What influences the automaticity of feature binding? The roles of unitisation, culture and prior knowledge

Hiu Wah Cheung

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Department of Psychology

University of Essex

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Abstract

Feature binding means integrating different features, such as colour and shape, into coherent objects in working memory (WM). The automaticity of feature binding may depend on whether the to-be-bound information is intrinsic (belonging to) or extrinsic (contextual). Furthermore, according to the Analytic and Holistic framework, extrinsic binding may be more automatic for Easterners who process information more holistically than Westerners. Additionally, prior knowledge in long-term memory (LTM) may facilitate binding in WM, such that Eastern participants may more automatically integrate extrinsic features that are further facilitated by LTM in Western participants. Whether the basic unit of storage in WM is object-based (store information as coherent object representation), feature-based (store information as independent features) or that both co-exist in WM may also influence the automaticity of feature binding. Based on this background, this thesis investigated how unitisation (Experiments 1 to 4), culture (Experiments 1 to 3), prior knowledge (Experiment 2) and the basic unit of storage in WM (Experiment 4) influence the automaticity of feature binding in four experiments. Accordingly, in Experiments 1, 2 and 3, I recruited Western and Eastern participants to complete a visual WM task wherein to-be-remembered colours are integrated within (i.e., intrinsic binding) or as backgrounds (i.e., extrinsic binding) of to-be-remembered shapes. In Experiment 4, I recruited Western participants to complete a continuous report paradigm with briefly presented arrays of individually calibrated numbers of shapes. Participants were required to recall the colour or location of the probed shape. The current results suggest that the automaticity of feature binding in WM depends on unitisation and the basic unit of storage in WM, but not cultural differences or prior knowledge. In addition, both feature-based and object-based storage may co-exist in WM, but whether WM is more feature-based or object-based storage depends on unitisation.

Keywords: working memory, cultural differences, binding, unitisation, prior knowledge

Chapter 1: Introduction

1.1 Psychology as universal versus culturally specific

The principal enterprise of psychology is to understand the processes underlying human behaviour and cognition, with an often-unstated assumption being that these processes are universal and immutable across adults. However, much work has demonstrated a complex tapestry of individual (e.g. Unsworth, 2019; Wierzba et al., 2018), developmental (e.g. Barrett et al., 2004; Rhodes et al., 2021), and cultural differences (e.g. Ji et al., 2000; Nisbett et al., 2001) across psychology, particularly memory performance (e.g. Park et al., 1999; Park & Gutchess, 2002; Park & Gutchess, 2006).

Despite assumptions that much of the human cognitive machinery is universal, the influence of culture is quite pervasive. Indeed, research has shown that people's perception of the physical and social world and associated memory processes are affected by culture (Nisbett et al., 2001). For example, Yoon et al. (2004) reported that culture-specific learning and experiences greatly influence memory. Another study also reported that when European Americans reported memories related to their own experiences, they more often describe their emotions and self-consciousness than Asian participants (Wang, 2004). On the other hand, Chinese and Asian Americans often reported memories related to group activities and interpersonal relationships instead of their own experience (Han et al., 1998; Wang & Leichtman, 2000). I will explain many more examples of cultural differences relevant to this thesis in the next sections.

The research conducted thus far on this distinction between Western[1] and Eastern participants has yet to be considered in the working memory (WM) literature. WM is the cognitive system responsible for temporarily maintaining information for further processing during perception and action (Baddeley, 2003; Cowan, 2017). For example, imagine that you are preparing for a science exam and need to remember some leaves to identify them during the exam. When trying to remember the features of those leaves, such as their shapes, colours, etc., you need to combine those features together in WM. The process of combining all the features of an object in WM is called feature binding. Based on the background I will develop in forthcoming sections; culture is very likely one of the factors that may influence feature binding. Additionally, there may be other factors, such as unitisation, prior knowledge, how we store information in our WM, that also influence the process of feature binding. This chapter will introduce all of them in detail, and this thesis will investigate all these possible factors that may influence the process of feature binding in WM in a series of experiments.

1.2 Working Memory and Cognition

Researchers have tried to explain the underlying mechanisms of WM using different models since James (1890) proposed the concept of primary memory and secondary memory. Primary memory refers to the memory of an event that just happened, and secondary memory refers to the memory of events that have left immediate awareness. Since then, researchers have introduced terminology for similar concepts. The three types of memory that are commonly used in the current literature and also most relevant to the topic of this thesis are long-term memory (LTM), short-term memory (STM) and WM. LTM is similar to secondary

[1] The term “Westerners” used in this thesis refers primarily to people living in the region of Europe, North America, and Australia. On the other hand, Easterners are the people who come from Asia and Middle Eastern regions.

memory, which comprises the storage of knowledge and past events (Atkinson & Shiffrin, 1968). Broadbent (1958) and Atkinson and Shiffrin (1968) proposed a new term, STM, which is similar to primary memory. STM reflects the cognitive system that holds a limited amount of information at an accessible state for a temporary period of time. Miller et al. (1960) proposed a new term WM, and Baddeley and Hitch (1974) proposed replacing STM with WM. As defined previously, WM is the cognitive system that maintains information for a short period of time when one is working or acting on that information. Baddeley (2003) clarified that STM is a system only maintains information, whereas WM additionally processes it. Cowan (2008) further suggested that the distinction between WM and STM is that WM includes STM and all other processing mechanisms that help to access STM. The relation between LTM, STM and WM will be discussed in more detail in the following section.

1.2.1 Working memory models

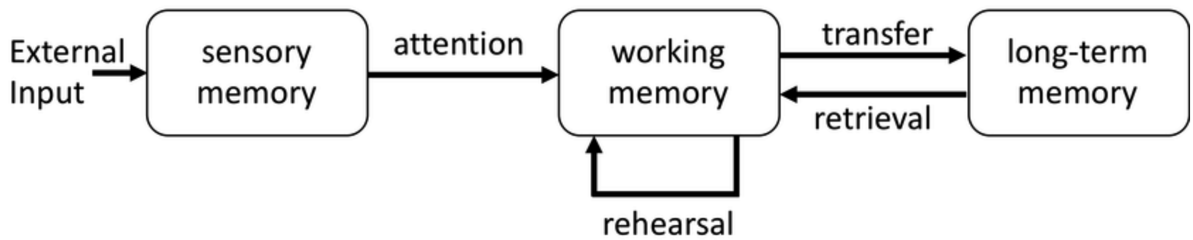
There are several models of memory that try to explain the underlying mechanisms of how WM works, why it is capacity-limited, and how it interacts with LTM. In this section, I will introduce the models that are most relevant to the topic of this thesis.

There is no consensus about whether WM and LTM are distinct systems or a single unitary store activated differently. Models of memory can be classified into three groups according to the different explanations about the relationship between WM and LTM. First, there are some who make no distinction between WM and LTM at all (Crowder, 1993; Nairne, 2002). Second, other models such as the multi-store model (Atkisnon & Shiffrin, 1968) and the multi-component model (Baddeley & Hitch, 1974) view WM and LTM as related but separable systems. Finally, the embedded-processes model (Cowan, 1999) and concentric model (Oberauer, 2002) similarly suggest a kind of middle-ground that WM is a temporarily activated subset of LTM. I will explain each of these models in the following section to consider the relationship between WM and LTM in this thesis.

Multi-store model (Atkinson & Shiffrin, 1968). The first one is the multi-store model (Atkinson & Shiffrin, 1968). As shown in Figure 1.1, this model assumes there are three main separate memory stores: sensory memory, STM and LTM. These three components differ in how the information is processed or encoded, how many items can be stored and for how long. This model proposed that information is transferred between these three components or stores in a linear sequence. Once a person perceives a piece of information from their surroundings, then that information will enter sensory memory first through the sensory register. After that if people pay attention to that information, it will be transferred to STM from sensory memory and stay in the STM for a short period of time. If the information is rehearsed, it will be consolidated into the LTM and it can be retrieved in the future.

Figure 1.1

An Illustration of the Multi-store Model (Atkinson & Shiffrin, 1968)



Note: Reproduced from "Referring to the recently seen: reference and perceptual memory in situated dialog" by J.D. Kelleher and S. Dobnik, 2019, *arXiv preprint arXiv:1903.09866*. Figure 2.

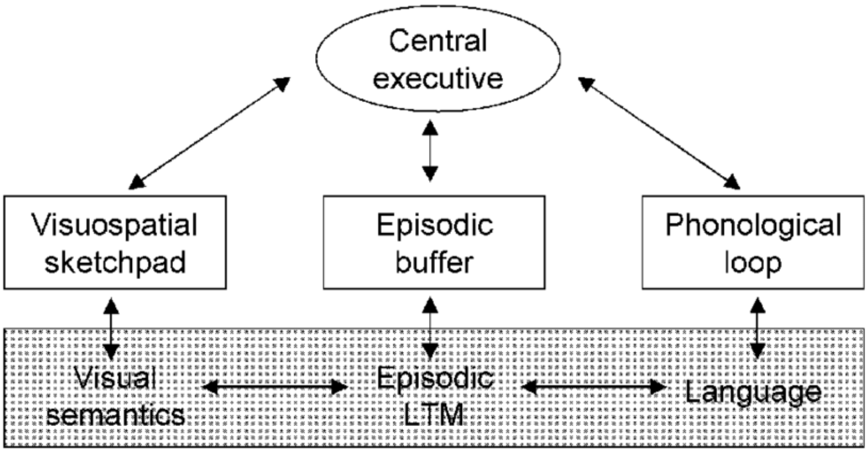
The architecture of this model (i.e. STM and LTM are two separated stores) is supported by a classic case study of HM (Scoville & Milner, 1957). HM is a man who lost the ability to make new memories. He could hold information in his STM, but he could not make new memories, as he could not transfer the information from his STM to LTM. If STM and LTM were not separate stores, then his STM would be impaired as well. However, this was not the case given that his impairments were specific to LTM but not STM. This was taken as evidence that LTM and STM are two separate systems.

Another classic case study of KF (Shallice & Warrington, 1974), a young man with brain damage after a motorcycling accident, challenged the multi-store model's claim that information flows from STM to LTM. Specifically, the LTM abilities of KF were normal, but he only could hold about two units of information in his STM, which is much less than normal people without brain damage (i.e. around 7 units, see section 1.2.2 on WM capacity limits). The case of KF thus contradicts the model's claim that information flows from STM to LTM: if information flows from STM to LTM, then he should have some deficit in creating new memories in LTM as well if his STM is impaired. However, it does not seem the case here for KF; instead, it seems like the information has by-passed STM to go straight into LTM. Therefore, the case of KF challenged the structure of multi-store model.

Multi-component model (Baddeley & Hitch, 1974). A schematic illustration of the multi-component model is given in Figure 1.2. The multi-component model was first proposed by Baddeley and Hitch in 1974. This model proposed some deviations from the multi-store model, such as replacing STM with WM, as STM can only hold information, but WM can hold and process information.

Figure 1.2

An Illustration of the Multi-component Model (Baddeley, 2000)



Note: Reproduced from 'The episodic buffer: a new component of working memory?' by A. Baddeley,*Trends in Cognitive Sciences*, 4(11),pp.286-291, Figure 1, https://doi.org/10.1016/S1364-6613(00)01538-2, Copyright 2000 Elsevier Science Ltd.

The original three-component model included the central executive, the visuospatial sketchpad and the phonological loop. The central executive manages the whole WM system and allocates data to the subsystems (i.e. phonological loop and visuospatial sketchpad). The visuospatial sketchpad is a component in WM that stores and processes information in a visual or spatial form. The phonological loop is a component of WM which deals with spoken and written materials. The two subsystems in the phonological loop are the phonological store and the articulatory process. The speech-based form of information is stored in the phonological store, and the articulatory process allows us to repeat verbal information in a loop. Evidence for the phonological loop comes from research showing the phonological similarity effect (Baddeley, 1966), the irrelevant sound or speech effect (Colle & Welsh, 1976) and the word length effect (Baddeley et al., 1975). For example, Baddeley (1966) reported that similarity of sounds reduced the number of words recalled, whereas the similarity of meaning has little effect. Colle and Welsh (1976) also found an deleterious effect of irrelevant sounds on both visually presented stimuli and auditorily presented items. Baddeley et al. (1975) found that immediate memory for word sequences declined as the spoken length of words increased. This evidence supported the assumption of the model that phonological information impacts maintenance of serial order.

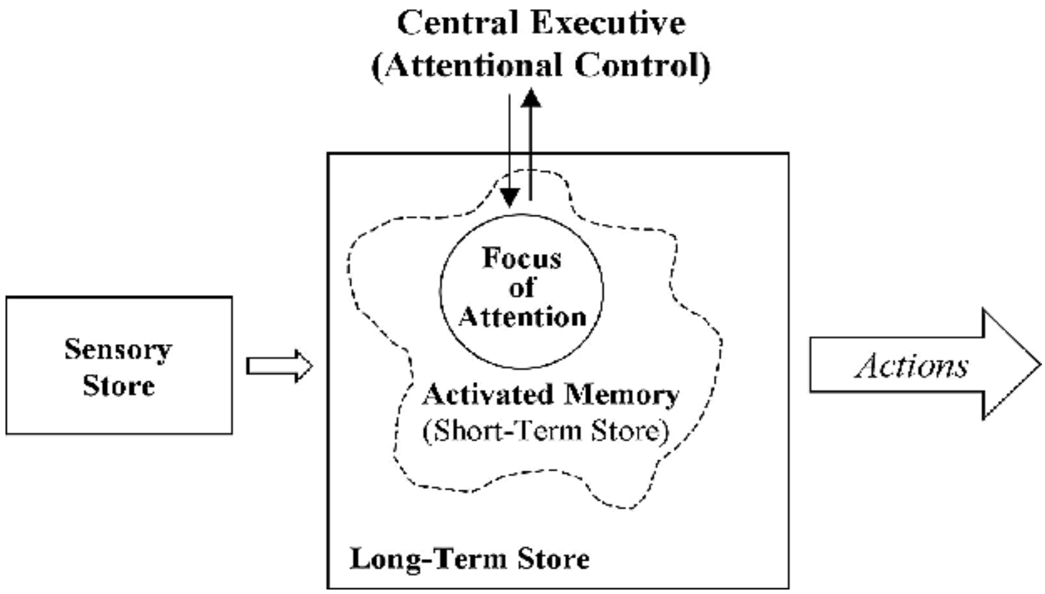
Several studies have also investigated the visual-spatial division of WM, providing evidence for the existence of a separate visuospatial store that uses rehearsal mechanisms independent of the central executive (e.g. Della Sala et al., 1999; Hartley et al., 2001; Klauer & Zhao, 2004). This model was updated with an additional component called ‘episodic buffer’ (Baddeley, 2000). The episodic buffer acts as a temporary multidimensional store, which communicates or connects between the subsystems of WM, LTM and the central executive.

Embedded-processes model (Cowan, 1988, 1999). A schematic illustration of the model is given in Figure 1.3. The most distinct difference between this model and the multicomponent model is that the embedded-processes model proposes that WM is not an independent system; instead, it is embedded within the LTM system.

The embedded-processes model of WM consists of several hierarchically organised components: LTM, activated LTM, central executive processes and focus of attention. For example, information from one’s surroundings is processed in a sensory store. If people actively pay attention to that information, it will go into the focus of attention and automatically activate information in LTM that represents those features. To keep a piece of information active in mind, central executive processes are recruited to keep that information in the most accessible state by keeping the focus of attention on it. On the other hand, if this information is repeated enough and associated with other information, it may gain a rich enough representation to become a new episodic LTM.

Figure 1.3

An Illustration of the Embedded-processes model of WM (Cowan, 1988, 1999)

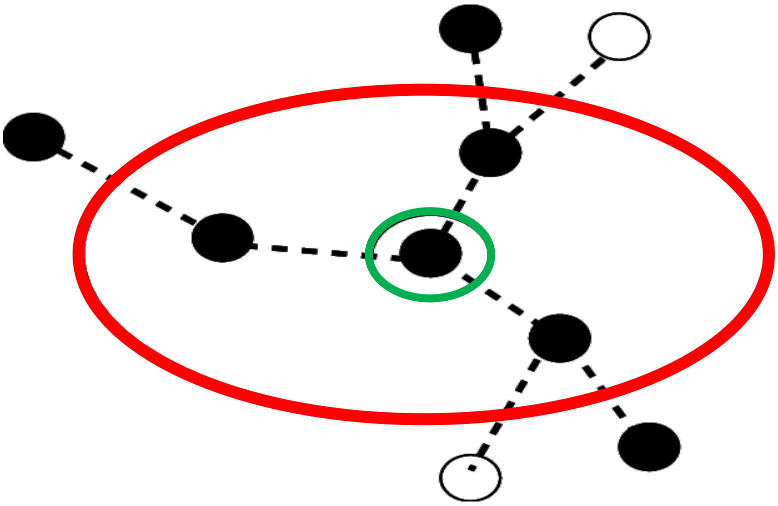


Note: Reproduced from *Cambridge Handbook of Thinking and Reasoning* (pp.463, Figure 19.4), by K.J. Holyoak & R.G. Morrison, Cambridge University Press. Copyright 2005.

Concentric Model (Oberauer, 2002). The last model that I will overview is the concentric model. Figure 1.4 showed the illustration of concentric model, that the nodes indicated the LTM representations and the lines represented the association of those representations. These lines and nodes formed the network of LTM representations. The black nodes indicated the activated LTM representations. The red large oval is the direct access component, which represent a subset of items in the LTM, while, the green small oval represents the focus of attention. This model proposed that within the direct access component (i.e. the red circle), a single item has been selected for processing by the focus of attention.

Figure 1.4

An Illustration of the Concentric model (Oberauer, 2002, 2009)



Note: Reproduced from “Access to Information in Working Memory: Exploring the Focus of Attention” by K. Oberauer, 2002, *Journal of Experimental Psychology: Learning, Memory, and Cognition, 28*(3), pp. 411-421. Copyright 2002 by the American Psychological Association.

This model is very similar to the previously discussed embedded-processes model in that both models suggest that WM is a temporarily activated subset of LTM. The main structural difference is that Cowan’s focus of attention is now split into a single-item focus of attention and direct access component. The direct access component corresponds to the overall capacity of WM, which is limited and most representations in this component are maintained in an offline but highly accessible state. On the other hand, the focus of attention operates over the direct access component and its capacity is limited to a single item. That means only the attended item is maintained in a state that can directly interact with other ongoing cognitive components.

1.2.2 The binding hypothesis of WM capacity limits

There is a debate in the current literature about what limits WM capacity. Miller (1956) proposed in his famous paper ‘the magical number seven plus or minus two’ that the WM capacity is seven plus or minus two items, which means that WM capacity ranges from five to nine items, and people, on average, can recall seven pieces of information or chunks. However, Cowan (2001) proposed that the WM capacity limit is actually 3 to 5 chunks. The change in limit stems from observations that young adults could recall only 3 or 4 longer verbal chunks, such as short sentences (e.g. Gilchrist et al., 2008). In the current literature, many studies indicate that WM capacity varies among people, as it may change across the life span, depending on the intellectual ability of individuals (Cowan, 2005) or depending on whether any WM enhanced processes are allowed in the test circumstances, such as grouping or rehearsal (Cowan, 2010).

One explanation of WM capacity limits comes from the concentric model (Oberauer, 2002, 2009, 2019), which proposes that the variation and limitations of WM capacity pertain to bindings between individual items (e.g. colours to remember) and their relative spatial-temporal context (e.g. their relative locations on the screen). Specifically, the binding hypothesis suggests that WM capacity is limited by the number of bindings (e.g. colour-location bindings, henceforth binding memory) rather than the number of items (e.g. just the colours irrespective of their locations, henceforth item memory; Oberauer, 2019). For example, Oberauer (2019) found that participant error rates increased with the length of a to-be-remembered list of word-location pairings (i.e. a “set size” effect), and this was almost exclusively due to binding errors (e.g. remembering the correct word in an incorrect location). As list length (or set size) increases, participants are required to remember more items, resulting in decreased binding memory, but item memory remained largely intact.

Similarly, memory representations are not simply holistic units but comprise separate features (e.g. colour and shape) of an object that must be bound together as a holistic unit in a process known as feature binding (e.g. remembering a red apple; Allen et al., 2006, 2012). There is a problem in binding: remembering more than one item at a time requires accurately distinguishing which set of specific features belongs to object A and object B, as they may be active simultaneously (Treisman, 1996). This binding problem must be solved in memory because the binding of features is necessary during encoding, consolidation, and retrieval.

Synchrony is the most popular physiological explanation of the process of binding (Singer et al., 1997). Synchrony is the notion that feature binding occurs due to the synchronous firing of cortical neurons; therefore, binding occurs throughout the brain. However, this explanation has two problems. First, the idea of synchrony cannot explain how two or more bound objects are differentiated. Second, this idea cannot explain how to account for the permanence of representations after the stimulus is no longer perceptually present. It seems the case that synchrony is an adequate explanation of binding only for a single object. Binding the elements of the same object and separate those elements from other features belonging to a different object can solve these problems. Therefore, binding mechanisms specify the input to memory during encoding, and binding may even be relevant for retrievals because features have to be re-bound at the time of remembering (Nader, 2003).

1.2.3 Theories of feature binding in perception and memory

The main aim of this thesis is to investigate the factors which may influence the automaticity of feature binding in WM. Now that I have introduced different memory models above, I will introduce different theories which explain the underlying processes of feature binding in the WM in this section.

1.2.3.1 Feature integration theory (FIT) (Treisman et al., 1977; Treisman, 1988). FIT is a perceptual and attentional theory that explains how individual features of an object are combined to perceive the whole object (Treisman & Gelade, 1980; see Figure 1.5). The model describes two functionally independent and sequential processing stages. In the first pre-attentive stage, basic features (e.g. colours, shapes, orientations, etc.) from the visual field are automatically processed. The second stage is focused attention, in which all the observed features are combined to make a complete perception. The second stage occurs only if the object does not stand out immediately. For example, if you were looking for something similar in colour and shape to other distractors (e.g. a blue ball pen in your pencil case full of pens and pencils), it would be more difficult to spot, in which case the second stage is required. On the other hand, if you are looking for something totally different from presented distractors (e.g. a rubber in the same pencil case), then it will be easier to spot; thus, only the pre-attentive stage is required.

Figure 1.5

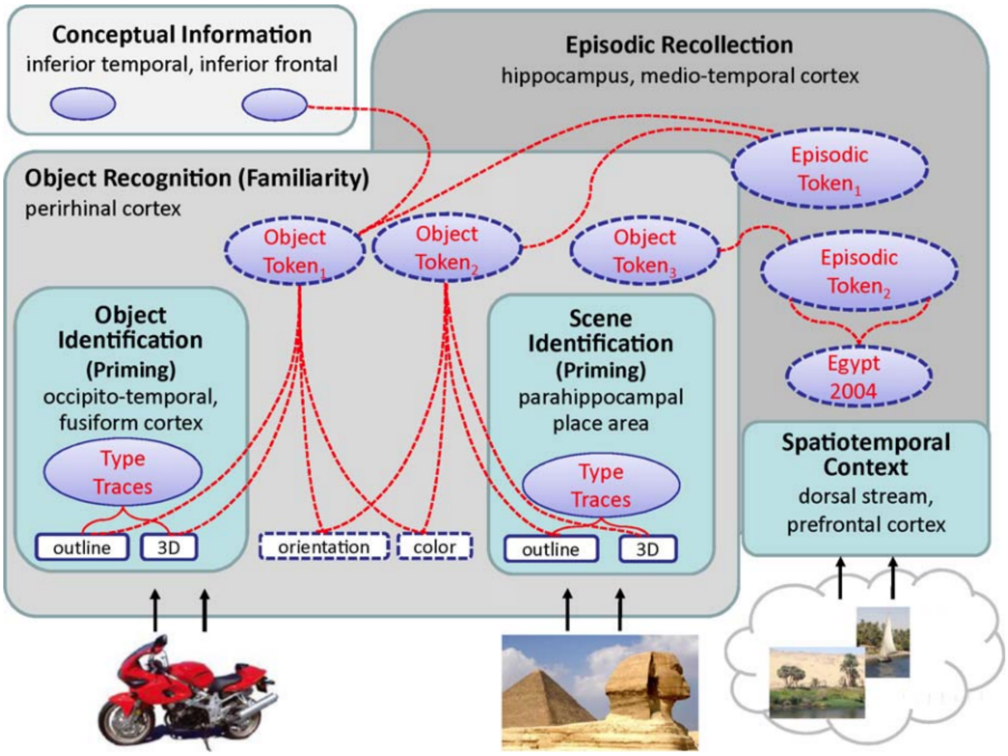
Feature Integration Theory (FIT)

Note: Recreated from Feature integration theory, In *Wikipedia*, n.d., Retrieved October 4, 2023, from https://en.m.wikipedia.org/wiki/File:FITstages.png. Copyright 2011 by Mrbazoun.

