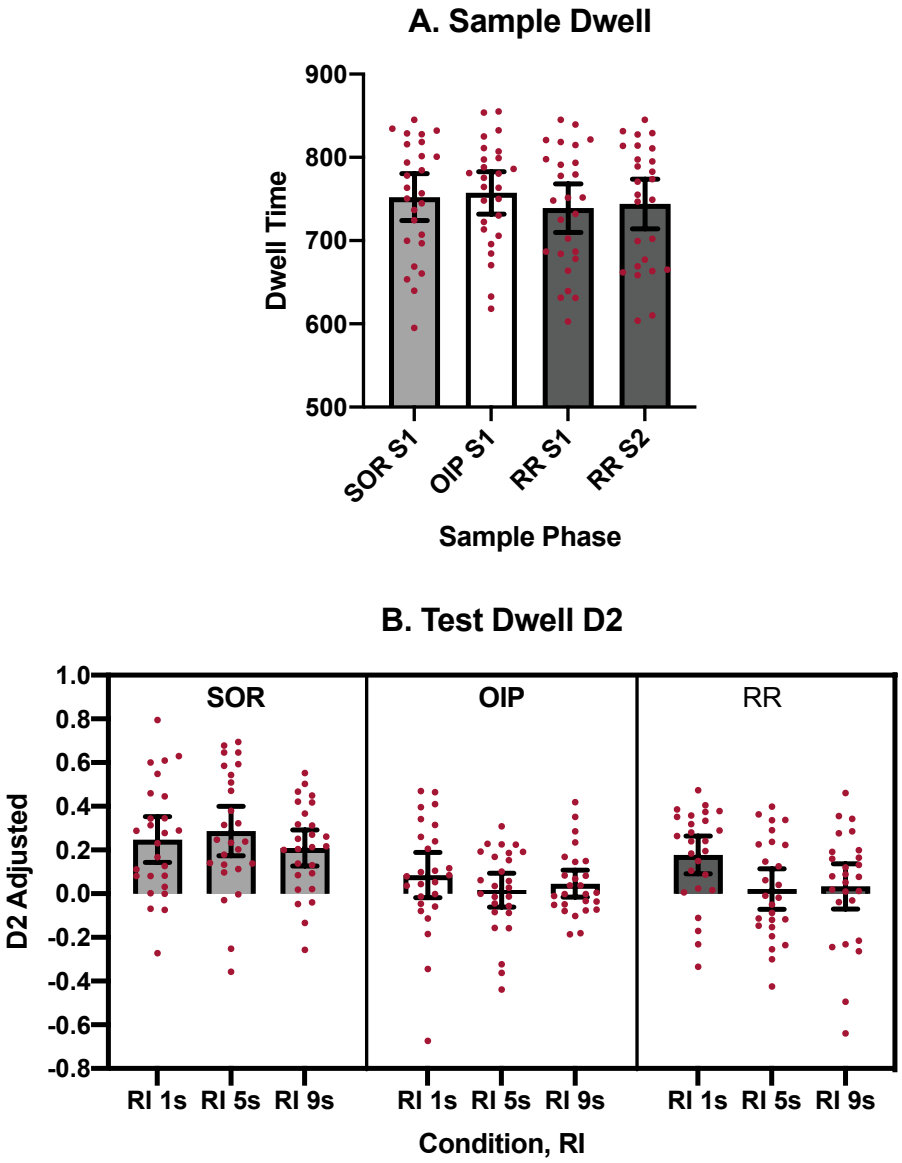


Figure 6.6: Experiment 6, **Panel A**, sample dwell for SOR, OIP and RR phases. Data presented is for the entire duration of a phase summed from both ROIs. Mean presented with 95% CI of the mean and subject-level means plotted as points. Sample phase on the x- and dwell time (units of eye tracker samples at 300Hz) on the y-axis. **Panel B**, Adjusted $D2_{adj}$ values for three experimental conditions, each with three RI levels. Means plotted with 95% CI of the mean and individual observations as points.

50) = 3.873, p = 0.028, η_p^2 = 0.133, *95% CI* η_p^2 = [0, 0.291], BF_{10} = 2.932. Post hoc test demonstrated significant effect of RR discrimination on RI 1s, $t(25)$ = 4.244, $p < 0.001$, d = 0.832, *95% CI* = [0.45, 1.201], BF_{10} = 111.729. No significant discrimination was observed at other RIs, smallest p = 0.095, BF_{01} = 4.338 and 3.954. Same one-way analysis performed for OIP was non significant; main effect of RI: $F(2, 50) = 0.717$, p = 0.493, BF_{01} = 4.759.

6.2.4 Discussion

A significant difference between the effects of novelty were observed when contrasted with OIP and RR. Although, the pattern of data in the RR does suggest a, hypothesised, short-lived effect of recency, the lack of significant interaction, supported by moderate evidence, does not allow for the effects of SGP in RR and RGP in OIP to be investigated further. When separate statistical models were built for each condition, the RR was only evident at the shortest RI and there was no effect in OIP. The hypothesised involvement of SGP in RR finds support in the data, an extension of RI eliminated discrimination of recency. Involvement of RGP in OIP could not be conclusively demonstrated nor falsified as evidence has not reached strong level. However, in the SOR a robust discrimination was observed on all RIs; an effect akin to RGP, which at least partly, enables the novelty discrimination.

Lack of OIP effects is contrasting with the effects of SOR. The data suggest that the effects of novelty are of greater magnitude than those of recency, which can be attributed to a summation of SGP and RGP effects. Therefore, it can be assumed that the RGP effects are present and experimentally inductable in humans, however the OIP procedure does not provide a sensitive test. In the OIP procedure,

the stimulus pair PR is first presented, then a pair PP' is presented on the left and right side of the screen. However, only the left and right locations are used and as such the manipulation of the location employed here has not led to learning. Perhaps because the participants could have predicted that a stimulus can appear in either of those two locations. It is also possible, that presenting a copy of P in novel location was not sufficient to disrupt the cognitive map formed during the sample.

Obtained here effects of temporal decay in the RR stand in contrast with the temporal stability of those observed by Mitchell and Laiacona (1998). However, it must be noted, that the authors employed different parameters in their experiments and a direct comparison is not fully justified. Here, it has been observed that the effects of preferential exploration of older stimuli are short-lived and decay quickly suggesting an involvement of trace-decay mechanism, SGP. Nevertheless, the effects of Mitchell and Laiacona (1998) have been obtained and were reliable at a very long RI, which begs the question whether, given certain conditions, a process mimicking the SGP-RR can occur and enable the RR-like effects at a much longer RIs. Two hypothesised solutions, both within the theoretical scope of SOP, have been put forward to account for the effect. The following two Experiments (7 and 8) aim to experimentally test this accounts.

6.3 Experiment 7

6.3.1 Introduction

The Mitchell and Laiacona (1998) investigation of RR demonstrated that the effect is time-dependent: extension of RI does eventually lead to an elimination of

preference in exploration. An influence of RI is well predicted by the SOP, the preference towards a stimulus is enabled by the differential number of representational elements available for $A1$ recruitment, and longer the time, the more elements will eventually become available. Given a long enough RI, all elements from both representations will reach Inactive state, this would allow for both stimuli representations to be activated in the same way leading to *null* preference. However, the results reported by Mitchell and Laiacona (1998) suggest that a full decay lasts between 24 and 72 hours which, in terms of SOP theory of SGP, is a problematic time duration (Robinson & Bonardi, 2015; Sanderson, 2016). The underpinning RR, SGP, mechanism is a process by which, following an exposure to a stimulus, its representation becomes activated. The activation becomes briefly focal, $A1$, transferring into a secondary state, $A2$. From that, after the stimulus is removed, it decays into the Inactive. The process of activating and decaying is time-dependent, however, assuming that the SGP is the main driving force behind the RR effects, the duration at which the Mitchell and Laiacona (1998) observed their effects is problematic. The SGP does not encompass a provision that would allow for an extension or slowing down of decay from $A2$ to I once the stimulus is removed. In summary, the observed 24h RI effects of RR (Mitchell & Laiacona, 1998) are problematic for SOP due to a short-term characteristic of SGP-based priming. Alternative, SOP-based, associative explanations of long-lasting RR have been put forward: one, in an informal conversation, by McLaren (personal communication) and second by Sanderson (2016). The following two experiments aim to test those accounts. Being associative in nature, based on theoretical assumptions of Wagner's RGP (Wagner, 1976) which holds that established associations are resistant to time-dependent decay, both

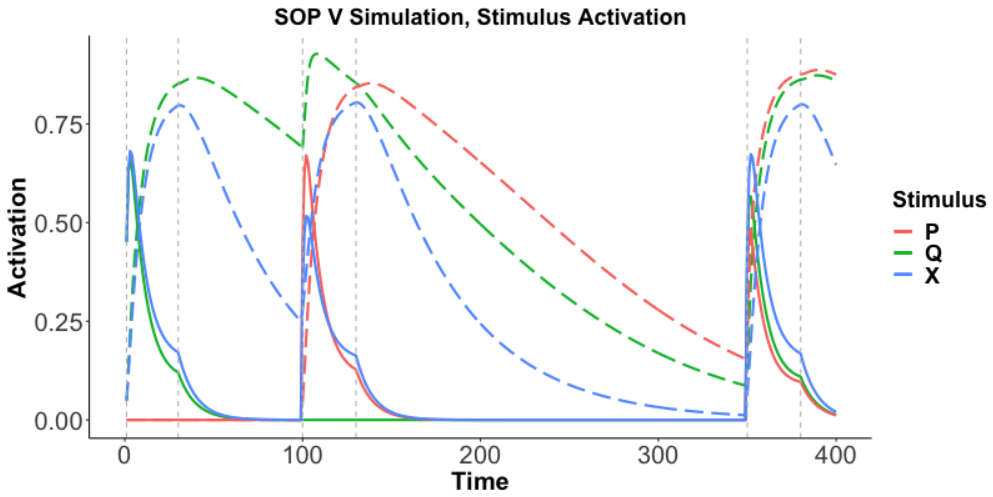


Figure 6.7: SOP simulation of a RR experiment with time in moments on x- and activation of y-axis. Simulation involved three phases: S1 (1 - 30), S2 (100 - 130) and test (350 - 380). Solid lines represent $A1$ and dashed $A2$ activation for Q (green), P (red) and latent context X (blue). Parameters were set as $p1$ = 0.5, $pd1$ = 0.1, $pd2$ = 0.02.

hypotheses should be able to explain the long-lasting effects of RR observed by Mitchell and Laiacona (1998).

The former associative account of RR attributed to McLaren (not published), holds that during the sample phase the stimuli Q and P enter into an association with the context. This occurs in the absence of explicit context manipulation by experimenters, but occurs nevertheless as the context here consists of all environmental features that cooccur with experimental events (B. Robertson, Eacott, & Easton, 2015). The McLaren's account (illustrated with the simulation in Figures 6.7, 6.8 and 6.9) of RR holds, in line with the SOP's RGP, that during the S1, where stimulus Q is presented with latent context X, the concurrent $A1$ activation of both representations would result in an excitatory association between the two representations. Figure 6.7 shows activation of the representation of context X and stimulus Q, here S1 lasts for 30 moments and begins at time 1.

When, during S2, an animal is reintroduced to the same context X and

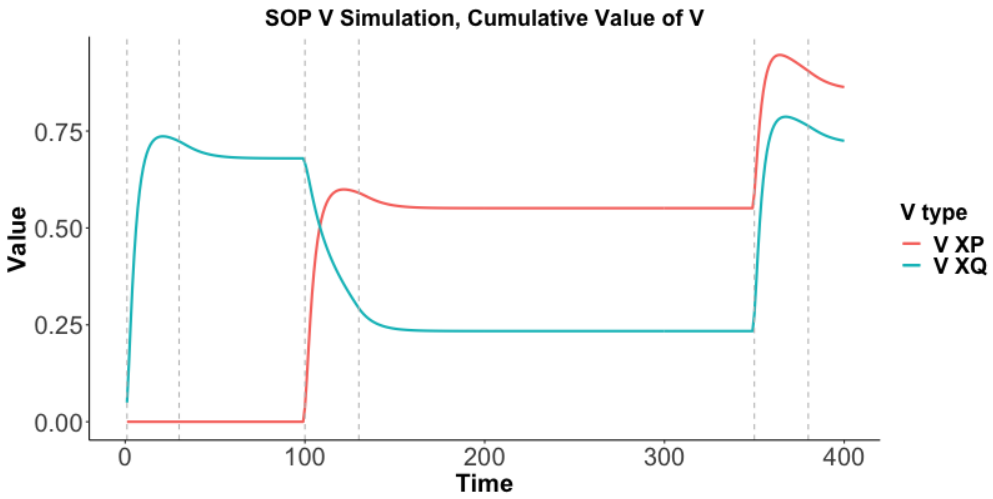


Figure 6.8: SOP simulation of A RR experiment with time in moments on x- and cumulative value of associative strength V on y-axis. S1, S2 and test phases as per Figure 6.7. Associative strength between context X and stimulus P is in red and between X and Q in blue lines. Value at each time point is cumulative, resulting from the difference between excitatory and inhibitory associative strengths. Activation parameters as per Figure 6.7 and $L^+ = 0.25$ and $L^- = 0.05$

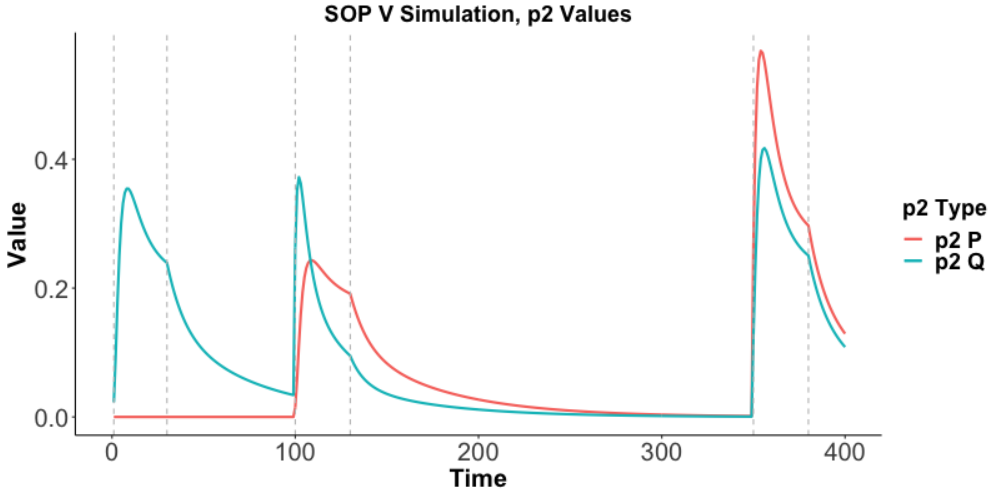


Figure 6.9: SOP simulation of a RR experiment with time in moments on x- and momentary value of priming parameter $p2$ on y-axis. Associative $p2$ value resulting from the $V_{X:P}$ association is in red and $p2$ from $V_{X:Q}$ in blue line. Corresponding activation are in Figure 6.7 and associative strength enabling the $p2$s in Figure 6.8. Parameters were set as $w_1 = 1$, $w_2 = 0.2$.

novel stimulus P a concurrent $A1$ activation of X and P's representations contributes to an excitatory association between the two. Figure 6.8 demonstrates this process following from the activation patterns presented in Figure 6.7. During S1, the concurrent activation of X and Q results in an increase in associative strength between the two representations (blue line, time between 1 and 30), whereas the association between X and P remains at 0. The associative strength between X and Q remains stable over the ISI. During S2, the associative strength between X and P (red line, 100 - 130 moment) increases, at the same time the value of V between X and Q reduces. The reduction comes from concurrent X's $A1$ and Q's $A2$ activation. Here, despite that Q is not presented during S2, its representation is primed because of the associative link forged during S1. Q's representation is primed according to the $p2$ parameter (Figure 6.9, blue line) which activates Q's elements directly to the $A2$. Following S2, the association between X and Q representations is lower than the one between X and P and both remain constant during the RI (Figure 6.9. Because of the difference, the context X is able to generate a stronger priming for P (Figure 6.9, red line at around 350th moment) than for Q (blue line) and consequently, stronger the priming the more of a given representation is able to be primed directly into $A2$ leaving less of elements of P to be primed into $A1$. Hence, the representation which can activate more elements into $A1$ will be explored more: $Q > P$. Although the results mirror those predicted by the SGP, as demonstrated by the constant value of V during the RI (Figure 6.8), the effects are resistant to time decay and the value of V is only mutable during the context presentation. This enables the discrimination to be present at much longer RIs and accounts for the results of Mitchell and Laiacona (1998) within the SOP theory.

To test the McLaren's account, which holds that the long-lasting effects of RR are due to the associative link between the context and experimental stimulus, participants took part in an experiment which involved two experimental conditions, SAME and DIFF, and each factor of RI set at three levels (1, 5 and 9 s). Both conditions involved a standard RR design, but each sample and test presentation involved a salient context stimulus presented alongside the experimental ones (Q, P). In the SAME Condition all three phases were presented with the same context X, whereas in the DIFF the sample phases involved context X which changed to a novel context Y during the test. According to McLaren's account, the association between the context enables the RR effects at longer RIs. It is then hypothesised that the effect of RR will be present in both conditions at the shortest RI. However, there will be a difference between the discrimination on longer RIs; D2 should be higher in SAME than in DIFF on RI 5 and/or 9 s.

6.3.2 Methods

6.3.2.1 Participants

Identical to that in Experiment 1 with the exception of sample size: 28 female and 6 male University of Nottingham students and staff participated. Their *M* age was 22.5 years (*SD* = 4.02, range 18-32). 21.47 years (*SD* = 6.765, range 18-57 years).

6.3.2.2 Apparatus

Identical to that in Experiment 1 with the exception of the sampling frequency which was 300 Hz and use of chin rest which was used to fix the distance from the screen at 50-55 cm.

Table 6.2: Experimental design for Experiment 8. In two Conditions (SAME and DIFF) participants were presented with an identical two sample phases (S1, S2) in which a stimulus, Q in S1 and P in S2, was accompanied by a salient context X. There was a 1 s ISI between the samples and RI between the S2 and test was set at three levels of either 1, 5 or 9 s. Two Conditions differed in their respective test presentations and in SAME Condition copies of P and Q were presented with the same context X, whereas in DIFF PQ pair was accompanied by a novel context Y.

Condition	S1	ISI	S2	RI	Test
SAME	XQ	1s	XP	1 / 5 / 9 s	XPQ
DIFF					YPQ

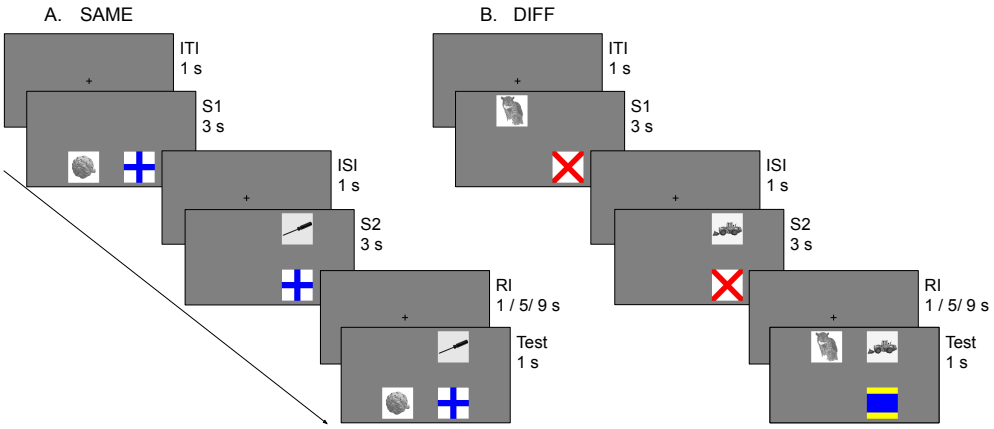


Figure 6.10: Experiment 7, demonstration of experimental sequences. **Sequence A** - SAME condition: each trial begun with a 1 s presentation of a fixation cross which was followed by a presentation of stimulus Q and context X lasting for 3 seconds. After an ISI of 1 s, a novel stimulus P was presented with the same context X, then after a RI of either 1, 5, or 9 s both PX were presented in context X. **Sequence B** - DIFF condition: only the Test phase was different from SAME condition, here instead of context X, a novel context Y was presented together with stimuli QP.

6.3.2.3 Stimuli

Identical to that used in Experiment 5.

6.3.2.4 Procedure

Calibration and cover taks were as in Experiment 4.

Experimental design is summarised in Table 6.2 and a demonstration of a sequences is presented in Figure 6.10. Each trial consisted of two phases: sample

and test and begun with a 1 s ITI. During the sample phase, there were two 3 s presentations of stimuli divided by 1 s ISI; S1 and S2. Then, after an RI which was set at three levels of either 1, 5, or 9 s, the test stimuli were displayed for 3 s. Participants were given an opportunity to take a break after completion of 18th, 36th, 54th, 72nd and 90th trials. There were two types of experimental trials, SAME and DIFF which differed in their test phases. In both Conditions, during the sample phase stimuli Q then P were presented in their respective phases together with a context stimulus X (XQ then XP). After the RI both Q and P were presented again in their original locations, in SAME Condition the context remained the same as in sample phase (XQP) but in DIFF Condition a novel context has been presented (YQP). Each Condition consisted of 48 experimental trials, with 16 trials for each RI, and 6 target trials, with 2 per each RI, resulting in a total of 108 trials (96 experimental trials + 12 targets). For the target trials, either Q or P were replaced with a stimulus from the clothing set. Participants received these trial types in a pseudo-random order, separated by a 1 s intertrial interval. A fixation cross (black, Arial, 100 px) was displayed during all ISI, RI, and ITIs. All remaining details were as in Experiment 4.

6.3.2.5 Data Treatment

Participants responded accurately to the targets with *M* = 1.823, *SD* = 1.749 false alarms and *M* = 1.294, *SD* = 1.219 misses. The non-parametric sensitivity metric *A'* was high with *M* = 0.971, *SD* = 0.025.

Target trials were removed from the analysis (12.5% of all trials). The DVs were calculated as in Experiment 4.

6.3.3 Results

6.3.3.1 Sample Dwell

Summary of the data collected during the sample phase of each trial is presented in Figure 6.11, panel A. Data were entered into a 2 (Condition) $\times$ 2 (Phase) repeated measures ANOVA. Inspection of the data indicates no difference between the Conditions and this description is supported by the inferential test with the main effect of Condition being not significant, $F(1, 33) = 0.645$, $p = 0.428$, $BF_{01} = 4.521$ (*Error* = 2.04%). There was a significant main effect of Sample Phase, $F(1, 33) = 48.235$, $p < 0.001$, $\eta_p^2 = 0.594$, *95% CI* $\eta_p^2 = [0.35, 0.72]$, $BF_{10} = 3.357 \times 10^9$. Interaction was not significant $p = 0.362$, $BF_{excl} = 3.306$. *Post hoc* analysis demonstrated a significant difference between the dwell time during the S1 and S2, $t(33) = -6.945$, $p < 0.001$ (Holm), $d = -1.919$, $BF_{10,U} = 5.124 \times 10^8$. A more complex model, with addition of main effect of RI, levels at 1, 5 and 9 s, has not yielded a significant result for that main effect, $F(2, 66) = 0.727$, $p = 0.487$, $BF_{01} = 15.453$, nor it resulted in significant interactions; smallest $p = 0.303$.

Patterns of increased dwell at S2 could stem from the fact that context stimuli were exposed for a second time at S2 where its representation was already primed by the presentation during S1. What follows is that during S2 less of the dwell time was given to the context and participants could look more at the experimental stimuli. A supplementary analysis was run to test this assumptions and summary data are presented in Figure 6.11, panel B. However, the analysis have resulted in the main effect of Sample Phase remaining significant; $F(1, 33) = 6.591$, $p = 0.015$, $\eta_p^2 = 0.166$, *95% CI* $\eta_p^2 = [0.006, 0.377]$, and supported by moderate

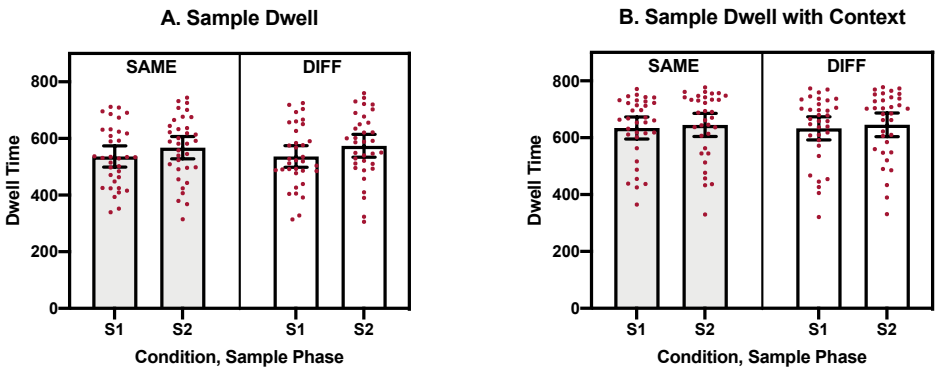


Figure 6.11: Experiment 7, data from sample phase; **panel A** presents dwell time to experimental stimuli (QQ and PP respectively for S1 and S2) and **panel B** presents the sample dwell to stimuli and context at each of the sample phases. Condition and Sample Phase are on x- and dwell time on y-axis. Data comes from the entire duration of the Sample Phase with means presented with *95% CI* of the mean and individual observations as points.

evidence, BF_{10} = 8.104, *Error* = 6.111%.

Overall, the dwell time in the second sample phase (S2) was increased when compared to the first sample (S1), the difference is supported by moderate evidence and does not result from a decrease in dwell time to the context at S2. However, this pattern of behaviour was the same in both Conditions which did not differ in design until the test phase.

6.3.3.2 Test Dwell

The $D2_{adj}$ data calculated from the test dwell were of main interest here and were entered into a 2 (Condition) $\times$ 3 (RI) repeated measures ANOVA. Summary of the data is presented in Figure 6.12, panels A and B, where the same data are plotted twice for clarity. The main effect of Condition was not significant, $F(1, 33) = 1.857$, $p = 0.182$, $BF_{01} = 3.914$. There was a significant main effect of RI, $F(1.669, 55.071) = 8.292$, $p = 0.001$, $\eta_p^2 = 0.201$, *95% CI* $\eta_p^2 = [0.036, 0.361]$, $BF_{10} = 590.459$. Critical to the hypothesis was the Condition $\times$ RI interaction, however it has not

reached significance, $F(2, 66) = 0.729$, $p = 0.486$, $BF_{excl} = 6.405$. Bonferroni corrected *post hoc* test demonstrated significant difference between the $D2_{adj}$ at RI of 1 s and 5 s, $t(33) = 3.254$, $p = 0.005$, $d = 0.558$, $BF_{10,U} = 43.621$, and between 1 s and 9 s, $t(33) = 3.747$, $p < 0.001$, $d = 0.643$, $BF_{01,U} = 29.596$, but not between $D2_{adj}$ at 5 s and 9 s, $p = 1$, $BF_{01,U} = 6.237$.

In summary, there was a robust effect of RI on the discrimination ratio $D2_{adj}$, where the preference towards the less recent stimulus Q decreased in favour of more recent P. The effect was well supported by decisive evidence. Critically, the inferential statistics could not demonstrate a significant difference between $D2_{adj}$ at the longest RI as the interaction was not reliable. with moderate evidence in support of the $\mathcal{H}_0$ model.

6.3.4 Discussion

There was a significant effect of RI on $D2_{adj}$, where the recency discrimination reduced as RI got longer. However, critical for the McLaren's RGP account of RR, the hypothesised difference between the two conditions at the longest RI, in particular the larger $D2_{adj}$ in the SAME condition, could not be conclusively verified. The account that the long-term effects observed in Mitchell and Laiacona (1998) were due to an extinction of XQ association during the XP event could not be conclusively falsified nor confirmed. Numerical differences in the test data indicate for the $D2_{adj}$ to be elevated in SAME on RI of 1 and, to a lesser extent, 5 s. Observed result is in line with the hypothesis, however could not be reliably detected with an inferential test. This can be attributed to a relatively short presentation of stimuli which could not have been adequate to establish a robust association (Richmond

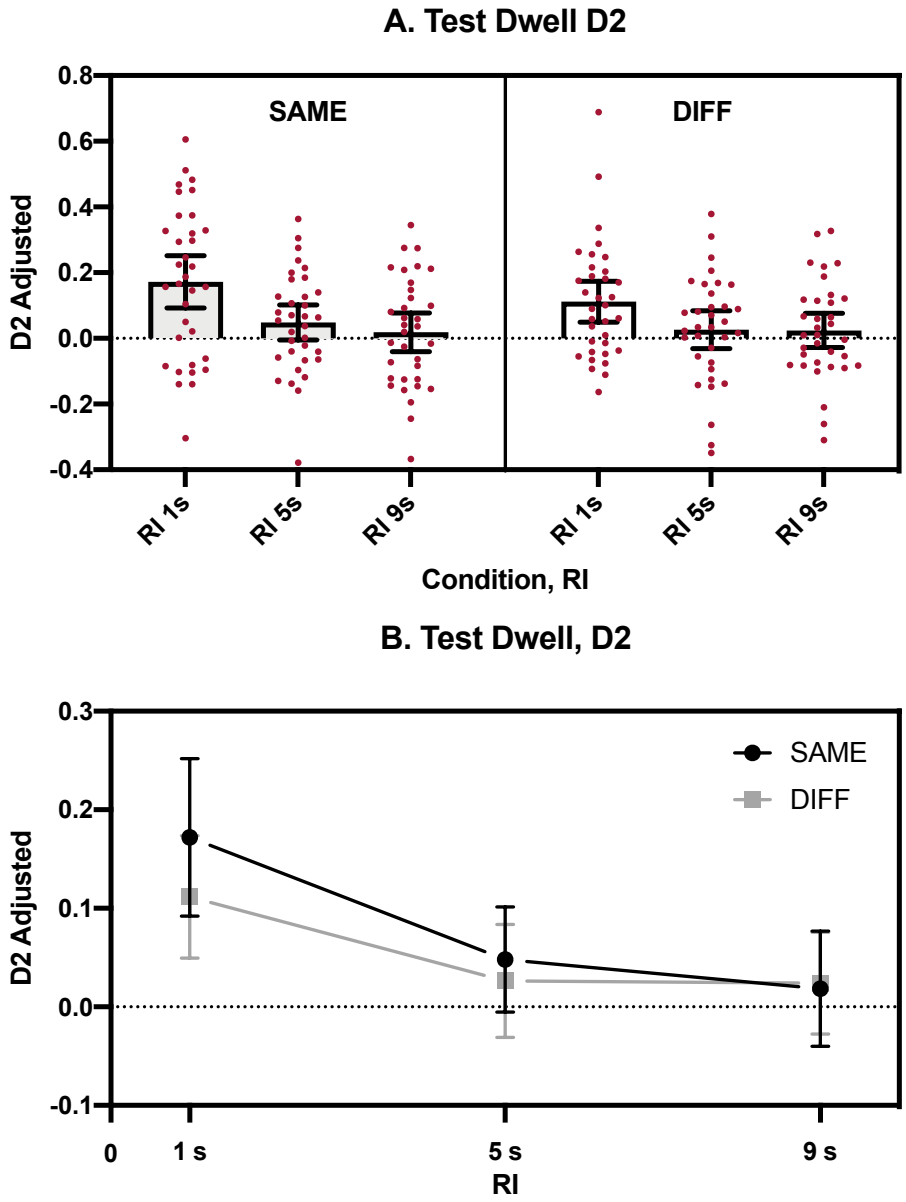


Figure 6.12: Experiment 7, data from the test phase in the Condition $\times$ RI analysis with DV of adjusted $D2_{adj}$. Both panels present the same data, but in panel B individual observations are not plotted for clarity. In **panel A**, Condition and RIs are plotted on x- and $D2_{adj}$ on y-axis. Means are plotted with *95% CI* of the mean and individual observations as points. In **panel B** RIs are presented on the x- and adjusted $D2_{adj}$ on the y-axis, data from SAME Condition are plotted in black and from DIFF in grey.

et al., 2004). Furthermore, excitatory associations strengthen with much less trials than inhibitory. In consequence, extinction of XQ association would require a lot of trials where Q is not presented with X. This is formally reflected with values of excitatory and inhibitory learning constants: $L^{+} = 5 * L^{-}$ (see page 16 for full formula). It is also possible that the XQ association could have been interfered with XP presentation which has interfered with memory consolidation of the first sample (E. M. Robertson, 2012; Seitz et al., 2005). The experiment has an important shortcoming as an alternative explanation for the observed, yet not significant, difference between the conditions at the shortest RI cannot be ruled out. It is possible that when pairs XQ and XP were displayed during the sample, representations of both stimuli included parts of X; a certain proportion of features was dependent on the context (Vogel, Ponce, & Wagner, 2017). This is in line with generalisation decrement, a perceptual effect by which CR to one stimulus incompletely transfers to an another because of similarity between the two. In terms of current experiment, this would manifest itself in a process where certain elements of representations of Q and P are dependent on context X; in other words X modified the perceptual features of both stimuli. At test when context X was kept unchanged (SAME), both representations could be primed. When context changed (DIFF) both representations would only partially match what is presented, consequently the remaining part of features would be able to be $A1$ activated. It is also possible, that the effects of RGP are difficult to be captured and do not survive the statistical test due to noise (Ameen-Ali et al., 2015) and this could be solved by an increased sample size or by an implementation of de-noising methods such as rejection of trials on which sample behaviour has not met a certain criterion, as in Sivakumaran et al. (2018).

However, there are important differences between the procedures used by Mitchell and Laiacona (1998) and the ones used here; these could have contributed to the inability to observe extinction of the XQ association.

6.4 Experiment 8

6.4.1 Introduction

In the previous experiment, I tested a SOP-derived account of long-lasting RR discrimination observed by Mitchell and Laiacona (1998). The data did not provide a clear support for the associative account suggested by McLaren (personal communication) as the results were inconclusive. Here, I will test an alternative account put forward by Sanderson (2016). Hippocampus, which has been implied in associative learning and memory, has also been demonstrated to be involved in RR (Barker & Warburton, 2011). Furthermore, performance in this task can be attributed to a process involving formation of a spatio-temporal memory episodes (DeVito & Eichenbaum, 2011; Barker et al., 2019). Whereas, it has been argued that SGP enables recency discrimination, Sanderson (2016) argues that involvement of hippocampus suggests an involvement of associative process and that it may be explained in terms of SOP's inhibitory associations between the sample stimuli. In a standard RR procedure, $Q \xrightarrow{ISI} P \xrightarrow{RI} QP$, both Q and P are associated with the experimental context, this allows both stimuli to be activated by the context on test and at a long RI (Mitchell & Laiacona, 1998). However, during the sample P presentation, part of Q's representation is in $A2$ activation, at the same time P is in $A1$. SOP predicts that when one stimulus is in $A1$ and the other in $A2$ (page 12) an

inhibitory associative link will be established. Because associative priming forces from multiple CSs which act on the same stimulus sum, then for Q the $p2$ priming from the context will be reduced by the negative $p2$ evoked by P, illustration of this representation in presented in Figure 6.13. What follows is that the context priming will be activating less of Q's elements $I \xrightarrow{p2} A2$, leaving more for $A1$ activation. This associative element of RR cannot be removed unless both P and Q are tested independently and to test involvement of SGP in an uncontaminated by RGP way Sanderson (2016) proposes a between-subject test in which Q's and P's exploration are tested in isolation.

Here I compare the proposed sequential paired procedure (SPP) with a RR used in this thesis. An addition of RI manipulation, set at three levels of 1, 5, and 9 s aims to compare results obtained from RR in previous experiments with SPP which could yield potentially better assessment of SGP. RR procedure follows the standard $QQ \xrightarrow{ISI} PP \xrightarrow{RI} QP$ and a SPP follows the sequence of stimuli presentation: $QQ \xrightarrow{ISI} PP \xrightarrow{RI} QQ \xrightarrow{ISI} UU \xrightarrow{ISI} VV \xrightarrow{RI} VV$. It is hypothesised that effects of RR obtained in previous experiments 6 and 7 will replicate in RR but also it is of interest to assess whether discrimination can be obtained with SPP.

6.4.2 Methods

6.4.2.1 Participants

Identical to that in Experiment 1 with the exception of sample size: 17 female and 5 male University of Nottingham students and staff participated. Their mean age was 20.5 years (*SD* = 3.6, range 18-35 years).

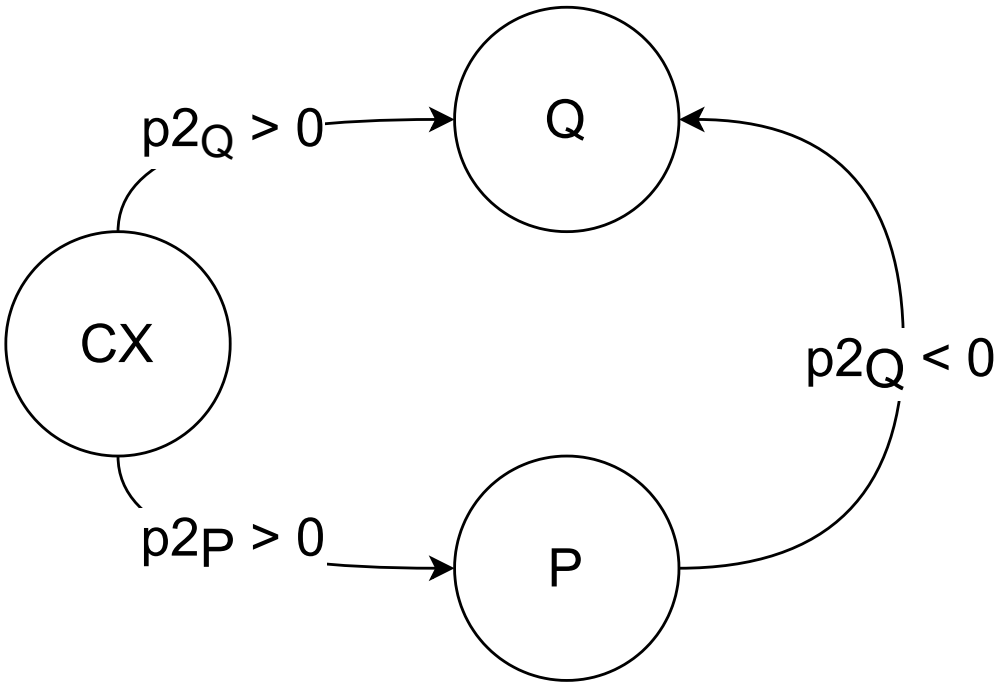


Figure 6.13: Experiment 8, demonstration of associative connections which enable RR at a long RI. Context representation is connected with both Q and P with an excitatory $p2$ links. This connections activate elements directly into $A2$: $I \xrightarrow{p2} A2$. However, P is connected with Q with an inhibitory $p2$ which reduces the total priming when added to contextual $p2$.

6.4.2.2 Apparatus

Identical to that in Experiment 1 with the exception of the sampling frequency which was 300 Hz and use of chin rest which was used to fix the distance from the screen at 50-55 cm.

6.4.2.3 Stimuli

Identical to that used in Experiment 4.

6.4.2.4 Procedure

Calibration and cover task were as in Experiment 4.

Table 6.3: Experiment 8, design. In two Conditions RR (concurrent) and SPP (sequential) participants were presented with sample and test phases. In RR S1 a pair of novel stimuli were presented: QQ, then following a 1 s ISI, two novel stimuli were presented in the S2: PP. After the RI, set at levels of 1, 5 or 9 s, a copy of Q and P were presented together. In the SPP Condition the trial consisted of two sample phases (S1 and S2) during which respective pairs of novel stimuli were presented as in the RR Condition. After the RI, the first test consisted of a pair of stimuli presented in S1 (QQ) and after an ISI S3 followed with a pair of novel stimuli UU and S4 with VV. After the second RI stimuli from S4 (VV) were presented. Hence, the SPP Condition trials followed an order of $QQ \xrightarrow{ISI} PP \xrightarrow{RI} QQ$ then $UU \xrightarrow{ISI} VV \xrightarrow{RI} VV$ where tested items were from S1 and S2, order was counterbalanced between trials.

Condition	S1	ISI	S2	RI	Test 1	ISI	S3	ISI	S4	RI	Test 2
RR	QQ	1s	PP	1 / 5 / 9 s	QP	—	—	—	—	—	—
SPP					QQ	1s	UU	1s	VV	1 / 5 / 9 s	VV

Design of the experiment is summarised in Table 6.3 and experimental sequence of SPP is summarised in Figure 6.14. There were two Conditions which tested relative recency in either a concurrent (RR) or sequential (SPP) procedure. The design of RR followed that of Experiment 6. In the SPP Condition, the sample phase consisted of QQ then PP presentation as in the RR Condition, then after a RI there was the first test phase which consisted of QQ. This was followed by a 1s ISI and the second sample phase which presented stimuli UU and VV. After the RI, a pair of VV stimuli were presented during the second test phase. On half of the SPP trials, the first test consisted of QQ-test and on the other PP-test stimuli. Hence, the RR condition follows the RR design and the SPP consists of two sequences of RR-like presentations, however, the test phase in each consists only of a pair of stimuli from either S1 or S2. The order in which the QQ and VV tests occurred was counterbalanced equally between the trials.

Each Condition and RI combination had 12 trials resulting in a total of 72 experimental trials, additionally there were 12 target trials (14%) during which a random stimulus was replaced with a stimulus from the clothing set. Participants were given the opportunity to take a break for as long as they wished after the 21st, 42nd and 63rd trial.

6.4.2.5 Data Treatment

Target trials were removed from the analysis. The main dependent variables were $D2_{adj}$ and raw dwell time during the temporal window of interest were calculated in accordance with Equations 4.3 and 4.4 on p. 73. The former was calculated from the average Q and P values in line with Equation 4.5 on the same page. In

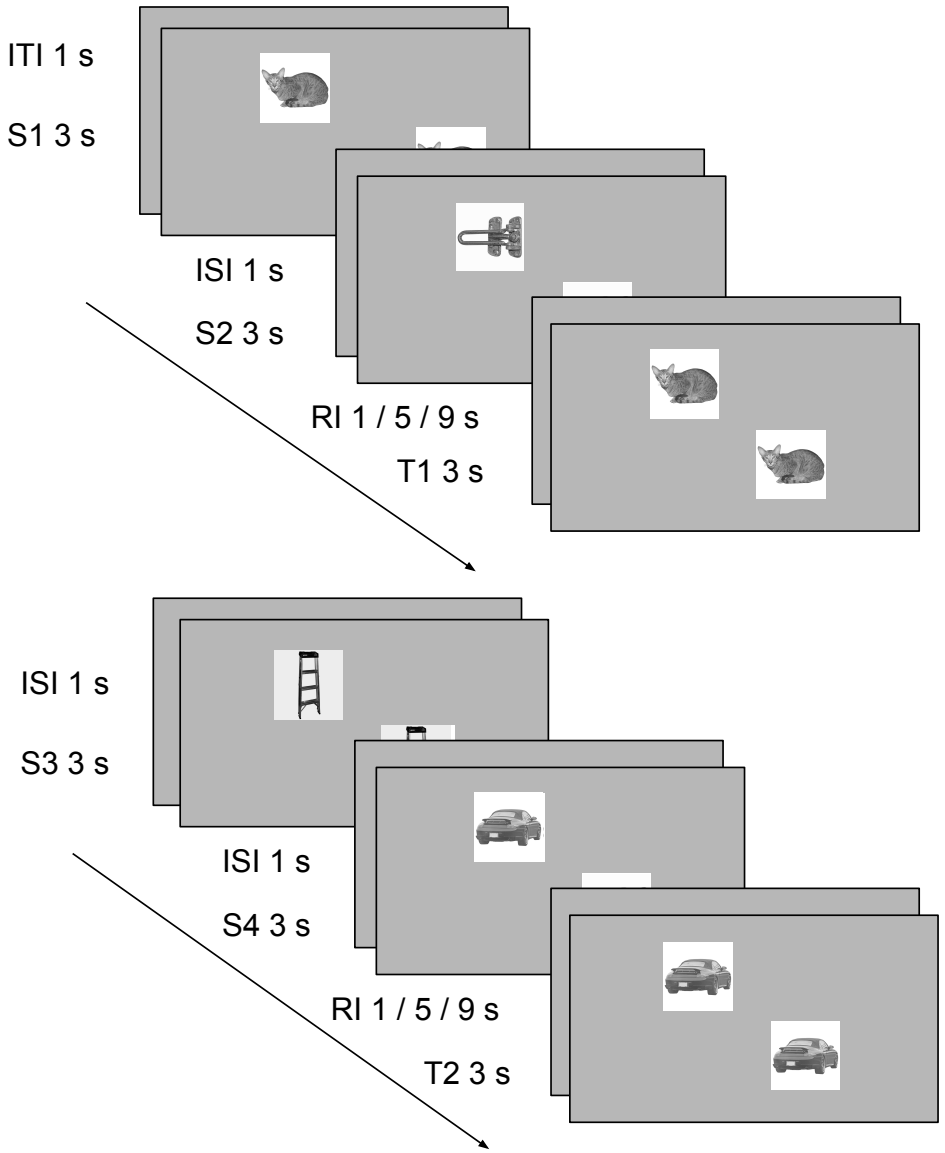


Figure 6.14: Experiment 8, demonstration of SPP sequence. Each trial begun with 1 s ITI, in following two sample phases pairs of stimuli QQ and PP were displayed for 3 seconds. After an RI of either 1, 5, or 8 s pair QQ was presented again. After an ISI of 1 s, two sample phases with UU and VV were presented, followed with a RI of the same length, and a pair VV.

the SPP condition the values of Q and P were the average of w_2 and w_3 from both ROIs around the both QQ or VV stimuli. Because the test phases differed across the conditions: in RR there was one stimulus Q and one P, however in the SPP QQ and VV were presented respectively in each test phase, it is not possible to compare the raw dwell times. Hence, in this experiment only the $D2_{adj}$ is used as a DV.

6.4.3 Results

6.4.3.1 Sample Dwell

Data of interest comes from the entire duration of the sample phase. Summary of the data are presented in Figure 6.15. Because of a difference in sample lengths between the Conditions, RR had 2 and SPP 4 sample phases, the data were analysed in two models. First model had one factor of Sample Phase with six levels which was not reliable, $F(5, 105) = 0.557$, $p = 0.733$, $BF_{01} = 20.771$. Second model had two factors: Condition with levels of RR, SPP1 (S1 and S2) and SPP2 (S3 and S4), Sample Phase (S1 and S2). The model yielded both main effects not significant, $F(2, 42) = 0.471$, $p = 0.627$, $BF_{01} = 7.905$ (*Error* = 2.081%), and $F(1, 21) = 0.47$, $p = 0.5$, $BF_{01} = 4.726$ (*Error* = 1.361%) as well as the interaction, $F(2, 42) = 0.713$, $p = 0.713$, $BF_{excl} = 5.015$. Overall, there was no evidence to indicate that participants' engagement with sample stimuli depended on either the Condition or Sample Phase.