1.2.3.2 Type-token memory model (Zimmer & Ecker, 2010). The Type-Token model is a neurocognitive model of long-term object memory (Zimmer & Ecker, 2010). A schematic illustration of the model is given in Figure 1.6. This model proposed three kinds of memory representations: type trace, object tokens and episodic tokens. Type trace is the basic unit for perceptual priming, wherein participants cannot recall any previous experiences of the object, but the object is still encoded more efficiently due to prior experience with the object. Therefore, perceptual priming can accelerate the encoding processes during object recognition. Perceptual priming results from changes in type traces when the object is perceptually processed. The second memory representation is object tokens. The model assumes that access to object token is related to familiarity. Familiarity means when a participant re-encounters the object again, they cannot consciously recall the details of the object, but they are still aware that they have encountered this object before. An object token is the memory trace of an object file, which is the bound representation of the sensory features representing the object already in perception. Each object token represents a single item. Multiple object tokens will result if multiple objects are presented. The last memory representation is episodic tokens. Episodic tokens are the representation of item-context associations assumed to be related to recollection. Recollection means that when the participants see the object again, they can remember and recall the details of previous experiences with it. In this model, episodic recognition can rely on familiarity and recollection. Recollection usually requires retrieving of additional information on the encoding context of the object or a consciously represented feature. Information required for recollection is bound in an episodic token. Therefore, an episodic token is a higher-level representation that combines both information contained in the object token and the additional information of the context.

Figure 1.6

Type-token memory model



Note: Reproduced from "Remembering perceptual features unequally bound in object and episodic tokens: Neural mechanisms and their electrophysiological correlates" by H. D. Zimmer and U.K.H. Ecker, 2010, *Neuroscience and Behavioural Reviews, 34*, pp. 1066-1079. Copyright 2010 by Elsevier Ltd.

1.2.3.3 Object file hypothesis (Kahneman et al., 1992). The object file framework is designed to account for object-position binding in visual WM (Kahneman et al., 1992). This framework accounts for the memory of the association of surface features to new locations of objects. This framework proposes that perceptual features of an object (e.g. its colour and shape) are retained briefly in memory when an individual pays attention to a visible object. The spatial index is recruited and thus marks the location of the object. The spatial index only serves as a pointing device. After that, perceptual features are bound to the spatial index marking that object and forming the object file.

These models proposed different underlying mechanism of feature binding. However, there is still a debate in the current literature whether feature binding is an automatic process. In the next section, I will discuss the automaticity of feature binding in WM.

1.2.4 The automaticity of feature binding in WM

Previous studies have shown that WM and attention are closely linked with each other (e.g. Awh et al., 1998; Baddeley, 1993; Chun, 2011; Gazzaley & Nobre, 2012; Kane et al., 2001; Kiyonaga & Egner, 2013; Oberauer, 2009; Olivers, 2008). There are different definitions of attention in the current literature. Some studies have indicated that attention is a limited resource for information processing (e.g. Wickens, 1981), some other have proposed another view that attention is a mechanism for selecting information which need to be processed with priority (e.g. Chun et al., 2011; Desimone & Duncan, 1995). For example, Wheeler and Treisman (2002) compared performance between conditions requiring remembering only the individual feature versus a binding (i.e. the association of at least two features). In the single test probe (i.e. only one item on the screen), accuracy was similar between the individual feature and binding conditions, whereas testing the whole array (i.e. having three items on the screen at the same time) showed reduced accuracy in the binding condition compared to the individual feature conditions. Wheeler and Treisman (2002) explained that the single test probe condition focused all attentional resources into the single tested array; however, in the whole array conditions, participants need to allocate some attentional resources to remember the bindings in the second and the third items, therefore reducing performance. This study supported the claim that attention is essential to binding.

As I have said, a persistent question in the literature concerns whether feature binding is either an automatic (i.e. requires less cognitive resources) or a resource-demanding (i.e.

requires more attention) process. Some of the studies have suggested that there are no extra costs or just little cost of binding (e.g. Allen et al., 2006; Cowan et al., 2006, 2013; Johnson et al., 2008; Morey & Bieler, 2013; Vergauwe et al., 2014). This means that performance is similar when participants are required to remember features and bindings. For example, there are some findings suggesting that memorising eight features is as accurate as four features (Luck & Vogel, 1997) and that imposing a cognitive load via a secondary, distracting task (e.g., counting backwards) does not disproportionately impair feature binding (Allen et al., 2006; but see Brown & Brockmole, 2010; Elsley & Parmentier, 2009). This suggests that visual WM binding is relatively automatic. Conversely, other studies have shown conjunction costs, such that memory is poorer for integrated object (e.g., remembering a red apple) compared to individual features (e.g., remembering red and apple individually; Bays et al., 2011; Fougnie & Alvarez, 2011; Johns & Mewhort, 2002; Parra et al., 2009; Stefurak & Boynton, 1986; Treisman et al., 1977; Vul & Rich, 2010; Wheeler & Treisman, 2002). Such results signal that feature binding is not automatic and requires cognitive resources.

1.2.5 Factors which may affect the automaticity of feature binding

Despite the lack of consensus, there are several factors that may influence the automaticity of feature binding, namely unitisation, prior knowledge, how information is stored in WM and culture. Each factor will be discussed in turn in this section.

Unitisation. Previous studies have suggested that the nature of whether feature binding is automatic or not may depend on unitisation, that is, whether the to-be-bound information is intrinsic (i.e., part of the stimulus itself, e.g., its colour) or extrinsic (i.e., not part of the stimulus itself, e.g., its context, background, or relationship to other memoranda; e.g., Ecker et al., 2013). Thus, extrinsic binding has been suggested to be more resource-demanding than intrinsic binding, given that it requires integrating objects with other contextual, spatial, or temporal elements (Troyer & Craik, 2000). This is evident in studies indicating that information that is intrinsic to an object is bound more tightly than extrinsic information (Ecker et al., 2004; Ecker, Zimmer, & Groh-Bordin, 2007; Ecker, Zimmer, Groh-Bordin, et al., 2007; Groh-Bordin et al., 2006; Nicholson & Humphrey, 2004; Srinivas & Verfaellie, 2000; Zimmer & Ecker, 2010). These studies have suggested that intrinsic feature information becomes available quickly and automatically influences object recognition, even when the feature is irrelevant to the object recognition task. However, the reintegration of extrinsic contextual information is slower and more controlled, suggesting that it is not automatically bound, as is the case for intrinsic feature information.

According to the Type-Token memory model explained previously (Zimmer & Ecker, 2010), the intrinsic features of an object are automatically bound into the object token (i.e. the basis of item memory), while its extrinsic features are more effortful to bind into the episodic token (i.e. addition information of the object token, e.g. its encoding context). Therefore, extrinsic features are considered as additional information of the object token. This is one of the possible explanations for why it is more effortful and resources demanding to bind extrinsic than intrinsic features.

Prior Knowledge. Prior knowledge may be another factor influencing the automaticity of feature binding. Prior knowledge in LTM may facilitate the feature binding formation in WM, such as remembering a feature related to the information in LTM will have a facilitation effect when compared with remembering a feature not related to the information in LTM.

Referring back to the discussion about the interaction between WM and LTM, different memory models have different illustrations of the relationship between WM and LTM; some of them suggest that they are two separate systems (Baddeley & Hitch, 1974), and some of them indicate that WM is embedded in LTM (Cowan, 1988, 1999; Oberauer, 2009). There has yet to be a consensus on the architecture between WM and LTM among different WM models; however, all of them agreed that there is an information exchange between WM and LTM. Prior studies found that WM only accesses information from LTM when it is beneficial to do so (Bartsch & Shepherdson, 2020; Mizrak & Oberauer, 2020; Oberauer et al., 2017), which is consistent with the flexible gate hypothesis. The flexible gate hypothesis (Oberauer, 2009) proposes that only information in LTM that is beneficial to the operation of WM can impact WM; otherwise, information in LTM is blocked. Norris et al. (2020) and Thalmann et al. (2019) also suggested that memory performance can be improved if WM can make use of relevant information in LTM, in which case it can free up some space in WM for information which is not directly supported by LTM (e.g. novel information). These studies supported that LTM can facilitate WM formation.

In addition, previous studies found that prior knowledge in LTM might facilitate the feature binding formation in WM (Brady & Störmer, 2022; Loaiza & Srokova, 2020). For example, Brady and Störmer (2022) tested three types of objects: fully scrambled objects, lightly scrambled objects and concrete objects. Unsurprisingly, the prior knowledge in their LTM facilitated their WM formation in the concrete object condition. Additionally, they found that in the lightly scrambled condition, participants still activated the prior knowledge in their LTM to remember the objects, as they may still be able to recognise the object. However, in the fully scrambled condition, participants were less likely to activate their prior knowledge when remembering the objects, as they were less able to recognise the objects. Therefore, the prior knowledge in the LTM is less likely to help to facilitate WM formation in this situation. In short, above evidence suggested that the prior knowledge in LTM will only be accessed if it is beneficial for the feature binding formation in WM.

How features are stored in WM. In the current literature, there are at least three views suggesting how we store features in WM, which may provide further information for the underlying process and automaticity of feature binding. Remembering an object, for example, a yellow leaf requires remembering its different features, such as its colour, shape, etc., in WM. As I explained previously, combining the features together into a coherent object representation is called feature binding (Allen et al., 2006, 2012). Researchers have yet to have a strong consensus on how features are stored in WM. Some have argued that objects are stored as a unit, with WM capacity only limited by the number of unified objects and not the individual features that compose them (e.g. Luck & Vogel, 1997). Conversely, others have proposed that storage in WM is feature-based, such that separate features individually contribute to the capacity limit of WM (e.g. Fougnie & Alvarez, 2011; Wheeler & Treisman, 2002). Another possibility is that whether storage in WM is object- or feature-based depends on unitisation, i.e. whether the features are intrinsic (i.e., integrated within) or extrinsic (i.e., relational or contextual) to the object (Ecker et al., 2013). In the following sections, I overview these three different views of how features are stored in WM.

Object-based storage in WM. The first view suggests that storage is object-based, such that WM is constrained by the number of objects held in mind rather than the number of features (Delvenne & Bruyer, 2004; Luck & Vogel, 1997; Experiment 3 of Olson & Jiang, 2002; Stevanovski & Jolicœur, 2011; Vogel et al., 2001). In this case, a yellow leaf is stored as a whole coherent object representation instead of remembering the features independently (i.e. yellow and leaf). This implies that increasing the number of features of an object (e.g. yellow leaf on the floor, so including a third feature of location) will not impact WM capacity compared to storing an object with fewer features (e.g. yellow leaf, so shape and colour only). On the other hand, increasing the number of objects, irrespective of their features (e.g. two types of leaves, a heart-shaped yellow leaf and a green oval leaf), will decrease WM capacity.

Luck and Vogel (1997, Experiment 3) found that remembering orientation only or remembering colour only was similar to the performance of remembering the conjunction.

However, an increase in set size reduced performance. Thus, remembering more features per object did not worsen the performance, but remembering more objects reduced performance. Therefore, Luck and Vogel (1997) suggested that a small set of bound objects is encoded and stored in WM, to which any number of features can be added for free if they characterise one of the original objects. Additionally, Experiment 3 of Olson & Jiang (2002) showed 2, 4, or 8 white lines to their participants and were required to remember either their orientation, size, or both in three respective blocks. They reported a similar performance between the individual feature condition (i.e. only orientation or size) and conjunction condition (i.e. both orientation and size) regardless of set size, which supports the claim of object-based view as the WM capacity is limited by the number of objects instead of the number of features.

Feature-based storage in WM. The second view proposes that storage in WM is feature-based (e.g. Fougnie & Alvarez, 2011; Experiment 4 of Olson & Jiang, 2002; Wheeler & Treisman, 2002). In this case, remembering a yellow leaf entails separate storage of its features (i.e. its colour and shape), perhaps because different features of the same object can be accessed at varying resolutions (Fougnie & Alvarez, 2011). Therefore, remembering a yellow leaf on the floor (i.e. three features: colour, shape, and location) will yield worse performance than just recalling a yellow leaf (i.e. two features: colour and shape).

Wheeler and Treisman (2002) found that the performance of remembering six unicoloured objects was not worse than remembering three bicoloured objects. If the object-based view were correct, then remembering three bicoloured objects should be better than remembering six unicoloured objects, as there should be a benefit from combining features into fewer objects. This result suggests a possibility that there may be independent feature stores and each feature with its own limited capacity as an explanation of memory for multidimensional stimuli. Wheeler and Treisman (2002) also compared memory for features (colour and location in Experiment 3, colour and shape in Experiment 4) with memory for their bindings. The features seemed to be stored at least partly independent of the bound object tokens. This evidence supported the feature-based view that features are stored independently in WM instead of a holistic object.

Both feature-based and object-based storage co-exist. A third possibility is that storage in WM is both object- or feature-based depending on the situation (e.g. Oberauer & Eichenberger, 2013; Vergauwe & Cowan, 2015; Xu & Chun, 2006). Olson and Jiang (2002) and Vergauwe and Cowan (2015) supported the third possibility. As mentioned previously, the result of Experiment 3 in Olson and Jiang (2002) supported the object-based view, while their Experiment 4 supported the feature-based view. This is surprising that they found an 'opposite' result in two experiments. This may suggest that other than object-based or feature-based view, there may be another possibility that both object-based and feature-based storage co-exist in WM, but whether using object-based or feature-based may depend on other factors. The result of Vergauwe and Cowan (2015) supported this claim. Their result shows that the basic unit used for retrieval can be either an object or a feature, depending on the testing situation.

Experiment 4 of Olson & Jiang (2002) supported the third view, both feature-based and object-based co-exist in WM. Their Experiment 4 tested three conditions, namely (1) homogenous simple feature condition (either colour squares or line orientations were shown in the encoding stage), so, only 1 feature need to be encoded; (2) heterogeneous simple feature condition (half of the items shown in encoding stage is colour squares and the other half of the item shown is line orientations), so, two features need to be encoded and (3) conjunction condition (items shown during encoding stage are the combination of colour squares and line orientation), so, two features needed to be encoded. The results of their experiment showed that participants performed better in the heterogeneous simple feature condition (only one feature needed to be recalled) than conjunction condition (needed to recall two features) at set size 4. This evidence supports the notion that additional features are bound with additional cost, and thus performance will be worse in the conjunction condition than heterogeneous simple feature condition.

In addition, Experiment 4 also showed that if the number of features to hold is the same, then participants performed better in conjunction condition than single feature condition. However, such improvement in performance was not doubled. If participants remember information as solely features, then the performance should be similar. On the other hand, if participants remember information as objects, then they only needed to remember half of the information, and thus, the improvement should be doubled. This finding may suggest that participants use both features and objects to store information in their WM instead of either one of them. Therefore, this suggests that both feature-based and object-based storage co-exist in WM.

Culture. Previously, most of the memory studies assumed that memory systems and processes are similar across cultures or culturally universal. However, cross-cultural studies found that people in different cultures show different memory abilities and neural pathways of attention (e.g. Martin & Jones, 2012; Meng, 2022). There is a lot of evidence in cultural psychology showing that there are significant differences between how Eastern and Western participants perceive and remember information. For example, Westerners are more focal in their attention, while Easterners are more global in their attention. Considering the previous discussion about the attention is essential to the binding, therefore, such cultural differences may be useful for understanding the fundamental processes of feature binding in WM. Based on this background, I will discuss in more detail about how culture influences memory in section 1.3.

1.3 Cultural Differences and Cognition

In the last three decades, research studies have started to investigate culture more systematically. Research studies have started not only using surveys, but also more heavily rely on experimental methods (e.g. Triad Task, Inclusion Task; discussed in the next sections). Previous studies suggested that some fundamental aspects of basic psychological processes, for example, cognition (e.g., Park et al., 1999; Park & Gutchess, 2002; Park & Gutchess, 2006), emotion (e.g., Kitayama et al., 1995, 2000, 2006), and motivation (e.g. Nisbett & Wilson, 1977; Winter et al., 1998) can be systematically influenced by culture. Previous studies have documented several dimensions underlying the cultural variation of people in the Eastern and Western world, such as social orientation (how they relate to others), self-construal (i.e. how they define themselves) and cognitive style (i.e. how they process information; e.g. Kitayama & Park, 2007; Kitayama & Uskul, 2011; Nisbett et al., 2001; Varnum et al., 2010). Additionally, some previous studies have proposed that other aspects of their daily life and social institute, such as honour (e.g. Uskul et al., 2012; Uskul & Cross, 2019, 2020), tightness (e.g. Gelfand et al., 2006), religiosity (e.g. Cohen & Rozin, 2001), and hierarchy (e.g. Shavitt et al., 2010), are also influenced by culture (e.g. Uskul et al., 2023; Uskul et al., 2012).

In addition to the behavioural findings, there is also extensive neural evidence and survey-based studies showing that there are cultural differences or the neural systems may contribute to behavioural differences across cultures (e.g. Kitayama & Uskul, 2011). Based on this background, I will discuss the aspects of cultural variation that are most related to this thesis.

1.3.1 Self-construal

Markus and Kitayama (1991) proposed a theory on independent and interdependent self-construal. They proposed that Easterners tend to construe themselves as interdependent, socially connected, and embedded within the social context. On the other hand, Westerners tend to construe themselves as independent, defined primarily by internal attributes, such as preferences, desires, traits, goals, and self-expression. For example, the cultural differences in self-construal can be reflected in autographical memory. Westerners are more interested in remembering personal experiences that can distinguish them from others, while, Easterners rely more on social networks, so they are more interested in remembering group activities related to social tradition and interpersonal relationships. For example, Han et al. (1998) asked Western (i.e. Euro-American) and Eastern (i.e. Chinese and Korean) children to recall recent personal events such as a special time or funny time for them. They found that Western children recalled more specific episodes and were more likely to refer to their preferences, feelings, and opinions (e.g., “I loved the birthday present”) than Eastern children, who tended to describe other people relative to themselves.

Lin et al. (2008) used a different or non-traditional approach to investigate cultural differences. Rather than comparing the differences between cultural groups, they primed participants to think more independently (i.e. thinking style of Westerners) or interdependently (i.e. thinking style of Easterners). They investigated the neural activity in the extra-striate cortex in response to spatial attention during global/local tasks. Prior behavioural findings suggested that Easterners’ spatial attention is more global (broader attention to larger shapes or spaces) than Westerners, who are more local focal attention to part of the shape or scene). P1 component is related to process visual stimuli. This study reported a different result in mean amplitude of P1 component between independent and interdependent conditions. The mean amplitude of P1 component was larger in local than global task when participants think more independently. On the other hand, when the participants think more interdependently, the mean amplitude of P1 component was larger in global than local. This result supports the claim that cultural differences in self-construal influence information processing.

In addition to the behavioural and neural evidence, Uskul et al. (2023) also conducted a large-scale survey to investigate the cultural differences in self-construal in eight dimensions, i.e. differences (vs. similarity), self-direction (vs. receptiveness to influence), self-reliance (vs. dependence on others), consistency (vs. variability), self-expression (vs. harmony), a decontextualised self (vs. contextualised self), connection to others (vs. self-containment), and commitment to others (vs. self-interest). They found that East Asians rated towards the interdependent pole on four dimensions (connection to others, variability, harmony and commitment to others), whereas Westerners rated towards the independent pole on the other four dimensions (differences, self-direction, self-reliance and decontextualised self). The result of this large-scale questionnaire showed that there is a significant difference in self-construal between Eastern and Western participants. In short, a combination of behavioural, neuroscientific and survey-based studies have provided evidence for cultural differences in self-construal.

1.3.2 Social Orientation

Easterners tend to have interdependent social orientation associated with harmony, relatedness, and connection, while Westerners tend to have independent social orientation associated with self-direction and autonomy (Kitayama & Park, 2007; Markus & Kitayama, 1991; Triandis & Suh, 2002). Kitayama and Park (2007) showed that Westerners view themselves as independent, which is defined by their internal attributions; however, Easterners view themselves as interdependent and their view of self is not only defined by their internal attributes, but also by social orders. Such cultural differences may be due to differences in societal values between Eastern and Western societies, since Western society values more concern individualism and Eastern society values are more about collectivism.

The cultural differences in independence and interdependence can also be viewed in public artefacts. Public artefacts mean media coverage, e.g. contents of advertisements, textbook materials, etc. Kitayama and Park (2007) reviewed different types of media in Eastern and Western world and suggested that independent and interdependent social orientation influence the media. For example, they reviewed the news in Japan and USA related to the Summer Olympic Games 2000 and Winter Olympic Games 2002. They found that Japanese media explained the performance of each athlete based on his or her background, such as their relationship with their coach playing an important role in their accomplishment. On the other hand, when American newspapers and TV programs explained the accomplishments of each athlete, they tended to emphasise more about their personal qualities, relating their performance to their internal attributes, such as talent, effort, and also their immediate goal of winning a competition. Furthermore, the values promoted in advertisements are significantly different between the Eastern and Western worlds. The advertisements in Korea were more likely to use conformity-related messages, such as promoting group harmony or following a trend instead of promoting uniqueness. However, American advertisements tend to promote uniqueness, for example, emphasising freedom of choice (Kitayama & Park, 2007).

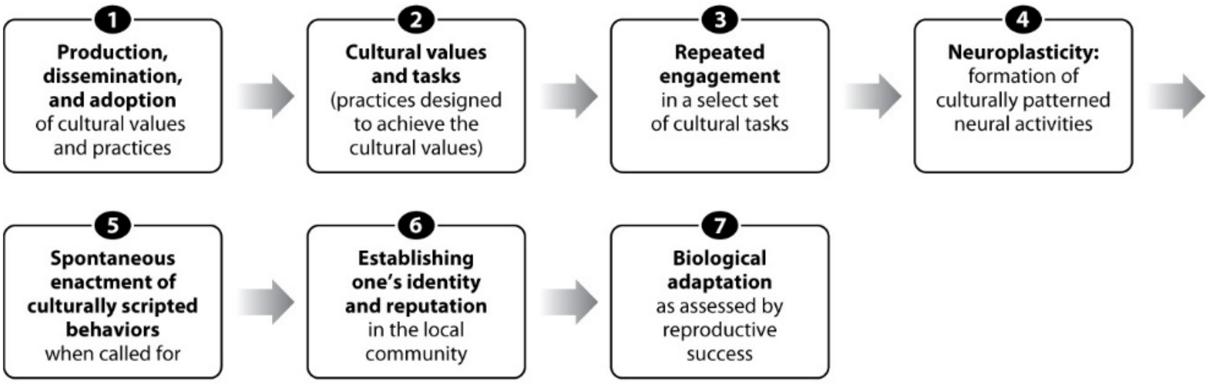
Kitayama and Park (2007) also reported that cultural values and beliefs used in textbooks are significantly differ across cultures. For example, the Eastern world values collectivism; therefore, Japanese stories had more pictures with two or three characters. Additionally, because of the collectivism culture, conformity and interdependence are more likely to be used in the Japanese textbooks. Therefore, the Japanese are more likely to attribute the outcomes to external factors, such as other people's behaviours or situations. However, the Western world values more about individualism, and thus, American stories had more pictures that focus on one person. In addition, because of the individualistic values, themes of self-direction, achievement and power are more likely to be used in the American textbooks. Therefore, Americans are more likely to attribute outcomes to internal factors. In short, the interdependent versus independent social orientation reflects the cultural differences in the definition of self as well as media coverage.

The neuro-culture interaction model (Kitayama & Uskul, 2011). Based on the previously discussed cultural differences in social orientation, Kitayama and Uskul (2011) proposed a seven-step model that describes the interaction between culture and the brain. The neuro-culture interaction model is illustrated in Figure 1.7. This model proposed that individuals would select a set of cultural values and practices as their own cultural tasks. Then, they will keep practising those cultural tasks. Those selected values and practices will become their cultural behaviour through repeated engagement and those cultural behaviours will systematically influence the brain, and thus result in the corresponding patterns of brain activations and psychological tendencies. For example, repeated participation in either a set of independent or interdependent cultural tasks will promote the corresponding cultural values that influence individual brain activation or psychological tendencies.