6.4.3.2 Test Dwell

Data of main interest here, $D2_{adj}$, comes from either the test phases of RR and SPP conditions. Summary of the data is presented in Figure 6.16. Data were analysed

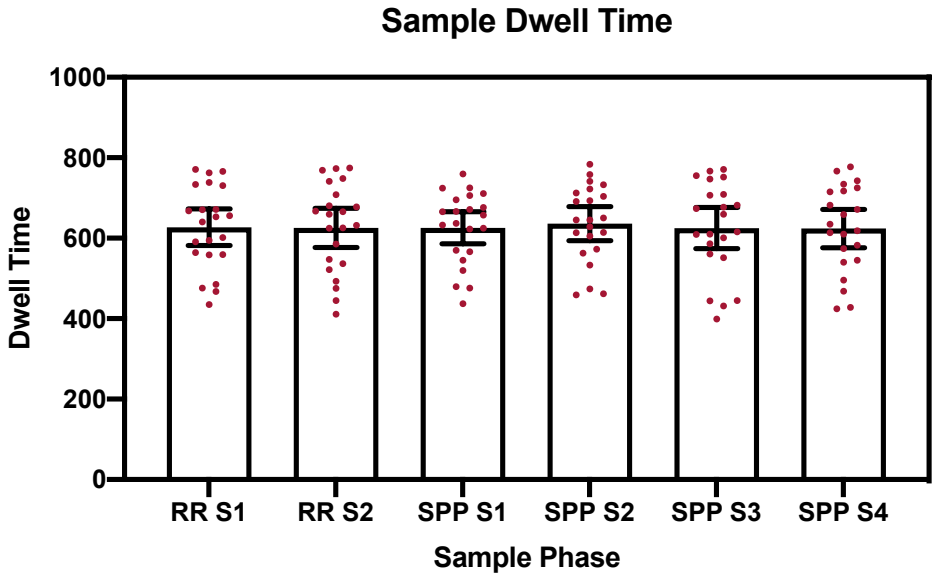


Figure 6.15: Experiment 8, sample phase dwell time. On the x-axis are the sample Phases in all Conditions, on the y-axis dwell time to stimuli during the entire duration of the sample phase (units of eye tracker samples at 300Hz). There were two sample phases in the RR (concurrent) Condition and four in the SPP (sequential), sample data were analysed in two models, neither of which demonstrated any differences between the dwell times. Means are presented with *95% CI* of the mean and individual observations as points.

with repeated measures ANOVA with factors of Condition and RI. The main effect of Condition was not significant, $F(1, 21) = 1.093$, $p = 0.308$, $BF_{01} = 3.646$. Nor was the main effect of RI, $F(2, 42) = 0.746$, $p = 0.48$, $BF_{01} = 7.89$. Same was true for the interaction, $F(2, 42) = 0.88$, $p = 0.422$, $BF_{excl} = 3.248$.

6.4.4 Discussion

The pattern of results presented here cannot offer conclusive answer to the question of applicability of SPP procedure in human recognition memory research. Lack of RR is concerning as it did not replicate the results from previous experiments reported in this chapter. Therefore, a possibility exists that due an unknown reason the experiment has not yielded results which would be informative.

From the RR results reported so far, it has been suggested that the prefer-

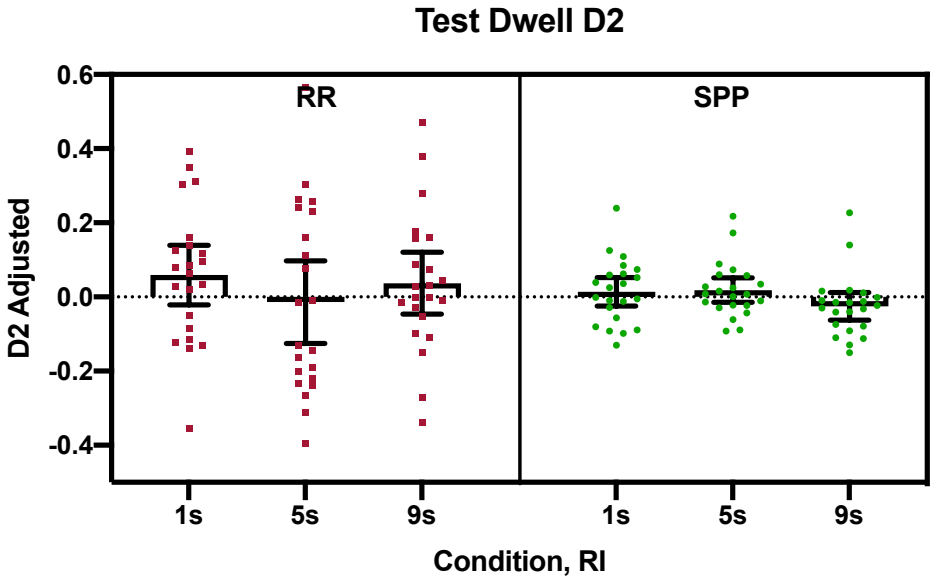


Figure 6.16: Experiment 8, Test $D2_{adj}$ calculated from windows w_2 and w_3 (0.5 - 1.5 s) of the test phases. Condition and RIs are presented on the x- and $D2_{adj}$ on the y-axis. Means are presented with *95% CI* of the mean and individual observations plotted as points.

ence for the *older* stimulus Q is vouched by a process which is based on $A1 \xrightarrow{pd1} A2$ decay. More time to decay results in higher response to a given stimulus and the more of its representation occupies the $A2$ state, the more responding to it will be inhibited. The difference between this and other RR Experiments reported here is the presence of sequential condition. While it can be argued that the lack of reliable RR is due to statistical anomalies or chance, an explanation plausible in light of the reliability of other replications of RR reported here, it is also possible that the presence of a secondary condition influenced the performance on the RR. However, it is unknown as to how this process would operate.

In contrast to RR experiments, the SPP procedure compared the exploration of stimuli between two test presentations. Approach to stimulus which has been presented immediately before the test phase (P in $Q \rightarrow P \rightarrow P$) should be reduced when compared to exploration when less recent stimulus is presented at test

(Q in $Q \rightarrow P \rightarrow Q$). However, the procedure failed to demonstrate any noticeable preference. Pertaining the lack of preference in SPP condition are the findings of (Saldanha & Bitterman, 1951; MacCaslin, 1954) who observed, that concurrent presentation of stimuli may yield better discrimination. Animals who were presented with pairs of stimuli to which they were trained to respond. Acquisition of the rule was much slower when the animals were presented with stimuli which was similar than when it was different. It must be noted that interspecies differences in vision may not allow for an effect to occur in humans as albino rats' visual capabilities are severely impaired in comparison. However, similarity to the design used here is evident. Yet, they cannot account for the effects, as the procedures used in the preparation enabled the formation of an association between the two concurrently presented stimuli, where one becomes a cue for an another (Honey, Bateson, & Horn, 1994). Here the association is not plausible, as the pair is only presented once, at test. The experimental design of SPP employed here differs to that offered by Sanderson (2016) and to the experiment which it aimed to explain (Mitchell & Laiacona, 1998). First of all, experiment at hand used eye tracking and human sample, whereas the account was offered in the context of animal studies. Second, the author argued for a between-subject design whereas here I relied on a repeated measures method. Third, perhaps the D2 cannot provide a sensitive discrimination index in SPP design.

Sanderson (2016) argues that the difference between the test exploration of Q and P is due to an inhibitory link which, given presentation of P, reduces the proportion of elements of Q primed by the context. However, inhibitory connections may require a more extensive training since such associations are more difficult to

develop. SOP reflects this fact as excitatory L^+ and inhibitory L^- learning constants are not equal; $L^+ = 5 * L^-$ (see page 16).

Nevertheless, the offered by Sanderson (2016) explanation should be tested in an appropriate experimental conditions which would resemble those of Mitchell and Laiacona (1998) closer than those employed in this experiment.

6.5 Experiment 9

6.5.1 Introduction

A key characteristic of the SGP effect is the influence of time: as demonstrated in Experiment 6 and Experiment 7 extension of the RI results in *null* preference, whereas when the RI is short the older stimulus is explored more. This is attributed to the decay of representations, given a longer time both, Q and P, representations will decay into their respective I states and, come the test, both will be able to evoke the same $A1$ activity. However, the SGP interpretation of RR offers another specific prediction: if the ISI between the two sample phases is extended, the magnitude of exploratory preference towards the earlier presented stimulus Q should increase. Figure 6.17 demonstrates an example of this with two simulated RR experiments where the ISI was either 1 (top) or 9 s (bottom). In the 1 s ISI experiment sample phases are presented in a close temporal proximity which results in only partial $A2 \xrightarrow{pd2} I$ decay of both Q (blue) and P (red) representations. At test the Q representation is able to recruit more of its representational elements into the $A1$ than P. This is because representation Q's $A2$ activation (blue, dashed) is at a lower level than that of P (red, dashed). When ISI is extended by a factor of 9, as in

the simulation presented in the bottom panel of Figure 6.17, the Q representation has much more time to decay from $A2$ into the Inactivity as demonstrated by the level of Q's $A2$ curve just before the test array onset. The results of the simulation show, that when the ISI is 1 s, just before the test array onset (moment 159 of the simulation, just before the test array onset) the $A2$ activity of Q is at 0.377 for P at 0.768, because the Q's $A1$ activation has ceased at that point the remainder (0.622) of representational elements at that moment is in the I state. On the other hand some proportion of P's elements is still in $A1$ (0.066) and some are still undergoing an $A2 \xrightarrow{pd2} I$ decay and a smaller part of its elements (0.166) is in the I state. Therefore, at onset, Q has around 62% of all of its elements available for $A1$ activation whereas P has only around 17% and the difference results in much higher activity for the former. When the ISI is extended nine-fold, the respective values for $A2$ for Q and P were 0.075 and 0.768 which means that Q has 92% of its representational elements available and P has only around 17%. A normalised difference between the two numbers of I elements at moment 159, calculated as: $(I_Q - I_Q)/(I_Q + I_P)$, for the ISI 1 s is 0.579 and for 9 s this is 0.695.

Tam et al. (2013) demonstrated that when the time between the sample phases, ISI, is extended from 5 min to 120 min the preference towards the older stimulus increases from 0.174 to 0.441. Similar results were obtained by Hatakeyama et al. (2018), keeping RI constant authors used three levels of ISI: 11, 65 and 125 minutes (Experiment 3.1). Discrimination, operationalised with D2, was reliable at all three ISIs, however the direction of exploratory preference at the shortest RI was opposite to that observed by Tam et al. (2013). Subjects demonstrated preference for the recent stimulus P, D2 = -0.193 and the effect was similar

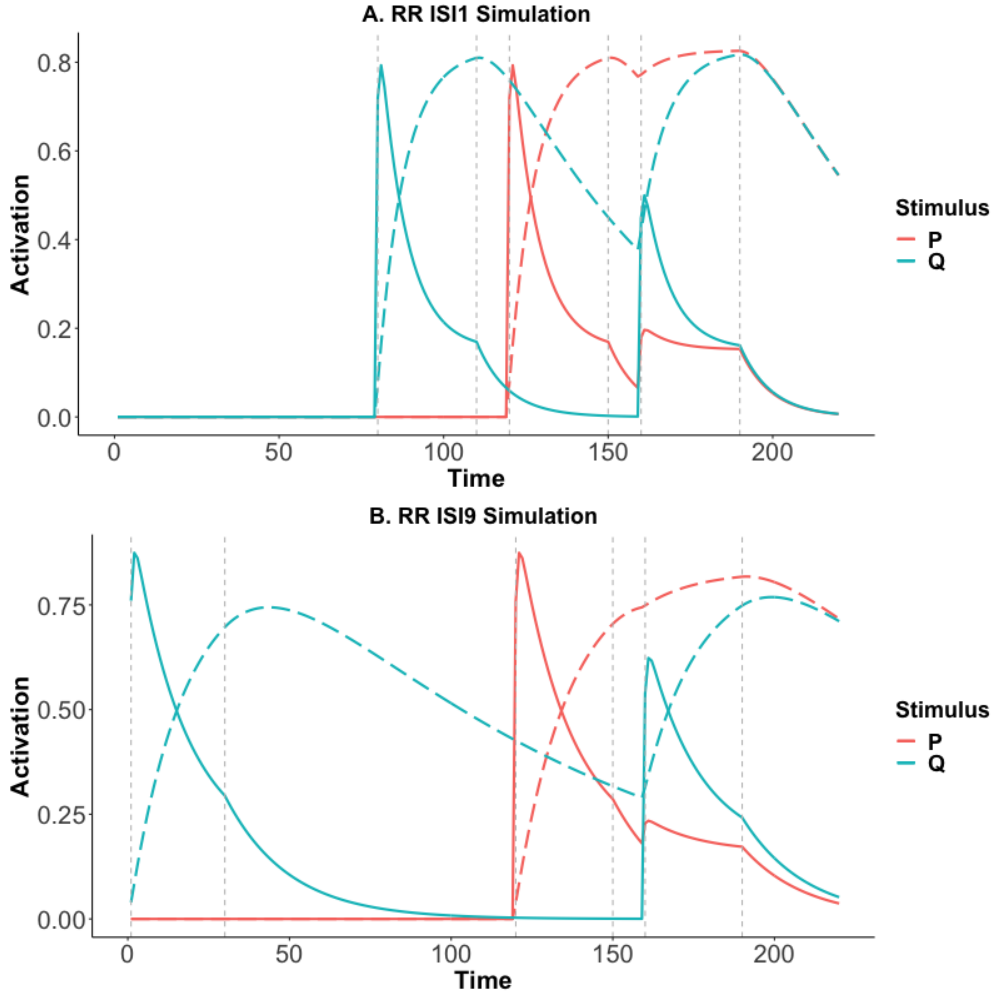


Figure 6.17: SOP simulation of two RR experiments (**panel A**: ISI of 10 moments and **panel B**: ISI of 90 moments) with time in moments on x- and activation of y-axis. Simulation involved three phases: S1 (panel A: 1 - 30, panel B: 80 - 110), S2 (120 - 150) and test (160 - 190). Solid lines represent $A1$ and dashed $A2$ activation for Q (green), P (red). Parameters were set as $p1$ = 0.8, $pd1$ = 0.1, $pd2$ = 0.02. Vertical dotted lines plotted in grey indicate onset and offset of each phase.

to the effect obtained in Experiment 1 from that study, D2 = -0.128, however this results has not reached the significance criterion. However, Hatakeyama et al. (2018) reported that progression from 65 min to 125 min resulted in an increase in D2 from 0.248 to 0.625, a result in line with the SOP prediction and Tam et al. (2013). It is not clear why Hatakeyama et al. (2018) observed effects opposite to that of Tam et al. (2013), as the latter used a shorter ISI and a similar RI of 5 min (Hatakeyama et al. (2018) used 3 m). The SOP does not predict such effects and preference towards more recent stimulus is not coherent with the body of literature; out of all RR experiments analysed, only Hatakeyama et al. (2018) reported negative D2 values. This may be an indication of a systematic error in design, animal handling, or data analysis which yielded a false positive and should be replicated.

The SGP account of RR implies that manipulation of time has two effects on discrimination: extension of RI results in a reduction of preferential exploration and that extension of ISI results in an increase in preferential exploration. Whereas the former has been directly tested in Experiment 7, the latter is a focus of this experiment. Based on SOP prediction, namely the SGP account of RR, experimentally confirmed by Tam et al. (2013); extension of ISI in RR procedure results in an increased preferential exploration of Q over the P. SOR condition was also included as a quasi-baseline which would act as a reference: in SOR Q is completely novel and in RR Q is in the process of being forgotten. Hence, if the pattern of results in the RR Conditions reflects the hypothesised effects, a comparison with SOR would allow help in establishing how long does it take for a representation to completely decay into Inactivity.

The hypothesised effects are expected to manifest themselves as a signifi-

cant RR at the longest ISI and to a lesser extent on ISI 5 s and 1 s. A significant main effect of Condition with significant paired test between the RR conditions where D2 values should present themselves as RR9 > RR5 > RR1 would provide evidence in support of the SGP involvement.

6.5.2 Methods

6.5.2.1 Participants

Identical to that in Experiment 1 with the exception of sample size: 19 female and 1 male University of Nottingham students and staff participated. Their mean age was 22.5 years (*SD* = 1.573, range 18-23 years).

6.5.2.2 Apparatus

Identical to that in Experiment 1 with the exception of the sampling frequency which was 300 Hz and use of chin rest which was used to fix the distance from the screen at 50-55 cm.

6.5.2.3 Stimuli

Identical to that used in Experiment 4.

6.5.2.4 Procedure

Calibration and cover task were as in Experiment 4. Experimental design is summarised in Table 6.4 and demonstrated in Figure 6.18. Four conditions (SOR, RR1, RR5, RR9) were used in the experiment, each with 24 experimental and 4 target trials (not analysed), resulting in a total of 114 trials. The SOR procedures follows

Table 6.4: Experimental design in Experiment 9. Participants were randomly presented with trials in SOR, RR1, RR5 or RR9 Conditions. The SOR trials had only one sample phase during which a stimulus P was presented for 3 s and after 1 s RI a copy of P and a novel stimulus Q were presented. In RR trials (RR1, RR5 and RR9) there were two sample phases each consisting of presentation of stimulus Q then P. The ISI between the two was set at three levels of either 1, 5 or 9 s. After RI of 1 s both P and Q were presented for test viewing which lasted 3 s.

Condition	Sample	RI	Test
SOR	P	1 s	PQ
RR1	$Q \xrightarrow{1s} P$		
RR5	$Q \xrightarrow{5s} P$		
RR9	$Q \xrightarrow{9s} P$		

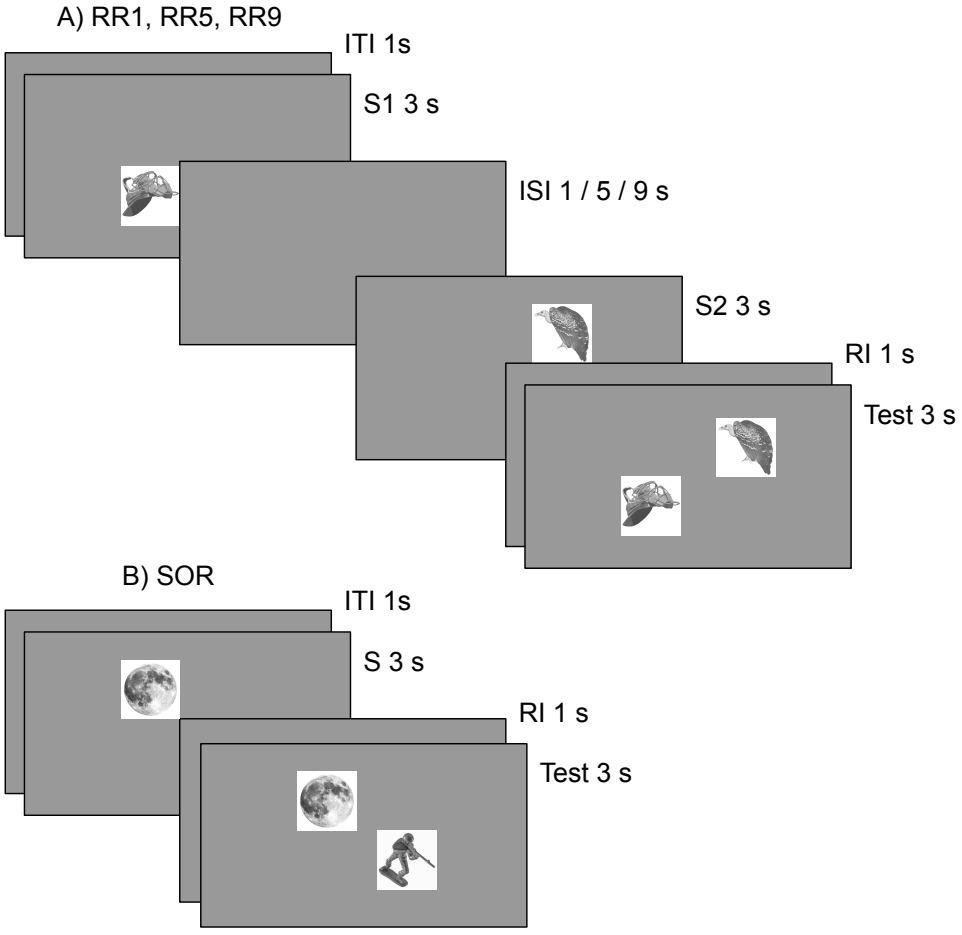


Figure 6.18: Experiment 9, sequence demonstration. **Panel A** - RR1, RR5, and RR9 conditions which differed in the duration of ISI. All had the same sample phase in which stimulus Q was first presented, followed by P. At test participants were presented with QP. **Panel B** - SOR, after a sample presentation of P, a copy of P and a novel stimulus Q were presented at test.

that from Experiment 3. The RR conditions were as in Experiment 3 with an exception of ISI between two sample phases being set at either 1, 5, or 9 s. Participants were given an opportunity to take a break after completion of 22nd, 55th and 83rd trials.

6.5.2.5 Data Treatment

Participants responded accurately to the targets with M = 1.6, SD = 1.046 *FA*s and M = 0.95, SD = 0.887 *M*s. The non-parametric sensitivity metric A' was high with M = 0.984, SD = 0.014.

Target trials were removed from the analysis (14% of all trials). DVs were calculated as in Experiment 3.

6.5.3 Results

6.5.3.1 Sample Dwell

Data of main interest comes from the sample phases of each trial. Summary of the data are presented in Figure 6.19, panel A. Data were entered into a repeated measures ANOVA with a factor of Sample Phase consisting of 7 levels (SOR S1, RR1 S1, RR1 S2, RR5 S1, RR5 S2, RR9 S1 and RR9 S2). The main effect has not reached the criterion of significance, $F(6, 114) = 0.823$, $p = 0.555$, $BF_{01} = 15.764$. In a simplified statistical model, involving only conditions with two sample phases (RR1, RR5, RR9): factor of Sample Phase, and ISI both main effects were not significant; ISI with $F(2, 38) = 0.227$, $p = 0.798$, $BF_{01} = 10.709$, *Error* = 1.166% and the Sample Phase with $F(1, 19) = 1.368$, $p = 0.257$, $BF_{01} = 2.374$. Interaction was also not significant, $F(2, 38) = 0.924$, $p = 0.406$, $BF_{excl} = 3.88$. Overall, there was

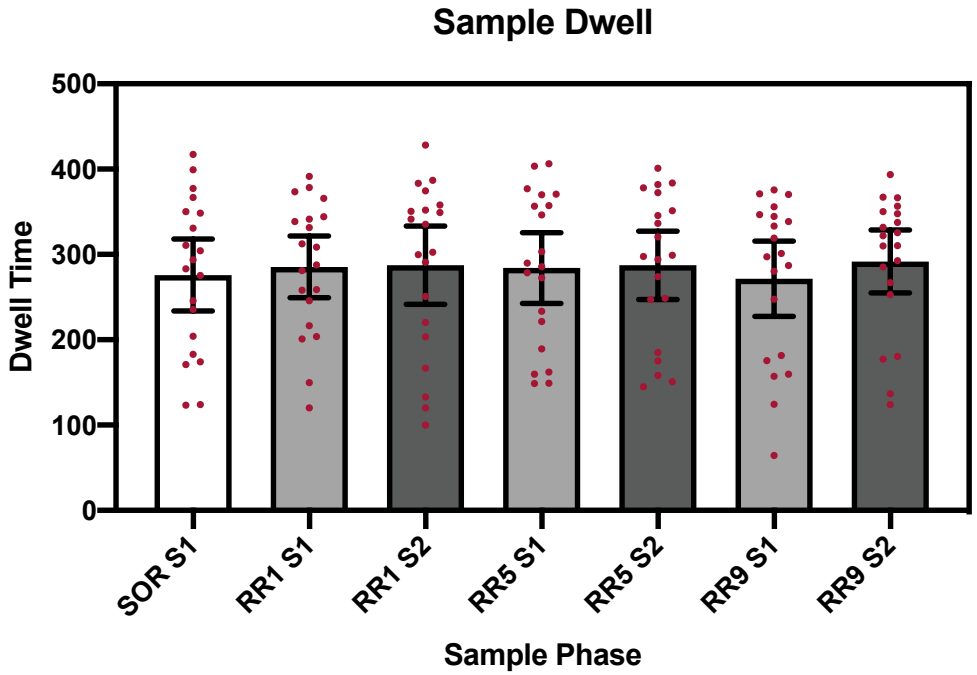


Figure 6.19: Experiment 9, dwell time data for sample phases from SOR and all RR ISI and phase combinations, means presented with *95% CI* of the mean as *Error* and subject-level means as points with Sample phase on the x- and dwell time on the y-axis (units of eye tracker samples at 300Hz).

no evidence that participants' engagement with stimuli differed between conditions or sample phases.

6.5.3.2 Test Dwell

Data of main interest were adjusted $D2_{adj}$ values and it were entered into a repeated measures ANOVA with a factor of Condition (levels of SOR, RR1, RR5 and RR9). Summary of the data are presented in Figure 6.20. The main effect of Condition was significant, $F(3, 57) = 23.079$, $p < 0.001$, $\eta_p^2 = 0.548$, *95% CI* $\eta_p^2 = [0.344, 0.652]$, $BF_{10} = 1.628 \times 10^7$.

Post hoc analysis of main interest was the difference between the SOR and the RR with longest ISI (RR9). SOR and RR9 demonstrated a significant difference, $t(19) = 7.404$, $p < 0.001$, $d = 1.656$, *95% CI* $d = [0.964, 2.328]$, $BF_{10} = 32686.755$.

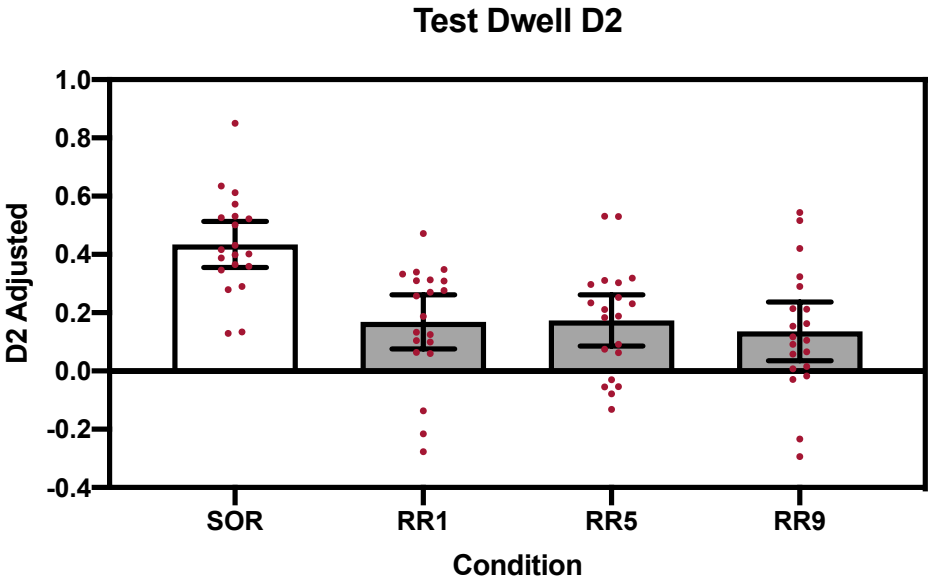


Figure 6.20: Experiment 9, $D2_{adj}$ for test phases from SOR and all RR ISI conditions, means presented with *95% CI* of the mean as error and subject-level means as points

Similar difference was observed between SOR and shorter ISI of RR5, $t(19) = 6.31$, $p < 0.001$, $d = 1.411$, *95% CI* $d = [0.777, 2.027]$, $BF_{10} = 4389.454$ and between SOR and RR1, $t(19) = 5.762$, $p < 0.001$, $d = 1.288$, *95% CI* $d = [0.681, 1.877]$, $BF_{10} = 1532.841$. None of the consecutive RR Conditions were significantly different from each other; RR1 and RR5 ($p = 0.904$, $BF_{01} = 4.275$), RR5 and RR9 ($p = 0.217$, $BF_{01} = 2.118$).

All four $D2_{adj}$ were significantly different from 0 indicating presence of the novelty and relative recency; SOR, $t(19) = 11.469$, $p < 0.001$, $d = 2.565$, *95% CI* $d = [1.637, 3.477]$ $BF_{10} = 1.852 \times 10^7$; RR1, $t(19) = 3.809$, $p = 0.001$, $d = 0.852$, *95% CI* $d = [0.329, 1.358]$, $BF_{10} = 31.521$; RR5, $t(19) = 4.125$, $p < 0.001$, $d = 0.922$, *95% CI* $d = [0.388, 1.44]$, $BF_{10} = 59.258$; RR9, $t(19) = 2.831$, $p = 0.011$, $d = 0.633$, *95% CI* $d = [0.144, 1.108]$, $BF_{10} = 4.849$.

6.5.4 Discussion

The results obtained demonstrate a reliable effect of RR and SOR, with the latter being of greater magnitude than all remaining RR Conditions. Counter to the hypothesis, the extension of ISI has not resulted in an increase of $D2_{adj}$ with the lack of the effect being supported with moderate evidence. Not being able to demonstrate the hypothesised effect suggests that the decay $A2 \xrightarrow{pd2} I$ may be much slower than expected, however this would carry consequences. To illustrate this simulated in Figure 6.21 are two experiments: with ISI of 1 and 9 s. The secondary decay rate $pd2$ has been reduced to 0.001 and all other parameters were kept as in simulation presented in Figure 6.17 on p. 203.

Here, as the ISI is extended, the $A2$ activation does not decay with the same rate as in the previous simulation, this causes the primed state to be maintained for a longer period of time and could account for the lack of effect expected by the hypothesis. However, parameter change would make it difficult to account for the effects observed in Experiment 6 as the slow decay rate would not result in differences in differential activation observed at shorter RIs. Figure 6.21 demonstrated two simulated RR experiments where the RI was extended from 10 (panel A) to 90 (panel B) moments using the same parameters as in Figure 6.17 on p. 203. The $A1$ activation at respective test does not appear to differ in a meaningful way: in RI 1 s simulation the peak $A1$ activation at test was for Q = 0.039 and P = 0.023 and in RI 9 s peak $A1$ at test for Q = 0.097 and P = 0.069. Therefore $A1$ activation for Q was higher in the longer RI, whereas the Experiment 11 yielded results opposite to that. An alternative account could explain the lack of difference between

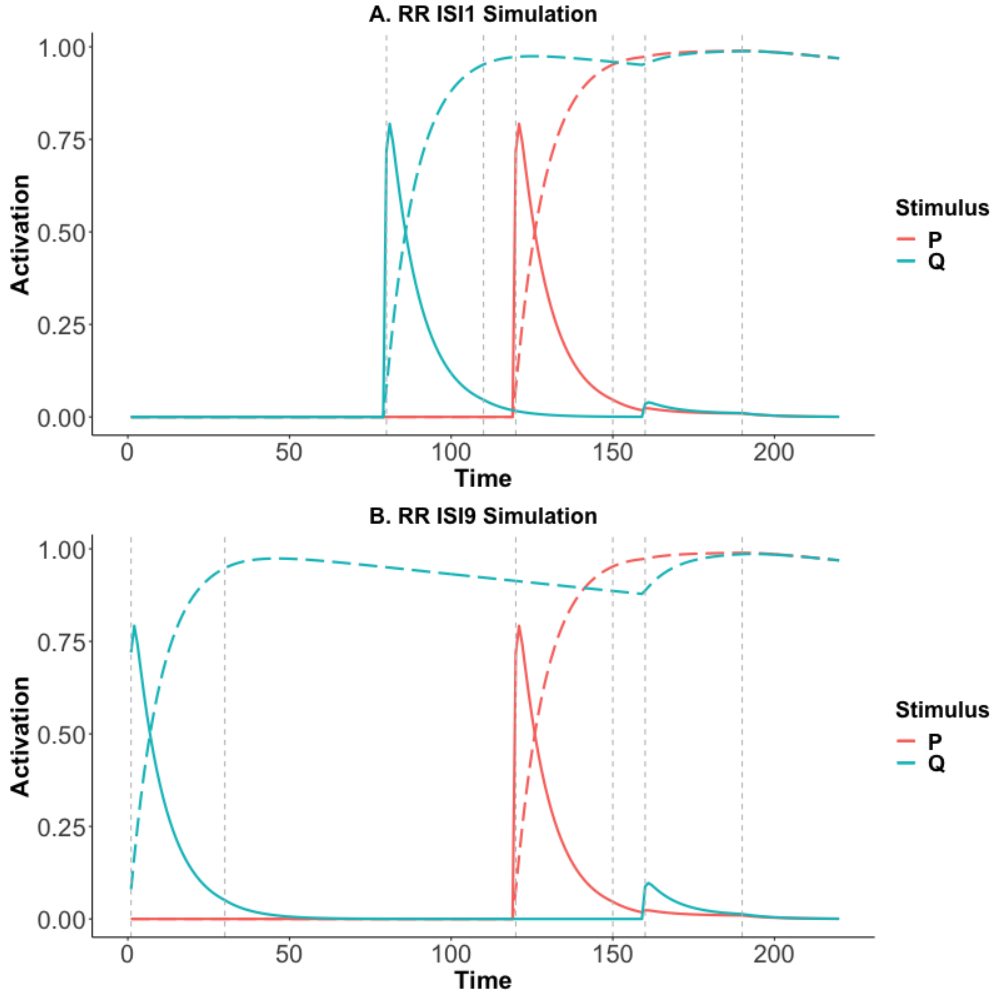


Figure 6.21: SOP simulation of two RR experiments (**panel A**: ISI of 10 moments and **panel B**: ISI of 90 moments) with time in moments on x- and activation of y-axis. Simulation involved three phases: S1 (panel A: 1 - 30, panel B: 80 - 110), S2 (120 - 150) and test (160 - 190). Solid lines represent $A1$ and dashed $A2$ activation for Q (green), P (red). Parameters were set as $p1$ = 0.8, $pd1$ = 0.1, $pd2$ = 0.001. Vertical dotted lines plotted in grey indicate onset and offset of each phase.

the ISIs due to slow $A1 \xrightarrow{pd1} A2$ decay, however a presentation of stimuli P would dramatically accelerate the decay. In accordance with the $pd1$ and $pd2$ update rules, described in Equations 1.5 and 1.6 (p. 10), both of the decay rates can be accelerated when a distractor is presented. Given a very slow $A1 \xrightarrow{pd1} A2 \xrightarrow{pd2} I$ decay the ISI does not considerably change the status of activated elements, however presentation of a new stimuli P may greatly shift the activated proportions by dramatically increasing the $pd1$ and $pd2$ rates for Q. Here, P acts as a distractor which representational elements require processing. Due to the capacity limitation of the attention and working memory (Cowan, 2010), Q's elements will be displaced, resulting in an accelerated decay into Inactivity. This would lead to a greater availability of Q elements in I on the test and greater orientation and critically would explain the results obtained here. In summary, stimulus representation decay may be slow, but the presentation of a distractor may accelerate the process. Temporal manipulation here could not have been sensitive enough to detect a change in decay, but the distractor-related acceleration of decay could account for the result.

Results of the Experiment 9 could possibly lend support to the episodic account argued by DeVito and Eichenbaum (2011) in which the recency discrimination is presented as a result of the order learning process. Events are mapped to, and interpreted in reference to a time frame of unique experiences (episodes). In support of that, the authors demonstrated that mice were able to retrieve an episode of the sequence learned and reliably discriminate an earlier stimulus from that sequence. However, stimuli presented in earlier sequence, when presented with stimuli from later one, has not yielded a reliable discrimination. Applying similar interpretation to the experiment at hand does appear to support this account. Participants could

have treated each trial as an distinct episode and hence no change in $D2_{adj}$ observed here could be attributed to place in sequence rather than the trace-decay. However, the DeVito and Eichenbaum (2011) procedure differed significantly to that used here as the authors used appetite and olfactory stimuli presented multiple times during the training phase, in contrast to visual, non-reinforced and two-sample procedure of RR. This causes methodological concerns as the experiment was designed in a way that encouraged associations to be formed. Hence, it would be difficult to examine argued here non-associative, SGP, process with method that does not allow for a fair comparison. The ISI manipulation in RR was also tested by Barker et al. (2019) who demonstrated that its extension yielded no difference in RR discrimination. Animals demonstrated same degree of preference towards the earlier stimuli, despite the different ISIs. Whereas there was a difference between the procedures of Tam et al. (2013) and Barker et al. (2019), it was limited to the number of sample phases: 2 and 4 respectively, however only the former was able to detect an influence of ISI. Barker et al. (2019) does not offer a robust explanation of differing results, however it could be argued that results presented here are enabled by a slower $A1 \xrightarrow{pd1} A2$ decay as described above.

6.6 Experiment 10

6.6.1 Introduction

In Experiment 5, reported in the previous chapter, p. 143, the effects of SGP and RGP priming were demonstrated with RR and OIC procedures. In the experiment reported in this section, I will test the temporal stability of the OIC procedure. Ac-

cording to the SOP theory, the temporal mutability of exploratory preference is a key difference between the effects of SGP and RGP on recognition memory. Enabled by the SGP preference for the older object in the RR procedure is reduced when the RI is increased, and such effects have been demonstrated in Experiment 6 and Experiment 7 of this chapter. On the other hand, the procedures of OIC and OIP should not suffer the same fate as the preferential exploration on those tasks as it is enabled by an associative RGP mechanism.

Using an OIP procedure, Tam et al. (2013) demonstrated that when the RI is extended from 5 to 120 min the preference for objects presented in novel locations does not change; which is an indication of temporal stability of a, RGP-enabled, behaviour. The results are consistent with the RGP mechanism with which the SOP predicts behaviour in OIP and OIC procedures. The preference for novel configuration demonstrated by Tam et al. (2014) are in line with findings from other researchers who have demonstrated that objects presented in a context which differs from that of the sample presentation (Dix & Aggleton, 1999; Honey et al., 2007; Honey & Good, 2000; Barker & Warburton, 2020; Honey et al., 1998; Langston & Wood, 2010; Tam et al., 2014) or in a novel configuration (Dix & Aggleton, 1999; Langston & Wood, 2010; Nelson et al., 2011; Good et al., 2007; Dere et al., 2005; Bachevalier & Nemanic, 2008; Barker et al., 2007) are attended more. However, the evidence from animal studies is in contradiction to the findings from human eye tracking research (Hannula & Ranganath, 2009; Hannula et al., 2007; Ryan et al., 2007; Mahoney et al., 2018; Ryan et al., 2020) where it has been argued, that the effects of presenting a test array consisting of stimuli QP in a sample-matching context X results in a higher exploration of P at test. As discussed in Chapter 5

(p. 96), effects of familiarity preference may have been due to the task demands as participants were asked to determine which stimulus was matching the sample set.

The associative account of recognition memory holds that the SOP offers a robust yet parsimonious model to subsume and predict behaviour in a range of learning and memory procedures, including recognition memory. In the Experiment 5 (p. 143) I have demonstrated that SOP-based prediction involving OIC and RR, which has been successfully demonstrated in animals by Tam et al. (2014), can also be obtained with human participants. To the best of my knowledge this was a first reported test of SOP predictions and RR in humans (Nitka et al., 2020). The current experiment aims to expand on those findings by testing the temporal influence on the effects of SGP and RGP. To that extent, this experiment adds a RI factor to the design described in the Experiment 5 with three levels set at 1, 5 and 9 s. As demonstrated in Experiments 1 and 2, reported in this Chapter, extension of RI reduces the preference towards the less recent object which is manifested with D2 approaching 0. Therefore, the effect is expected to be replicated in the RR Condition. In OX and OY Conditions I also expect to replicate the findings from Experiment 5 in Development of Human Recognition Memory Procedure where, in line with SOP-based prediction and Tam et al. (2014), the D2 in OX was lower than that of OY. Both OX and OY Conditions have identical sample phases: $XQ \xrightarrow{ISI} YP$ but differ in their respective test phases: respectively XPQ and YPQ. Bearing in mind that the amount of exploration depends on priming and more priming results in less exploration of a given stimulus. Influences of the SGP mechanism, demonstrated with RR, manifest themselves with increased exploration of the less recent stimulus Q over the recently presented P. However, the associative priming mechanism, RGP,

will result in less exploration of the context (X or Y) matching stimulus. Hence, in the OX Condition, the SGP results in less exploration of P, but the RGP reduces exploration of Q. The former mechanism acts in the same way in OY, however the associative latter one further reduces the exploration of P.

The hypothesis of this experiment complements that of Experiment 5. It is expected that SGP effects will be modified by RGP so that D2 in OY will be significantly different from OX. Furthermore, as the SGP effects weaken with time, as demonstrated in RR in Experiment 6, it is expected that D2 at longer RIs will reflect only the RGP influences, however same difference OY > OX should be observed with *null* effect in RR. Hence, a significant Condition x RI interaction is expected.

6.6.2 Methods

6.6.2.1 Participants

Identical to that in Experiment 1 with the exception of sample size: 19 female and 2 male University of Nottingham students and staff participated. Their mean age was 21.762 years (*SD* = 3.448, range 18-35 years).

6.6.2.2 Apparatus

Identical to that in Experiment 1 with the exception of the sampling frequency which was 300 Hz and use of chin rest which was used to fix the distance from the screen at 50-55 cm.

Table 6.5: Experimental design in Experiment 10. In three Conditions (RR, OX and OY) participants were presented with two samples (S1, S2) and a test phase. In RR Condition a single stimulus Q was presented for 3 s in S1 and, following a 1 s ISI, P was presented in S2. Following RI, set at three levels of either 1, 5 or 9 s, both P and Q were presented for a free viewing test phase which lasted for 3 s. In both OX and OY Conditions participants were first presented (S1) with stimulus P accompanied with context X, then after an ISI of 1 s, stimulus P was shown with context Y. RI was set at either 1, 5 or 9 s and was followed by a test phase. In OX Condition stimuli P and Q were shown with context X, while in OY Condition P and Q were shown with context Y. Viewing lasted for 3 s and was followed by a 1 s ITI.

Condition	S1	ISI	S2	RI	Test
RR	Q	1 s	P	1 / 5 / 9 s	PQ
OX	XQ		YP		XPQ
OY					YPQ

6.6.2.3 Stimuli

Identical to that used in Experiment 5.

6.6.2.4 Procedure

Table 6.5 summarises the experimental design, the experimental sequence is an adaptation of Experiment 5 (Figure 6.22 illustrates the procedure) with a modification of RI parameters. Three Conditions (RR, OX, and OY), each with three RIs (1, 5, and 9 s) were used in the experiment. 84 trials consisted of 24 experimental trials for each Condition; 8 trials per each RI. In addition, 12 target trials were split into 4 for each RI; of which 2 were with and 2 without context. Trials were presented in a pseudo-random order, without replacement, determined by experimental software.

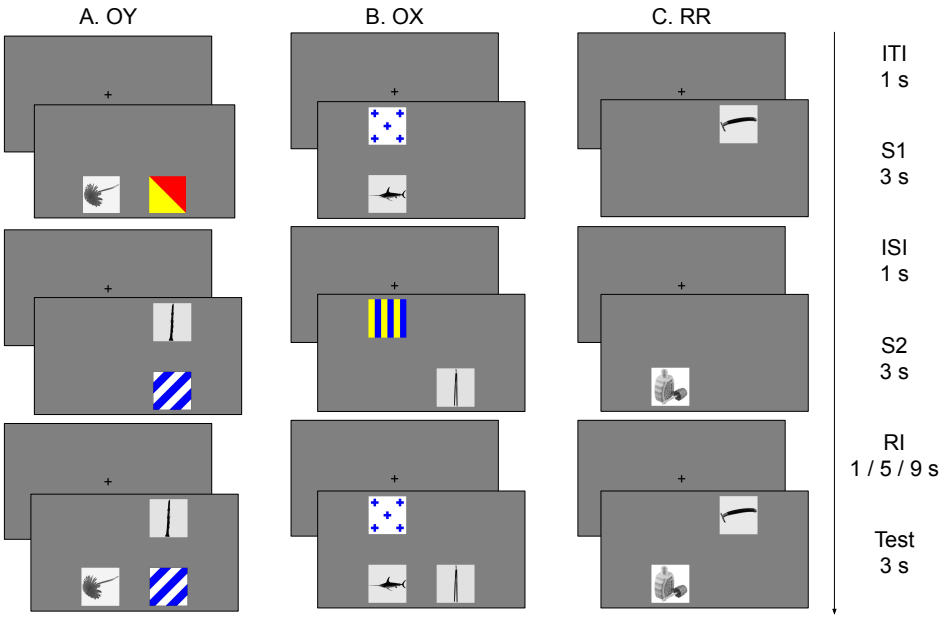


Figure 6.22: Experiment 10, sequence demonstration. **Panel A** - OY: after S1 consisting of stimulus Q and context X and S2 with P and context Y participants were presented with an array of QP with context Y. **Panel B** - OX: sample phases were as in OY, but the Test phase consisted of stimuli pair QP and context X. **Panel C** - RR: on each sample phase a single stimulus was presented; Q in S1 and P in S2, on Test QP were presented. All stimuli presentations lasted for 3s and the ITI and ISI were set at 1 s. RI was set at three levels of 1, 5, or 9 s.

6.6.2.5 Data Treatment

Participants responded accurately to the targets with *M* = 1.905, *SD* = 1.513 false alarms and *M* = 1, *SD* = 1.14 misses. The nonparametric sensitivity metric *A'* was high with *M* = 0.987, *SD* = 0.013. Target trials were removed from the analysis. DVs were calculated as in Experiment 3.

6.6.3 Results

6.6.3.1 Sample Dwell

Data collected during the sample phases were entered into a 3 (Condition) $\times$ 2 (Phase) repeated measures ANOVA and the summary of data are presented in Figure 6.23. The main effect of Condition was significant, $F(1.448, 28.966) = 71.292$, $p < 0.001$, $\eta_p^2 = 0.781$, *95% CI* $\eta_p^2 = [0.598, 0.85]$, $BF_{10} = 7.123 \times 10^{15}$. There was a significant main effect of Sample Phase, $F(1, 20) = 6.478$, $p = 0.019$, $\eta_p^2 = 0.245$, *95% CI* $\eta_p^2 = [0.005, 0.493]$, however the Bayesian test yielded higher support for the $\mathcal{H}_0$, $BF_{10} = 0.272$ ($BF_{01} = 3.679$, *Error* = 1.621%). The two main effects did not interact, $F(2, 40) = 1.878$, $p = 0.166$, $BF_{excl} = 4.488$. *Post hoc* analysis in the factor of Condition yielded significant difference between the RR and both OX, $t(20) = 10.252$, $p < 0.001$ (Bonferroni), $d = 2.237$, $BF_{10,U} = 1.595 \times 10^{12}$ and OY, $t(20) = 10.428$, $p < 0.001$, $d = 2.276$, $BF_{10,U} = 1.912 \times 10^{12}$, while the difference between the OX and OY was not reliable, $p = 1$, $BF_{01,U} = 5.734$. The difference between the levels of S1 and S2 was significant, $t(20) = -2.545$, $p = 0.019$ (Holm), $d = -0.555$, $BF_{10,U} = 3.299$.

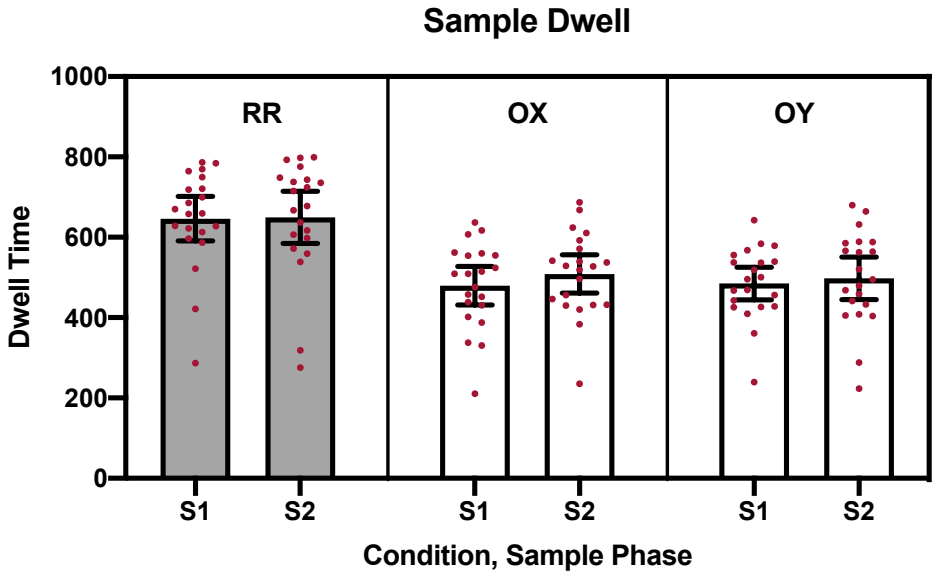


Figure 6.23: Experiment 10 sample dwell for RR, OX and OY Conditions split between two levels of sample phase (S1, S2). Means are presented with *95% CI* of the mean as error and subject-level means as points with Sample phase on the x- and dwell time on the y-axis (units of eye tracker samples at 300Hz).