Another example is a previous Functional Magnetic Resonance Imaging (fMRI) study that reported cultural differences even when Japanese participants were tested in their non-native language (i.e. English) but who lived in Japan most of their lives (Kobayashi et al., 2007). They tested English monolingual children with English story task and Japanese-English bilingual children with both English version and Japanese version of story tasks. When both groups read the story in English, they found a slightly greater activation in the right superior temporal gyrus (STG) in the monolingual group than the bilingual group. Such differences in brain activations might imply the relative significance of early socialisation and repeated engagement with cultural tasks instead of language in establishing the style of social perception and social inference of an individual.

Figure 1.7

The Neuro-culture Interaction Model (Kitayama & Uskul, 2011)



Note: Reproduced from "Culture, Mind, and the Brain: Current Evidence and Future Directions", by S. Kitayama and A.K. Uskul, 2011, *The Annual Review of Psychology, 62*, pp. 419-449. Copyright 2011 by Annual Reviews.

In addition to the above findings, Triandis and Suh (2002) found that East Asians emphasise relationships with others and interdependence, whereas Westerners value uniqueness and independence. Such differences in value also influence their concept of self, attitude and desires. Markus and Kitayama (1991) reported that Westerners consider 'self' in an independent manner; however, Easterners consider 'self' as part of the group. An fMRI study has supported this claim (Zhu et al., 2007). Zhu et al. (2007) suggested that there is a cultural difference in activity in the medial prefrontal cortex, suggesting that both American and Chinese differentiate self from distant, unfamiliar others, while only Americans differentiate self from close others (i.e. mother). Cultural identity influences the focus of attention and information retrieval from memory.

To sum up, as the social orientation hypothesis proposed, Easterners are more interdependent, and Westerners are more independent. Such cultural differences can be explained by the neuro-culture interaction model, which proposes that the style of social perception and social inference of an individual is the result of early engagement and early socialisation.

1.3.3 Cognitive style

There are also cultural differences in thinking style or cognitive style. Nisbett et al. (2001) proposed that the thinking style of East Asians is more holistic, whereas the thinking style of Westerners is more analytic. Varnum et al. (2010) proposed that the previously discussed differences in social orientation are responsible for cultural differences in cognitive style. Prior behavioural studies (e.g. Lin and Han, 2009) also indicated that self-construal plays an important role in modulation of cognitive processing styles, leading to context-dependent or context-independent mode of processing.

Analytic and Holistic Framework. The analytic and holistic framework (e.g. Masuda & Nisbett, 2001; Nisbett et al., 2001; Nisbett & Miyamoto, 2005) proposed that since the thinking style of Easterners is more holistic, therefore, they tend to pay equal attention to both foreground objects and background. However, the thinking style of Westerners is more analytic; therefore, they tend to pay more attention to foreground objects but not the background. Different cognitive tasks in cultural psychology have widely confirmed the analytic and holistic framework (e.g. Uskul et al., 2023). For example, an eye-tracking study indicated that East Asians make fewer fixations to objects during the first 300ms of picture viewing compared to Americans (Chua et al., 2005). This result is not only consistent with previous behavioural findings (e.g. Masuda & Nisbett, 2001), but also indicates cultural differences in the processing of objects. In addition, Lin et al. (2008) suggested that Easterners are more global (which requires broader attention to larger shapes or spaces) in spatial attention than Westerners, who are more local (which requires focal attention to part of the shape or scene), which are in line with prior behavioural findings. The above evidences suggested that Easterners are processing the relationship between foreground and background objects to a greater degree than Westerners, which is consistent with what the analytic and holistic framework that predicts greater holistic processing among Easterners.

1.3.4 How memory interacts with culture

Considering the discussion in the previous section, culture interacts with many other cognitive processes, e.g. language production, etc. Therefore, culture is very likely to influence memory in many ways (e.g. attention, semantic processing, etc.). For example, prior behavioural and neuroimaging work confirmed that Western and Eastern participants are different in attention, such that Westerners are more objects focused and Easterners are more context focused. Prior studies have explained cultural differences in perceptual orientation, consistent with the analytic and holistic framework (Masuda & Nisbett, 2001; Nisbett et al., 2001; Nisbett & Miyamoto, 2005). This cultural difference in perceptual orientation may likewise impact memory performance, particularly such that Easterners and Westerners may show different patterns of results when it comes to binding and item memory.

Cultural differences in LTM. There is a great deal of evidence that there are significant cultural differences in LTM (e.g. Park et al., 1999; Park & Gutchess, 2002; Park & Gutchess, 2006). Considering the previous discussion in section 1.2 regarding the relationship between WM and LTM, it is very likely that culture similarly impacts WM.

Extensive evidence suggests culture may shape memory and cognitive processes, e.g. semantic processing, attention, etc. (Leger & Gutchess, 2021). That evidence is not only limited to behavioural findings but also shows differences in the neural systems, which may contribute to the behavioural differences across cultures (Gutchess & Indeck, 2009). The neuro-culture interaction model (Kitayama & Uskul, 2011) suggests that repeatedly engaging in selected cultural tasks will systematically shape individuals' brains and their way of processing information. Another study reported that European Americans who reported memories related to their own experiences more often described their emotions and self-consciousness than Asians, whereas Chinese and Asian Americans often reported memories related to group activities and interpersonal relationships instead of their own experience (Wang, 2004).

The differences observed in LTM may stem from how cultural groups differently process information. For example, an fMRI study required East Asians and Americans to encode three types of complex photographs: (1) pictures of objects alone without backgrounds, (2) pictures of meaningful backgrounds alone without objects, and (3) pictures containing both objects and meaningfully related backgrounds (Gutchess, Welsh, et al., 2006). The results of this study showed that Americans engaged more semantic object processing regions, e.g. bilateral middle temporal gyrus, left superior parietal/angular gyrus, and right superior temporal/supramarginal gyrus, than East Asians. However, similar background processing regions were engaged between the two cultural groups (Gutchess, Welsh, et al., 2006). The result of this study is consistent with previously explained behavioural findings that Americans may be more object-focused than East Asians (e.g., Chua et al., 2005). Furthermore, prior studies have reported that Americans prefer to group items by categories; however, the preference of East Asians is to group by relationships (Chiu, 1972; Gutchess, Yoon, et al., 2006; Ji et al., 2004; Unsworth et al., 2005). This cultural difference in preference influences the cognitive processes of information processing.

In short, a combination of behavioural and neural evidence shows that culture influences LTM perhaps because it influences the way that cultural groups process information. Therefore, those cultural differences in LTM may likely happen in WM as well, given that culture influences the way that individuals process information.

Cultural differences in binding. Given the evidence that culture influences how people process and remember information, it is possible that culture influences how they build bindings in WM. As explained previously, prior work has demonstrated that Western participants were more focused on specific focal items and their attributes, and thus, less sensitive to contextual changes compared to Eastern participants (Chua et al., 2005; Masuda & Nisbett, 2001). In contrast, Eastern participants seem to process stimuli more relationally and contextually, showing better recall and recognition of background stimuli and reduced likelihood to recognise target objects when tested with different backgrounds to what had been initially presented during encoding (Masuda & Nisbett, 2001). This suggests that item-context binding differs between cultures. Meng (2022) also showed that Easterners and Westerners are different in memorising content and autobiographical memory. When comparing the content, Westerners are better at remembering the characteristics of specific objects, whereas Easterners are better at remembering background information about objects. When comparing autobiographical memory, Westerners tend to remember the contents related to individuals. Easterners remember things about relationships and group activities.

The research conducted thus far on this distinction between Western and Eastern participants has not been considered in the WM literature, but given the extant findings explained in LTM in the previous section, they may inform the nature of binding in WM. The above evidence is consistent with the Analytic and Holistic framework; Westerners tend to focus on the foreground object, while Easterners tend to pay equal attention to both foreground and background. This evidence suggests that culture influences how Easterners and Westerners encode and process information. Such fundamental differences between Easterners and Westerners may be useful for us to investigate the underlying mechanism of feature binding. Considering the previous discussion regarding unitisation and binding, binding intrinsic features may be less effortful than extrinsic features since Easterners tend to be more global and pay more attention to the background of the image than their Western counterparts. Therefore, such cultural differences may indicate that extrinsic binding in WM is less automatic for Western versus Eastern participants. Moreover, the potential dissociation in the automaticity between extrinsic and intrinsic binding based on cultural group may explain what drives the previously described cultural differences in perception and memory performance.

1.4 Statistical considerations

In this thesis, I have used a variety of analysis. I have performed Bayesian t-tests and Bayesian analyses of variance (BANOVAs) to analyse the behavioural data in the Chapters 3 and 4. In addition, I have used cognitive modelling techniques to explore the information that behavioural data cannot provide in Chapters 2 and 4. I will explain each of them in turn below.

1.4.1 Bayesian Statistics

Most Psychology research studies use either Bayesian statistics or Frequentist statistics, the latter of which is more common in psychology. Frequentist statistics is a type of statistics that draws conclusions based on the frequency and proportion of the sampled data. Conversely, Bayesian statistics is based on the Bayes Theorem wherein the value of parameters in a statistical model are updated with the information in observed data. The main different between Bayesian and Frequentist statistics is when testing hypothesis, Frequentist approach is providing the evidence to show the hypothesis is true or false by using the point estimate (i.e. p-value). On the other hand, the output of Bayesian approach is the probability for or against that hypothesis in the given set of data, and thus, the probability would keep updating if more data are become available.

There are a few components in Bayesian statistics: prior, likelihood, and posterior. The prior reflects the background knowledge or information learned from previous observations. Likelihood refers to the probability of observing a particular response in the experiment. The prior distribution and the likelihood determine the posterior distribution and the posterior can be used as a prior for future studies.

This thesis uses Bayesian statistics, as Bayesian statistics allowed us to update the Prior beliefs about particular events continually Bayesian inference if more data becomes available. I have performed BANOVAs and Bayesian t-tests to analyse the behavioural data and I will report the resulting Bayes Factor (BF) from the analysis. BANOVA computes the strength of evidence for different models (i.e. a combination of main effects and/or interactions) compared with a null model that includes only a random effect of the participant. The BF is the probability of the data under one hypothesis relative to the other. For example, $BF_{10} = 2$ means that the data are twice as likely to have occurred under the alternative model assuming an effect (H1) than the null model (H0). Furthermore, Wetzels et al. (2011) proposed another approach of reporting BFs and I will use this approach to report results in this thesis. In the Wetzels et al. (2011)'s approach, the main effect of a term of interest (e.g. binding) is equal to the ratio of BFs between the model including the term of interest (e.g. binding) and another term of interest (e.g. congruence) against the null model [i.e. $(M_{B+C})/(M_{null})$] relative to the model excluding the term of interest against the null model [i.e. $(M_C)/(M_{null})$]. In short, the main effect of binding = $[(M_{B+C}/M_{null})]/[(M_C/M_{null})]$. The resulting BF is showing the probability of the data support or against the model in the numerator (i.e. $[(M_C)/(M_{null})]$ in this case). The larger the BF is, the more evidence I have supporting the model in the numerator. BFs greater than 10 are considered as strong evidence for the tested model, whereas BFs between 3 to 10 are considered as moderate evidence, and BFs between 1 and 3 are considered ambiguous evidence for the model in the numerator.

1.4.2 Cognitive modelling techniques

Cognitive modelling techniques have become more popular in psychology in the last couple of decades to model how specific underlying psychological processes work

(McClelland, 2009). The cognitive modelling techniques can be used to explore the likelihood of possible responses or sources of error underlying performance on the WM tasks. There are many classes of cognitive modelling, but I will focus on those classes of model relevant to this thesis.

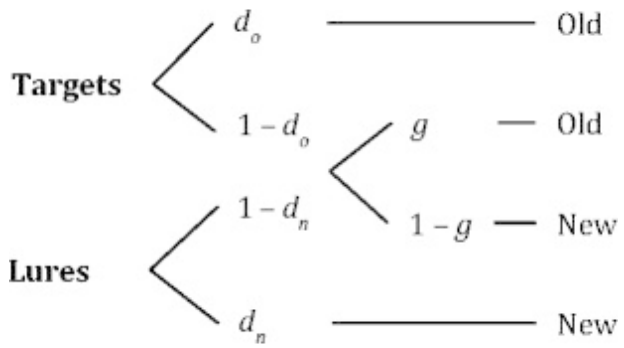
1.4.3 Multinomial-processing Tree (MPT) modelling

MPT models are a class of measurement models that estimate the cognitive parameters assumed to underlie the observed frequencies of each possible response of the underlying cognitive processes. Usually, MPT models are specifically designed for a particular experimental task to test the assumptions about the underlying psychological processes that contribute to task performance. For example, in a three-alternative-forced-choice (3AFC) task, participants have three options to choose; therefore, a MPT model can be used to estimate the cognitive processes that lead to the frequency of each of the three options.

One of the examples of a simple MPT model is a two-high threshold model (2HTM; see Figure 1.8). d_o in the model indicates correct target detection and g in the model indicates guessing when the target is not detected. This model accounts for a binary recognition paradigm, wherein participants first learn a list of items in the encoding stage and later need to decide whether a test probe is old or new. By using 2HTM, researchers can obtain frequencies of hits (i.e. correctly identified the old item is ‘old’), misses (i.e. incorrectly identified the old item is ‘new’), false alarms (i.e. incorrectly identified the new item is ‘old’), and correct rejections (i.e. correctly identified the new item is ‘new’). Given that the two possible processing paths are disjointed, the overall probability of an old response to an old item is given by the sum of the first process (i.e. d_o) and the second process (i.e. $(1-d_o) \times g$). Similarly, correct rejections can come from either lure detection (i.e. d_n) or participants were unable to detect the lure but guessed correctly (i.e. the probability of $1 - d_n \times 1 - g$). In contrast, incorrect old and new responses always result from being unable to detect whether the item is old or new and incorrect guesses.

Figure 1.8

A two-high threshold model (2HTM)



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The 2HTM is the basic model from which many other more complex MPT models were based, such as source memory (Bayen et al., 1996; Klauer & Wegener, 1998; Meiser & Bröder, 2002) or process dissociation (Buchner et al., 1997; Jacoby, 1991; Steffens et al., 2000). These more complex memory models have a similar structure to the 2HTM, as they assumed that correct responses either result from some memory processes of theoretical interest or come from some kind of guessing.

1.4.4 Mixture modelling

Zhang and Luck (2008) were the first to propose a mixture model that assumes a mixture of two parameters underlie continuous recall from visual WM (e.g., recalling colours from a continuous 360-degree wheel). These parameters reflect the probability that a tested item is in WM (P_m) with a certain precision. Later, Bays et al. (2009) added one more component to the mixture model, known as the three-parameter mixture model, that includes a third parameter, P(non-target) or P(binding error). This parameter reflects the probability of mixing up the tested item with another item shown during encoding and thus reporting the feature of the other item. Mixture modelling provides a further exploration of estimating the likelihood of the source of error, which is not possible to know if I only perform the traditional statistical analysis on observed recall performance.

1.5 Overview of the Present Work

I have overviewed a wide range of models explaining the factors that may contribute to WM performance. These factors include cultural differences between Eastern and Western participants, prior knowledge benefits, and how features are stored in WM. Such differences may be useful for us to understand the underlying process of feature binding in WM and answer a long-lasting question whether feature binding is an automatic or resource-demanding process. All the experiments that I report to investigate this question in this thesis received ethical approval from the University of Essex Ethics Committee [Protocol number: ETH2021-0507].

Based on this background, this thesis will explore each possible factor in different chapters. Chapter 2 regards whether culture and prior knowledge influence feature binding. According to the analytic and holistic framework, such cultural differences may be related to the differences in the focus of attention between Eastern and Western participants. In addition, the second experiment in Chapter 2 will further determine whether established prior knowledge of the studied objects' features facilitate automatic integration of extrinsic features for Western participants to match that of Eastern participants. The findings would indicate that LTM may influence visual WM to such an extent that extrinsic features can be processed automatically in Western participants as well as Eastern participants. If prior knowledge promotes WM performance by specifically facilitating extrinsic binding in WM (Loaiza & Srokova, 2020), then prior knowledge should improve extrinsic binding more strongly than intrinsic binding. Furthermore, if there is a cultural difference in the automaticity of extrinsic binding, then this facilitation effect should be observed in British participants to a greater extent than in Chinese participants. However, if extrinsic and intrinsic bindings are similarly automatic, then both cultural groups should show a prior knowledge benefit to both extrinsic and intrinsic bindings.

Chapter 3 is a confirmation experiment, as I did not find any cultural differences or prior knowledge differences in binding in the experiments in Chapter 2. Ecker and colleagues (2013, Experiment 1) tested 24 Western participants and reported that intrinsic binding is more automatic than extrinsic binding. Therefore, I tried to replicate this experiment with British and Chinese participants to confirm whether there are no significant differences between intrinsic and extrinsic bindings. Additionally, I added an independent task, Cognitive Attribution task, to the experiment of Chapter 3, to confirm the null effect of cultural differences in Chapter 2 is due to there being no true culture differences in feature binding instead of failing to detect the cultural differences. If intrinsic binding is more automatic than extrinsic binding, then the hit rate will be higher and the RT will be faster during intrinsic than extrinsic binding. Furthermore, if there are cultural differences in the Cognitive Attribution task but not in the WM task, then this may indicate that there are no cultural differences in feature binding. On the other hand, if there are no cultural differences at all in this group of participants, then both the Cognitive Attribution task as well as the WM task should not show any differences between Eastern and Western participants.

Finally, since I did not find any true effect of culture on WM performance in Chapters 2 and 3, and thus, Chapter 4 further examined other possibilities that may affect the automaticity of feature binding, such as how information is stored in WM. As I have explained previously, there are three different views about the nature of storage in WM, namely, the feature-based view (i.e. features are stored independently in the WM), the object-based view (i.e. the basic unit of storage in the WM is object instead of feature), and the view that whether WM storage is more feature-based or object-based depends on the unitisation of the features. Therefore, if object-based view is the case, then participants should show a similar performance in both intrinsic and extrinsic block in both single- and two-feature conditions. However, if feature-based view is the case and both intrinsic and extrinsic features are similarly automatic, then participants should show a greater recall error in the two-feature than single-feature condition in both intrinsic and extrinsic features. Lastly, if feature-based view is the case, and intrinsic feature is more automatic than extrinsic features, then, participants will show a greater recall error in the two-feature than single-feature condition in extrinsic feature but not intrinsic feature.

Chapter 2: Do Cultural Differences and Prior Knowledge Influence Feature Binding in Working Memory?

2.1 Introduction

A persistent question in the literature concerns whether feature binding is an automatic or resource-demanding process. There is no consensus on this question so far due to conflicting results. Some findings indicate that memorising more features does not reduce performance. For example, in their seminal paper, Luck and Vogel (1997) reported that memorising eight features is as accurate as four features. Furthermore, some work has shown that imposing a cognitive load via a secondary, distracting task (e.g., counting backwards) does not disproportionately impair feature binding (Allen et al., 2006; but see Brown & Brockmole, 2010; Elsley & Parmentier, 2009). These findings suggest that visual working memory (WM) binding is relatively automatic. Conversely, other studies have shown conjunction costs (Johns & Mewhort, 2002; Parra et al., 2009; Stefurak & Boynton, 1986; Treisman et al., 1977), such that memory is poorer for combinations (e.g., remembering a red apple) compared to individual features (e.g., remembering red and apple individually). Such results signal that feature binding may not be automatic and requires cognitive resources.

Previous studies (Asch et al., 1960; Ceraso, 1985, 1990; Ecker et al., 2013; Garner, 1974; Wilton, 1989) have suggested that whether feature binding is automatic may depend on unitisation, that is, whether the to-be-bound information is intrinsic (i.e., part of the stimulus itself, e.g., its colour) or extrinsic (i.e., not part of the stimulus itself, e.g., its context, background, or relationship to other memoranda). Extrinsic binding has been suggested to be more resource-demanding than intrinsic binding given that it requires integrating objects with other contextual, spatial, or temporal elements (Troyer & Craik, 2000). This is evident in studies indicating that information that is intrinsic to an object is more strongly bound than extrinsic information (Ecker et al., 2004; Ecker, Zimmer, & Groh-Bordin, 2007; Ecker, Zimmer, Groh-Bordin, et al., 2007; Groh-Bordin et al., 2006; Nicholson & Humphrey, 2004; Srinivas & Verfaellie, 2000; Zimmer & Ecker, 2010). These studies suggest that intrinsic feature information becomes available quickly and automatically influences object recognition, even when the feature is irrelevant to the object recognition task. However, the reintegration of extrinsic contextual information is slower and more controlled, suggesting that extrinsic feature is not automatically bound, which is not the case for intrinsic feature information.

2.1.1 Cultural differences in perception and memory

Despite assumptions that much of the human cognitive machinery is universal, the influence of culture is quite pervasive. Indeed, research has shown that culture affects people's perception of the physical and social world and associated memory processes (Nisbett et al., 2001). Prior studies have explained such cultural differences according to the analytic and holistic framework (Masuda & Nisbett, 2001; Nisbett et al., 2001; Nisbett & Miyamoto, 2005). Analytic thinking, more common among Westerners, is a thinking style in which an object is perceived and identified through its key features and separated from its context. In contrast, holistic thinking, more common among Easterners, is a thinking style in which objects are an integral part of their context. Consequently, holistic thinkers would be predicted to focus equally on a foreground object and its background. For example, in an eye-tracking study, Chua and colleagues (2005) reported that American participants spent more time looking at objects in the foreground of presented images compared to Chinese participants, whereas Chinese participants showed more fixations to the backgrounds of the images compared to the American participants (see also Goh et al., 2009). The source of this difference is argued to originate from an adaptive response to different eco-cultural environments (Berry, 1976) and has been demonstrated in a variety of perceptual tasks (Chua et al., 2005; Kitayama et al., 2003; Nisbett & Masuda, 2003).

This cultural difference in perceptual orientation may likewise impact memory performance, particularly such that Easterners and Westerners may show different patterns of results when it comes to binding and item memory. For example, prior work has demonstrated that object recognition memory was relatively unaffected by any background change for Westerners, whereas Easterners were less likely to recognise the target objects when tested with different backgrounds to what had been initially presented during encoding (Chua et al., 2005; Masuda & Nisbett, 2001). This suggests that Western participants were more focused on specific focal items and their attributes and thus, less sensitive to contextual changes compared to Eastern participants. In contrast, Eastern participants seem to process stimuli in a more relational and contextual manner, showing better recall and recognition of background stimuli (Masuda & Nisbett, 2001). These cross-cultural differences have not previously been considered in the WM literature, but given these extant findings, it may inform the nature of binding in WM. Considering the previous discussion regarding unitisation and binding, such findings may indicate that extrinsic binding in WM is less automatic for Western versus Eastern participants. Moreover, the potential dissociation in the automaticity between extrinsic and intrinsic binding may likewise clarify the sources of such cultural differences in perception and memory performance.

2.1.2 Prior knowledge benefit

There is some evidence in the current literature showing that prior knowledge from long-term memory (LTM) boosts WM performance (e.g., Oberauer et al., 2017), particularly for relating the to-be-learned information to our prior knowledge (e.g., Loaiza & Srokova, 2020). Thus, prior knowledge may enhance WM by facilitating the construction of extrinsic bindings specifically, whereas intrinsic bindings may be unaffected, given that they are more automatically established in WM. Furthermore, if extrinsic binding is more automatic in Easterners than in Westerners, then prior knowledge may facilitate extrinsic binding for Westerners. However, if extrinsic and intrinsic bindings are similarly automatic, then prior knowledge should similarly benefit intrinsic and extrinsic binding in both cultural groups.

Based on this background, this chapter aims to investigate whether cultural differences and prior knowledge influence the automaticity of feature binding in WM. The first experiment in this chapter concerns whether a cultural difference between Eastern and Western participants in how they perceive and attend to information may inform a longstanding theoretical discussion regarding the nature of feature binding in WM. In addition to cultural differences, the second experiment in this chapter moves further to investigate whether prior knowledge in LTM will differently influence feature binding in WM between the two cultural groups.