6.6.3.2 Test Dwell

Data of main interest, discrimination ratios $D2_{adj}$ were entered into the 3 $\times$ 3 repeated measures ANOVA with factors of Condition (RR, OX and OY) and RI (1, 5 and 9 s). The main effect of Condition was not significant, $F(2, 40) = 1.576$, $p = 0.219$, $BF_{01} = 4.989$, *Error* = 2.855%. There was a significant main effect of RI, $F(2, 40) = 11.523$, $p < 0.001$, $\eta_p^2 = 0.366$, *95% CI* $\eta_p^2 = [0.118, 0.527]$, $BF_{10} = 651.835$. The interaction between the two main effects was not significant, $F(4, 80) = 1.493$, $p = 0.212$, $BF_{excl} = 3.303$. *post hoc* analysis yielded difference between the $D2_{adj}$ at RI 1 s and RI 5 s significant, $t(20) = 4.695$, $p < 0.001$ (Holm), $d = 1.024$, $BF_{10,U} = 586.015$. This was also the case between the $D2_{adj}$ at RI 1 s and RI 9 s, $t(20) = 3.216$, $p = 0.005$, $d = 0.702$, $BF_{10,U} = 11.257$, but the difference between the RI 5 s and RI 9 s was not, $p = 0.147$, $BF_{01,U} = 2.7$. When a separate model involving only the two Conditions, OX and OY, was constructed neither the main

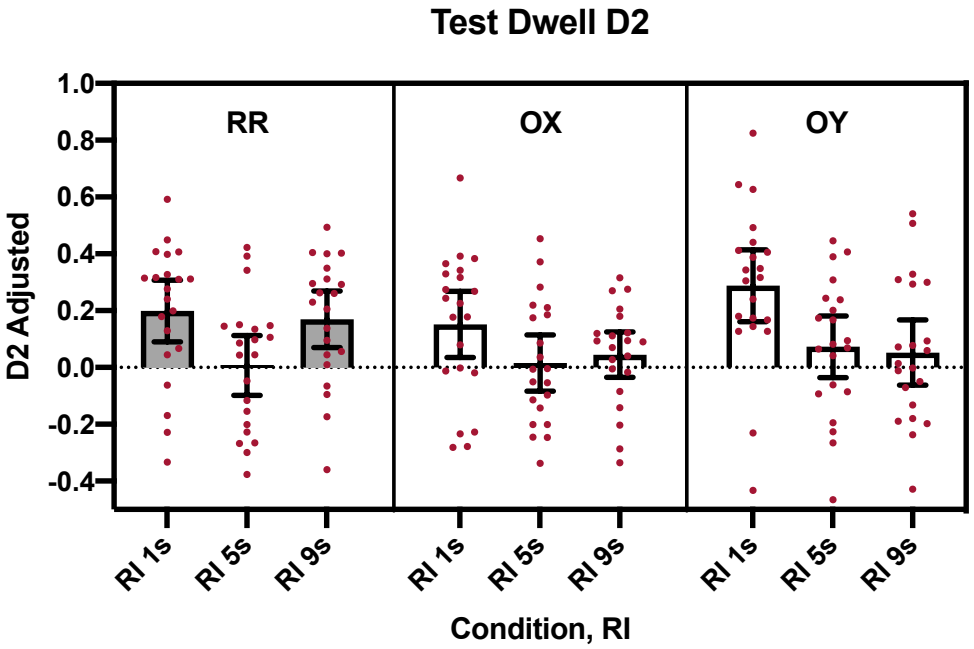


Figure 6.24: Experiment 10, test $D2_{adj}$ for RR, OX and OY Conditions split between three RI levels (1, 5 and 9 s) Means are presented with *95% CI* of the mean as error and subject-level means as points.

effect of Condition ($F(1, 20) = 2.257$, $p = 0.149$, $BF_{01} = 1.626$, *Error* = 1.067%), nor the interaction between Condition $\times$ RI were significant ($F(2, 40) = 0.861$, $p = 0.43$, $BF_{excl} = 3.903$) and the effect of RI was significant, $F(2, 40) = 10.324$, $p < 0.001$, $\eta_p^2 = 0.34$, *95% CI* $\eta_p^2 = [0.097, 0.506]$, $BF_{10} = 91.57$.

6.6.4 Discussion

Result demonstrated a significant effect of RI; discrimination was the most robust when the RI was at 1 s. Due to lack of significance the hypothesised effects of SGP and RGP interactions could not be conclusively evaluated. However, the evidence for the *null* provides only anecdotal to moderate support for the lack of the hypothesised effect. In the Experiment 5 (p. 143) interaction between the SGP and RGP effects was observed. The main purpose of this experiment was to replicate the results and to investigate the influence of RI extension on recognition memory. Participants

spent more time looking at the less recent stimulus Q over the recent P across all conditions. Data from OX and OY at RI 1 and 5 s resemble predicted by the SOP difference where $D2_{adj}$ OX < OY however, it was only numeric and there was no indication for a predicted pattern to be present at the longest RI. Overall, the results from the OX and OY conditions suggest that the associative priming, enabled by the RGP, could not be reliably detected, however its influence was smaller than that of SGP and, what was unexpected, its effects decayed with extension of the RI. It is not immediately obvious why the effects would be sensitive to time-based decay as the SOP theory predicts that the associative link should not decay as a function of time. Eacott and Norman (2004) presented rodents with $XAB \xrightarrow{ISI} YBA \xrightarrow{RI} XAB$ procedure with RI set at 2, 5, 10, 15, 30, 60 and 120 min, animals presented exploratory preference of an object presented in a novel context and location, however the effects were only present at 60 but not at 120 min RI. This mirrors the pattern of results, albeit scaled down, from the current Experiment. It could be argued, that the results obtained at the short RI were due to SGP and lack of expected RGP at longer duration was due to inability of the procedure to obtain appropriate learning, however the pattern of results observed in the Experiment 5 in the previous chapter, cannot be explained with SGP alone. It then appears, that the procedure was not able to reliably detect the effects of RGP, despite the pattern of results in line with expected outcome and $\mathcal{H}_0$ being supported anecdotally.

6.7 Experiment 11

6.7.1 Introduction

Experiments reported in this chapter so far demonstrated an evidence supporting the RR in human participants which can be obtained with eye tracking. Furthermore, it has been demonstrated that RR is enabled by a SGP as an extension of RI nullified the difference between the time spent looking at a less and more recently preexposed stimulus. Experiment 10 could not replicate the findings from Chapter 5 which has demonstrated that SGP effects can be modified by manipulation of context associations. And the results demonstrate an involvement of RGP in human recognition memory. The unexpected suggestion resulting from the RI manipulation was that both SGP and RGP effects could undergo decay as a function of RI extension. This experiment aims to replicate those findings using the procedures of RR, Object in Place (OP) as well as two procedures which involve Object in Place and RR: OR+, where the RR effects and OP manipulations prime the same test stimulus, and OR-, where the other stimulus is primed. All four conditions also involve similar 4-item test arrays, which allows for a better comparison. In contrast to previous experiments, each RR trial involves four different stimuli, two presented during S1 (AB) and two during S2 (CD). Similar are the OR+ and OR- Conditions which share the same sample structure, however at test in the OR+ AB stimuli swap their respective positions and in OR- same happens to the CD. In OP Condition participants were presented with two consecutive presentations of 4-item sample arrays, $ABCD$, then at test either AB or CD switched their respective locations. A parallel can be made between the OIC tasks reported in 5 and 10, the OX condition is an analogue of OR-

and OY maps onto OR+.

Whereas the alterations in the RR condition are limited to an increased number of stimuli presented (four instead of two), in the OP and both OR Conditions, the associative effects are to be obtained by means of the spatial location of stimuli. In previous experiments, the effects were obtained using salient context stimuli, which changed depending on the test condition. However, the spatial location of stimuli remained the same across the sample and test phases. Here, the SOP-derived expectation is similar: stimuli which are presented in a novel location will not be primed by the spatial context encoded during the sample and be explored more than stimuli which are presented in the same location as during the sample phase. This chapter's Experiment 10 demonstrated that RI extension influenced both the SGP and RGP effects with *null* exploratory preference demonstrated at the longest RI, here I aim to replicate this effect by setting RI at two levels or 1 and 10 s. Based on the SOP theory, the behaviour enabled by the RGP should not be influenced by the RI and so the increased exploration of objects in novel locations in OP and to a lesser extent in OR+ and OR- as both conditions involve SGP components, should not reduce as a function of time.

It is hypothesised that the effects of SGP obtained in the previous experiments will be replicated using an altered paradigm of RR, namely, that the less recently presented stimuli AB will be explored more than the recently presented CD. The RR should only be significant and positive at RI 1s. It is also predicted, that in OP task displaced stimuli pair will be explored more than those presented in old locations. This effect is expected on both RIs. Furthermore, interaction between the SGP and RGP in OR+ and OR- conditions should result in significantly

higher discrimination in OR+ than in RR, and lower than RR in OR-; OR+ > RR > OR-. This should be manifested at both RIs. Finally, a difference between the experimental groups is expected, however this aspect of the study is exploratory.

6.7.2 Methods

6.7.2.1 Participants

35 female and 22 male participants were recruited in exchange for an inconvenience allowance of $£5$ or during a community engagement event. The mean age was 27.8 years (*SD* = 3.6, range 18-81 years). One participant was excluded from the analysis due to equipment failure resulting in excessive loss of data. Based on reported age, participants were assigned to two groups: young adults YA (age =< 35 years) and mature adults (age > 35 years), yielding for the YA: n = 37 (M_{Age} = 22.84, SD_{Age} = 4.08) and for MA: n = 20 (M_{Age} = 65.4, SD_{Age} = 11.19). All other details as in Experiment 1.

6.7.2.2 Apparatus

Identical to that in Experiment 1 with the exception of the sampling frequency which was 300 Hz and use of chin rest which was used to fix the distance from the screen at 50-55 cm.

6.7.2.3 Stimuli

Identical to that used in Experiment 4.

Table 6.6: Experiment 11, experimental design. In each Condition participants were presented with two sample phases (S1, S2) separated with a 1 s ISI, and a test phase. RI was set at two levels of 1 and 10 s. In the RR Condition participants were first presented with a pair of stimuli AB, then by another pair CD at S2. At test stimuli from both samples were presented together in their respective, sample locations. In the OP participants were presented with four different stimuli twice at S1 and S2, then at test either two top or two bottom stimuli swapped their respective places. In the OR+ two stimuli were presented in S1, then another two in S2, at test all four were presented again, however stimuli presented in the S1 swapped their respective places. In OR- the sample presentation was the same as in OR+, however at test stimuli which were presented in S2 swapped their locations.

Condition	S1	ISI	S2	RI	Test
RR	AB		CD		AB CD
OP	AB CD	1 s	AB CD	1 / 10 s	BA CD
OR+	AB		CD		BA CD
OR-	AB		CD		AB DC

6.7.2.4 Procedure

Each participant completed a calibration procedure to ensure that the apparatus provides accurate gaze coordinates, they were then provided on-screen and verbal instructions. Participants were not asked to remember the stimuli, but to pay attention to the screen, there were no catch trials.

Table 6.6 summarises the experimental design and Figure 6.25 visualises the sequence of presentations. Four conditions (RR, OP, OR+ and OR -), each with two RIs (1 and 10 s) were used in the experiment. 62 trials consisted of 16 experimental trials for each Condition; 8 trials per each RI. Trials were presented in a pseudo-random order, without replacement, determined by experimental software. All trials had the same structure, each begun with a 1 s ITI, followed by two sample phases (S1, S2) which lasted for 3 s and were separated with a 1 s ISI. RI was set at

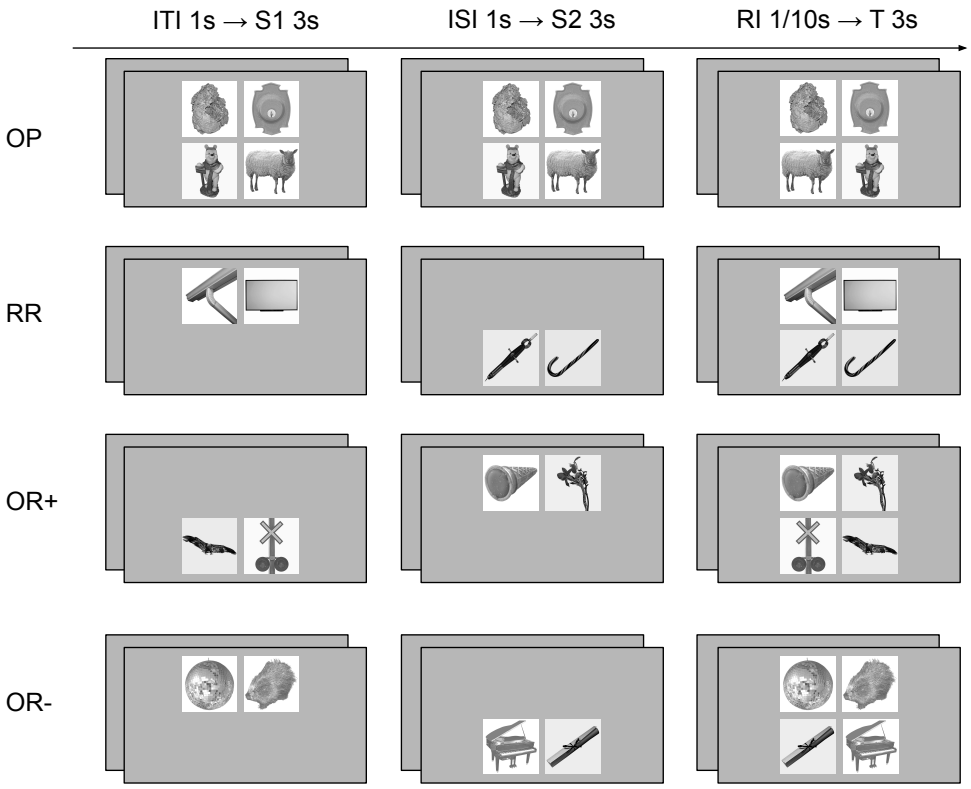


Figure 6.25: Experiment 11, sequence demonstration. **OP**: two identical arrays of 4 stimuli were presented in S1 and S2, on test either two bottom or two top stimuli swapped locations. **RR**: two stimuli were displayed in S1 and two in S2, on test all four were shown in their original locations. **OR+**: sample phases as in RR, but on test stimuli from S1 swapped locations. **OR-**: sample as in RR, but on test stimuli from S2 swapped locations. All presentations lasted for 3s and the ITI and ISI were set at 1 s. RI was set at two levels of 1 or 10 s.

two levels of 1 or 9 s and was followed by the test presentation which lasted for 3 s, the next trial followed immediately after. In the RR, OR+ and OR- conditions, S1 array consisted of two novel stimuli AB presented in either two bottom or two top locations, in S2 a pair of two novel stimuli CD were presented in locations which were not used in S1. Sample phases in the OP condition involved a presentation of four stimuli $ABCD$ twice, without any changes in both sample phases. Test arrays in all conditions involved the presentation of four stimuli; in the RR, all previously presented stimuli appeared in their respective locations as per sample phase. In the remaining conditions (OP, OR+ and OR-), two either top or bottom stimuli exchanged their respective locations. In the OP condition, on half of the trials, two top stimuli swapped locations and on another half the same happened to the two bottom stimuli. In the OR+, the first presented (S1) pair AB swapped their places whereas in the OR- the second (S2) pair CD switched locations. Participants were given an opportunity to take a break after completion of 15th, 31st and 47th trials.

6.7.2.5 Data Treatment

For the sample data, dwell time was calculated in a similar way, however the values were calculated as a sum of all six windows. Test discrimination ratio $D2_{adj}$ was calculated according to the Equation 4.5 on p. 73 where Q was the dwell time towards the more temporally distal stimuli pair (AB in RR, OR+, OR-, Table 6.6) or stimuli which switched locations (BA in OP).

6.7.3 Results

6.7.3.1 Sample Dwell

Data of the main concern here comes from the entire duration of sample phases S1 and S2 and are the sum of dwell time towards all sampled stimuli. Summary is presented in Figure 6.26. Data were analysed with 4 x 2 repeated measures ANOVA with factors of Condition and Sample Phase. The main effect of Condition was not significant; $F(3, 168) = 1.035$, $p = 0.379$, $BF_{01} = 16.373$. The main effect of Sample Phase was significant, $F(1, 56) = 12.71$, $p < 0.001$, $\eta_p^2 = 0.185$, *95% CI* $\eta_p^2 = [0.037, 0.352]$, $BF_{10} = 22.226$, *Error* = 2.304% and the interaction was not; $F(3, 168) = 2.018$, $p = 0.113$, $BF_{excl} = 10.788$. *Post hoc* comparison between the levels yielded dwell in S1 lower than in S2, $t(56) = -3.565$, $p < 0.001$, $d = -0.472$, $BF_{10,U} = 196.228$. There was no influence of the between-subject factor of age group, when it was added to the model, the main effect was not reliable, $F(1, 55) = 1.382$, $p = 0.245$, $BF_{01} = 1.429$ (*Error* = 2.57%), none of the interactions involving this factor yielded significant either; smallest $F(1, 55) = 1.379$, $p = 0.245$. Overall, participants engaged with the sample stimuli in the same way independently of Condition. Furthermore, when age group was considered as a factor, there was no evidence to support its influence on behaviour.

6.7.3.2 Test Dwell

Analysis was performed with repeated measures 4 x 2 ANOVA with factors of Condition and RI and DV of $D2_{adj}$. Summary of the data is presented in Figure 6.27 panels A and B. There was a significant main effect of Condition, $F(3, 168) = 8.433$,

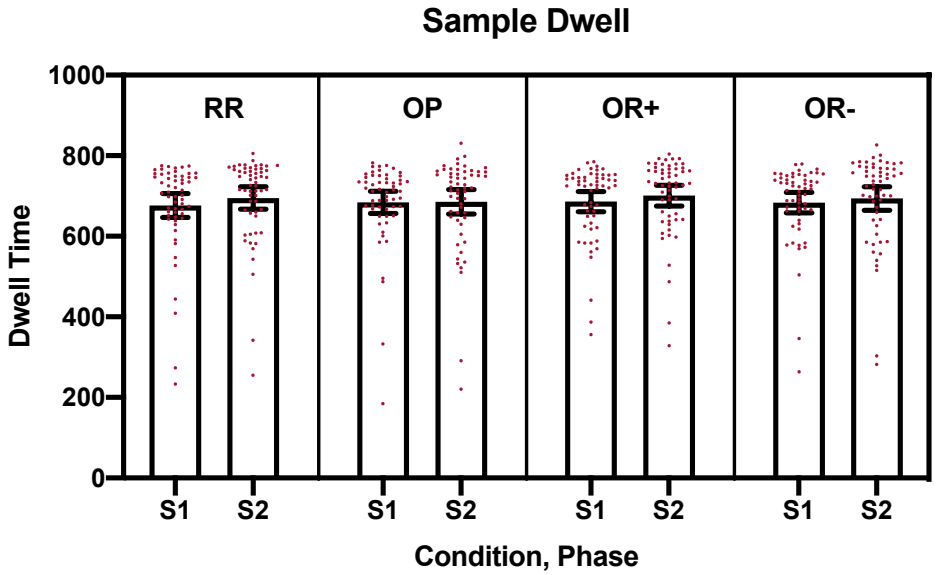


Figure 6.26: Experiment 11, sample dwell from the entire duration of sample phases in all Conditions. On the x-axis Condition and sample phase are presented and on the y-axis the dwell time during the entire sample phase towards all stimuli presented summed (units of eye tracker samples at 300Hz). Means presented with *95% CI* of the mean and individual observations as points.

$p < 0.001$, $\eta_p^2 = 0.131$, *95% CI* $\eta_p^2 = [0.041, 0.216]$, $BF_{10} = 354.167$. There was a significant main effect of RI, $F(1, 56) = 18.691$, $p < 0.001$, $\eta_p^2 = 0.25$, *95% CI* $\eta_p^2 = [0.076, 0.416]$, $BF_{10} = 5447.39$, *Error* = 1.385%. There was also a significant interaction between the main effects, $F(3, 168) = 3.131$, $p = 0.027$, $\eta_p^2 = 0.053$, *95% CI* $\eta_p^2 = [0, 0.118]$, however there was no evidence to support the $\mathcal{H}_1$, $BF_{incl} = 0.995$. *Post hoc* analysis first focused on the effects of RI extension on $D2_{adj}$ in each Condition; both RR and OR+ shown a significant effect. $D2_{adj}$ decreased between RR's 1 and 10 s RIs, $t(56) = 3.888$, $p < 0.001$, $d = 0.515$, *95% CI* $d = [0.237, 0.79]$, $BF_{10} = 89.17$ and so did OR+'s $D2_{adj}$, $t(56) = 3.973$, $p < 0.001$, $d = 0.526$, *95% CI* $d = [0.247, 0.801]$, $BF_{10} = 114.66$. There were no significant effects of RI on $D2_{adj}$ in either the OP, $p = 0.155$, $BF_{01} = 2.598$, or OR-, $p = 0.652$, $BF_{01} = 6.263$. Further analysis focused on differences between Conditions at the same RI levels. When OR+ and OR- were compared in a paired sample *t*-test the difference was

significant at RI 1 s; $t(56) = 5.372$, $p < 0.001$, but not at 10 s; $p = 1$. There was also a difference between RR and OR- at 1 s; $t(56) = 3.971$. $p = 0.002$, but not at longer interval, $p = 1$. OP was different from OR+ at RI 1 s; $t(56) = 2.334$, p = 0.049. All remaining paired comparisons were not significant, smallest $p = 0.323$.

Furthermore, when data were evaluated with one-sample t-test ($\mu = 0$), all but OR-'s $D2_{adj}$ ($p = 0.508$, $BF_{01} = 5.593$) were significant at RI 1 s, RR: $t(56) = 6.026$, $p < 0.001$, $d = 0.798$, *95% CI d* = [0.497, 1.094], $BF_{10} = 102837.951$, OP: $t(56) = 3.513$, $p < 0.001$, $d = 0.465$, *95% CI d* = [0.19, 0.737], $BF_{10} = 30.433$, OR+: $t(56) = 6.806$, $p < 0.001$, $d = 0.901$, *95% CI d* = [0.59, 1.207], $BF_{10} = 1.680 \times 10^6$. On the longer RI, of 10 s, only the $D2_{adj}$ in OP, $t(56) = 2.083$, $p = 0.042$, $d = 0.276$, *95% CI d* = [0.01, 0.539] and OR+, $t(56) = 2.532$, $p = 0.014$, $d = 0.335$, *95% CI d* = [0.067, 0.601] were significant, however the support for the model was anecdotal in both, $BF_{10} = 1.071$ and 2.652 respectively. Both RR, $p = 0.127$, $BF_{01} = 2.249$, and OR-, $p = 0.889$, $BF_{01} = 6.846$, have not had their respective $D2_{adj}$ different from 0 at 10 s RI. When a between-subject factor or Age Group was added to the model, the main effect was not reliable, $F(1, 55) = 3.409$, $p = 0.07$, $BF_{01} = 2.57$. There was also no evidence that age group interacted with any other main effects in a significant manner, smallest $F(1, 55) = 0.073$, $p = 0.788$.