2.2 Experiment 1: Do cultural differences influence feature binding in working memory?

Although there is some evidence that Easterners and Westerners perceive and remember presented information differently, more work is needed to investigate whether this cultural difference is evident in WM. This is particularly relevant given a longstanding research question in the WM literature regarding whether feature binding is an automatic or resource-demanding process. That is, cultural differences between Eastern and Western participants in the way they attend to information in WM may impact the automaticity of feature binding in WM differently. According to the Analytic and Holistic framework proposed by Nisbett and colleagues (Masuda & Nisbett, 2001; Nisbett et al., 2001; Nisbett & Miyamoto, 2005), if Eastern participants perceive and attend to information more holistically, then, extrinsic binding of background context of to-be-remembered information should be more automatic compared to Western participants who may tend to focus more on the foreground content. Moreover, much of the prior work has limited analyses to observed task performance, which does not directly reflect item or binding memory. This study addressed this gap in the literature and expanded upon prior work by applying hierarchical Bayesian multinomial processing tree (MPT) modelling to derive and analyse latent cognitive parameters of item and binding memory, as I discuss later in further detail. Therefore, this study investigated whether Easterners, compared to Westerners, show more automatic processing of extrinsic features given previous work suggesting that East Asians are more sensitive to context changes (Chua et al., 2005; Masuda & Nisbett, 2001). Thus, I hypothesised that Eastern participants would show greater extrinsic binding memory than their Western counterparts. Intrinsic binding memory in Westerners has been demonstrated to be relatively automatic (e.g., Troyer & Craik, 2000). For Easterners, one of two possible patterns is likely to emerge. If this process is automatic for Easterners as well, then intrinsic binding memory should be similar between Eastern and Western participants. Alternatively, Easterners' focus on the context may be at the expense of intrinsic binding, in which case Western participants should have greater intrinsic binding memory than their Eastern counterparts.

2.2.1 Method

The pre-registrations, experimental materials, raw data and analysis scripts can be found on the OSF: https://osf.io/md2rz/?view_only=f267564f7f8a4a34bc792fd7f7c3d0c2.

Participants. Sixty Chinese and British participants (30 of each group) between the ages of 18 and 35 with normal colour vision were recruited from the University of Essex or Prolific to participate in the study (see Table 2.1). Chinese participants were born in mainland China and had not lived in other countries for more than three years, and British participants were born in the UK and had not lived in other countries for more than three years. Participants also self-identified as either Chinese or British, respectively. Individuals who did not meet these criteria were excluded from the study.

Furthermore, participants were instructed to complete the experiment in one continuous sitting that is free of distractions, and if they failed to respond to over 10% of the probes resulted in their data being excluded and thus uncompensated. The data of participants who performed at or worse than chance (33%) were excluded. Participants were compensated with partial course credit or the equivalent of £8/hour of participation. All participants in this experiment provided informed consent and were fully debriefed at the conclusion of the experiment.

Table 2.1

Descriptive Statistics of Demographical Information

	Experiment 1		Experiment 2	
Cultural Group	British	Chinese	British	Chinese
Mean Age (SD)	20.33 (2.41)	27.00 (4.90)	26.63 (4.22)	27.03 (4.58)
Gender	23 Females 6 Males 1 Prefer not to say	24 Females 6 Males	15 Females 14 Males 1 Prefer not to say	25 Females 5 Males
Sampling	All of them are the students from the University of Essex	9 of them are the students from the University of Essex and 21 of them were recruited from Prolific	All of them are recruited from Prolific	9 of them are recruited from Prolific, 5 of them are recruited from Hong Kong and 16 of them are recruited from the University of Essex
Average years lived outside the birth country (SD)	0 (0)	1.73 (0.81)	0 (0)	0.97 (1.00)

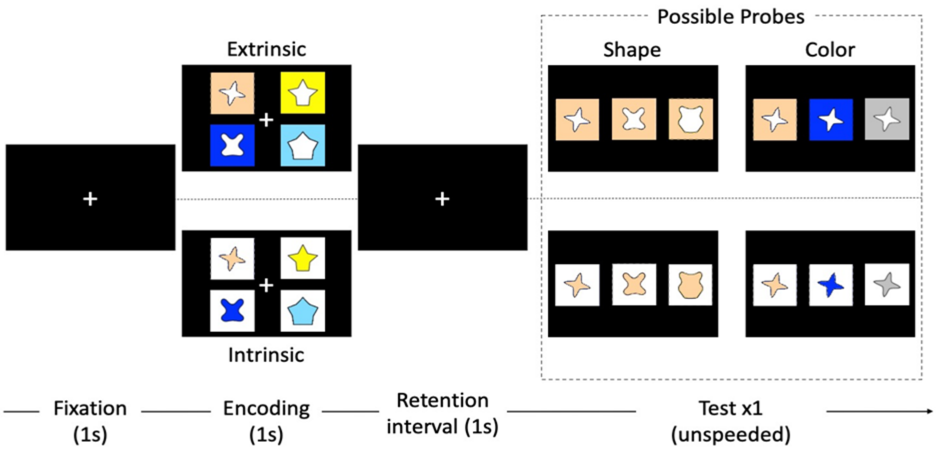
Power analysis. I determined this sample size in a Monte Carlo simulation of the planned MPT models (explained further on) using the R package TreeBUGS (Heck et al., 2018). The data generation and simulation functions allowed estimation of the precision of the parameters of interest with a given sample size and number of trials. The analysis script and the results of our simulations can be found on the OSF. In brief, 500 replications were conducted that generated responses of 60 participants (30 of each cultural group) completing 288 trials based on initial parameter values estimated from a small pilot study (see OSF for further details). The data were generated under two scenarios: (1) greater extrinsic binding in the Eastern group than the Western group (difference at the latent probit mean level = 0.5), in line with the primary hypothesis, and (2) identical extrinsic binding between the cultural groups (difference = 0). The results of the Independence model showed that the 95% credibility intervals of the parameter estimate representing extrinsic binding excluded 0 in 100% of the replications in the first scenario in which an effect of cultural group was present and included 0 in over 94% of the replications in the second scenario in which an effect of cultural group was absent. Thus, the planned sample size and number of trials was considered adequate to achieve reliable parameter estimates that directly address the hypothesis. Given that Bayesian inference is considered immune to problems relating to the sampling plan (Rouder, 2014), the sampling was planned to continue until 50 participants per cultural group were collected if necessary to reach clear evidence for or against the hypotheses (i.e., credibility intervals that do not overlap with 0).

Materials and Procedure. This experiment was programmed in PsychoPy (Peirce et al., 2019) and took place online with two phases. In the first phase, participants were invited to complete a brief demographics questionnaire and colour blindness test to identify prospective Chinese and British participants with normal colour vision, in line with the inclusion criteria. Those who met the criteria were invited to the second phase, wherein participants completed 12 blocks of a visual WM task, with eight practice trials preceding the first block and 24 critical trials per block. Participants received ongoing feedback on their performance and were offered a break after each block.

The trial sequence is presented in Figure 2.1. Each trial began with a fixation cross appearing on the screen for 1s. Four different to-be-remembered shapes, either presented in four different colours on a white background (intrinsic) or white shapes on differently coloured backgrounds (extrinsic), then appeared in an invisible 2 x 2 quadrant array for 1s. After a retention interval of 1s, three test probes appeared in a single row at the centre of the screen: the target (i.e., exactly the same coloured shape as one of the originally presented items), a lure (i.e., a recombination of a presented colour and shape from the trial), and a new item (i.e., a colour or shape that were new to the trial). These probes either comprised different probe shapes (i.e., target, lure, new shape) integrated with the same target colour or the same target shape integrated with different probe colours (i.e., target, lure, new colour) to balance the nature of the decision across the features of the stimuli. Participants made a decision without any time limit regarding which probe was the target with their mouse, after which a new trial began following an inter-trial interval of 1s.

Figure 2.1

Schematic of the Task in Experiment 1.



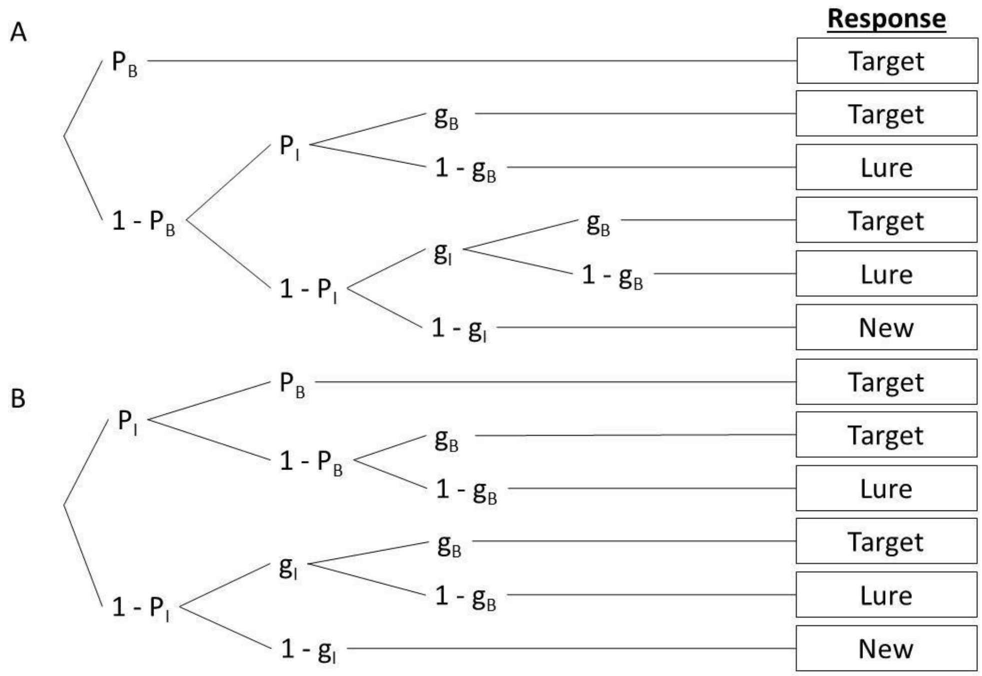
The shapes of the memoranda were abstract shapes randomly drawn from a shape wheel (Li et al., 2020), with an angular separation of 72° between the four shape memoranda and a fifth shape serving as the new probe. This experiment used the same set of 12 colours, comprising two of options of the following six principal colours (RGB values): red ([255,0,0]; [255,128,128]), yellow ([255,255,0]; [255,255,153]), blue ([0,0,255]; [0,0,128]), green ([0,255,0]; [0,128,0]), grey ([64,64,64]; [191,191,191]), and brown ([199,99,0]; [97,48,0]). The colours of the four memoranda presented during encoding were randomly drawn from two of these colour families (e.g., two shapes presented in yellow, and two shapes presented in blue), and the colour of the new probe was randomly selected from the remaining colour families. In this experiment, the recombined lure was a shape or colour from the other colour family in order to avoid an easy rejection of the new colour that is not in the same colour family (e.g., one yellow, blue, and grey instead of two yellows and one grey in Figure 2.1). The on-screen arrangement of the memoranda during encoding and the probes during retrieval were random.

Design and Analysis. This experiment followed a 2 (Culture: Western, Eastern) x 2 (Binding Type: Intrinsic, Extrinsic) x 2 (Probe Type: Shape, Colour) mixed design, with the last two factors manipulated within-subjects, randomly and evenly implemented across trials for all participants. For the analysis, I fitted the data to separate hierarchical Bayesian MPT models for each cultural group using the TreeBUGS package in R. MPT models are a class of measurement models that estimate the cognitive parameters assumed to underlie the observed frequencies of responses of each possible category (i.e., target, lure, and new). Rather than aggregating these responses across participants, hierarchical MPT models explicitly allow for heterogeneity across participants and trials and assume that the resulting individual parameter estimates are drawn from a population distribution. Furthermore, the Bayesian approach focuses on the posterior distribution of the parameters that are sampled using Markov-Chain

Monte Carlo (MCMC) methods. The measures of interest are the mean and quantiles computed for the posterior distribution of the samples, which reflect the updated knowledge about the parameters in light of the data and given some prior beliefs. I used the default weakly informative priors of TreeBUGS that follow the recommendations of prior work (Gelman & Hill, 2006; Klauer, 2010; Matzke et al., 2015; Rouder & Lu, 2005; see Heck et al., 2018 for further information).

Figure 2.2

Multinomial processing tree (MPT) model, showing the Independence model (Panel A) and Dependence model (Panel B). The parameters shown represent the accuracy of binding memory (P_B), the accuracy of item memory (P_I), and associated probabilities for guessing (g_B, g_I).



The two tested models are visually depicted in Figure 2.2. The difference between these models is the assumption of whether binding memory is independent of or dependent on accurate memory of the individual features (i.e., item memory). The Independence model (Figure 2.2A) assumes that participants may correctly select the target probe when they have accurate binding memory (P_B). In the absence of binding memory ($1 - P_B$), participants may still accurately remember the independent shape or colour features of the item (P_I), in which case they may simply guess with equal probability between the target ($g_B = 0.5$) and the lure ($1 - g_B$). In the absence of item memory ($1 - P_I$), participants then guess with equal probability between the probes with features that had been presented ($g_I = 0.5$; after which they guess either the target or lure as specified previously) and the new item ($1 - g_I$). The Dependence model (Figure 2.2B) assumes that participants may correctly select the target probe when they first accurately remember the independent shape or colour features of the item (P_I) as well as their correct binding (P_B). In the absence of binding memory ($1 - P_B$), then they may guess with equal probability between the target ($g_B = 0.5$) and the lure ($1 - g_B$). Thereafter the Dependence model follows the same structure as the Independence model in the absence of item memory ($1 - P_I$). Fixing the guessing parameters ($g_B = 0.5$ and $g_I = 0.5$) in both models allows them to be identifiable and follows prior work (Bartsch et al., 2019; Loaiza & Srokova, 2020).

The analysis procedure was as follows: Model convergence was checked by visually inspecting the MCMC chains and by ensuring that the Gelman-Rubin statistic ($\hat{R}$) was close to 1 for all parameters. Model fit was also assessed by confirming that the posterior predictive p-values (*ppp*) of the discrepancies between observed and predicted mean frequencies and covariances are greater than 0.05 (Klauer, 2010; see Heck et al., 2018 for further information). Given prior work with these models (Bartsch et al., 2019; Loaiza & Srokova, 2020) and a small pilot study, I expected model convergence and fit to be adequate. The comparative fit of the Independence model or Dependence model to the data was tested to understand the structure of these processes by comparing the deviance information criterion

(DIC) of the resulting models. For the winning model, the binding memory and item memory parameter estimates were compared between cultural groups as a function of binding type (extrinsic and intrinsic) and probe type (shape and colour) in order to address the hypotheses. Specifically, given the Bayesian approach and following prior work (e.g., Bartsch et al., 2019; Loaiza & Srokova, 2020), I drew inferences by inspecting the 95% credibility interval (CI) of the mean cultural and binding difference for each of the posterior estimates of binding and item memory. The cultural difference reflects the mean difference between the two cultural groups for each type of binding and probe (i.e., extrinsic-shape, extrinsic-colour, intrinsic-shape, intrinsic-colour). The binding difference reflects the mean difference between the extrinsic and intrinsic binding conditions for each probe type and cultural group. A 95% CI that does not contain 0 would suggest a difference between conditions for the corresponding parameter estimates.

2.2.2 Results and Discussion

The results of Experiment 1 are displayed in Figure 2.3 and Tables 2.2, 2.3 and 2.4. Both the fitted Independence and Dependence models successfully converged (all $\hat{R}$s < 1.02) and provided good fit to the data (all *ppp*s > .05). The Dependence model fit the data of Chinese participants better than the Independence model, whereas the Independence model fit the data of British participants better than the Dependence model (see Table 2.3). The results of both models were similar and are both shown for comprehensiveness (see Figure 2.3).

For all binding-probe combinations, the 95% CI of the estimated mean cultural difference in all the parameters contained 0 (see the column labelled cultural difference in Table 2.4). This suggests that the parameter estimates of binding and item memory were similar between the British and Chinese participants. There was also no credible binding difference for either colour or shape conditions in either cultural group (see the rows labelled binding difference in Table 2.4). This suggests that extrinsic and intrinsic binding were similar regardless of the type of probe or cultural group. These results were consistent regardless of whether the parameter estimates originated from the Independence or Dependence models.

Table 2.2

Mean (and Standard Deviation) and Cohen's d of Accuracy.

Binding	Probe	Culture	Mean(SD)	Cohen's d
Extrinsic	Colour	British	0.588 (0.492)	0.076
		Chinese	0.625 (0.484)	
	Shape	British	0.572 (0.495)	0.041
		Chinese	0.592 (0.492)	
Intrinsic	Colour	British	0.610 (0.488)	0.045
		Chinese	0.632 (0.482)	
	Shape	British	0.590 (0.492)	0.029
		Chinese	0.604 (0.489)	

Table 2.3

Penalised Deviance of the Dependence and Independence Models for Both Cultural Groups.

	British	Chinese
Dependence	1305	1306
Independence	1303	1311

Figure 2.3

Memory Parameter Estimates for the (A) Independence Model and (B) Dependence Model for Each Cultural Group and Binding Condition.

A

B

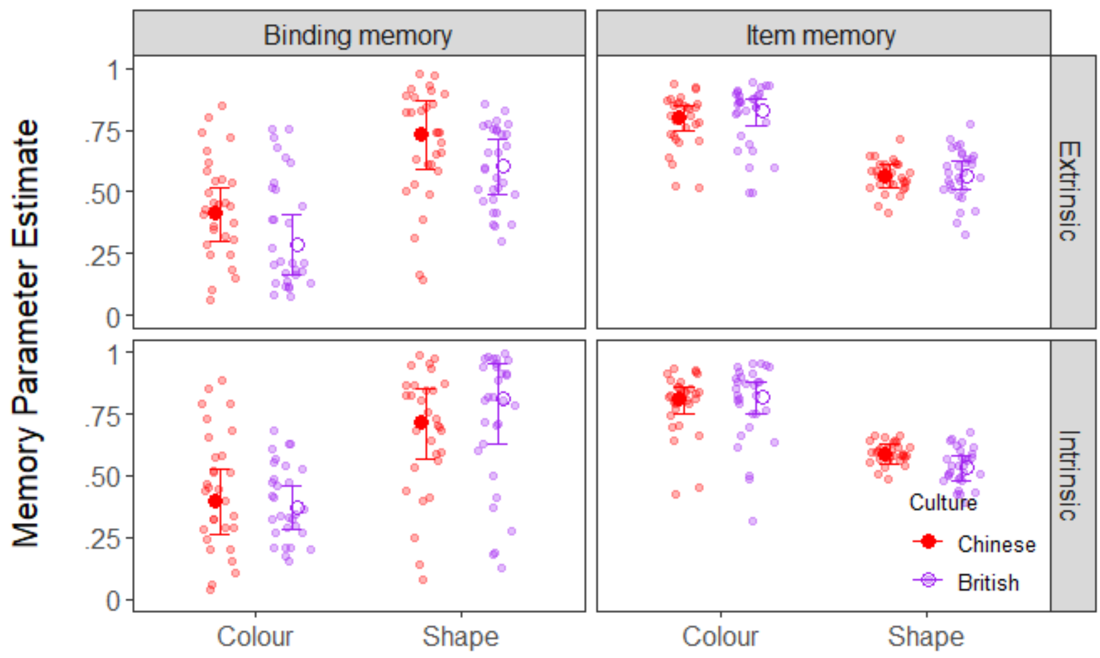


Table 2.4

Posterior-Mean Estimates for the Binding Memory Parameters (Pb) and 95% Bayesian Credible Intervals (CI) as a Function of Cultural Group and Binding Condition.

			Cultural group				*Cultural difference*	
			British		Chinese			
	Binding Condition		Mean	95% CI	Mean	95% CI	Mean	95% CI
Dependence model	Extrinsic	Colour	0.287	[0.166, 0.407]	0.412	[0.303, 0.518]	0.073	[-0.239, 0.498]
		Shape	0.605	[0.490, 0.711]	0.731	[0.590, 0.870]	-0.006	[-0.457, 0.351]
	Intrinsic	Colour	0.373	[0.282, 0.457]	0.398	[0.263, 0.527]	-0.074	[-0.304, 0.177]
		Shape	0.809	[0.631, 0.954]	0.718	[0.570, 0.855]	-0.334	[-0.726, 0.078]
	Binding difference	Colour	-0.084	[-0.200, 0.029]	0.064	[-0.296, 0.499]		
		Shape	-0.203	[-0.358, -0.0379]	0.125	[-0.387, 0.603]		
Independence model	Extrinsic	Colour	0.243	[0.157, 0.330]	0.332	[0.240, 0.430]	0.064	[-0.143, 0.286]
		Shape	0.343	[0.266, 0.417]	0.393	[0.317, 0.469]	0.020	[-0.174, 0.230]
	Intrinsic	Colour	0.304	[0.224, 0.381]	0.331	[0.218, 0.452]	-0.033	[-0.275, 0.305]
		Shape	0.402	[0.319, 0.481]	0.406	[0.331, 0.481]	-0.040	[-0.276, 0.223]
	Binding difference	Colour	-0.032	[-0.165, 0.099]	0.064	[-0.279, -0.335]		
		Shape	-0.077	[-0.181, 0.027]	-0.017	[-0.288, -0.237]		

To sum-up, the results of Experiment 1 yielded three findings. First, the results of this experiment showed that intrinsic and extrinsic binding were similar given the lack of a binding difference. It means that the automaticity of feature binding may not depend on unitisation. Second, there was no evidence for a cultural difference, as the binding parameter estimates for the intrinsic and extrinsic trials were similar between the two cultural groups. Third, the fit of the two versions of the models differed between cultural groups, such that the Independence model fit the data of the British participants better compared to the Dependence model's fit of the Chinese participants' data, but this will require replication before any strong interpretation. The next experiment further investigated whether prior knowledge from long-term memory may impact this pattern of results.

2.3 Experiment 2: Does prior knowledge facilitate binding memory?

Previous work has demonstrated that binding in WM may be facilitated by prior knowledge of the studied information (Loaiza & Srokova, 2020). Therefore, this experiment determined whether established prior knowledge of the studied objects' features facilitated the relatively automatic integration of the extrinsic features for Western participants to match that of Eastern participants. The findings indicate that long-term memory may influence visual WM to such an extent that extrinsic features can be processed automatically in Western participants as well as Eastern participants.

Accordingly, Experiment 2 used a similar paradigm to Experiment 1, wherein British and Chinese participants studied and recalled shapes that were presented in different colours (intrinsic binding) or with coloured backgrounds (extrinsic binding). The most important difference is that the prior knowledge of the presented information was manipulated by varying the consistency between the presented shapes and colours (e.g., red apple vs. blue apple). If prior knowledge promotes WM performance by specifically facilitating extrinsic binding in WM (Loaiza & Srokova, 2020), then prior knowledge should improve extrinsic binding more strongly than intrinsic binding. Furthermore, if there is a cultural difference in the automaticity of extrinsic binding, then this facilitation effect should be observed in British participants to a greater extent than Chinese participants. However, if extrinsic and intrinsic binding are similar, as the results of Experiment 1 suggested, then both cultural groups should show a prior knowledge benefit to both extrinsic and intrinsic binding memory.

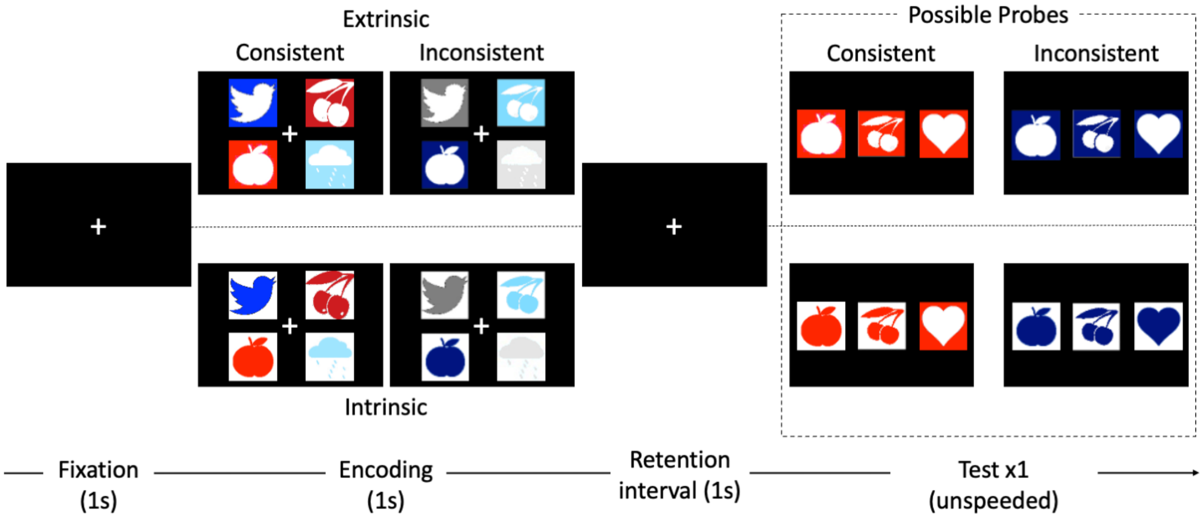
2.3.1 Method

Participants. Similar to Experiment 1, 60 Western and Eastern participants (30 of each cultural group) aged 18-35 were recruited from the University of Essex or Prolific to participate with the same criteria as Experiment 1.