6.7.4 Discussion

When RI was short all but OR- demonstrated a significant discrimination. At a longer RI, only the OP discrimination was reliable. Discrimination in both RR and OR+ decayed as a function of RI extension. Differences between discrimination in conditions were limited to the short RI; both RR and and OR+ had stronger

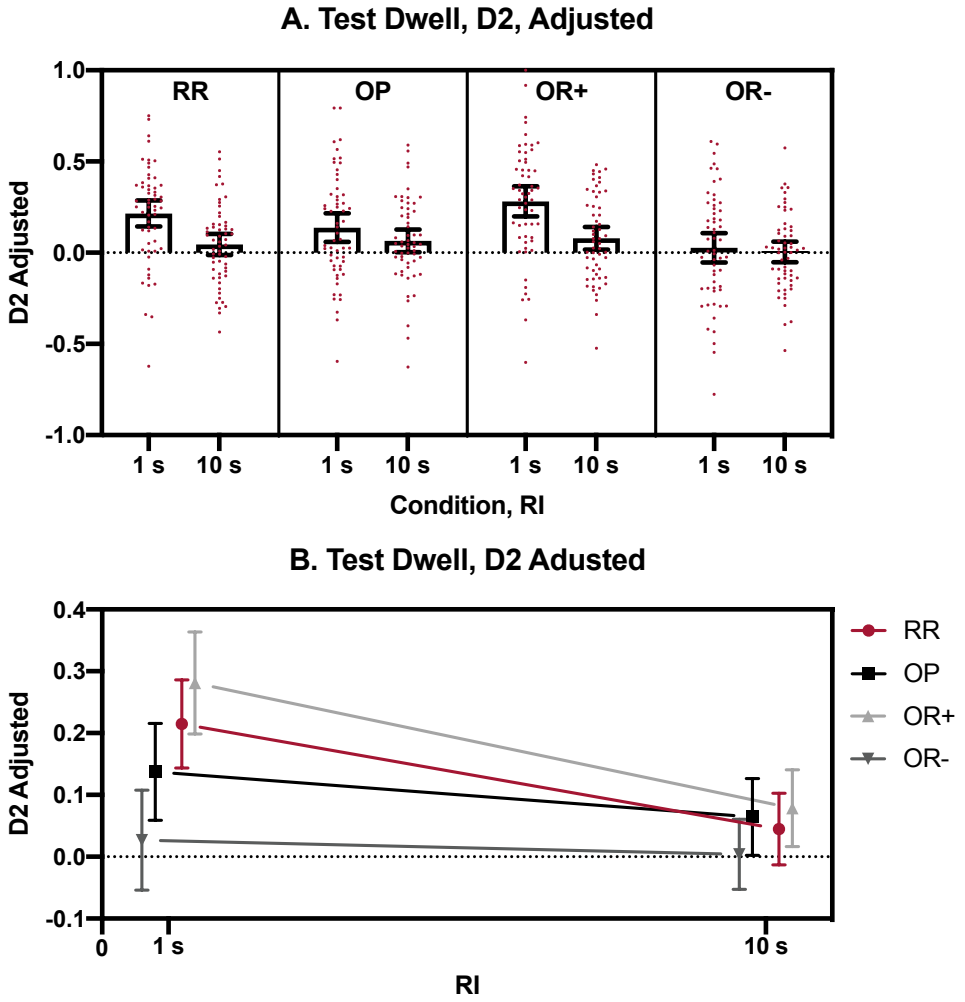


Figure 6.27: Experiment 11, $D2_{adj}$ data from test phase with DV of $D2_{adj}$ (calculated from w_2 and w_3 of the test phase; 0.5 - 1.5 s). Panels A and B show the same data, however data in panel B were reported for clarity without the individual observations. In **panel A** Condition and RIs are presented on x- and $D2_{adj}$ on the y-axis. Means are plotted with *95% CI* of the mean and individual observations as points. In **panel B**, RI levels are on the x- and adjusted D2 on the y-axis, separate Conditions are plotted as different points and lines with *95% CI* of the mean as error. Mean points at RI levels have been jittered along the x-axis for clarity and do not indicate differences in RI between Conditions.

discrimination than OR- and OR+ demonstrated have stronger discrimination than OP. Age group had no influence on the results and did not significantly interact with any effects. Results from the RR Condition demonstrate a preference for less recent stimulus which decays when RI is extended, a finding consistent with the SGP account of RR. In contrast to the previous OIP experiments reported in this thesis (Experiments 3, 4, and 6), which have not yielded reliable discrimination, here in the OP condition a significant result was obtained at both RIs. It can be then assumed that the OP procedure involving the four stimuli arrays yielded results which are in line with SOP-predicted RGP effects. According to SOP account, the discrimination here relies on an cognitive map that was forged between the spatial cues (arrangement of stimuli) during the sample phase. Displaced stimuli are less affected by the $I \xrightarrow{p2} A2$ priming and can evoke stronger orienting, in contrast to stimulus presented in the old location which is primed by such arrangement. Because RGP-based associations do not undergo time-dependent erosion, the effect of OP is predicted to be temporally stable and this is supported by the results.

Supporting the involvement of RGP and SGP account were also the results from OR+ and OR-. In the former, the influence of priming operates in the same direction, that is: the stimulus which has been presented during S1 is displaced on test. This results in a summation of priming forces. In the OR- both mechanisms operate in the opposite direction, the SGP primes the stimulus presented in S1, but the RGP is disabled for the displaced one. Hence, the two mechanisms can influence each other. The differential pattern of priming is demonstrated with the direction (OR+ > OR-) of the results on RI 1 s. Where the displaced and less recent stimulus was looked at more than stimuli which were not displaced and

recent. However, the preference was influenced by a change in displacement; there was no preference in a test where nondisplaced and recent stimuli were compared. Hence, the only difference between the OR+ and OR- procedures was due to RGP, it can be argued that the effect of RGP cancelled out the SGP.

In contrast to the current experiment, the previous OIP Experiments reported in this thesis could not provide compelling evidence in support of discrimination. There are few differences which might have played a role in enabling the discrimination observed here. Presentation of four items during the sample phase provided more spatial cues which enabled more robust association. Apart from that, the stimulus array was presented twice: in S1 and S2, which suggests that repeated presentation enabled more efficient formation between the stimuli and environmental cues. Third consideration relates to the sample size, which was the largest of all experiments in this report. This might have reduced the signal-to-noise ratio and help in detecting the discrimination as the behaviour in analogous animal procedures in inherently noisy (Ameen-Ali et al., 2015).

The pattern of results in OR+ and OR- Conditions reflects the SOP prediction and replicates the findings from Experiment 5 as well as findings of Tam et al. (2014). However, in contrast with Experiment 10 the results of associative priming enabled by the RGP were also demonstrated at a longer RI. Procedures used here demonstrated to be applicable in older mature age groups as such participants did not demonstrate any differences with younger adults. The lack of difference is not indicative of a lack of sensitivity in detecting age-related subclinical impairment in older adults as participants in this age group were not selected from the population by a random method.

6.8 Conclusion

The goal of this chapter was twofold: to investigate how time, namely, the RI and ISI duration, influence the behaviour on the recognition memory procedures of SOR, RR, OIC, and OIP. This is of essence, as the mechanism of SGP is exemplified in RR, and OIC/OIP procedures provide a RGP assessment. To that extent, the SOP-based predictions have been directly tested, for the first time using human participants. The second, albeit related, goal was to explore two potential explanations for the long-lasting RR effects observed by Mitchell and Laiacona (1998).

This chapter investigated how time influences the behaviour observed in the RR procedure. In Experiment 11, but also in Experiments 6, 7, and 10, it has been demonstrated that extension of RI reduces the effects of preferential exploration of stimulus which copy was presented earlier in the sample. This finding supports the assertion that RR is enabled by the non-associative SGP. At the same time the effects of novelty observed in SOR condition were reliable and robust at all RIs. In contrast with RR, the SOR can be explained by both mechanisms, SGP and RGP. The pattern of results observed here, would suggests that the contrasting temporal stability is most likely due to the RGP. The effects of RR could be observed when RI was set as 1 s but the preference was null as 5 and 9 s. It can be then assumed, that in context of current preparation, the time for both stimuli to considerably decay into I is not longer than 5 s. With regards to the Mitchell and Laiacona (1998), a similar patter of results observed by the authors could not have been observed. It is possible, that the long lasting effect of RR might have been enabled by an unspecified and uncontrolled features of the experiment, environment or design.

For example, Barker et al. (2019) states that a discrepancy between the results of Mitchell and Laiacona (1998) and those of Tam et al. (2013) and Hatakeyama et al. (2018) might have been due to testing being carried out during different times of the day cycle. It must also be emphasised that the RR experimental procedures reported here took their inspiration in the Mitchell and Laiacona (1998). However, there are several differences which may make a comparison between the Mitchell and Laiacona (1998) study and the results reported here difficult. The procedure employed by the authors (Mitchell & Laiacona, 1998) involved a longer sample and test presentations, both of which lasted for 5 min, and a longer ISI of 1 h. In all experiments reported here, this parameters have been set at 3 s and (with an exception of Experiment 9) 1 s respectively. Furthermore, while the authors used RI ranging from 1 to 168 h, the span of RI used for this thesis ranged between 1 and 10 s. Furthermore, the authors used a within-subject design where all animals were tested once at each RI, whereas in the experiments reported, the participants completed multiple trials per each condition. As I was unaware of any prior studies of human RR, both the selection of timing and number of trials were driven by the requirements of the practices involved in human-centred experiments and by a pilot test performed early during my PhD program, which have yielded a reliable RR discrimination (Experiment 2). Using the same timings as Mitchell and Laiacona (1998) would not be possible with human participants as controlling for the distractors during the ISI and RI would not be possible. Lack of control for this, important for trace decay, factor could have yielded an unreliable results. Furthermore, the attrition rate of participants in a multiphase experiment might have been problematic. Selection of shorter stimuli presentations, ISIs and RIs were also mo-

tivated by a similar durations being used in related human research. For example Sivakumaran et al. (2018) presented sampled stimuli for 2 s with 0.5 s RI in their VPC procedure. Finally, the selection of shorter time parameters allowed for the experiment to be feasible in terms of participants' ability to maintain appropriate levels of attention and alertness. This, combined with a relatively large number of trials per condition, was deliberately selected to improve signal to noise ratio cause by the variance in behaviour observed in similar animal procedures (Ameen-Ali et al., 2015). Due to the differences in spices, nature of stimuli, and timing parameters employed, the reported here experiments cannot be taken as a direct replication of Mitchell and Laiacona (1998). Same consideration has to be made when evaluating the outcomes of Experiments 7 (McLaren's account) and 8 (Sanderson's account), which aimed to explain observed by Mitchell and Laiacona (1998) long-lasting RR. In both cases, an animal procedure with parameters specified in Mitchell and Laiacona (1998) would be a much better suited test. Further investigations into human RR could perhaps involve an adaptation of the procedure into a virtual reality (VR) scenario using experimental software such as Maze Suite (Ayaz, Allen, Platek, & Onaral, 2008), Openmaze (Alsbury-Nealy et al., 2020), VREX (Vasser et al., 2017), PandaEPL (Solway, Miller, & Kahana, 2013) or Landmarks (Starrett et al., 2020). This technology would allow experimental environment to closely resemble the one using in animal procedures.

The results from RR procedures demonstrated in this chapter lend support for the effects of SGP and SOP interpretation of judgement of recency. However, the pattern of results observed in Experiment 9 appears to complicate that interpretation and lend some some to the episodic account of RM. Findings from that exper-

iment align with those obtained by DeVito and Eichenbaum (2011) and Barker et al. (2019) who argued that animals construct a spatio-temporal map to which occurrence of events is related to. Although the SOP can offer an account by which such results could be interpreted and simulation of the model, described on page 210, can offer some possible paths of enquiry in that context. Given that the evidence in support of SGP in RR has also been offered (Tam et al., 2013), the matter of ISI influence on RR will need to be solved in subsequent research.

The OIP procedure which was employed for the sole purpose of parsing out the effects of RGP failed to demonstrate the effects. This failure is echoed with similar outcomes reported in Chapter 5 which were addressed with an attempt to increase stimuli salience, yet to no significant effect. In the Experiment 5 of previous Chapter the effects of also associative in nature, OIC, were demonstrated through the modulation of RR effects. A modification of the procedure is used in Experiment 7 reported in this Chapter to investigate a potential solution to the long-lasting effects of RR, observed by Mitchell and Laiacona (1998). The account tested, put forward by McLaren (personal communication), suggests involvement of an RGP though which a long-lasting performance can be enabled. Here sample stimuli Q and P enter into associations with the context X, however because of the sequence of samples presentation and as a result of associative priming $I \xrightarrow{p2} A2$, the V_{XQ} association is extinguished during the XP presentation. This in turn results in reduced priming of Q at test. An experimental test was inconclusive in the assessment of argued process. 'An alternative method to test RR, offered by Sanderson (2016) and tested in Experiment 8, held that the sequence of $Q \xrightarrow{ISI} P$ presentation in the sample phases encourages development of an inhibitory association between the re-

spective representations, V_{PQ}. Concurrent presentation of stimuli at test encourages associative priming enabled by this association. To obtain an uncontaminated by RGP RR is to present stimuli in a sequential manner. An experimental test employed to verify develop an experimental procedure which would test the Sanderson's account. However, the test could not yield conclusive data. Hence, both assessments of the associative accounts of RR could not be verified. Experiment 9 focused on a SOP-derived and demonstrated in rodents (Tam et al., 2013) the influence of ISI extension on RR. The experiment manipulated the ISI between 1 and 9 s as this time durations, when used as RI, resulted in *null* preference in Experiment 5. However, the results could demonstrate pattern of results suggested by the simulation (Figure 6.17, p. 203). The result is not obvious to interpret in terms of the SOP, however it is possible, that the decay rates $pd1$, $pd2$ may operate at a much slower rate. However, when a new stimulus is presented the decay accelerates; this explanation is consistent with SOP. Both Experiment 10 and Experiment 11 investigated the temporal influence on the SGP and RGP enabled effects. In the Experiment 10 reliable results of OIC, observed in Development of Human Recognition Memory Procedure, were assessed at three RIs. At the shortest RI, an influence of RGP on SGP effects could not be confirmed, same could not have been done at longer RIs. However, the pattern of results obtained in Experiment 11 demonstrated robust effects of SGP, RGP, and an interaction between the two mechanisms. Most importantly, the SGP, exemplified by the effects of RR, underwent the time-dependent decay as predicted by the SOP. Furthermore, the RGP-enabled effects in OP have not suffered from a decay, which is implied by the associative nature of mechanisms. In conclusion, the body of results reported in this chapter suggest that a RR effect is obtainable in

human participants and that the extension of RI reduces the preference towards the stimuli presented earlier in the sample phase, a result consistent with SOP prediction and involvement of SGP in this recognition memory procedure.

7 | Discussion

The main aim of this thesis was to assess the SOP as a reliable tool for human recognition memory. In the two experimental Chapters, 5 and 6, I have documented the development of a novel procedure, based on a human eye-tracking adaptation of SOR, which would be capable of parsing out the influences of associative and non-associative components of recognition. I have also assessed the influence of time on the established effects with particular reference to the SOP-derived predictions.

In Chapter 5, in a series of experiments, I demonstrated that, in addition to SOR/VPC, which has been previously used in human research, participants demonstrated the effects of RR and OIC. This is of particular importance as either of those maps to the two mechanisms postulated by (Wagner, 1976), namely the non-associative SGP and associative RGP. The ability to obtain results, which are in line with those from animal studies, suggests that the developed procedures are sensitive to the effects of interest. Furthermore, when specific SOP-based predictions were tested, the experimental results were largely in line with the hypothesised effects.

In Chapter 6 I examined the temporal dimension of the effects of interest. Here, the pattern of results was largely in line with SOP-derived predictions. However, certain findings are not easy to be accounted for by theory. Two asserted by McLaren (personal communication) and Sanderson (2016) alternative accounts of RR were tested, in an attempt to provide solution for the long-lasting effects of RR (Mitchell & Laiacona, 1998). However, both of the accounts were demonstrated to be not reliable.

The effects obtained from experiments reported in this thesis are meta-analysed using the Bayesian Model-Averaged method (BMA) performed in Jasp (JASP Team, 2020). Bayesian approach to meta-analysis allows for evidence levels to be quantified with relation to the *null* hypothesis ($\mathcal{H}_0$) and alternative ($\mathcal{H}_1$), furthermore the analysis can quantify support for both, unlike the classical frequentist approach. Prior model probabilities were set at 0.25 for fixed and random $\mathcal{H}_0$ and $\mathcal{H}_1$ with estimation settings (*MCMC*): iterations to 2000 in 4 chains, default distribution (*Cauchy*, 0.707) was used as a prior.

7.1 Spontaneous Object Recognition

Experiments reported in this thesis demonstrated robust effects of novelty. Six experiments tested the SOR with RI of 1 s, each time yielding reliable results. Of interest were the data from one-sample *t*-test with dependent variable of D2 or $D2_{adj}$. Summary data for the results of SOR experiments with RI 1 s are presented in Figures 7.1 and 7.2. Fixed effects were estimated as μ = 1.48, *95% CI* = [1.2, 1.77] with BF_{10} = 3.567 $\times$ 10^{20} and for random effects, μ = 1.6, *95% CI* = [0.66, 2.33], BF_{10} = 56.827 yielding an overall averaged BF_{10} = 58.079 indicating an very strong level of evidence in support of the $\mathcal{H}_1$ model and μ = 1.59 *95% CI* = [0.63, 2.33].

Experiment 1 in Chapter 5 tested the temporal stability of the SOR demonstrating that the effect does not decay with time. The results suggest an involvement of RGP in SOR which supports the argument that effects obtained from this procedure are enabled by SGP and RGP (Robinson & Bonardi, 2015). Findings from the SOR procedure contribute to a well established effects of novelty prefer-

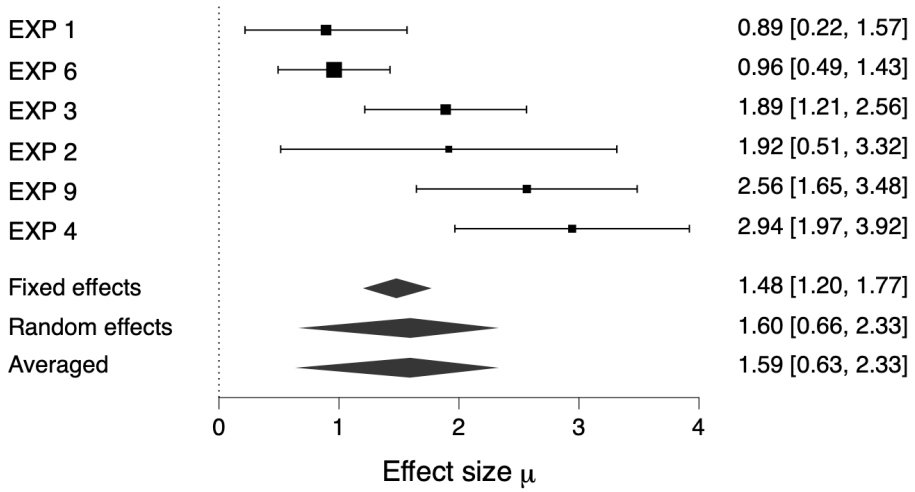


Figure 7.1: Meta Analysis SOR, forest plot for the effects observed in experiments reported in this thesis. Effect size μ on the x-axis and experiments reported in rows. Effect size with *95% CI* on the right hand side of the plot.

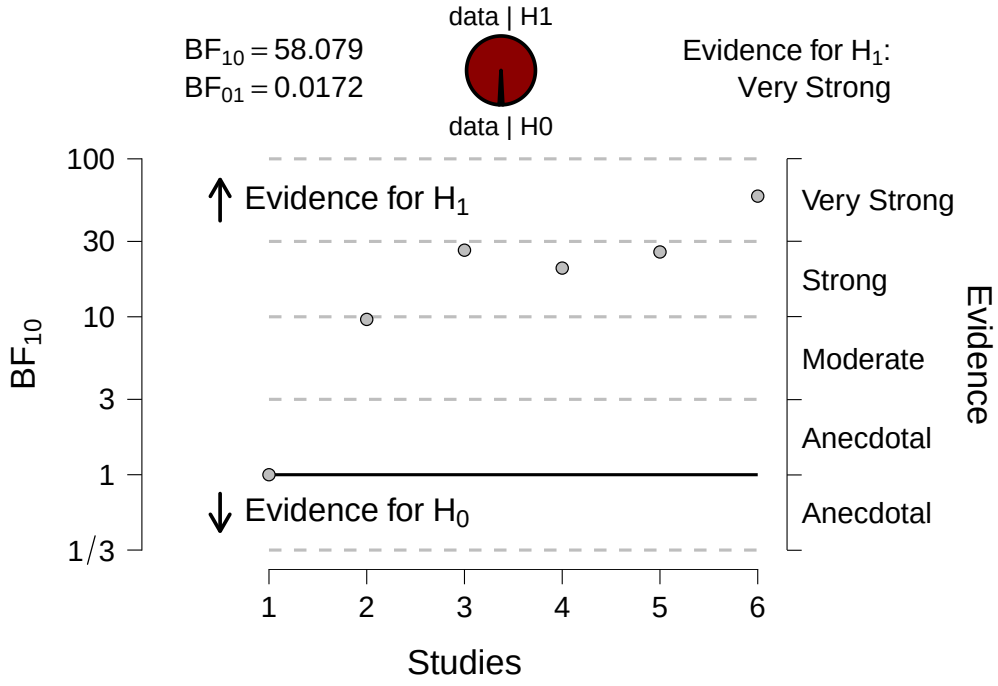


Figure 7.2: Meta Analysis, SOR, BF_{10}. Sequential Bayes Factor effect size for SOR procedure. BF_{10} on the y-axis and studies on the x-axis

ence demonstrated in rodents (Ennaceur & Delacour, 1988; Dix & Aggleton, 1999; Hotte et al., 2005; Good et al., 2007; Barker et al., 2007; Hannesson et al., 2004a; Langston & Wood, 2010; Nelson et al., 2011; Tam et al., 2013; Barker & Warburton, 2020), nonhuman primates (Bachevalier & Nemanic, 2008) and human infants (Fantz, 1964; Fagan, 1970, 1973; Fagan & Haiken-Vasen, 1997; Morgan & Hayne, 2011; Reynolds, 2015) as well as adults (Squire & McKee, 1993; Manns et al., 2000; Richmond et al., 2004; Sivakumaran et al., 2018). However, the procedure is subpar in the context of recognition memory model argued here, as it cannot parse out the influences of associative and non-associative mechanisms. In the work reported here, it was mainly used as a benchmark or control condition to test whether the experimental procedures are fit for purpose. Hence more focus was given to the, sensitive to the non-associative, Relative Recency and, associative, Object in Context / Object in Place procedures.

7.2 Relative Recency

Experiments reported in this thesis demonstrated a reliable effects of recency. Nine experiments involving the procedure have been performed with RI set at 1 s and majority of those yielded demonstrated results of discrimination. Of interest were the data from one-sample *t*-test with dependent variable of D2 or $D2_{adj}$. Summary data for the results of RR experiments with RI 1 s are presented in Figures 7.3 and 7.4. Fixed effects were estimated as μ = 0.78, *95% CI* = [0.64, 0.93] with BF_{10} = 4.577 $\times$ 10^{20} and for random effects, μ = 0.77, *95% CI* = [0.46, 1.07], BF_{10} = 248.036 yielding an overall averaged BF_{10} = 291.996 indicating an extreme level of evidence in support of the $\mathcal{H}_1$ and μ = 0.77, *95% CI* = [0.47, 1.06].

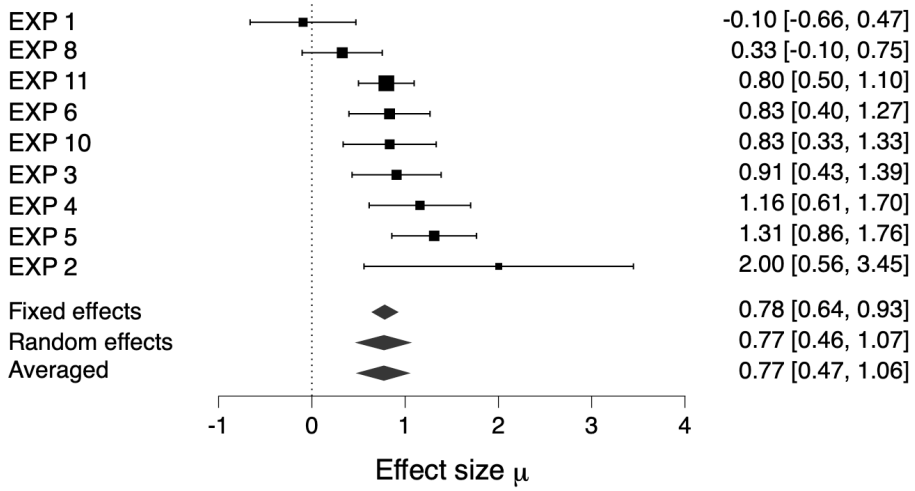


Figure 7.3: Meta Analysis RR with RI of 1 s, forest plot for the effects observed in experiments reported in this thesis. Effect size μ on the x-axis and experiments reported in rows. Effect size with *95% CI* on the right hand side of the plot.