Materials and Procedure. Experiment 2 was very similar to Experiment 1, with the following exceptions: First this experiment included nameable shapes (e.g., an apple) drawn from Sutter and Awh (2016). These images were presented in different colours (intrinsic) or on different-coloured backgrounds (extrinsic) that are consistent or inconsistent with reality (e.g., a red apple versus a blue apple; see Figure 2.4). Because of the difficulty in selecting three colour shades in each colour family, I only used the “shape” probe type of Experiment 1, such that the three different probe shapes (i.e., target, lure, and new shape) appeared integrated with the same target colour. In this experiment, the recombined lure was a shape from the same colour family to ensure that the probes were similarly consistent or inconsistent with reality depending on the condition. The new probe was also selected such that its colour was consistent or inconsistent with reality to ensure that it was a plausible option.

Figure 2.4

Schematic of the Task in Experiment 2.



Design and Analysis. Experiment 2 followed a 2 (Culture: Western, Eastern) x 2 (Binding Type: Intrinsic, Extrinsic) x 2 (Prior Knowledge: Consistent, Inconsistent) mixed design, with the last two factors manipulated within-subjects, randomly and evenly implemented across trials for all participants. The analysis method was the same as Experiment 1.

2.3.2 Results and Discussion

The results of Experiment 2 are displayed in Figure 2.5 and Tables 2.5, 2.6 and 2.7. Both models successfully converged (all $\hat{R}$s < 1.02) and provided good fit to the data (all *ppp*s > .05). The Dependence model fits the data of both British and Chinese participants better than the Independence model (see Table 2.6). The results of both models were similar and are shown for comprehensiveness (see Figure 2.5).

As in Experiment 1, mean (and 95% CIs) differences between cultural group and binding type were computed, as well as a difference reflecting the prior knowledge benefit (i.e., the difference between the consistent and inconsistent conditions for each binding parameter in each cultural group). Once again, the cultural differences and binding differences' CIs included 0. It indicated that there are no cultural differences or binding differences between intrinsic and extrinsic bindings in these two cultural groups. In addition, there were no credible prior knowledge benefits for either intrinsic or extrinsic binding in either cultural group (i.e., the rows labelled prior knowledge benefit in Table 2.7).

Table 2.5

Mean (and Standard Deviation) and Cohen's d of Accuracy.

Binding	Probe	Culture	Mean(SD)	Cohen's d
Extrinsic	Consistent	British	0.601(0.490)	0.075
		Chinese	0.564 (0.496)	
	Inconsistent	British	0.614(0.487)	0.075
		Chinese	0.577(0.494)	
Intrinsic	Consistent	British	0.589(0.492)	0.020
		Chinese	0.579(0.494)	
	Inconsistent	British	0.634(0.482)	0.060
		Chinese	0.605(0.489)	

Table 2.6

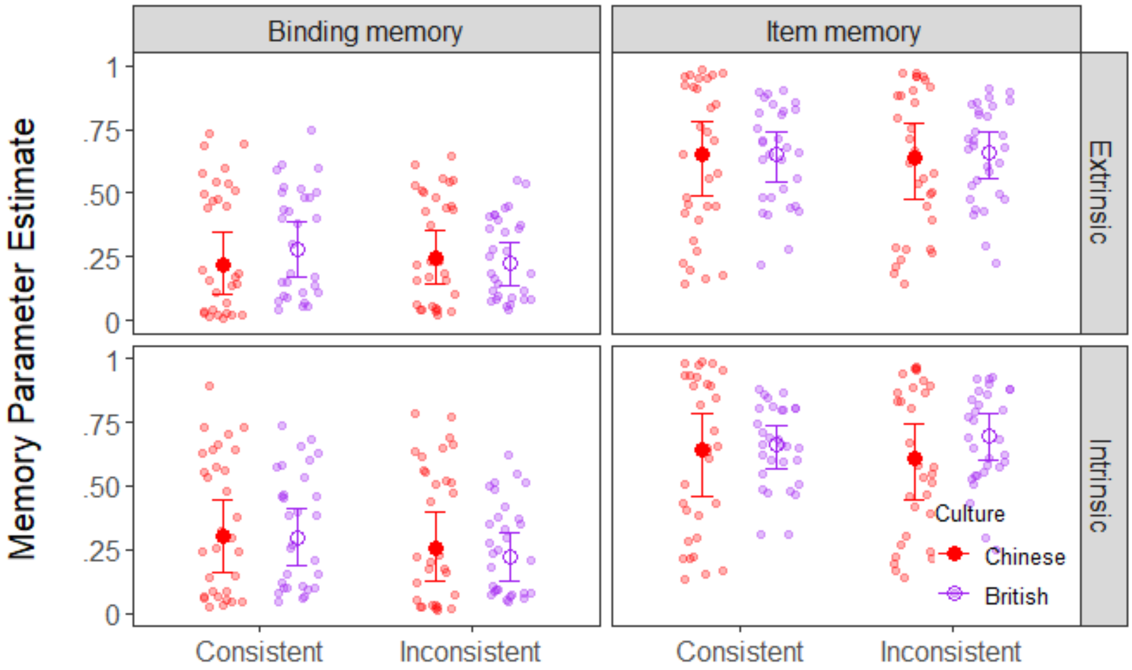
Penalised Deviance of the Dependence and Independence Models for Both Cultural Groups.

	British	Chinese
Dependence	1283	1316
Independence	1289	1319

Figure 2.5

Memory Parameter Estimates for the (A) Independence Model and (B) Dependence Model for Each Cultural Group and Binding Condition.

A



B

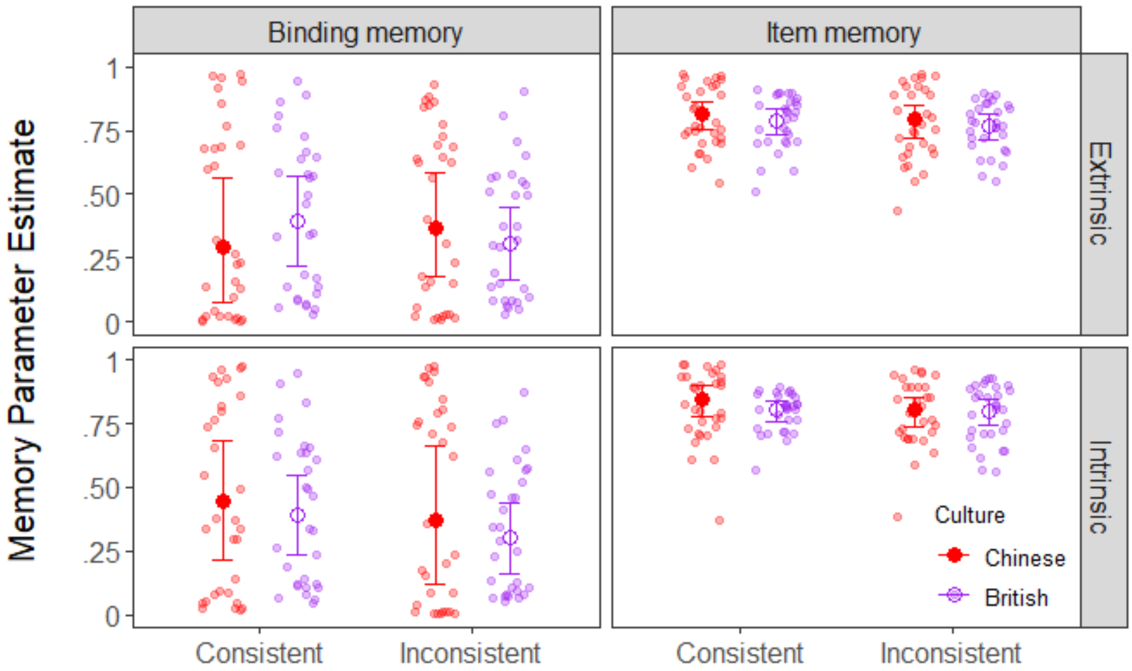


Table 2.7

Posterior-Mean Estimates for the Binding Memory Parameters (Pb) and 95% Bayesian Credible Intervals (CI)

			Cultural group				*Cultural difference*	
			British		Chinese			
	Binding	Condition	Mean	95% CI	Mean	95% CI	Mean	95% CI
Dependence model	Extrinsic	Consistent	0.392	[0.218, 0.570]	0.292	[0.079, 0.562]	0.015	[-0.421, 0.564]
		Inconsistent	0.305	[0.164, 0.449]	0.369	[0.178, 0.585]	0.104	[-0.315, 0.638]
	Prior Knowledge Benefit		0.086	[-0.055, 0.225]	-0.003	[-0.687, 0.689]		
	Intrinsic	Consistent	0.394	[0.238, 0.551]	0.445	[0.214, 0.684]	0.106	[-0.388, 0.605]
		Inconsistent	0.300	[0.162, 0.440]	0.371	[0.121, 0.662]	0.168	[-0.303, 0.688]
	Prior Knowledge Benefit		0.092	[-0.043, 0.226]	0.030	[-0.707, 0.738]		
	Binding difference	Consistent	0.086	[-0.055, 0.225]	-0.003	[-0.687, 0.689]		
		Inconsistent	0.092	[-0.043, 0.226]	0.030	[-0.707, 0.738]		
Independence model	Extrinsic	Consistent	0.279	[0.170, 0.389]	0.219	[0.104, 0.345]	0.094	[-0.291, 0.632]
		Inconsistent	0.223	[0.139, 0.307]	0.244	[0.144, 0.351]	0.157	[-0.222, 0.689]
	Prior Knowledge Benefit		0.058	[-0.033, 0.146]	-0.004	[-0.657, 0.653]		
	Intrinsic	Consistent	0.299	[0.187, 0.412]	0.304	[0.160, 0.449]	0.089	[-0.303, 0.605]
		Inconsistent	0.221	[0.126, 0.317]	0.253	[0.127, 0.395]	0.145	[-0.228, 0.694]
	Prior Knowledge Benefit		0.079	[-0.012, 0.169]	0.023	[-0.651, 0.662]		
	Binding difference	Consistent	0.058	[-0.033, 0.146]	-0.004	[-0.657, 0.653]		
		Inconsistent	0.079	[-0.012, 0.170]	0.023	[-0.651, 0.662]		

2.4 General Discussion

The goal of this chapter was to investigate whether previously documented cultural differences between Eastern and Western participants in perception and memory (Chua et al., 2005; Masuda & Nisbett, 2001) inform a longstanding research question regarding the nature of feature binding in WM. In particular, a great deal of conflicting prior research has concerned whether integrating different features (e.g., shape, colour) into a cohesive object representation in visual WM is a resource-demanding process or is relatively automatic (Allen et al., 2006, 2012; Brown & Brockmole, 2010; Morey & Bieler, 2013). Whether feature binding is automatic or not may depend on unitisation, such that intrinsic features (i.e. information inherent to the object, such as its colour) may be more automatically bound than extrinsic features (i.e. information that is not part of the object, such as its background; Ecker et al., 2013; Troyer & Craik, 2000). One so-far unconsidered means to investigate this issue is to draw upon the well-documented cultural differences between Easterners and Westerners in how they perceive and remember information. According to the Analytic and Holistic framework (Masuda & Nisbett, 2001; Nisbett et al., 2001; Nisbett & Miyamoto, 2005), Eastern participants tend to perceive and attend to information more holistically than Western participants. Therefore, investigating how culture impacts the automaticity of feature binding in WM would provide novel insight into the potential distinction between extrinsic and intrinsic binding as well as clarify the source of cultural differences in perception and memory performance.

To address these issues, the two experiments in this chapter determined whether Eastern participants more automatically bind background contexts of to-be-remembered information, thereby exhibiting greater extrinsic binding memory than Western participants, who may tend to focus more on the foreground content. The results of these two experiments would provide a novel advance for both fields of WM and cultural psychology by indicating either that intrinsic and extrinsic binding are dissociable on the basis of culture, or that extrinsic and intrinsic binding are similar for Eastern and Western participants.

The results of Experiments 1 and 2 yielded four main findings. First, the binding memory parameter estimates were similar between intrinsic and extrinsic trials, and thus, the automaticity of feature binding may not depend on unitisation. As I will explain in more detail further on, this conflicts with the suggestion that intrinsic and extrinsic binding are distinct (e.g., Ecker et al., 2013) and instead suggests that feature binding is relatively automatic regardless of the nature of the to-be-bound features (e.g., Allen et al., 2006, 2012).

Second, there were also no credible differences between the two cultural groups in extrinsic binding memory, regardless of the nature of the probe (either colour or shape; Experiment 1 and 2) or the memoranda's prior knowledge in LTM (either consistent or inconsistent with reality; Experiment 2). This result goes against the prediction based on the Analytic and Holistic framework that Eastern participants equally focus on foreground objects and their backgrounds given their more holistic style of thinking (Masuda and Nisbett, 2001). Based on the thinking styles theory, extrinsic binding should have been more automatic in Easterners than in Westerners if they process information more relationally and contextually. However, given the similar extrinsic binding memory parameters between the cultural groups, the results suggest that extrinsic binding is not more automatic in Chinese participants than British participants. Furthermore, intrinsic binding memory was also similar between the cultural groups, which at first glance could indicate that intrinsic binding was similarly automatic between British and Chinese participants, in line with one of the possible predictions regarding intrinsic binding. However, there were no differences between intrinsic and extrinsic binding memory for either cultural group, calling into question the basic premise that intrinsic binding is more automatic than extrinsic binding in general. Thus, a null cultural difference in extrinsic binding may have occurred simply because intrinsic and extrinsic binding are similarly automatic.

These findings go against my hypotheses, perhaps because there are some other factors that may affect feature binding. Experiment 2 further investigated this possibility by manipulating a third factor, prior knowledge in LTM, to determine its impact on intrinsic and extrinsic binding between cultural groups. The results were consistent with those of Experiment 1 in that there were no differences between intrinsic and extrinsic binding memory for either cultural group. Most importantly for Experiment 2, both British and Chinese participants showed similar parameter estimates between the consistent and inconsistent conditions, which goes against the prediction and previous findings that prior knowledge in LTM facilitates binding (Bartsch & Shepherdson, 2020; Loaiza & Srokova, 2020). That is, binding in WM should benefit when the features of the memoranda are consistent with prior knowledge. However, there were no differences between consistent and inconsistent conditions for either cultural group, thus suggesting that LTM does not facilitate binding memory.

Finally, the results of the experiments cannot distinguish whether Independence or Dependence model shows the underlying process of feature binding in WM as the penalised deviance in both models are similar in both experiments (see Table 2.3 and 2.6). Therefore, it is still unclear whether the underlying process of feature binding is like what the Independence model proposed that I remember the combination of the features (i.e. the binding memory) first or on the other way round, like what the Dependence model proposed that I encode the individual features (i.e. the item memory) first. Further experiments are needed to investigate on the underlying process of feature binding and validate the Dependence model.

2.4.1 Cultural Differences

Based on the results of Experiments 1 and 2, I did not find any credible differences in the memory parameters between intrinsic and extrinsic binding of both Eastern and Western participants, which go against the Analytic and Holistic framework. This is perhaps surprising, as previous studies have demonstrated cultural differences between the Eastern and Western worlds in many areas. The difference in cognitive thinking styles can be demonstrated using different tasks or indicators (Uskul et al., 2023). Specifically, compared with Westerners, East Asians have been shown to use more situational attributions in causal attributions (Kitayama, Ishii, et al., 2006), make more thematic categorisations or classifications of objects (Chiu, 1972; Ji et al., 2004; Miyamoto & Ji, 2011), include more contextual information in their casual decisions (Choi et al., 2003), and prove superior in third-person perspective (Cohen & Gunz, 2002). All of these findings are seen as indicators for holistic thinking.

Also, previous studies found significant cultural differences in long-term memory (Park et al., 1999; Park & Gutchess, 2002; Park & Gutchess, 2006). For example, Wang and Ross (2005) tested 526 Caucasian and Asian American adults on cultural differences in self-priming effects. The results showed that Asians tended to recall more general memories of collective activities and social interactions, while Caucasians recalled more memories about the specific event that self is the central character. Wang and Conway (2004) also recruited 108 European American and Chinese adults for a questionnaire study. Their results showed that Chinese participants have emphases more on social interactions and their significant others in their memory. In contrast, European American participants recalled more self-centred memories about their personal experiences or specific events. These two studies have demonstrated the cultural differences in Eastern and Western participants when they recall the autobiographical memory in their LTM.

Despite there are extensive evidence showing cultural differences in cognition between Eastern and Western population, but I did not find any cultural differences between British and Chinese participants in these two experiments. There are a couple of reasons why our research did not yield cultural differences. The first reason may be because of globalisation. Globalisation means that different nations are more rely on and similar to each other. Therefore, it reduced the distance between different nations and may also reduce the differences between different cultures. As suggested by the neuro-culture interaction model (Kitayama & Uskul, 2011), cultural values and psychological tendencies of an individual were influenced by repeated exposure to a particular set of cultural practice, therefore, globalisation may minimise the cultural differences between Eastern and Western world. As a result of globalisation, Eastern participants may expose to Western culture, while Western participants may expose to Eastern culture more frequently, and thus, the cultural differences proposed by the Analytic and Holistic framework may be reduced as well. This can be confirmed by comparing children's and young adults' performances. If there are cultural differences in children between two cultural groups but not in the young adults, in that case, globalisation is very likely one of the reasons for the results of these two experiments, as young children are relatively immune from globalisation. Since I did not include any studies related to children in this thesis, it is still unclear whether globalisation explains why I did not find any cultural differences. Therefore, globalisation can be a possible explanation, but it requires further studies to support this argument.

Second, I was not able to detect such cultural differences in these two experiments, one of the possibilities is that encoding colour is relatively automatic regardless it is an intrinsic or extrinsic features. Brady et al. (2016) investigated how many items participants can remember in three different conditions, namely, colours only (showing coloured squares), objects only (showing distinct real-world objects, e.g. a bell and a mud) and objects with details (showing similar real-world objects, e.g. two different type of muds). They found in their Experiment 1 that participants could encode colour within 200ms, which is more automatic than encoding real world objects. In this case, if simply encoding intrinsic and extrinsic colours in these two experiments may not be able to show a huge different in attention allocation between two cultural groups as encoding colour is relatively fast and automatic. Therefore, encoding intrinsic and extrinsic colours which may not maximise the cognitive control abilities between British and Chinese participants. Previous studies pointed out that Western participants are more able to control and separate the useful information from complicated scenes due to their societal value is more individualistic and also their thinking style is more analytic than Eastern participants (Ji et al., 2000). On the other hand, Easterners are more used to complicated information due to their holistic thinking style and collectivism societal value (Masuda et al., 2008; Miyamoto et al., 2006). Encoding colour is fast and automatic, and thus it may not allow British participants to show how able they can separate useful and important information from the stimuli and suppress interference from irrelevant information. On the other hand, it also minimised how able Chinese participants process complex information and how they allocate their attention differently, which is the cultural differences reported in the previous cross-cultural studies (e.g. Masuda et al., 2008; Miyamoto et al., 2006). In short, one of the possible reasons of no cultural differences found is because encoding colour is relatively automatic regardless it is an intrinsic or extrinsic features.

Another possibility is the design of Experiment 1 and 2 significantly deviate from the other cross-cultural studies, which found cultural differences between Easterners and Westerners in several ways (e.g., Masuda & Nisbett, 2001; Nisbett et al., 2001). This study measures the differences in prioritisation of attention allocation between Easterners and Westerners, and previous cross-cultural studies are measuring how these two cultural groups allocated attention and processed information. For example, Kitayama and Cohen (2007) used the framed-line test to investigate holistic and analytic thinking style. Participants were asked to finish the same number of absolute task and relative task. In the relative task, participants were asked to draw a line which is in the absolute length to the earlier presented line within a frame, while, in the relative task, participants were asked to draw a line in proportion to the height of the surrounding frame. They found that most East Asian performed better in the relative task due to their holistic thinking style, whereas most Westerners did better in the absolute task, which is facilitated by their analytic thinking style and thus more able to extract the important information away from the context. In addition, Willey and Liu (2022) showed that East Asians were having more errors in judging whether a rotated rod inside a titled square was vertical than their Western counterparts. The performance of East Asian participants on Rod and Frame test are impacted by their holistic thinking style, therefore, they were more influenced by the tilted frame perception and thus, affected their judgement of the rod's orientation. These studies supported the claim that Easterners and Westerners are different in information processing. Therefore, such differences in measurements resulted that these two experiments are a significant difference from other cross-cultural studies (e.g. Kitayama & Cohen 2007; Willey & Liu, 2022). For example, the presentation time in the encoding stage of these two experiments is only 1 second, which is enough to recognise the preferences of prioritisation in attention of the participants, whereas other cultural studies are much longer. Such as the presentation time in Masuda and Nisbett (2001) was 20 seconds, and they presented the stimuli to participants twice. Significant longer presentation time may allow participants to access their LTM, and thus what was measuring in the previous cross-cultural studies may be their LTM instead of WM.

Based on this background, a subsequent experiment (i.e. Experiment 3) has been designed to confirm whether there are no cultural differences at all in feature binding or the null effect found in these two experiments are due to fail to detect the cultural differences in these two experiments.

2.4.2 Unitisation

These two experiments did not show any differences between intrinsic and extrinsic binding memory in either or across groups, which is inconsistent with our hypothesis and also the findings of prior studies (e.g., Ecker et al., 2013). One of the possible explanations for this result is that to-be-remembered stimuli may be stored as a whole object in their working memory instead of individual features (Luck & Vogel, 1997). In the current literature, there are three different views about how we store information in our WM, namely object-based (e.g. Luck & Vogel, 1997), feature-based (e.g. Fougnie & Alvarez, 2011; Wheeler & Treisman, 2002) and both object-based and feature-based co-exist in the WM (e.g. Oberauer & Eichenberger, 2013; Vergauwe & Cowan, 2015; Xu & Chun, 2006). Object-based view proposed that I remember the whole object in our working memory instead of individual features. For example, when I remember a red apple, I remember it as a red apple instead of remembering its colour and the shape of the red apple. Feature-based view proposed an opposite view; I am remembering the object as independent features in the WM instead of a coherent object. That means, when I remember a red apple, I am remembering both its colour and shape, therefore, the automaticity of intrinsic and extrinsic features matters. The last view proposed that both feature-based and object-based storage co-exist in WM. So, if the object-based view is the case, I remember the object as a coherent representation regardless of the individual features. Therefore, intrinsic and extrinsic binding will be similarly automatic, as I do not remember any single features of the object. These two experiments show that intrinsic and extrinsic features are similarly automatic. Therefore, the results of these two experiments support the object-based view (e.g. Luck & Vogel, 1997) and go against the feature-based view (e.g. Fougnie & Alvarez, 2011; Wheeler & Treisman, 2002) and the third view, which is both object-based and feature-based storage co-exist in the WM (e.g. Oberauer & Eichenberger, 2013; Vergauwe & Cowan, 2015; Xu & Chun, 2006). To confirm this explanation, a subsequent experiment (i.e. Experiment 4) has been designed to investigate how we store information in WM by using different combination of intrinsic and extrinsic features (e.g. intrinsic colour and extrinsic location).

2.4.3 Prior Knowledge Benefits

One of the reasons why I could not find any prior knowledge benefit in this study may be because the contrast between the consistent and inconsistent conditions is not huge enough. Prior studies reported that the prior knowledge benefits are stronger if they were using the concrete objects compare to the fully scrambled objects rather than the lightly scrambled objects (Brady & Störmer, 2022). Brady and Störmer (2022) tested three types of objects: fully scrambled objects (i.e. coloured blobs), lightly scrambled objects (i.e. lightly scrambled concrete objects but still meaningful) and concrete objects. Unsurprisingly, the prior knowledge in their LTM facilitated their WM formation in the concrete object condition. Additionally, they found that in the lightly scrambled condition, participants still activated the prior knowledge in their LTM to remember the objects, as they may still be able to recognise the object. However, in the fully scrambled condition, participants are less likely to activate their prior knowledge when remembering the objects, as they are less able to recognise the objects. Therefore, the prior knowledge in the LTM is less likely to help to facilitate the WM formation. So, based on this background, in the inconsistent condition of Experiment 2, I asked participants to bind different concrete objects with colours which are inconsistent with reality to investigate the prior knowledge benefit; however, those concrete shapes in the inconsistent condition may still be able to activate the prior knowledge in their

LTM and thus facilitated their WM formation. Therefore, those concrete shapes in the inconsistent condition may minimise the prior knowledge benefit between the consistent and inconsistent conditions; then, the prior knowledge benefits may become less obvious in this experiment.

Based on these results, a subsequent experiment (i.e. Experiment 3) was designed to replicate the result of Experiment 1 of Ecker et al. (2013), including both Western and Eastern participants. The aim was to use Ecker et al. (2013)'s paradigm, which previously showed differences between intrinsic and extrinsic binding, to determine whether there truly are no cultural differences in feature binding. Furthermore, unlike Experiments 1 and 2, an independent Cognitive Attribution task was included in Experiment 3, which has consistently shown cultural differences (Kitayama, Ishii, et al., 2006; Uskul et al., 2023). This was useful to determine whether the null effects in this chapter accurately represent reality, in which case the Analytic and Holistic framework may apply to some forms of memory and cognition but not feature binding in working memory. It is still unclear whether null cultural differences in Experiments 1 and 2 occurred because there truly are no cultural differences at all in feature binding in visual working memory or whether there are other factors (e.g. the design of the paradigm) influencing the automaticity of feature binding. Therefore, in Experiment 3, adding the Cognitive Attribution task will determine either there are no true cultural differences at all in visual working memory, but still in other cognition (i.e. only a cultural difference in the Cognitive Attribution task); or that there are no cultural differences at all in this group of participants (i.e. no cultural differences in either the WM task or the attribution task).

To conclude, the findings of those two experiments in this chapter provided a more comprehensive understanding regarding how theoretical processes underlying WM differ across cultures. Specifically, the results simultaneously shed light on a longstanding theoretical issue in the WM field regarding the automaticity of feature binding while also providing greater insight into the nature of observed cultural differences in perception and memory. This advance brings together two otherwise independent pieces of literature.

Chapter 3: Cultural Differences in Working Memory – Replication of Experiment 1 in Ecker et al. (2013)

3.1 Introduction

The results of Experiment 1 and 2 in the last chapter showed that there were no cultural differences in feature binding, and Experiment 2 also showed that there were no prior knowledge benefits to feature binding either. Thus, the experiment in this chapter aims to replicate the result of Experiment 1 of Ecker and colleagues (2013) who found that the automaticity of feature binding depends on unitisation. As a reminder, feature binding means integrating different features (e.g. colour and shape) into a coherent object representations in working memory (WM), and unitisation means the to-be-bound information is either intrinsic (i.e., the feature is part of the stimulus; e.g., the colour or shape of the object) or extrinsic (i.e., the feature is not part of the stimulus; e.g., its background). Ecker and colleagues (2013) reported that intrinsic but not extrinsic colour influenced shape recognition, suggesting that intrinsic feature binding is more automatic than extrinsic feature binding.

Referring back to the Analytic and Holistic framework (Masuda & Nisbett, 2001; Nisbett et al., 2001; Nisbett & Miyamoto, 2005), there may be differences in the orientation of attention to different features between Eastern and Western participants. Nisbett and colleagues proposed that Eastern participants tend to pay attention to foreground objects and their backgrounds equally, whereas Western participants tend to pay more attention to foreground objects. Such cultural differences may be useful to understanding fundamental processes in WM, like feature binding. If the Analytic and Holistic framework is correct, then Western and Eastern participants should show similar intrinsic binding memory, as it is more automatic than extrinsic binding memory. On the other hand, Eastern participants should show greater extrinsic binding memory than Western participants. Therefore, Experiment 3 in this chapter aims to replicate the Experiment 1 of Ecker and colleagues (2013) using British and Chinese participants, so as to determine whether the cultural differences that the Analytic and Holistic framework predict are evident in the original paradigm that demonstrated a difference between intrinsic and extrinsic binding.

An additional unrelated task was included to detect cultural differences since no cultural differences were observed in the two previous experiments reported in Chapter 2. If this unrelated task detects a cultural difference, that has been reliably shown in previous research (e.g. Kitayama et al., 2006, 2009; Uskul et al., 2023), then this will confirm that the null cultural effect in the previous two experiments, and possibly in this experiment, is due to no true cultural differences in feature binding rather than a failure to detect a cultural difference. In other words, a cultural difference in a non-memory task would show that there are true cultural differences between the groups that are not evident in feature binding. The Cognitive Attribution task, which examines the tendency to attribute behaviour to situational versus dispositional factors, was selected for this purpose.

As I explained in Chapter 1, according to the social orientation hypothesis, Easterners tend to be more interdependent (i.e. emphasise relationships with others), whereas Westerners tend to be more independent (i.e. emphasise uniqueness). Several studies in the current literature proposed that interdependent people show a lesser degree of dispositional bias because they are relatively more attentive to situational constraints (e.g. Kitayama, Ishii, et al., 2006; Masuda & Kitayama, 2004; Miller, 1984; Morris & Peng, 1994). On the other hand, independent people (e.g. European Americans) are more likely than interdependent people (e.g. Asians) to assign greater importance to dispositional factors than to situational factors. Masuda and Kitayama (2004) also found that independent people may ignore obvious situational constraints and conclude that a person’s attitude would correspond to their stated opinion. This Cognitive Attribution task has been well validated by previous studies and previous work has reported that Easterners make significantly more situational attributions than Westerners (Kitayama, Mesquita, et al., 2006; Kitayama et al., 2009; Uskul et al., 2023).

Based on this background, the aims of this study were the following. First, I aimed to replicate the results of Experiment 1 in Ecker and colleagues (2013) to confirm that intrinsic binding is more automatic than extrinsic binding in a sample of Western participants (as Ecker and colleagues had used) as well as a sample of Eastern participants. If so, then both Eastern and Western participants will perform better during trials requiring intrinsic binding than extrinsic binding. Second, this study will determine whether the cultural differences predicted by the Analytic and Holistic framework apply to feature binding. If this is the case, then Eastern participants will show greater performance during trials that require extrinsic binding than Western participants, but both cultural groups will show similar performance during trials that require intrinsic binding. Third, I aimed to replicate the result of the Cognitive Attribution task in previous studies (e.g. Kitayama et al., 2006, 2009; Uskul et al., 2023) to better determine that there is a true cultural difference between the British and Chinese groups. This will ensure that a failure to detect a cultural difference is not responsible for any lack of cultural differences in the WM task.

3.2 Method

Participants

The original aim was to recruit 100 participants who come from either the UK (Western) or mainland China/Hong Kong (Eastern; 50 of each cultural group) between the ages of 18 and 35 with normal colour vision and normal hearing to participate in this study. The sample size was justified with the power analyses described further on. Due to circumstances explained further on, data collection for this experiment was stopped before achieving the target sample size (see Table 3.1). All the British participants were recruited from the University of Essex and 3 Chinese participants were recruited from the University of Essex and the rest were recruited from Hong Kong.

The inclusion/exclusion criteria were the following: (1) Eastern participants who were born in mainland China or Hong Kong and had not lived outside mainland China/Hong Kong for more than 3 years, and Western participants were born in the UK and had not lived outside the UK for more than 3 years; (2) Eastern and Western participants also self-identified as belonging to the Chinese/Hong Kong or British cultural group, respectively; (3) Participants from any similar previous experiments were not allowed to participate; (4) Participants were required to be aged 18 to 35 and pass a colour blindness test and hearing test. Participants who did not meet these criteria were not invited to proceed to the experiment. Furthermore, participants were instructed to complete the experiment in one continuous sitting that was free of distractions, such that receiving a reminder to respond to over 10% of the probes resulted in their data being excluded and thus uncompensated. The data of participants who performed at or worse than chance were excluded. Participants were compensated with partial course credit, payment (£8/hour pro rata), or participated on a voluntary basis. All participants in this experiment provided informed consent and were fully debriefed at the conclusion of the experiment.

Table 3.1

Sample Details and Exclusions.

Sample details	British	Chinese
Total N attempted	187	247
N failed to pass the colour blindness/demographic screening phase	96	187
N excluded for pre-registered reasons:		
Did not start the experiment after passing the screening phase	29	19
Incomplete data (e.g., from exiting the full screen, quitting/ restarting the experiment)	27	10
Reported having experienced issues (e.g. technical) affecting performance	1	0
Reported not completing the experiment in one distraction-free sitting	0	0
Recall responses exceeded 5s on more than 10% of trials	10	9
Final N for analysis after pre-registered exclusions	24	22

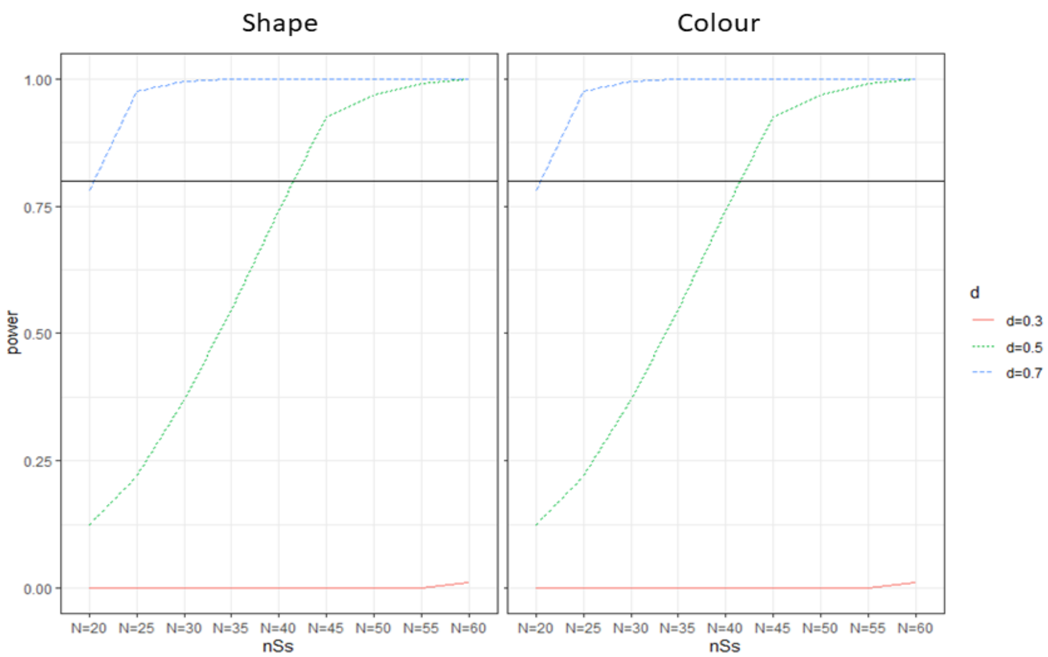
Power analysis

To estimate a reasonable effect size for this study, I performed a literature search on Google Scholar, PsycARTICLES, and PsycINFO using the key phrase 'cross-cultural differences in memory'. Studies published between 2000 to 2022 were included, and all book chapters, review articles, theses, and studies not reporting any memory performance data were excluded. Additionally, I only included those studies that reported mean and standard deviation or standard errors in their manuscript for the power analysis estimation. Only six papers comprising seven total studies fulfilled all of these requirements. The effect sizes ranged from 0 to 4.63, and the mean effect size was 0.5.

To determine the sample size of this study, I performed two power analyses. In the first power analysis, I generated data for trials requiring extrinsic binding based on the means and standard deviations reported in Experiment 1 of Ecker and colleagues (2013), whose experiments presumably included Western participants. In brief, I conducted 200 replications of the colour and shape conditions and nine different sample sizes (i.e., 20, 25, 30, 35, 40, 45, 50, 55, and 60 participants per cultural group). Then, I generated the data of the Eastern participants to be greater than that of the Western participants under three different effect sizes (i.e., 0.3, 0.5, and 0.7). I then examined whether the Bayes factor of a one-sided t-test in favour of the alternative hypothesis of a cultural difference in correct recognition of old extrinsic colours/shapes was greater than 3 in at least 80% of the 200 replications. The results of this power analysis showed that at least 45 participants per cultural group would be required to achieve at least 80% power to detect a cultural group effect size of 0.5 (i.e., the mean effect size of the previous studies). Figure 3.1 shows the results of these power analyses.

Figure 3.1

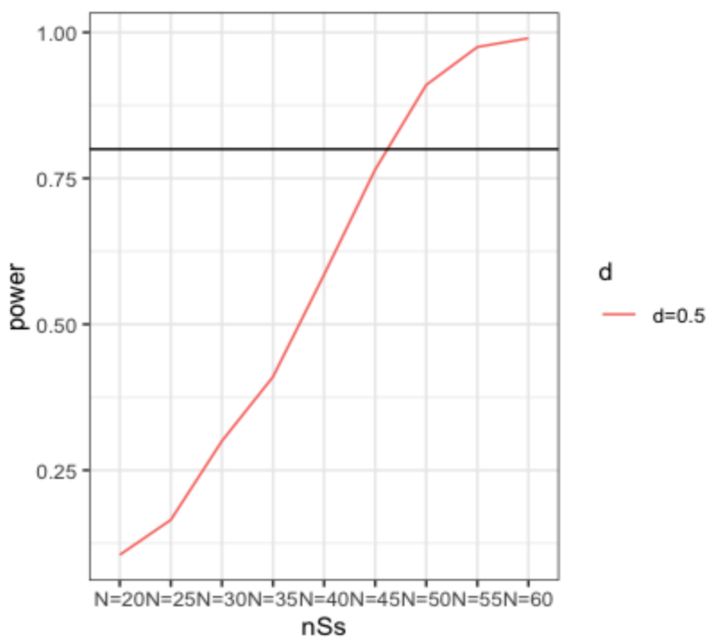
The Results of the First Power Analysis For the Shape (Left) and Colour (Right) Conditions



For the second power analysis, I generated data for the Cognitive Attribution task based on the effect size of the cultural differences observed in Uskul and colleagues (2023), whose experiments included both Eastern and Western participants. In brief, I conducted 200 replications and nine different sample sizes (i.e., 20, 25, 30, 35, 40, 45, 50, 55, and 60 participants per cultural group). I then examined whether the Bayes factor of a one-sided t-test in favour of the alternative hypothesis of cultural differences in the tendency to attribute behaviour to situational rather than person-related (i.e. dispositional) factors in the attribution test was greater than 3 in at least 80% of the 200 replications. The results of this power analysis showed that at least 50 participants per cultural group would be required to achieve at least 80% power to detect a cultural group effect size of 0.5 (i.e. the effect size observed in Uskul et al., 2023). Figure 3.2 shows the results of this power analysis. The analysis script and the results of both power analyses can be found on the OSF (https://osf.io/md2rz/?view_only=f267564f7f8a4a34bc792fd7f7c3d0c2).

Figure 3.2

The Results of the Second Power Analysis for the Cognitive Attribution Task



Materials and Procedure

Cognitive Attribution Task. The Cognitive Attribution task (Kitayama, Mesquita, et al., 2006) examined how participants perceive the cause of the behaviour in different scenarios, and whether such behaviour tends to be related to personal-related factors or situational factors. Each participant was required to read four different situational stories. Two of the stories described a protagonist engaging in a socially undesirable behaviour (e.g. concealing an avoidable mistake that caused the death of a patient), and the other two described the protagonist engaging in a socially desirable behaviour (e.g. donating malaria medicine to countries in Africa needing assistance).

Participants were then asked to think about the reasons for the protagonist's behaviour by answering the same four questions for each story. For example, whether the described action was caused by dispositional/situational factors (e.g. *"Features of [the main chapter in the story] (such as her character, attitude, or temperament) influenced her behaviour [what she has done in the story]"*). All items were rated using a 7-point scale ranging from 1 = strongly disagree to 7 = strongly agree. The stories presented to British participants were in British English, and the stories presented to Chinese participants were either in traditional Chinese or simplified Chinese, depending on which one they were more familiar with. Following the method of previous studies, for each story I created an index of situational attribution (averaging the two questions of situational attribution) and an index of dispositional attribution (averaging the two questions of dispositional attribution). Then, a situational score was computed by averaging the index of situational attribution of all four stories and a dispositional score was computed by the index of dispositional attribution of all four stories. After that, a causal situational attribution index was computed by subtracting the dispositional score from the situational score.

A positive causal situational (dispositional) attribution score (score above 0) indicates that the perceived cause of those behaviours related more to situational than dispositional factors (i.e. a form of interdependence). On the other hand, a negative attribution score (score below 0) indicates that the perceived cause of those behaviours related more to dispositional than situational factors (i.e. a form of independence).

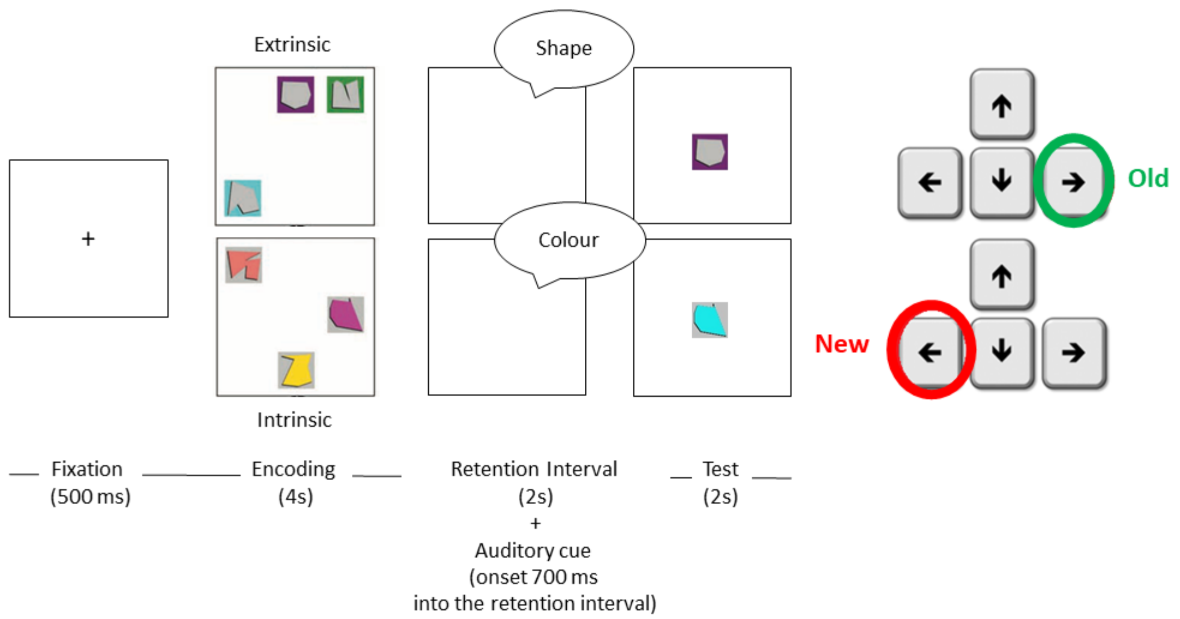
Working memory task. After participants completed the Cognitive Attribution task, they were redirected to the third phase of the study comprising the main experiment. The materials and procedure were identical to the Experiment 1 of Ecker and colleagues (2013; see Figure 3.3), except that this experiment was conducted online (and not in person), offered a break after every 40 trials (rather than after every 80 trials), and provided feedback to the participants on their ongoing performance after each block of 80 trials (rather than no feedback provided). The latter two changes were implemented only to facilitate the burden of participating in the task in an online setting.

The colours used in this experiment were a set of eight colours used by Parra and colleagues (2009). The shapes of this experiment were a set of eight intrinsic or extrinsic abstract "Attneave" shapes with six to eight angles used in Ecker and colleagues (2013) experiments. In the intrinsic versions, the shapes were coloured in one of eight colours on a light-grey background. In the extrinsic condition, the shapes were coloured in light grey on a coloured background.

The experiment was programmed in PsychoPy (Peirce et al., 2019) and conducted online through Pavlovia.org. The experiment task filled the screen prior to starting. Participants were informed both in the study advertisement and during the experiment that any of the following actions could risk their data being excluded and uncompensated: Failing to complete the experiment in one continuous, distraction-free setting, reloading the page, hitting the back button, quitting and restarting the study, escaping the full-screen mode/switching windows, or failing to respond to more than 10% of the trials. If participants switched windows away from the full-screen mode, the experiment was designed to quit immediately, whereas the other exclusion criteria were implemented during the data pre-processing (see Design and Analytic Procedure).

Figure 3.3

An Illustration of the Current Experiment Task.



The trial sequence is presented in Figure 3.3. Each trial began with a fixation cross presented for 500ms on screen. Three to-be-remembered differently coloured shapes on a light-grey background (intrinsic) or light-grey shapes on different coloured backgrounds (extrinsic) then appeared in a random location (in an invisible 3x3 grid) for 4s. The coloured images only appeared in the eight outer positions, with no more than two appearing in the same row or column. After that, there was a retention interval of 2s, during which an auditory cue was presented (700 ms after retention interval onset). The auditory cue was either 'Colour' or 'Shape' to indicate which feature would be tested. Then, a test probe appeared at the centre of the screen: a target (i.e., exactly the same as one of the originally presented items), a lure (i.e., a recombination of a presented colour and shape from the trial), or a new item (i.e., a colour or shape that was new to the trial). Participants made a decision within 2s regarding whether the colour or shape of the probe (depending on the trial) was presented in the previous array or not, after which a new trial began following an inter-trial interval of 1s. Participants had a self-paced break after 40 trials. At the end of each block of 80 trials, participants also received performance feedback and warnings about too many missed responses.

Design and Analytic Procedure

This experiment followed a 2 (Culture: British, Chinese) x 2 (Probe: Shape, Colour) x 2 (Binding: Intrinsic, Extrinsic) x 3 (Congruence: Same, Recombined, New) mixed design, with the last three factors manipulated within-subjects, and randomly and evenly implemented across trials for all participants. There were 4 blocks each consisting of 80 trials (320 total trials). Half the trials required participants to respond to the test probe regarding the shape, and half were colour (i.e. 160 of each probe type). Of each probe type, half were extrinsic and half were intrinsic stimuli (i.e., 80 trials of each probe and binding combination). Finally, of each probe-binding combination, 24 trials presented a test probe that was identical to a studied item (*same*; correct response “old”), 24 trials presented a test probe that is a recombination of a studied shape and colour (*recombined*; correct response “old”), and 32 trials presented a novel test probe (*new*; correct response “new”) that depended on the probe type. If the trial was the shape task, then the new test probe was an unstudied shape with a studied colour from the trial, whereas the colour task presented a test probe that was an unstudied colour with a studied shape from the trial.

Cognitive Attribution Task. To follow the practice of previous studies (e.g. Kitayama et al., 2006; Uskul et al., 2023), I computed both a Frequentist and a Bayesian one-sided between-subjects t-test to confirm whether a cultural difference was observed in the Cognitive Attribution task, such that Easterners more strongly agree that situational factors underlie behaviours than Westerners. The result would replicate prior work (Kitayama et al., 2009; Kitayama, Mesquita, et al., 2006) and, most importantly, indicate that the sample of the study shows a typical cultural difference in an independent measure, thereby reinforcing the pattern of results regarding any (null) cultural differences in feature binding.

Working Memory Task. First, as pre-registered and following Ecker et al. (2013), a 2 (Culture: British, Chinese) x 2 (Probe: Shape, Colour) x 2 (Binding: Intrinsic, Extrinsic) x 2 (Congruence: Same, Recombined) Bayesian analysis of variance (BANOVA) was performed on hit rate (i.e. proportion of correct "old" responses to targets) using the BayesFactor R package (R. D. Morey et al., 2015) with its default settings. Two additional analyses that were not pre-registered were conducted to be consistent with Ecker et al. (2013). A 2 (Culture: British, Chinese) x 2 (Probe: Shape, Colour) x 2 (Binding: Intrinsic, Extrinsic) BANOVA was conducted on corrected recognition (sometimes referred to as discrimination score). I computed corrected recognition by subtracting the false alarm rate (proportion of incorrect "old" to new items) from the hit rate (the combination of same and recombined, following Ecker et al., 2013). Finally, I analysed the response times (RTs) during correct retrieval decisions via a 2 (Culture: British, Chinese) x 2 (Probe: Shape, Colour) x 2 (Binding: Intrinsic, Extrinsic) x 2 (Congruence: Same, Recombined) BANOVA[2]. Responses faster than 200ms and outliers (+/- 3SDs) were removed.