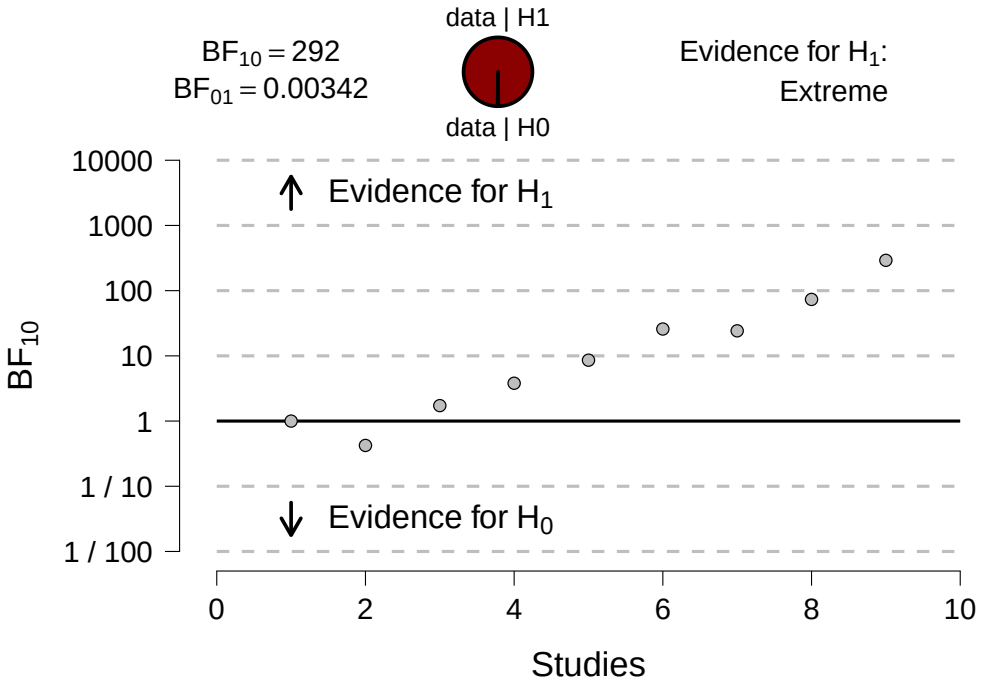


Figure 7.4: Meta Analysis, RR with RI of 1 s, BF_{10}. Sequential Bayes Factor effect size for RR procedure. BF_{10} on the y-axis and studies on the x-axis

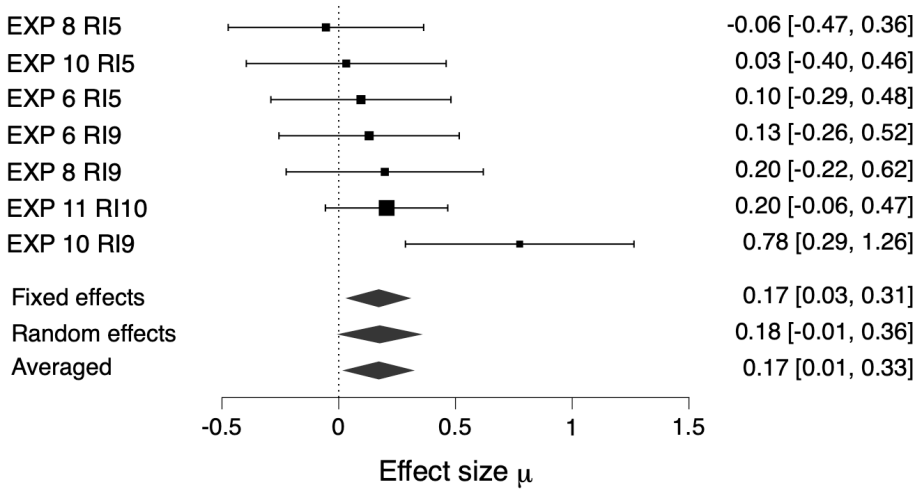


Figure 7.5: Meta Analysis RR with RI of at least 5 s, forest plot for the effects observed in experiments reported in this thesis. Effect size μ on the x-axis and experiments reported in rows. Labels reported as shorthand for Experiment number and RI in s. Effect size with *95% CI* on the right hand side of the plot.

Three experiments had RI set a 5 s and none of those demonstrated a reliable recency discrimination. In four experiments the RI was set at 9 or 10 s with only one experiment yielding a significant discrimination. Of interest were the data from one-sample *t*-test with dependent variable of D2 or $D2_{adj}$. Analysis of results from all experiments with RI of 5 s and longer, summary data presented in Figures 7.5 and 7.6, yielded fixed effects estimate as μ = 0.17, *95% CI* = [0.03, 0.31] with BF_{10} = 1.495 and for random effects, μ = 0.18, *95% CI* = [-0.01, 0.36], BF_{10} = 0.698 yielding an overall averaged BF_{10} = 1.088 indicating an anecdotal level of evidence in support of the $\mathcal{H}_1$ model and μ = 0.17, *95% CI* = [0.01, 0.33].

The key question relating to the SOP is its long lasting temporal stability reported by Mitchell and Laiacona (1998). Authors have demonstrated that the effects of recency are reliable when the RI is at 24, but decline before 72 h. The duration is problematic in terms of SGP, as the process is short term, and implies an involvement of long-term RGP mechanisms. To that extent two potential explana-

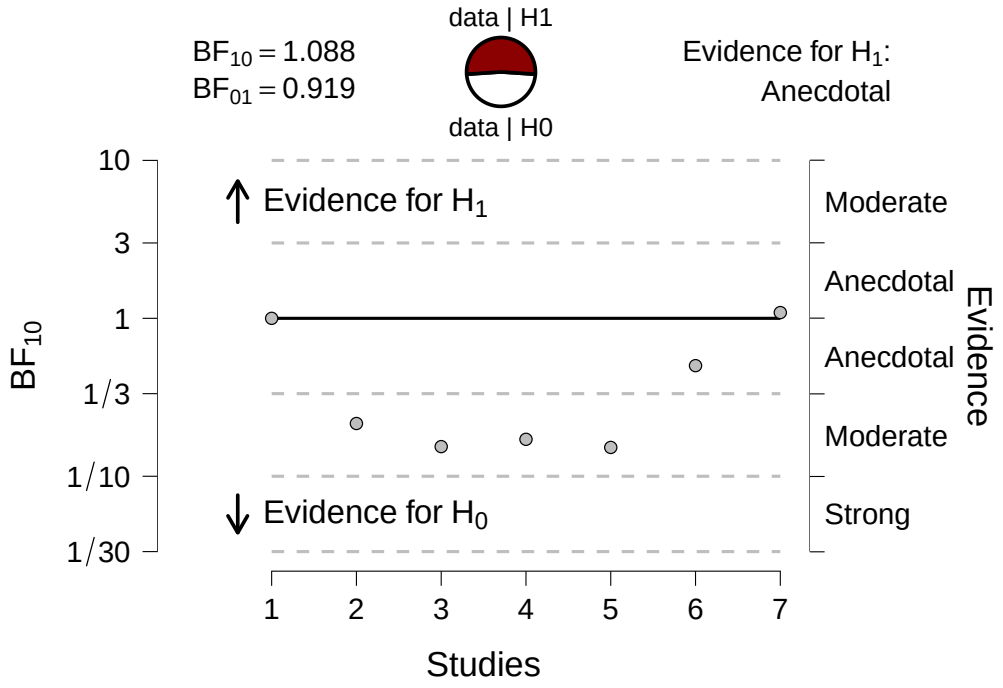


Figure 7.6: Meta Analysis, RR with RI of 1 s, BF_{10}. Sequential Bayes Factor effect size for RR procedure. BF_{10} on the y-axis and studies on the x-axis

tions have been put forward, one attributed to McLaren (personal communication) and one to (Sanderson, 2016), neither of those yielded results which could lend support to the RGP involvement in RR. Results of Experiments, where the RI was manipulated, suggest that the RR is supported by SGP. When the RI was short, 1 s, the preference for the less recent stimulus Q was reliable and supported with extreme level of evidence, however at longer RIs the effect was only supported with anecdotal evidence. However, it must be emphasised that the level of evidence does not directly speak against the *null* model, nor does it support it, and more tests of RR at longer RIs should be performed. Hence, at this point, it would be safe to say that the presence of RR effect at a longer RIs should be deemed inconclusive. The SGP account of RR is further complicated with results from the Experiment 9 (Chapter 6 p. 201), there I have tested the SOP-derived prediction according to which an extension of ISI should result in an improved discrimination on test. This effects have

been demonstrated by Tam et al. (2013) in rodents, however results obtained with human participants could not support the hypothesis, as the extension of ISI from 1 to 9 s yielded no change in $D2_{adj}$. Barker et al. (2019) have recently challenged the SGP account of RR demonstrating that manipulation of ISI has not resulted in a change in D2, arguing that the trace decay mechanism cannot account for the effects of RR. However, an experiment reported there provided only anecdotal and moderate support for the $\mathcal{H}_0$ (BF_{01} = 2.2, BF_{01} = 3.2), lack of difference between the D2 at different levels of ISI. However, both the results of Barker et al. (2019) and those of Experiment 9 potentially be explained with an SOP account operating with much slower decay rates and a robust acceleration of decay when a new stimuli is presented. Overall, there was no evidence to reject the involvement of SGP in RR, but an extreme of support for an involvement of the effect demonstrated on a short RI, but not at longer ones. Outcomes of the simulated RR trials where the RI was extended in time were supported by the data from experimental procedures. The effects of RR discrimination were short-lived supporting the hypothesised involvement of SGP in human recognition memory.

7.3 Object in Place and Object in Context

Out of four experiments, which used OIP procedure and had a RI of 1s, two yielded reliable discrimination where participants spent more time looking at stimuli in novel location. The discrimination was the most robust when four-object version of the task was used (Chapter 6, Experiment 11). Of interest were the data from one-sample *t*-test with dependent variable of D2 or $D2_{adj}$. Analysis of results from all OIP experiments with RI of 1 s, summary data presented in Figures 7.7 and 7.8,

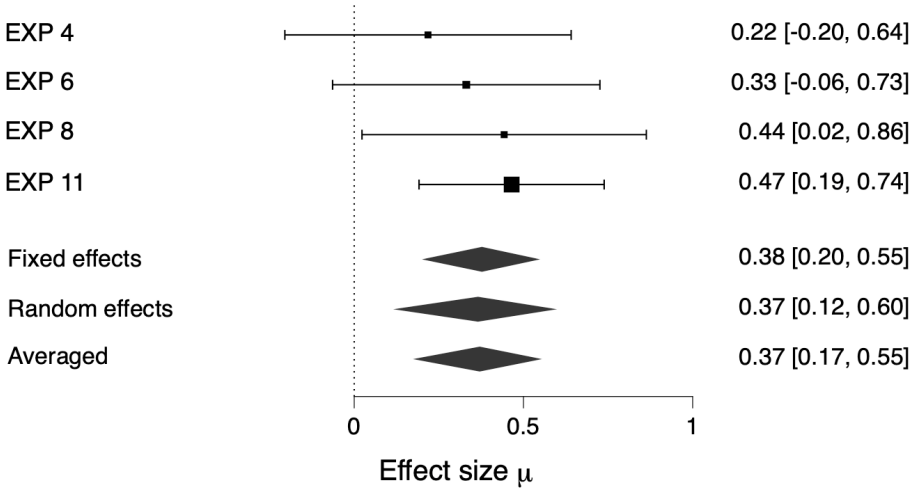


Figure 7.7: Meta Analysis OIP with RI of 1 s, forest plot for the effects observed in experiments reported in this thesis. Effect size μ on the x-axis and experiments reported in rows. Effect size with *95% CI* on the right hand side of the plot.

yielded fixed effects estimate as $\mu = 0.38$, *95% CI* = [0.2, 0.55] with $BF_{10} = 650.225$ and for random effects, μ = 0.37, *95% CI* = [0.12, 0.6], BF_{10} = 6.996 yielding an overall averaged BF_{10} = 22.927 indicating a strong level of evidence in support of the $\mathcal{H}_1$ model and $\mu = 0.37$, *95% CI* = [0.17, 0.55].

One experiment used had a RI of 5 s and the discrimination was not reliable. Longer RIs were used in two experiments, but only one yielded significant discrimination. This finds its reflection in meta-analysis aggregating RIs of 5 s and longer, summary data presented in Figures 7.9 and 7.10, which has yielded fixed effects estimate as μ = 0.18, *95% CI* = [-0.01, 0.36] with BF_{01} = 1.417 and for random effects, $\mu = 0.18$, *95% CI* = [-0.11, 0.48], BF_{01} = 2.377 yielding an overall averaged BF_{01} = 1.762 indicating an anecdotal level of evidence in support of the $\mathcal{H}_0$ model and μ = 0.18, *95% CI* = [-0.04, 0.39]. Of interest were the data from one-sample *t*-test with dependent variable of D2 or $D2_{adj}$.

Data in the OIC experimental conditions was aggregated across three ex-

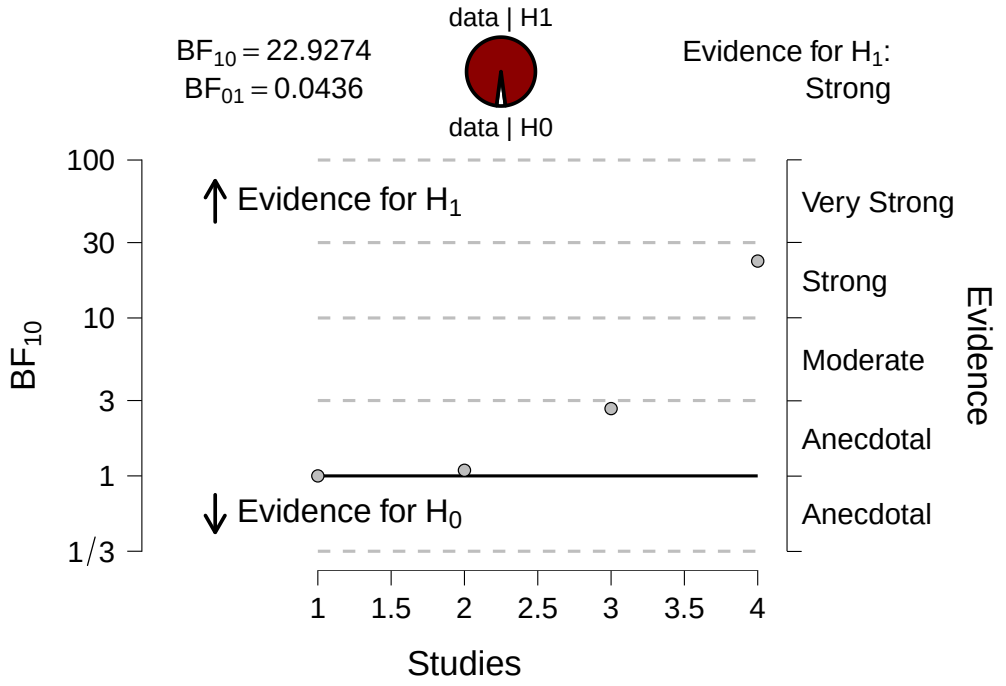


Figure 7.8: Meta Analysis, OIP with RI of 1 s, BF_{10}. Sequential Bayes Factor effect size for RR procedure. BF_{10} on the y-axis and studies on the x-axis

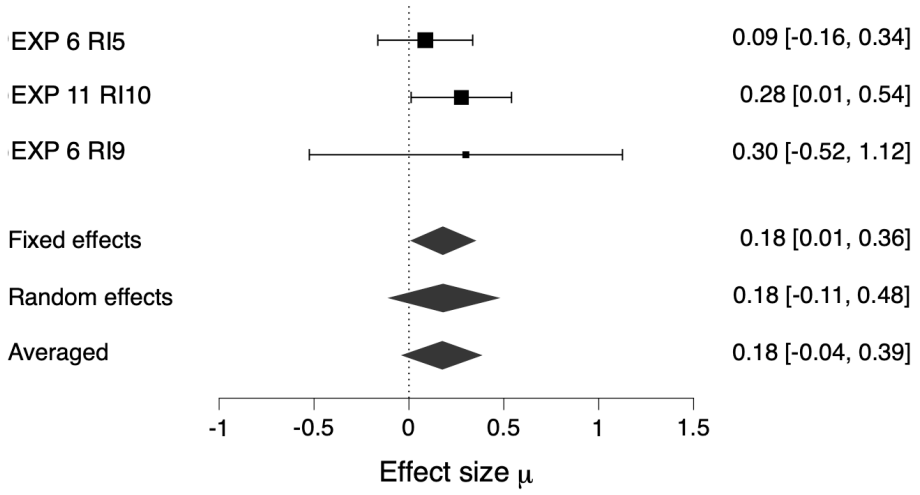


Figure 7.9: Meta Analysis OIP with RI of 5 s or longer, forest plot for the effects observed in experiments reported in this thesis. Effect size μ on the x-axis and experiments reported in rows. Labels reported as shorthand for Experiment number and RI in s. Effect size with *95% CI* on the right hand side of the plot.

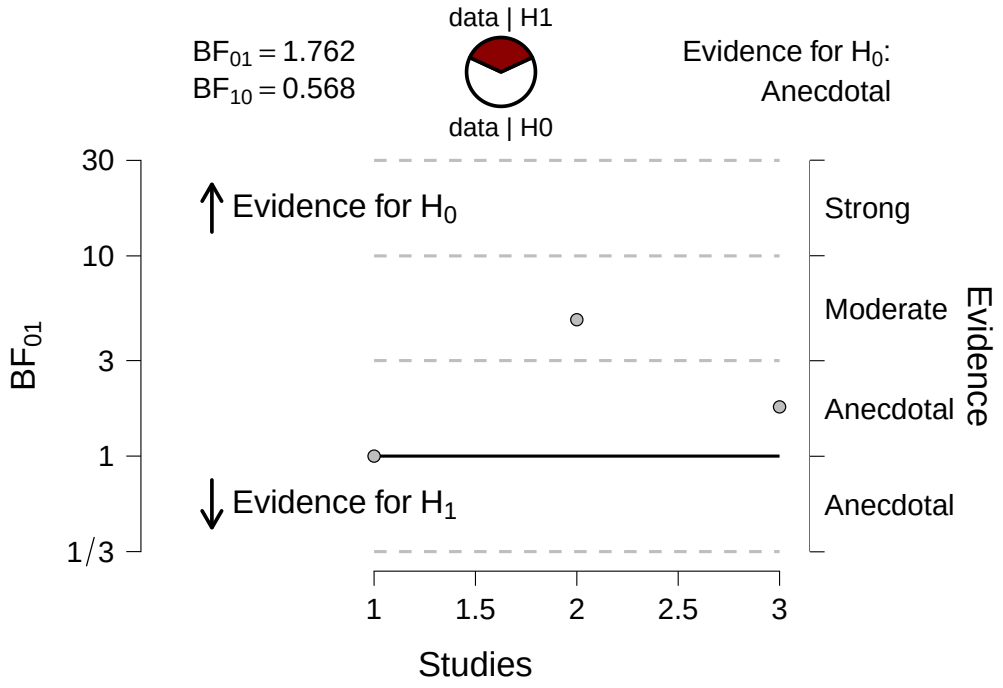


Figure 7.10: Meta Analysis, OIP with RI of 5 s or longer, BF_{01}. Sequential Bayes Factor effect size for RR procedure. BF_{10} on the y-axis and studies on the x-axis

periments, however as OIC conditions were OX and OY the influence of the context was a difference between the D2 or $D2_{adj}$ in both conditions. Hence the data of interest comes from paired-sample *t*-test between the respective means at a given RI, summary data are presented in Figures 7.11 and 7.12. On the RI of 1 s the meta-analysis based on three studies of which two demonstrated a reliable difference between the D2 or $D2_{adj}$ in OX and OY or, as in case of Experiment 11 from Chapter 6, between the OR+ and OR-, yielded fixed effects estimate as μ = 0.49, *95% CI* = [0.3, 0.68] with BF_{10} = 23671.061 and for random effects, μ = 0.47, *95% CI* = [0.15, 0.75], BF_{10} = 7.312 yielding an overall averaged BF_{10} = 20.69 indicating a strong level of evidence in support of the $\mathcal{H}_1$ model and μ = 0.48, *95% CI* = [0.24, 0.71].

For the experimental conditions with RI of 5 s and longer, summary data presented in Figures 7.13 and 7.14, the fixed effect was μ = 0.17, *95% CI* = [-0.02,

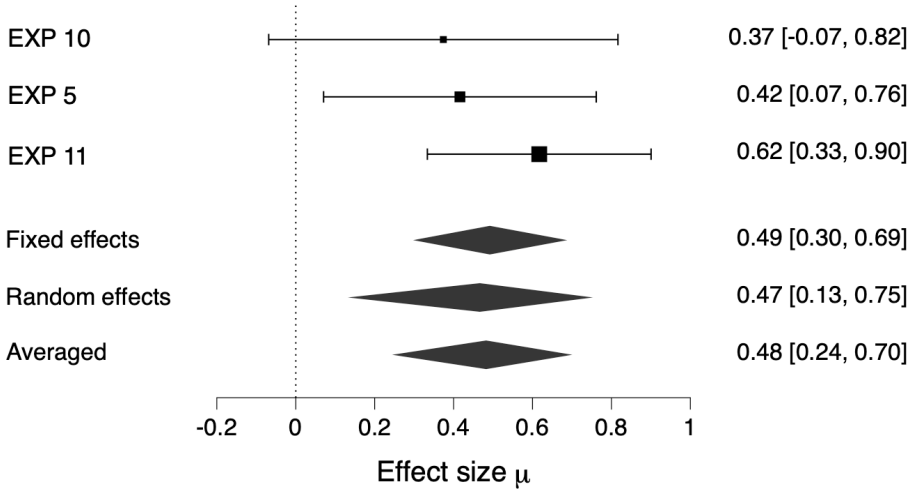


Figure 7.11: Meta Analysis OIC with RI of 1 s, forest plot for the effects observed in experiments reported in this thesis. Effect size μ on the x-axis and experiments reported in rows. Effect size with *95% CI* on the right hand side of the plot.

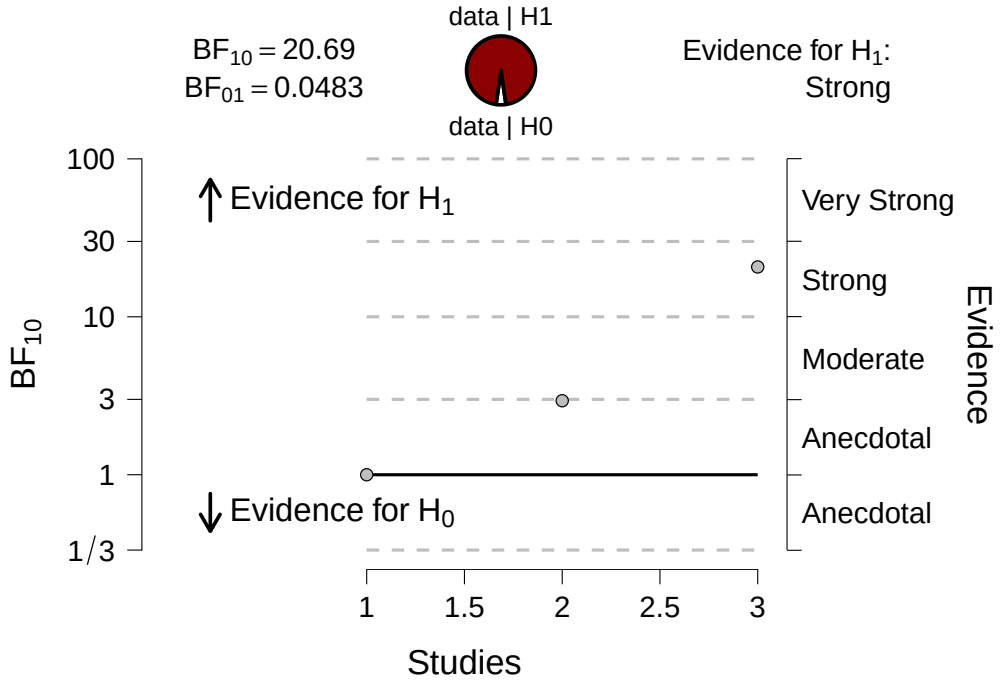


Figure 7.12: Meta Analysis, OIC with RI of 1 s, BF_{10}. Sequential Bayes Factor effect size for RR procedure. BF_{10} on the y-axis and studies on the x-axis

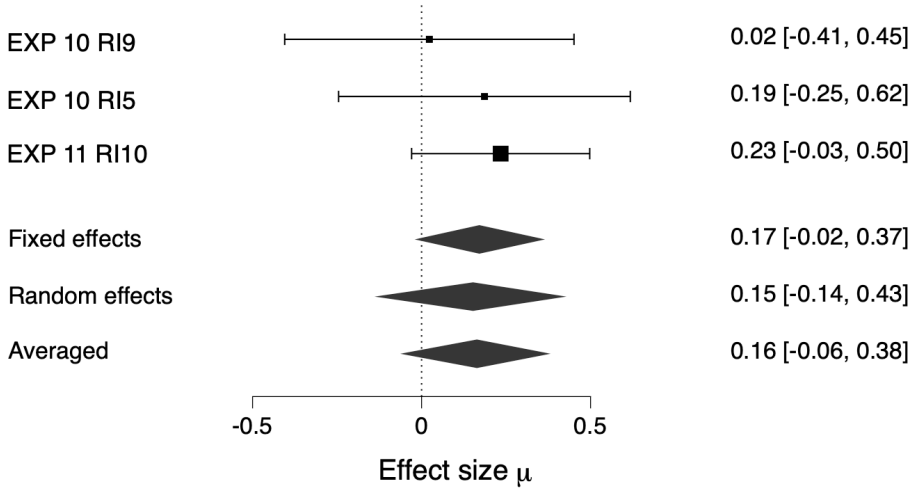


Figure 7.13: Meta Analysis OIC with RI of 5 s or longer, forest plot for the effects observed in experiments reported in this thesis. Effect size μ on the x-axis and experiments reported in rows. Labels reported as shorthand for Experiment number and RI in s. Effect size with *95% CI* on the right hand side of the plot.