As I explained in Chapter 1, BANOVA computes the strength of evidence for different models (i.e. a combination of main effects and/ or interactions) compared with a null

[2] Note that I did not report RTs in the other empirical chapters, because (1) I followed Ecker et al. (2013) in this chapter who analysed RTs, and (2) I did conduct exploratory analyses of RTs for the other empirical chapters, however, there were no new insights or inconsistencies with the results of accuracy/recall error. Therefore, for the sake of brevity, I have decided not to report RT analyses in the other empirical chapters. They can be found on the OSF.

model that includes only a random effect of the participant. The resulting Bayes factor (BF) is the likelihood of the data under one model (e.g., a model assuming a main effect of binding, M_B) over another (e.g., the null model, M_{Null}). I reported the main effects and interactions according to Wetzels and colleagues' (2011) method. For example, the main effect of a term of interest (e.g. binding) is equal to the ratio of BFs between the model including the term of interest (e.g. binding) and another term of interest (e.g. congruence) against the null model [i.e. $(M_{B+C})/(M_{null})$] relative to the model excluding the term of interest against the null model [i.e. $(M_C)/(M_{null})$]. In short, the main effect of binding = $[(M_{B+C}/M_{null})]/[(M_C/M_{null})]$. The larger the BF is, the more evidence supporting the model in the numerator. BFs greater than 10 are considered as strong evidence for the tested model, whereas BFs between 3 to 10 are considered as moderate evidence, and BFs between 1 and 3 are considered ambiguous evidence for the model in the numerator.

3.3 Results

As I mentioned above, I stopped data collection for this experiment after reaching 24 sets of valid British data and 22 sets of valid Chinese data (see the WM task section for more details).

Table 3.2

Descriptive Statistics of Demographical Information

	British	Chinese
Mean Age (SD)	22.2 (3.64)	28.5 (4.25)
Gender	21 Females 3 Males	19 Females 3 Males
Average years lived outside the birth country (SD)	0 (0)	0.64 (0.93)

Cognitive Attribution Task

The results of the Cognitive Attribution task are presented in Table 3.3 and Figure 3.4. As shown in Figure 3.4, Western participants tended to be more dispositional than Eastern participants, as Eastern participants who tended to be more situational than Western participants (BF_{10} = 18.76, $t(44) = -3.3128$, $p = 0.002$, Cohen's $d = -0.978$). This finding is consistent with previous studies (e.g. Kitayama et al., 2006; Uskul et al., 2023).

Figure 3.4

Mean Performance on the Cognitive Attribution Task.

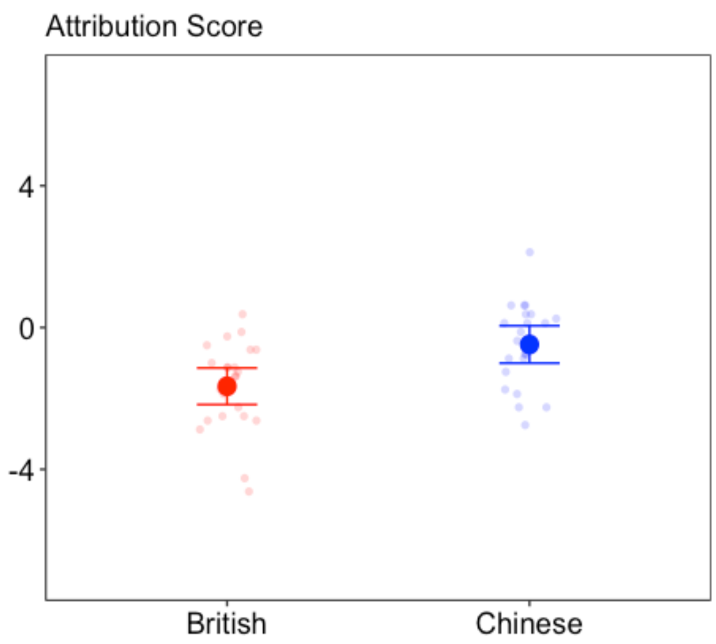


Table 3.3

Results of the Cognitive Attribution Task

	Mean	SD	Max	Min
Index of situational attribution				
British	4.11	1.02	5.50	1.38
Chinese	4.02	1.11	5.75	2.12
Index of dispositional attribution				
British	5.77	1.17	7.00	1.62
Chinese	4.49	1.51	7.12	2.38
Causal situational attribution index				
British	-1.66	1.22	0.38	-4.62
Chinese	-0.48	1.19	2.12	-2.75

Working memory task

I stopped data collection for this experiment after reaching 24 sets of valid British data and 22 sets of valid Chinese data. This is because the performance of the Chinese participants suggested that they did not perform the WM task as instructed. For example, whereas British participants' hit rate was well above chance (all BFs > 11), only in three of the experimental conditions was there evidence that Chinese participants performed substantially greater than chance (BFs > 4), with the other conditions showing weak to strong evidence that their hit rate did not differ from 50% (see Table 3.4). Furthermore, Chinese participants were significantly faster than their British counterparts (e.g. 62.8% of trials in Chinese participants were faster than 200 ms compared to 2.3% of trials in British participants), suggesting the Chinese participants may have rushed through the experiment. Therefore, it was not possible to confirm whether the Chinese participants paid enough attention to the WM task. Based on this background, I decided to terminate the experiment (see the discussion section for more details). Thus, in the following section, I only analysed the British participants' data to address my first hypothesis (i.e. whether intrinsic binding is more automatic than extrinsic binding).

Hit Rate. To address the first hypothesis concerning whether intrinsic binding is more automatic than extrinsic binding, I performed a 2 (binding) x 2 (probe) x 2 (congruence) BANOVA on hit rate (see Tables 3.4 and 3.5 and Figure 3.5). The results confirmed that colour was easier to accurately recall than shape (BF = 456.76). However, there was no evidence for differences between identifying intrinsic and extrinsic stimuli (BF = 0.16) and ambiguous evidence for an effect of congruence (BF = 1.71). There was also no evidence for the two-way or three-way interactions (BFs < 0.79). The best model only included main effects of probe type and congruence, which was only weakly preferred to the next best model that additionally included the interaction between congruence and probe.

Table 3.4

Mean (and Standard Deviation) of Hit Rate, False Alarm Rate, Corrected Recognition, and Response Times

Measure	Binding	Probe	Congruence	British	Chinese
Hit rate	Extrinsic	Colour	-	0.79 (0.11)	0.54 (0.15)
		Shape	-	0.75 (0.15)	0.59 (0.16)
	Intrinsic	Colour	-	0.81 (0.13)	0.59 (0.12)
		Shape	-	0.73 (0.14)	0.57 (0.16)
False alarm rate	Extrinsic	Colour	-	0.28 (0.25)	0.44 (0.22)
		Shape	-	0.37 (0.19)	0.47 (0.19)
	Intrinsic	Colour	-	0.28 (0.26)	0.42 (0.24)
		Shape	-	0.38 (0.17)	0.47 (0.18)
Corrected recognition	Extrinsic	Colour	-	0.51 (0.31)	0.09 (0.31)
		Shape	-	0.37 (0.25)	0.13 (0.25)
	Intrinsic	Colour	-	0.52 (0.32)	0.17 (0.36)
		Shape	-	0.35 (0.23)	0.10 (0.30)
Response times (s)	Extrinsic	Colour	Same	0.78 (0.22)	0.64 (0.21)
			Recombined	0.78 (0.22)	0.64 (0.21)
			New	0.77 (0.21)	0.63 (0.21)
		Shape	Same	0.86 (0.19)	0.70 (0.18)
			Recombined	0.88 (0.19)	0.71 (0.19)
			New	1.02 (0.20)	0.76 (0.31)
	Intrinsic	Colour	Same	0.77 (0.19)	0.72 (0.21)
			Recombined	0.81 (0.24)	0.67 (0.14)
			New	0.82 (0.21)	0.73 (0.21)
		Shape	Same	0.84 (0.21)	0.71 (0.30)
			Recombined	0.89 (0.24)	0.68 (0.23)
			New	1.01 (0.22)	0.74 (0.27)

Table 3.5

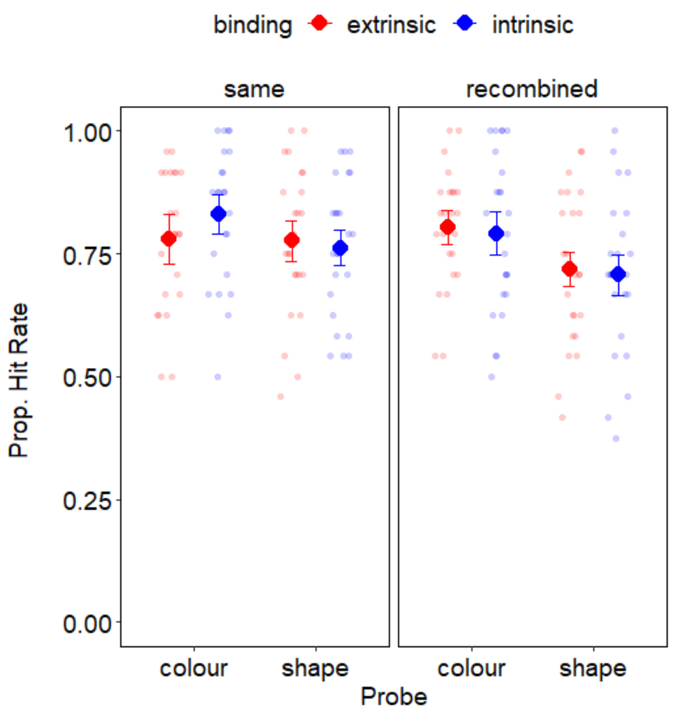
Results of the Bayesian Analysis of Variance (BANOVA)

	Hit Rate	Corrected Recognition	Hit RT
Best model	Congruence + Probe + ID	Probe + ID	Congruence + Probe + ID
BF	**759.80**	**26409.80**	**5.11e+8**
Best Model/Second Best Model	1.34	**4.65**	2.40
Main effects			
Binding	0.16	0.22	0.16
Probe	**456.76**	**26541.13**	**4.04e+8**
Congruence	1.71	-	2.41
Interactions			
Binding x Probe	0.39	0.34	0.22
Binding x Congruence	0.36	-	0.46
Congruence x Probe	0.79	-	0.26
Binding x Congruence x Probe	0.51	-	0.29

Note. BFs in boldface > 3 are considered substantial evidence for the effect of that row.

Figure 3.5

Hit Rate of British Participants as a Function of Binding, Probe and Congruence.



Corrected Recognition. The results of the 2 (binding) x 2 (probe) BANOVA are presented in Figure 3.6 and Tables 3.4 and 3.5. The results indicated that corrected recognition was higher overall in the colour than shape condition (BF = 26541.13). However, there was no difference between intrinsic and extrinsic binding (BF = 0.22) and no evidence for an interaction between probe and binding (BF = 0.34). The best model included only a main effect of probe (i.e. the different between colour and shape condition) and was moderately preferred (BF = 4.65) to the next best model which included main effects of probe and binding (i.e. the different between intrinsic and extrinsic binding).

Response Times. Finally, I performed a 2 (binding) x 2 (probe) x 2 (congruence) BANOVA on RTs during correct retrieval decisions (see Figure 3.7 and Tables 3.4 and 3.5). There was strong evidence that RTs were faster in the colour task than in the shape task (BF = 4.04e+9). However, there was evidence against an effect of binding (BF = 0.16) and weak evidence for an effect of congruence (BF = 2.41). Finally, there was weak to moderate evidence against the two-way and three-way interactions (BFs < 0.46). The best model included main effects of congruence and probe, which was weakly preferred (BF = 2.40) to the next best model that included only a main effect of probe.

Figure 3.6

Corrected recognition scores of British participants from the working memory task across different binding types and probes.

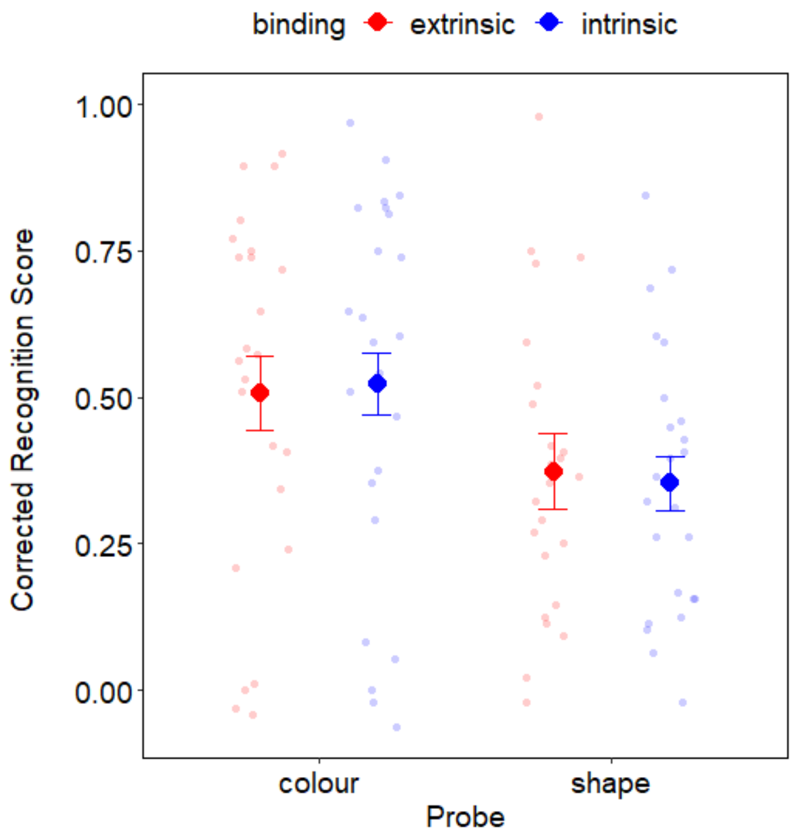
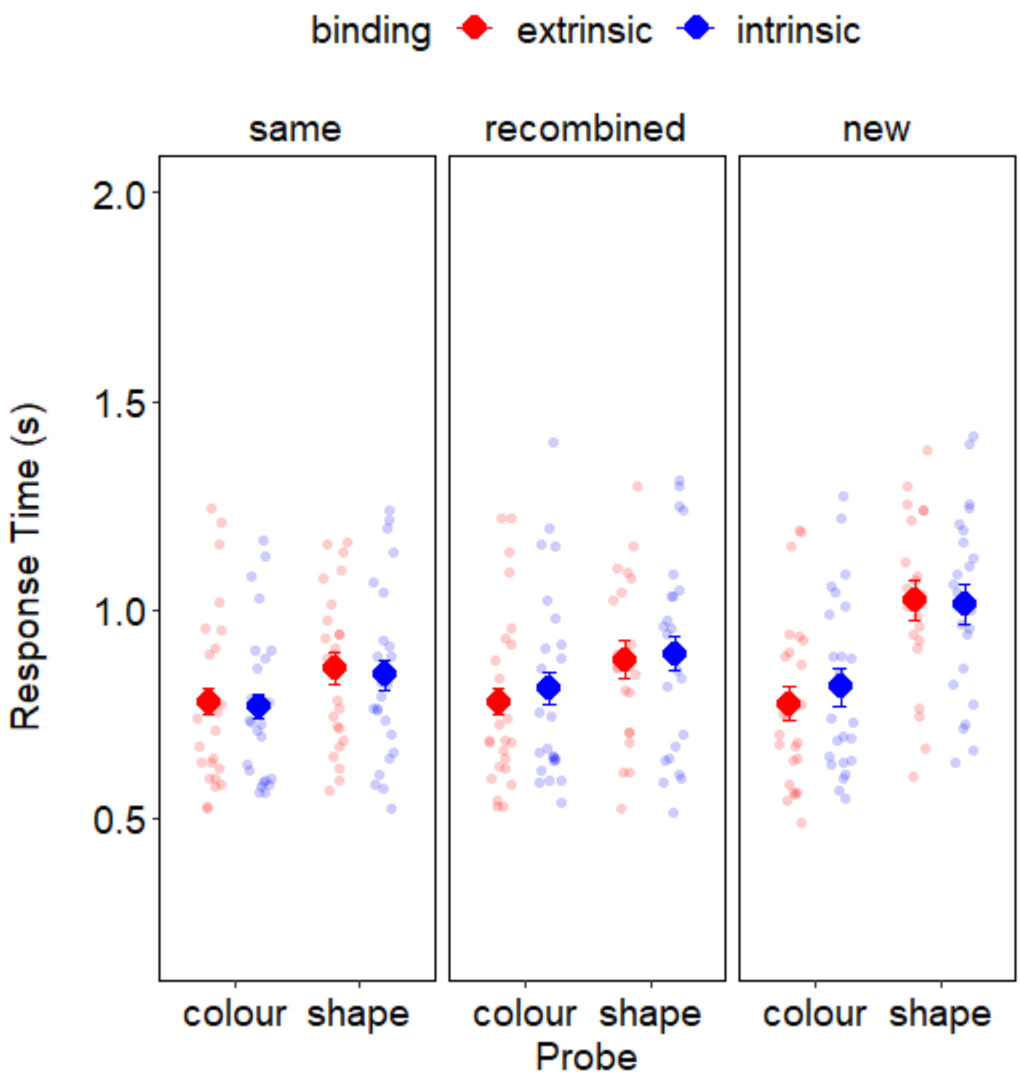


Figure 3.7

Retrieval Response Time (RTs, s) of British participants as a Function of Binding, Probe and Congruence.



3.4 Discussion

There were some interesting findings in this experiment. First, in the cognitive attribution task, I found that Chinese participants tended to attribute the cause of an event to situational factors more than dispositional factors. On the other hand, Western participants tended to attribute the cause of an event to dispositional factors instead of situational. Second, for the WM task, I found that British participants were faster and more accurate to respond in colour than shape trials. I discuss each of these results in the next sections.

The Cognitive Attribution Task

The result of the Cognitive Attribution task in this study is consistent with previous findings showing that Eastern participants tend to attribute the behaviour to situational factors relative to person-related (dispositional) factors, whereas Western participants tend to be more dispositional when they are attributing the cause of an event (e.g. Kitayama et al., 2006, 2009; Uskul et al., 2023). Such cultural differences may be due to different thinking styles and societal values (Masuda & Nisbett, 2001).

According to the Analytic and Holistic framework (Masuda & Nisbett, 2001; Nisbett et al., 2001; Nisbett & Miyamoto, 2005), Eastern participants are more holistic in thinking style and thus they pay more attention to contextual details and relational elements. This may cause them to attribute the causes of an event to situational factors. On the other hand, Western participants are more analytic in thinking style and thus they pay more attention to individual objects and their categories. Likewise, they tend to attribute the causes of an event to dispositional factors.

According to the neuro-culture interaction model (Kitayama & Uskul, 2011), repeated engagement into the cultural values or practice in society will systematically influence the brain. Therefore, differences in societal values are very likely one of the reasons that may create cultural differences. Eastern societies value interdependence and collectivism; thus, the thinking style of Easterners tends to be more holistic. On the other hand, Western society values independence and individualism; therefore, the thinking style of Westerners is more analytic. Previous studies (e.g. Masuda & Kitayama, 2004) found that in some circumstances, Westerners tend to attribute the causes to a personal related factors even there is obviously a situational reason. Overall, the result replicates prior work using the Cognitive Attribution task and suggests that the null cultural difference in feature binding in the previous experiments is unlikely due to an overall lack of cultural differences given that this experiment drew from the same sample bases.

The WM Task

As explained in the results section, I have analysed the WM data of British participants only given that the pre-registered criteria would require me to remove a huge number of trials from Chinese participants whose performance was largely at chance. Thus, I could not confirm whether Chinese participants were paying enough attention to the task or whether there was a cultural difference in the trade-off between speed and accuracy between these two cultural groups. To clarify these ambiguous results, a subsequent experiment has been proposed. The new experiment is very similar to the current one, which aimed to replicate the Experiment 1 of Ecker et al. (2013), with the exception that there will be more attention checks so as to make sure participants are paying attention to the task during the experiment.

One of the aims of this chapter was to replicate the results of Experiment 1 of Ecker et al. (2013), so as to investigate whether the automaticity of feature binding depends on unitisation. I partially replicated Ecker et al. (2013): (1) Participants were faster and more accurate to respond to colour than shape trials; (2) the false alarm rate was higher in the shape than colour trials, and (3) participants were faster to respond to the same and recombined than new trials. However, other important findings were not replicated. In the original study, Ecker et al. (2013) found that the hit rate for intrinsic stimuli was higher overall than extrinsic stimuli, whereas the current study showed that the hit rate was similar between intrinsic and extrinsic stimuli (main effect of binding, BF = 0.16). Additionally, Ecker et al. (2013) found that only the hit rate of shape trials was affected by binding type, but the result of current study showed that the hit rate was similar across different probe type and binding type. Thus, the main finding that intrinsic and extrinsic binding are distinguishable was not observed in this experiment.

A possible reason for why the main findings of interest were not replicated is the trade-off between speed and accuracy. Since participants were required to respond within two seconds and would not be compensated if they missed more than 10% of the trials, it is possible that they rushed to make a decision within the time limit so as to avoid being uncompensated. According to the speed-accuracy trade-off phenomenon (Bogacz et al., 2010; Franks et al., 2003; Pachella, 1974; Wickelgren, 1977), people either take longer time to process information more accurately or exhibit lower accuracy to process the information more quickly. Additionally, the cascaded approach (McClelland, 1979) proposed that RT reflects the number of processing cycles required to activate the output with a particular threshold. Since participants aim for a correct response, they will automatically set a high threshold to produce a correct response which requires a longer time to process information. If the participant rushes to respond, then the cascaded approach proposes that they can simply lower the threshold, making it is easier for them to activate the output and thus taking a shorter time to process information. However, the consequence of lowering the threshold is that the output is less accurate than taking a longer time to process information (Bullinaria, 2000). In the current experiment, participants may have decided to shorten the processing time, and thus, they may not recall what they have seen in the encoding stage properly in those 2 seconds; instead, they may need to guess whether that shape or colour is an old item or new item. This could have obscured a difference between intrinsic and extrinsic stimuli. Ecker et al. (2013) also required participants to respond within 2 seconds, but they did not impose the same attention check criterion of missing no more than 10% of trials as in the current experiment. This may have inadvertently impacted the motivation and performance of the participants.

Alternatively, it could be the case that there is no true difference between intrinsic and extrinsic binding, consistent with the result of Experiments 1 and 2 in Chapter 2. As shown in the prior work that it is similarly automatic in binding different type of features (Zhao et al., 2022). For example, Experiment 3 and 4 of Luck and Vogel (1997) and Experiment 13 of Vogel et al. (2001) showed a similar performance between colour (i.e. intrinsic feature) and orientation (i.e. extrinsic feature) conditions. In the Experiment 3 and 4 of Luck and Vogel (1997), participants were instructed to detect the changes of colour, orientation or either one of the features in their experiment. Their result showed that participants have a similar percentage of correct in all three conditions. Additionally, in the Experiment 13 of Vogel et al. (2001), participants are required to recall either colour or orientation. They found that participants had a similar percentage correct in both colour and orientation conditions. These two studies supported the claim that intrinsic and extrinsic binding are similarly automatic, and thus it may be possibly due to the fact that the basic unit of storage in WM is an integrated object instead of independent features (e.g. Lee & Chun, 2001; Luck & Vogel, 1997; Vogel et al., 2001). As I have mentioned in Chapter 1 and 2, there is an inconclusive debate about whether the storage in the WM is object-based, feature-based or both of them co-exist in the WM. If object-based view is the case, that means the WM capacity is constrained by the number of integrated objects instead of independent features, then, binding more features or different types of features will not create additional cost for binding. Therefore, binding intrinsic and extrinsic features will be similarly automatic. I will investigate this possibility in Experiment 4 in Chapter 4 of this thesis.

Even though I did not replicate all the results of Ecker et al.'s (2013) Experiment 1, there was still an interesting finding that participants were faster and more accurate during the colour than shape trials. This is consistent with a great deal of prior work (e.g., Allen et al., 2006; Wheeler & Treisman, 2002). The likely explanation is that it is easier to name the colour than the shape. Ecker et al. (2013) claimed that easily named items in WM experiments may blur the differences between intrinsic and extrinsic binding and thus avoided using nameable shapes. Previous studies have found that nameable items are easier to remember as verbal strategies may play less role in unnameable items (Brady & Störmer, 2022). Therefore, colour may be easier to encode than shape when it is a more meaningful feature, such that prior knowledge or semantic memory in long-term memory (LTM) may facilitate the memory formation of meaningful but not meaningless information (Norris et al., 2020; Thalmann et al., 2019). Different WM models support this explanation: For example, the embedded-processes model suggests that activated LTM facilitates memory formation (Cowan, 1999). The multi-component model also proposes that the episodic buffer interfaces between WM and LTM (Baddeley, 2000). Prior studies have also suggested that WM will only access the information in LTM if it is beneficial to do so (Bartsch & Shepherdson, 2020; Mizrak & Oberauer, 2020; Oberauer et al., 2017). Therefore, with the help of prior knowledge in LTM, it may have been easier to name the colours than shapes in this experiment, and thus LTM facilitated the WM formation of colour more than the shape. This is one of the possible explanations of why naming colour is faster and more accurate than shape.