0.37] with BF_{01} = 2.022 and for random effects, μ = 0.15, *95% CI* = [-0.14, 0.43], BF_{01} = 3.004 yielding an overall averaged BF_{01} = 2.346 indicating an anecdotal level of evidence in support of the $\mathcal{H}_0$ model and μ = 0.16, *95% CI* = [-0.06, 0.38].

Results of OIP and OIC meta-analysis with RI of 1 s demonstrated a strong evidence in support of an associative RGP in recognition memory. This is of importance as the results are in line with animal preparations (Langston & Wood, 2010; Honey et al., 2007; Tam et al., 2014; Barker & Warburton, 2020; Eacott & Norman, 2004; Honey et al., 1998; Honey & Good, 2000; Good et al., 2007; Barker et al., 2007; Tam et al., 2013) but in a stark contrast with results from human studies (Ryan et al., 2020, 2000; Hannula et al., 2007; Mahoney et al., 2018; Ryan et al., 2007; Hannula & Ranganath, 2009). Evidence stemming from OIP and OIC procedures, reported in the thesis support the hypothesis that participants spend more time looking at stimulus which is presented in a novel context or when environmental cues cannot predict the location of stimuli. The difference between my

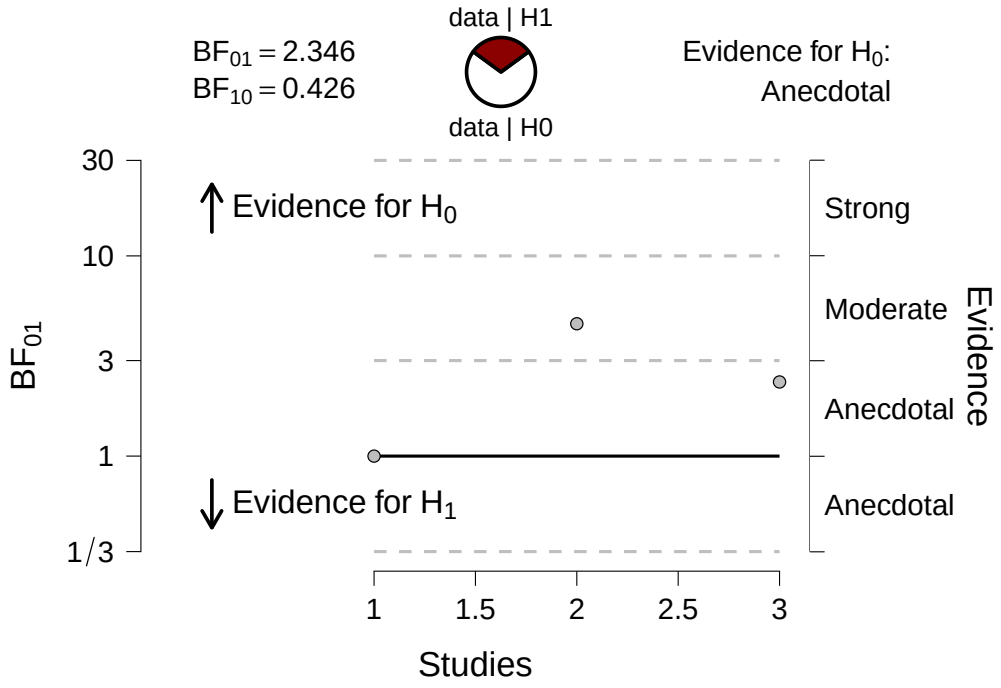


Figure 7.14: Meta Analysis, OIC with RI of 5 s or longer, BF_{10}. Sequential Bayes Factor effect size for RR procedure. BF_{10} on the y-axis and studies on the x-axis

findings and findings of Hannula and colleagues can be explained by the nature of tasks which were used; whereas the task instructions employed in the experiments reported here did not include any reference to the recognition memory being studied but asked participants to respond to stimuli in a way which would imply memory test. Experiments from Hannula and others involved identification of context-match stimulus. In Ryan et al. (2007) authors noted that, despite the robust novelty preference demonstrated as obligatory and automatic, the task demands have an influence on looking time. Findings reported here make contact with those of Loftus and Mackworth (1978) who demonstrated that participants spent more time looking at objects which were not coherent with the scene showing that prior knowledge about objects' relations influence the scene exploration.

The results presented here demonstrate the associative priming effects in humans which are in line with the SOP-derived predictions. However, the evident

temporal decay of RGP effects is surprising in terms of SOP theory. Difference between the OR+ and OR-, robust at a short RI in Experiment 11 (Chapter 6), were not reliable at a longer RI. While this observation is not surprising for the effects of RR, it is unclear as to why the effects of RGP did not survive at a longer RI. In contrast, in the OP condition the preference for displaced items was reliable at both RIs. This might have been due to the better facilitation of associations between the spatial cues and experimental stimuli in the OP. There, during the sample phase, an array of four objects was presented twice, whereas in the OR+/- conditions stimuli AB was presented in S1 and CD in S2. Hence, the OP could have provided an environment which could foster better associative learning, each stimuli could have potentially entered into bilateral relationships with other stimuli. Furthermore, because the array was repeated twice, an associations had a better opportunity to develop. In the OR+/- the association could have been formed with the other stimuli with which it was presented during the sample. Test performance, which in OP was reliable at both RIs, could have been then explained by the summation of, at least, two environmental cues provided by the stimuli which has not been displaced on test. However, even the OP underwent a certain, albeit small with $\mathcal{H}_0$ = 2.598, degree of $D2_{adj}$ reduction at a longer RI. However, the effects are better illustrated with the reduction in preference observed in OR+, which from a very robust effect (BF_{10} = 114.66) reduced to an anecdotal (BF_{10} = 2.652).

In contrast to SGP, the associative effects should not undergo a decay; the only way by which the associative strength can be reduced is through extinction. The signalling stimulus (*CS*) is presented without the stimulus it signals (*US*) and as a result, only the inhibitory learning value will increase. However, it is possible

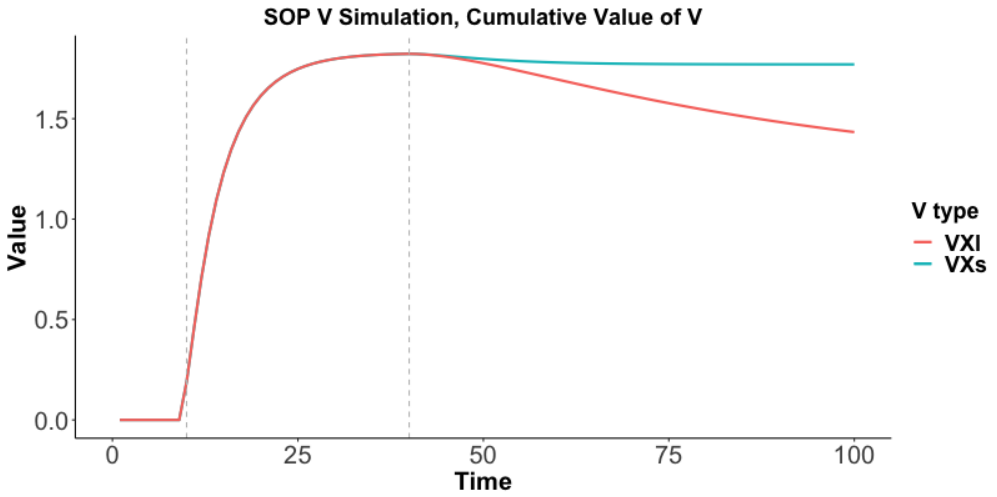


Figure 7.15: Simulation of two models of associative strength V_{XP} based on different X and P presentations. In *VXs* (green) both P and Q were presented between 10 - 40 moments and in VXl X was presented between 10 - 100 moments while duration of P remained the same. Simulation run with parameters $p1_X$ = 0.6 and $p1_P$ = 0.8, $pd1$ = 0.1 and $pd2$ = 0.02, learning parameters were set at L^+ = 0.5 and L^- = 0.1.

the effects are enabled by an association between the stimulus and latent context, experimental environment such as screen background or other features which were not controlled, and during the RI, when the background remains on the screen, the association is extinguished. Simulation presented in Figure 7.15 demonstrates results of two hypothetical experiments, in *VXl* the context X was presented for a longer duration (10 - 100th moments) than P (10 - 40th) and in *VXs* presentation of both was of the same length (10 - 40). Both models were able to achieve the same level of V_{XP}, however strength V in the former was considerably reduced during the time when the X was presented without the P.

Here, the longer presentation of the context X resulted in reduction of V_{XP}, and given a longer presentation, it would follow the gradient of decay to finally be completely extinguished. In the context of meta analysis of results in OIP and OIC at 1 s and 5 s < RIs, which demonstrated strong support for the $\mathcal{H}_1$ at the

former, but an anecdotal support the $\mathcal{H}_0$ at the latter, this interpretation is plausible.

7.4 SOP as a model of human recognition memory

Reported here experiments used a modification of VPC/SOR procedure to better test the associative and non-associative effects involved in human recognition memory. Two contrasting points between the episodic and associative accounts have been brought forward in Chapter 2 (pg. 54).

First point, regarded the effects of associative memory on VPC performance. In contrast to evidence presented in support of the episodic account I have not obtained results which would support such account. Collectively, the evidence from experiments using OIC and OIP procedures provided a strong support to the predictions of SOP; participants spent more time exploring stimulus which did not match the cognitive map. RGP influence on the human recognition memory resembles that of other mammals, namely that stimulus presented in novel context will be explored more than one presented in previously paired context, a finding which goes against the current opinion (Ryan et al., 2020, 2000; Hannula et al., 2007; Mahoney et al., 2018; Ryan et al., 2007; Hannula & Ranganath, 2009). However, the support for associative account was limited to the short retention interval, an effect which is problematic for either the SOP and episodic accounts. In Experiment 11 (Chapter 6) it has been demonstrated that when repeated presentation is used and more time is given to form an associations between the stimuli and environmental cues an influence of RGP can be detected at a short and long retention interval. However,

the effect could not have been observed in Experiment 10 where the effects of OIC were detectable at a short but not at the long RI. The key differences here were the number of sample phases and amount of stimuli presented. Hence, it is plausible that longer time allowed for stimuli to be sampled would yield better discrimination.

Second point of contention point was regarding the nature of RR. Here, the episodic account argued, that each sequence of stimuli forms an event and time manipulation should not interfere with the effects of RR. Experiments reported here demonstrated a robust effect of recency discrimination supported with extreme level of evidence when the RI was short. Longer RIs resulted in inconclusive evidence. However, the results of Experiment 8 and Experiment 9 may put some doubt in this statement. In the former the the RR could not be observed at the shortest RI, although the direction of $D2_{adj}$ was in line with expected effect. While the lack of sensitivity to recency in a sequential test may be due to procedural issues, the lack of RR cannot be attributed to the same factor as all other experiments demonstrated a reliable RR with the exactly same procedure. In light of replication of this result with reliable effects, it can then be assumed that lack of significance is due to chance. Demonstrated in Experiment 9 lack of influence of ISI extension on the $D2_{adj}$, is problematic for the SOP and the results are more in line with episodic account, as extension of ISI have not resulted in change in predicted by the SOP recency discrimination. Finally, I was unable to resolve puzzling results of Mitchell and Laiacona (1998) as neither of the assessments of the proposed RGP-based accounts were conclusive. This however does not disqualify the SOP as a model of recognition memory, but should encourage further research in this area.

7.5 Implications for the SOP account of recognition memory

Given the plethora of research which have been successfully applied the SOR-derived procedures of RR, OIC/P to study recognition in animals, human adaptations are of a lesser popularity and are mainly limited to clinical and developmental scholarship. However, the use of procedures presented in this report may be of benefit as they offer a more sensitive measure (Sivakumaran et al., 2018) of memory signal. It has been argued that the effects of recognition memory should be distinguished from those of priming (Chen & Hutchinson, 2018) and because recognition is akin to declarative memory, classical conditioning is not adequate to fully appreciate it. However, it has been demonstrated that the effects observed in SOR are in line with those used in mainstream recognition procedures (Richmond et al., 2007; Smith, Hopkins, & Squire, 2006; Sivakumaran et al., 2018) and that SOR is well equipped to study human recognition memory (Smith et al., 2006). Hence, if SOR, being a recognition memory test, can be understood in terms of an associative process, then the same approach will be valid to study its human analogue. Capturing human recognition memory as an associative process benefits from parsimony of the approach and extensive findings reported in this line of research. Furthermore, use of the SOP can yield quantifiable predictions an encouraged practice in current day scientific research.

The temporal specificity of SOP-suggested influences on recognition were replicated with experimental data. The window of most sensitivity was temporary

located in the early phases after the onset of stimuli array. Same pattern of results is suggested by the model simulations but its temporal specificity has not been verified in a direct test in human population. This contributes to the assertion that the SOP is an robust tool in study of temporal dynamics of learning and memory, particularly at the level of single trial.

Results of Experiment 1 when contrasted with findings from research concerning influence of LTM on attention (Summerfield et al., 2006; Chun & Jiang, 1998) hint at an interesting path of enquiry pertaining to influence on processing speed and $A1$, $A2$ activation. An hypothetical argument can be put forward that the $A2$ activation results in a facilitation of RT to the representation matching stimulus, whereas the $A1$ results in slower RT resulting from a requirement for higher processing of stimuli in $A1$ activation.

Further SOP model development should aim to reduce the number of parameters. In the spirit of model parsimony, both the Bayesian Information Criterion (BIC; Neath & Cavanaugh, 2012; Vrieze, 2012; Wagenmakers, 2007) and Akaike Information Criterion (AIK;Wagenmakers & Farrell, 2004) model selection methods, are biased towards selecting those with less parameters. Hence, the SOP should aim to reduce the amount of free parameters to be competitive from the purely computational perspective. One suggestion would be to fix $pd1$ and $pd2$ decay parameters with mathematically defined functions, such as exponential decay.

Finally, contact could be made with activation states and neural correlates and areas of media temporal lobe and prefrontal cortex should be of interest as they have been implied in associative and non-associative processes. Because temporal

dynamics are crucial for the SOP the best candidate here would be analysis of time-frequency neural oscillations (Cohen, 2014; Cohen, 2011; Ranganath, Cohen, & Brozinsky, 2005; Kucewicz et al., 2014). This attempt would enable biological plausibility of the model which is tenable in light of early study of Wagner and Donegan (1989) who demonstrated that rabbits' eye blink neural circuitry response resembles SOP prediction.

7.6 Methodological considerations

Experiments reported in this thesis demonstrated that the best sensitivity to the effects of recognition memory are obtained under specific experimental conditions. Foremost, in Experiment 1 it has been demonstrated that task demands have to be set with caution, certain instructions can bias the eye movements which would obscure the effects that can be attributed to recognition memory. The key implications here are two-fold: firstly an experiment must be designed in a way which finds a balance between keeping participants engaged with, often lengthy and repetitive, experiments and employing a task that would ensure engagement but could potentially interfere with studied phenomena (Holmqvist et al., 2011). I argue that using engagement tasks similar to those used in the majority of experiments reported in this thesis finds this balance. The second, related, matter applies to interpretation of results from human recognition memory experiments which used eye tracking methods. This problem is evident when results from animal recognition memory procedures of OIC and human adaptations are contrasted, as demonstrated in Experiment 5 (Chapter 5), Experiment 10 and Experiment 11 (Chapter 6). I have demonstrated that tasks used in this thesis are fit for purpose, while it is possible

that other, better, procedures would be more sensitive, the directly tested adaptation of Posner (Posner, 1980) and dot probe (MacLeod et al., 1986) tasks have been demonstrated not to be sensitive to the effects of interest. In general, the takeaway for future research that I would like to offer here, is that the cover task should encourage participants to engage with experimental stimuli, however it should not in any way bias the selection of certain stimuli based on characteristics of interest related to memory (Holmqvist et al., 2011). Furthermore, the task should be easy to comprehend and should not tax participants' cognitive resources, here the simpler-the-better is a suggested rule of thumb.

Another crucial consideration concerns the temporal aspect of the effects of interest. Multiple simulations performed for the purpose of this report demonstrated that the effects of preferential exploration should be most profound in the early stages of stimulus presentation. This dynamics follow those presented in the other simulations of SOP (Brandon et al., 2003; Vogel et al., 2019) and mirror findings of Sivakumaran et al. (2018), who used VPC in human participants. However, to the best of my knowledge, such effects have not been experimentally demonstrated in the context of RR, OIC or in animal procedures. Here, across multiple experiments, I have shown that the dynamics of $A1$ activation, limited to the early stages of stimuli processing, find reflection in the pattern of preferential exploration evident from the data. The onset of the effect is not immediate and the time it takes for saccade to be initiated (Carpenter, 1988), which appears to occur during the first 0.5 s. However, during the time following that window, that is between 0.5 and 1.5 s, the preferential exploration of stimuli is in line with SOP-modelled behaviour. Tracking method developed for the purpose of this thesis enabled this analysis.

7.6.1 Software Development

Two software applications have been developed for the purpose of this thesis. First was the eye tracking method which enabled a more reliable, less taxing and more temporally precise analysis of the data. Based on the PsychoPy (Peirce & MacAskill, 2018) experimental software and Tobii TX300 device, the method is easy to use and adapt with minimal programming experience and have been described elsewhere in detail (Nitka, 2020). The method allows for easy implementation of high density data collection during the experiment with each second of eye tracking yielding up to 300 data points for each eye. The data can then be extracted to user-friendly csv file format for further processing.

Second application encompasses a computational implementation of the SOP tenets into a simulation software. The implementation focuses mainly on a single trial simulation of RR and OIC/OIP which is a key difference with software developed by Byers, Mondragon, and Alonso (2017). The code is fully open source and all code used for simulations performed for this thesis is available from author's github website. Furthermore, a responsive, intuitive to use simulation has been developed in R Shiny (Chang et al., 2020) environment. The software allows for simulation of procedures with different parameters which may serve as a teaching tool or development of SOP-based experimental predictions.

8 | Placement Report

Between September and December 2018 I have spent three months at Carlisle Attention & Memory Lab (CAML) run by Dr. Nancy Carlisle at the Lehigh University (Bethlehem, Pennsylvania, USA). During my time in the lab I was involved in research concerning influences of working memory on human visual attention. This was through running experimental sessions with participants and supervising undergraduate voluntary research assistant helping with data collection. I have also helped with data analysis of previous, related experiments and prepared experiments in PsychoPy and Matlab. Furthermore, having some experience in the area of EEG research, I developed a data processing pipeline based off EEGLAB (Delorme & Makeig, 2004) and ERPLAB (Lopez-Calderon & Luck, 2014) software (Matlab).

Outside of the data-related work I was also able to finalise a manuscript which have later appeared in print (Carlisle & Nitka, 2019). I was also given a chance to present my PhD work during the CAML, Cognition and Language group as well as during the departmental Brown Bag meetings. Each of this opportunities were a great experience as it gave me an opportunity to engage with audiences of different expertise levels and interests.

On two occasions I also engaged with the postgraduate colleagues; I have organised a session where I demonstrated how to work with PsychoPy, and on another occasion I gave an informal teaching session on the R Shiny package.

Perhaps the most valuable to me was an opportunity to experience an academic setting in a non-British environment, which I have found to have some differ-

ences. One difference was the emphasis on collaboration and ease with which a new working relationships were made. Departmental culture relied on frequent meetings which were well attended, faculty, postgraduates and undergraduate students had a weekly meeting during which they discussed research or their projects (lab meetings). Also weekly were the group meetings (Cognition and Language) where faculty and graduates discussed own or recently published research. Furthermore, also on a weekly basis were the Brown Bag meetings, an hour-long departmental lunch sessions during which faculty and graduate students gave a presentation on research ideas they had or presented recent findings. Slightly less often were the seminars for which invited speakers came, such meetings were open to all faculty and students in the Department and were followed by a lunch, for interested, during which less formal networking would be fostered. Invited speakers included scholars Cornell, Princeton, Rutgers and SUNY Albany who talked about their research in the areas of psychology and cognitive science.

The ethos of collaboration also crossed the departmental lines, I was involved in an initial, brainstorming meeting with researchers from Computer Science department who wished to collaborate on a project which evaluated Amazon and Yelp reviews. It was an exacting opportunity to apply my knowledge in a different setting and to foster my science communication skills.

Overall, the placement was of a great value in my development, I have had a chance to experience a different model of academia, polish my programming and EEG analysis skills, network with researchers and improve science communication skills.

A | Appendix

A.1 Appendix A

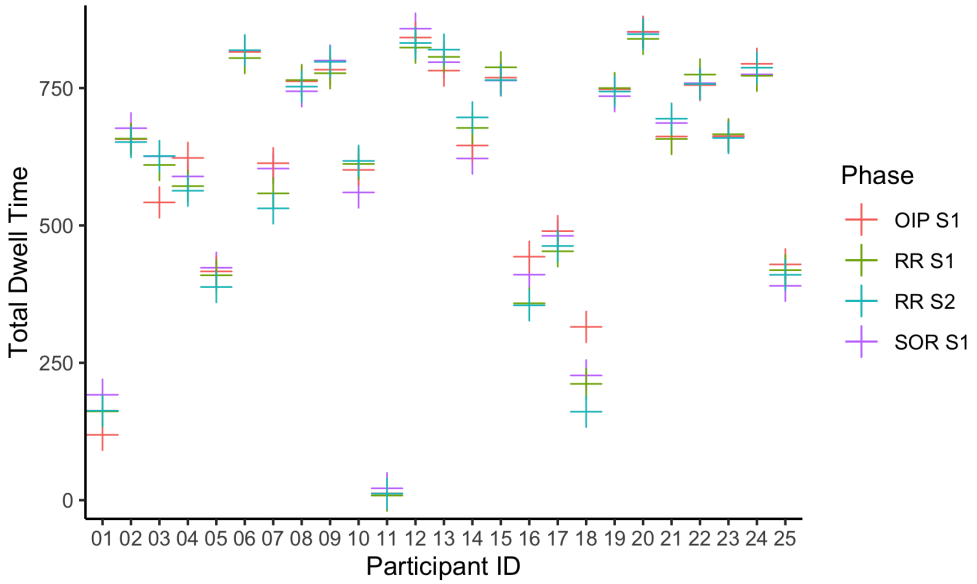


Figure A.1: Appendix A, Chapter 5, Experiment 3: mean dwell time for each participant recorded during the sample phases. Each point represents an average dwell time during a given phase labelled with different colours. Dwell time (y-axis) is in total dwell time to stimuli during an entire sample phase. On x-axis is the participant ID.

A.2 Appendix B

Algorithm (meta code) for location selection, performed in an iterative way, step-by-step, for each trial:

- Set available locations = [top left, top right, bottom left, bottom right]
- Location for Q assigned from design, with all locations represented equally, remove Q-assigned from available locations.
- From available locations select locations which are on the opposite side to Q,

randomly select location for P from that set. Remove P-assigned location from available locations.

- For OX and OY trials only: From all remaining available locations randomly select location for X/Y.

- Repeat for each trial.

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