3.5 Final Conclusions

To conclude, the results of the Cognitive Attribution task confirmed that there are cultural differences between Eastern and Western cultures. However, it was not possible to confirm whether there are cultural differences in feature binding due to problems with the Chinese participants' data. The WM task of this experiment confirmed that the automaticity of feature binding may depend on the type of feature (i.e. colour versus shape) but not unitisation of the stimulus (i.e. intrinsic versus extrinsic). Since I did not find any cultural differences or any differences in the automaticity between intrinsic and extrinsic features in the first three experiments of this thesis, I am curious to know is there any other factors (e.g. how we store information in WM) which may influence the automaticity of feature binding in WM. Based on this background, the next chapter details a subsequent experiment (i.e. Experiment 4) to investigate further about how we store information in WM may influence feature binding.

Chapter 4: Are additional features in visual working memory bound up automatically or depend on unitisation?

4.1 Introduction

The results of the Experiments 1, 2 and 3 suggested that culture, unitisation and prior knowledge do not affect the automaticity of feature binding at all. Therefore, I am curious to know how features are stored in working memory (WM), i.e. whether storage in WM is feature-based or object-based, is a possible factor that influences the automaticity of feature binding.

Currently, there is no strong consensus on how features are stored in WM. Some have argued that objects are stored as a unit, with WM capacity only limited by the number of unified objects and not the individual features that compose them (e.g. Luck & Vogel, 1997). Conversely, others have proposed that storage in WM is feature-based, such that separate features individually contribute to the capacity limit of WM (e.g. Fougnie & Alvarez, 2011; Wheeler & Treisman, 2002). Alternatively, whether storage in WM is object- or feature-based may also depend on whether the features are intrinsic (i.e., integrated within) or extrinsic (i.e., relational or contextual) to the object (Ecker et al., 2013). In the next sections, I overview these three different views of how features are stored in WM in turn.

Object-based storage in working memory

As previously explained in Chapter 1, the first view suggests that storage in WM is object-based, such that WM is constrained by the number of objects held in mind rather than the number of features (e.g. Delvenne & Bruyer, 2004; Luck & Vogel, 1997; Ngiam et al., 2023; Olson & Jiang, 2002; Sone et al., 2021; Stevanovski & Jolicœur, 2011; Vogel et al., 2001). This implies that increasing the number of features of an object (e.g. yellow leaf on the floor, so three features: shape, colour and location) will not impact WM capacity compared to storing an object with fewer features (e.g. yellow leaf, so two features only: shape and colour). On the other hand, increasing the number of objects needed to remember, irrespective of their features (e.g. two different leaves, a heart-shaped yellow leaf and a green oval leaf), will decrease WM capacity.

In their seminal paper, Luck and Vogel (1997) showed evidence for the object-based account of WM storage: They reported that more features can be added without a cost to performance if the features are integral to the original object. In addition, Olson and Jiang (2002), Experiment 3, also showed a similar result: In their experiment, participants viewed 2, 4, or 8 white lines and were required to remember either their orientation, size, or both in three respective blocks. They found that the accuracy was similar between the individual feature blocks (i.e. only orientation or size) and conjunction block (i.e. both orientation or size), regardless of the set size. This result shows that participants remembered the white lines as coherent objects instead of independent features. This evidence supports the object-based view, such that features of an object are stored as such in WM instead of individual features; therefore, additional features are automatically or cost-free to bind.

Feature-based storage in working memory

The second view proposes that storage in WM is feature-based (e.g. Fougnie & Alvarez, 2011; Shin & Ma, 2017; Wheeler & Treisman, 2002), which means each feature is stored independently and separately in WM. In this case, using the previous example, remembering a yellow leaf entails separate storage of its features (i.e. two features: its colour and shape), while, remembering a yellow leaf on the floor (i.e. three features: colour, shape, and location) will yield worse performance than just recalling a yellow leaf because remembering additional features comes at an extra cost. For example, Fougnie and Alvarez (2002) found that participants failed to recall one feature of an object, but they were still able to recall another feature of that object. Similarly, Wheeler and Treisman (2002) suggested that remembering six single-coloured objects (i.e. six features in total) is not worse than remembering three bi-coloured objects (i.e. six features in total), as both groups of objects have the same number of features. Therefore, participants may store information in WM as independent features instead of coherent objects.

The role of unitisation in feature-based or object-based storage

A third possibility is that whether storage in WM is more object- or feature-based depends on unitisation. Unitisation refers to whether an object's features are intrinsic (i.e. part of the stimulus itself, for example, its colour) or extrinsic (i.e. relational or contextual to the stimulus, for example, its background or location). This possibility is consistent with prior work showing that intrinsic binding is more automatic and less resource-demanding than extrinsic binding (Ecker et al., 2013).

There is a lot of evidence in the current literature showing that feature-based and object-based storage co-exist in WM, but the extent to which WM storage is more feature-based or object-based may depend on the situation. For example, Olson and Jiang (2002) reported opposing findings between their Experiments 3 and 4: the result of Experiment 3 supported object-based view as explained previously, while Experiment 4 supported the third view that both feature-based and object-based storage co-exist in WM. Their Experiment 4 tested three conditions, namely (1) homogenous simple feature condition wherein only one feature needed to be encoded (either coloured squares or line orientations were shown at the encoding stage); (2) heterogeneous simple feature condition wherein two features needed to be encoded but only one recalled (half of the items shown in encoding stage were colour squares and the other half were line orientations), and (3) conjunction condition wherein two features needed to be encoded and recalled (items shown during encoding stage were the combination of colour squares and line orientation). The results of their experiment showed that participants performed better in the heterogeneous simple feature condition (when only one feature needed to be recalled) than the conjunction condition (when two features needed to be recalled) at set size 4. This evidence supports the notion that additional features are bound with additional cost, and thus performance was worse in the conjunction condition than heterogeneous simple feature condition.

In addition, in Experiment 4, they also found that if the number of features participants needed to maintain is the same, then participants performed better in the conjunction condition than the simple feature condition. However, such improvement in performance in the conjunction condition is not doubled when compared to the single feature condition. If participants remember information solely as features, then the performance should be similar as they are remembering the same number of features in both single and conjunction conditions. On the other hand, if the same number of features that participants needed to remember, for example the colour and the orientation of the single item, then, participants need to remember two features in total. However, if participants are remembering them as objects, then they have combined two features into a single coherent object only, and thus, they need to remember half of the information only. In this case, their performance should be doubled in the conjunction condition, however, the result of this study showed that the performance in the conjunction condition is not doubled when compared to the single feature condition. This finding may suggest that participants store both features and objects in WM instead of one or the other. Vergauwe and Cowan (2015) also found that feature-based and object-based storage may co-exist in WM, but whether the WM storage is feature-based or object-based storage may depend on the testing conditions. In their study, four different testing conditions either encouraged or discouraged participants to perform colour and shape bindings (encourage vs discourage instructions), and test probes were presented either as an integrated object or separated features (integrated vs separated). They found that WM storage was object-based when colour-shape binding was encouraged, as well as when the probe was presented as an integrated object, given that the response time (RT) search slope was similar between one-feature and two-feature conditions. Conversely, in the three other testing conditions WM storage was mostly feature-based, given that the RT search slope was larger in two-feature than one-feature conditions. Vergauwe and Cowan (2015) concluded that whether storage in WM is object-based or feature-based depends on the test probe and testing instructions. As I mentioned previously, unitisation may be further possible factor contributing to whether storage in WM is more object- or feature-based.

Current study and predictions

Based on this background, the current study investigated whether storage in visual WM is object-based, feature-based, or whether this depends on the extrinsic or intrinsic nature of the stimuli. This study used a continuous reproduction paradigm wherein participants were shown an array of coloured shapes in different locations, followed by recalling either the colour (intrinsic feature type) or location (extrinsic feature type) of the shape along a 360° retrieval wheel. During the calibration phase, the number of shapes to remember was individually calibrated to each participant according to their ongoing performance of either the colour or location of the shapes, with the to-be-recalled feature blocked and counterbalanced. This individually-calibrated set size was used during the test blocks that required participants to recall either the colour or location only (so, only one feature to keep in mind) or a random mix of either type of feature (two features to keep in mind). The test blocks thus manipulated the number of features (one or two) and type of feature (colour/intrinsic or location/extrinsic) to maintain in WM.

I had four hypotheses. The first hypothesis concerned the calibration phase: (1) if intrinsic binding is more automatic than extrinsic binding, then the set size to achieve similar performance between the colour and location conditions should be greater for colour (intrinsic feature) than location (extrinsic feature). The next three hypotheses pertained to the test phase: (2) If the object-based view is correct, then there should be similar performance regardless of how many features need to be remembered (i.e. no main effects of number or type of features and no interaction). (3) However, if the feature-based view is correct, then remembering a single feature should yield greater performance than two features (i.e. a main effect of the number of features, but not the type of features nor an interaction). (4) Finally, if object- and feature-based storage depends on unitisation, then the number of features should only impact recall of location but not colour, consistent with the notion that intrinsic feature binding is more automatic than extrinsic feature binding (i.e. a number of features x type of feature interaction).

4.2 Method

Participants

I collected 36 valid datasets from UK-based participants aged 18-35 (M = 23.24, SD = 5.44, 22 Females) who were fluent English speakers with normal colour vision and no diagnosed memory or cognitive impairments. The sample size follows similar prior experiments that recruited 30 participants to investigate object- versus feature-based storage using a continuous reproduction paradigm (Ngiam et al., 2023). An additional six participants were required for equal counterbalances. Thirty-two participants were recruited from the University of Essex and 4 participants were recruited from Prolific (www.prolific.co). Participants were compensated with partial course credit or the equivalent of £8/hour of participation. All participants in this experiment provided informed consent and were fully debriefed at the conclusion of the experiment.

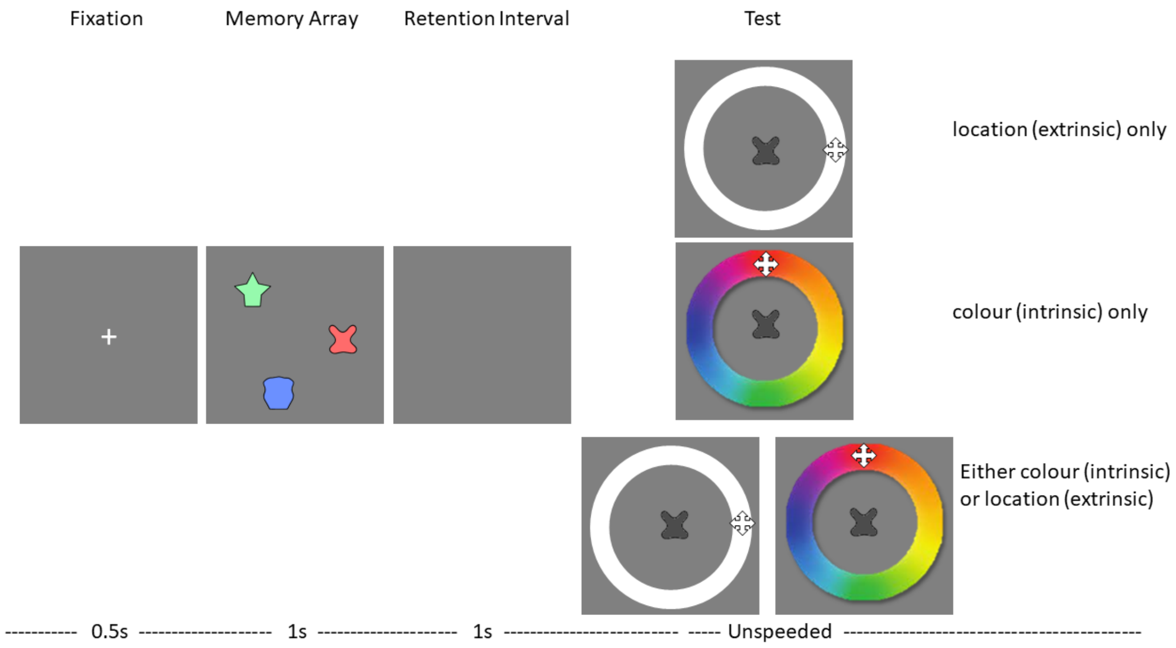
Data were considered valid if participants finished the entire experiment and fulfilled all the pre-registered exclusion criteria. 41 participants were not able to proceed to the WM experiment as they did not pass the colour blindness or demographic screening phase. For those participants who did pass the screening phase, 5 participants were excluded as they quit or restarted in the middle of the experiment and 1 participant were excluded as their recall responses exceeded 5s or more on 10% of the trials.

This experiment was conducted online through an open-source platform, lab.js (Henninger et al., 2019) and hosted on the server Mindprobe (https://jatos.mindprobe.eu/; Lange et al., 2015). In the first phase, participants were required to complete a brief demographics survey and a colour blindness test. Those who met the inclusion criteria (see Participants subsection) immediately continued to the WM experiment. Participants were informed at the beginning of the experiment that any of the following actions would risk their data being excluded and uncompensated: (1) Failing to complete the experiment in one continuous and distraction-free setting; (2) reloading the page or hitting the back button; (3) quitting and restarting the study; (4) escaping the full-screen mode or switching windows; or (5) failing to respond to more than 10% of the trials. If participants switched windows away from the full screen, the experiment was designed to immediately quit, whereas the other exclusion criteria were implemented during data pre-processing (see Design and Analytic Procedure).

The visual WM task included five blocks, wherein participants first completed two calibration blocks of recalling the colour of a shape in one block and the location of a shape in another block. After that, there were three test blocks of recalling the colour only (intrinsic), location only (extrinsic), and either colour or location (randomly intermixed), respectively. The order of calibration and test blocks was counterbalanced across participants. Participants received instructions and four practice trials before starting each block. The experiment concluded with a final survey enquiring about the participant's experience with the task (see Design and Analytic Procedure).

Figure 4.1

An Illustration of the Experiment Trial Sequence.



As shown in Figure 4.1, each trial of the calibration and test phases began by displaying a fixation cross for 0.5s followed by an array of coloured shapes for 1s. The number of shapes depended on the participant's performance in the calibration phase (but see below). The shapes (on-screen size = 90 pixels) and their colours/locations for each trial were randomly selected without replacement from 1 to 360, with a minimum angular separation of 15° (plus/minus random noise) between each feature of the same domain. The shape memoranda were drawn from Li and colleagues' (2020) shape wheel, and the colours of the shapes were sampled from the CIELAB colour space, with L = 70, a = 20, b = 38, and radius = 60, and the locations were randomly drawn along an invisible circle (radius = 150 pixels; see Goldenhaus-Manning et al., 2023 for a similar approach). After a retention interval of 1s, participants were presented with one of the shapes at the centre of the screen, probing them to recall its colour or location (depending on the feature type of the trial) by using the mouse to click along a continuous wheel. When the participants moved the mouse around the wheel, the colour or location of the shape adjusted accordingly. Participants had unlimited time to decide but were encouraged to respond as quickly and accurately as possible. Recall error (i.e. the distance between the target colour/location and the participant's response) was recorded. After responding, the subsequent trial began after an inter-trial interval of 1s. Participants had an opportunity for a break and received feedback after the practice trials and every 10 test trials during both the calibration and test blocks. Furthermore, the response time was checked after every trial, and if participants took longer than 5s to response in any trial in the last 10 trials, they received a warning during the break which mentioned how many trials they took more than 5s to response with a reminder of the instructions. However, if they did not take longer than 5s to respond in any trials, then they received a reminder of the instructions only.

The initial calibration phase had 40 trials for each block and was used to determine the ideal number of shapes presented during encoding (i.e. set size) for participants to achieve 40 degrees of recall error. This threshold follows similar prior experiments using a continuous reproduction paradigm (see Loaiza & Souza, 2019). Participants were required to recall the colour of the shape in one block (i.e. one intrinsic feature) and location of the shape in another block (i.e. one extrinsic feature). The set size started with five shapes in the first four trials; after that, the set size was adjusted according to the ongoing recall error of the participant in the last four trials. If the average ongoing recall error of the last four trials exceeded or below 40, then the set size of the subsequent calibration trials decreased or increased by 1 respectively. The minimum set size was 2 and the maximum set size was 9. The set size of the subsequent test blocks depended on the average set size in the last 20 calibration trials. For example, if the average set size was 5.3 shapes, then the subsequent test block contained a memory array with 5 shapes for 70% of the trials and 6 shapes for 30% of the trials (see Loaiza & Souza, 2019 for a similar approach).

The three counterbalanced test blocks were (1) colour-only (i.e. one intrinsic feature), (2) location-only (i.e. one extrinsic feature), and (3) colour or location (i.e. two features, either intrinsic or extrinsic). The colour-only and location-only test blocks were the same as the calibration phase, with the exception that there were 50 trials per block. Participants were informed upfront about which feature was relevant for recall prior to starting each block. The two-feature block was very similar to the calibration phase, with two exceptions. First, both colour and location were relevant, such that either feature to recall was randomly probed within the block and second, there were 100 trials in this block (50 of each type of feature). As mentioned previously, the set size of the test blocks was based on the performance of the individual during their calibration phase. For example, if the calibrated set size was 4 for the location and 5 for the colour features, then there would always be 4 shapes presented during trials which required participants to recall location and 5 shapes during trials which required participants to recall colour, regardless of the block.

Design and Analytic Procedure

This experiment followed a 2 (feature type: colour-intrinsic, location-extrinsic) x 2 (number of relevant features to remember: 1, 2) within-subjects design, with both factors blocked and counterbalanced across participants. The dependent variables were set size and recall error.

The anonymized raw data were deposited on the OSF (https://osf.io/wjk58/?view_only=6727dd138a514a6bb64a5f8bd227bd70). All practice trials were excluded from the analysis. Data were excluded and replaced if participants (1) noted during the final survey that they experienced legitimate technical difficulties (e.g. internet disruption) that impacted their performance; (2) noted that they did not complete the experiment in one continuous, distraction-free sitting; and/or (3) failed to respond within 5s to more than 10% of the trials.

I used the R package BayesFactor (R. D. Morey et al., 2015) to analyse the observed recall error and calibrated set size. To address the first hypothesis, I used a Bayesian t-test to compare the set size determined during the two calibration blocks of colour and location features. To address the other hypotheses, I used a 2 (number of features) x 2 (type of features) within-subjects Bayesian Analysis of Variance (BANOVA) to compare the observed recall error during the test blocks. As previously mentioned, BANOVA computes the strength of evidence for different models (i.e. a combination of main effects and/or interactions) compared with a null model that includes only a random effect of participant. BFs ranging between 1 to 3 are considered ambiguous, whereas BFs greater than 3 and 10 are substantial and strong evidence for the model in the numerator of the ratio, respectively (Jeffreys, 1961).

Three-Parameter Mixture Model

I also fitted recall error with a hierarchical Bayesian three-parameter mixture model (Oberauer et al., 2017) as an additional exploratory analysis. The mixture model assumes that observed recall error reflects the contributions of: (1) the probability that the response comes from the accurate memory of the tested item in WM (2) with a specific precision (i.e. the standard deviation of the circular normal distribution); and (3) the probability of binding errors (i.e. recalled the colour or location of another shape presented during encoding) or (4) the probability that the response comes from guessing when no information is in WM. I used the rjags package (Plummer et al., 2006) in R to fit the model. Checks were conducted to ensure the convergence and model fit were good, i.e. visual inspection of the convergence of the four Markov Chain Monte Carlo (MCMC) chains, checking that the R-hat values for all parameters were low (R-hats <1.06), and also posterior predictive checks to ensure an appropriate model fit to the data. The full model and its priors can be found on the OSF.

4.3 Results

Calibration Phase

To address the first hypothesis regarding whether intrinsic binding is more automatic than extrinsic binding, I used a Bayesian t-test to compare the set sizes and recall error determined during the two calibration blocks of colour and location. I expected that the set sizes to achieve 40 degrees of recall error would be larger for the colour (intrinsic) than the location (extrinsic) conditions, thus supporting previous studies that intrinsic binding is more automatic than extrinsic binding (Ecker et al., 2013). Furthermore, I expected that there should be a null difference in recall error between the colour and location conditions, thus confirming that I successfully calibrated performance between two different features at the single feature baseline.

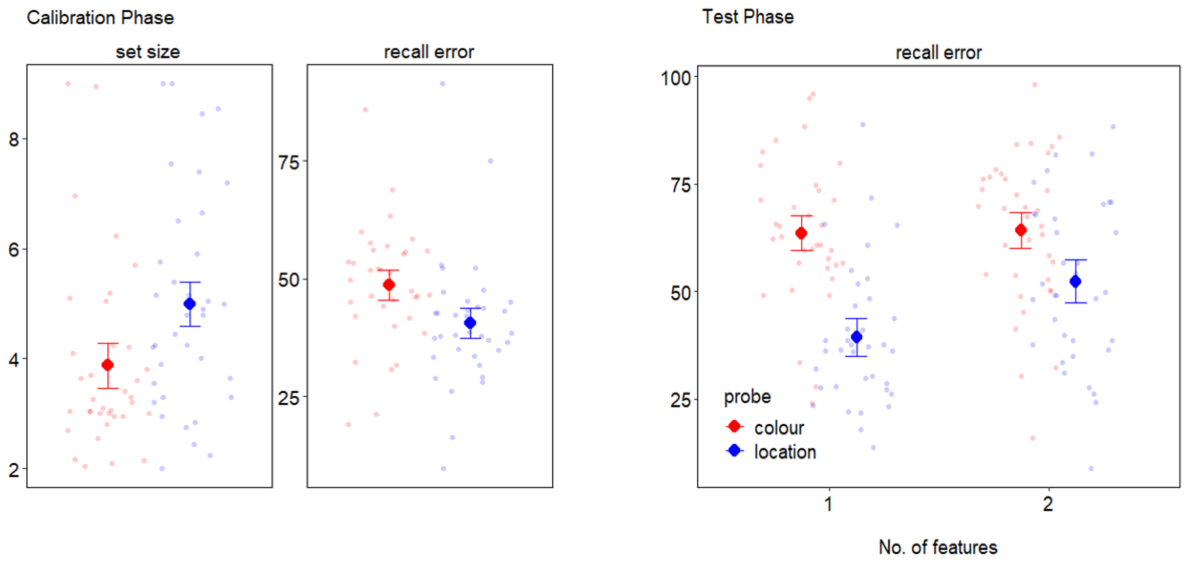
The results are shown in Figure 4.2. First, there was moderate evidence that the recall error was lower during the location than the colour condition, $BF_{10} = 3.91$, meaning that the calibration procedure was unsuccessful to match performance between two different features conditions at the single feature baseline. In addition, there was moderate evidence that the set size of the location (extrinsic) condition was greater than the colour (intrinsic) condition, $BF_{10} = 3.95$. Thus, participants required a greater calibrated set size during the location than the colour block to achieve similar performance, but still ended up performing better (i.e. lower recall error) during the location block than the colour block despite the intent to match performance.

Test Phase

To address the next hypotheses regarding whether object-based or feature-based theories correctly describe how information is stored in WM, I performed a 2 (number of features) x 2 (type of features) BANOVA on recall error (see Figure 4.2). The best model included an interaction between number and type of features ($BF_{10} = 1.11 \times 10^{11}$), and this was strongly preferred (BF = 78.81) to the next best model that did not include an interaction (BF_{10} =1.46 × 10^{10}). This is consistent with the fourth hypothesis that intrinsic feature binding is more automatic than extrinsic feature binding (i.e., a number x type of features interaction). The results of the follow-up t-test showed that there was strong evidence for a difference in recall error between one and two features when recalling location (BF_{10} = 13.45) but not colour (BF_{10} = 0.25).

Figure 4.2

Set Size and Recall Error of Calibration Phase and Test Phase. Large dark points indicate the overall means of that condition, small faded points indicate individual means, and error bars reflect 95% within-subject credible intervals.



Exploratory Modelling: Three-Parameter Mixture Model

So far, the results of the primary analysis of this experiment found that (1) the calibrated set size was larger in the location than the colour condition, thus in the opposite predicted direction; and (2) recall error was substantially greater when two features were relevant for recall than one feature, but only during the location trials, consistent with the fourth prediction that whether storage in WM is feature- or object-based depends on unitisation. The three-parameter hierarchical mixture model will help to explore the information that observable data cannot provide, such as how likely the recall error reflects guessing or selecting the non-target items. Figure 4.3 and Table 4.1 shows the parameter estimates across the conditions. The results showed that target recall and guessing were credibly worse when recalling two versus one feature during the location condition, but not the colour condition. On the other hand, there was a credible effect of the number of features on the probability of binding errors for colour only and not location, such that recalling two features reduced binding errors compared to one feature.

Table 4.1

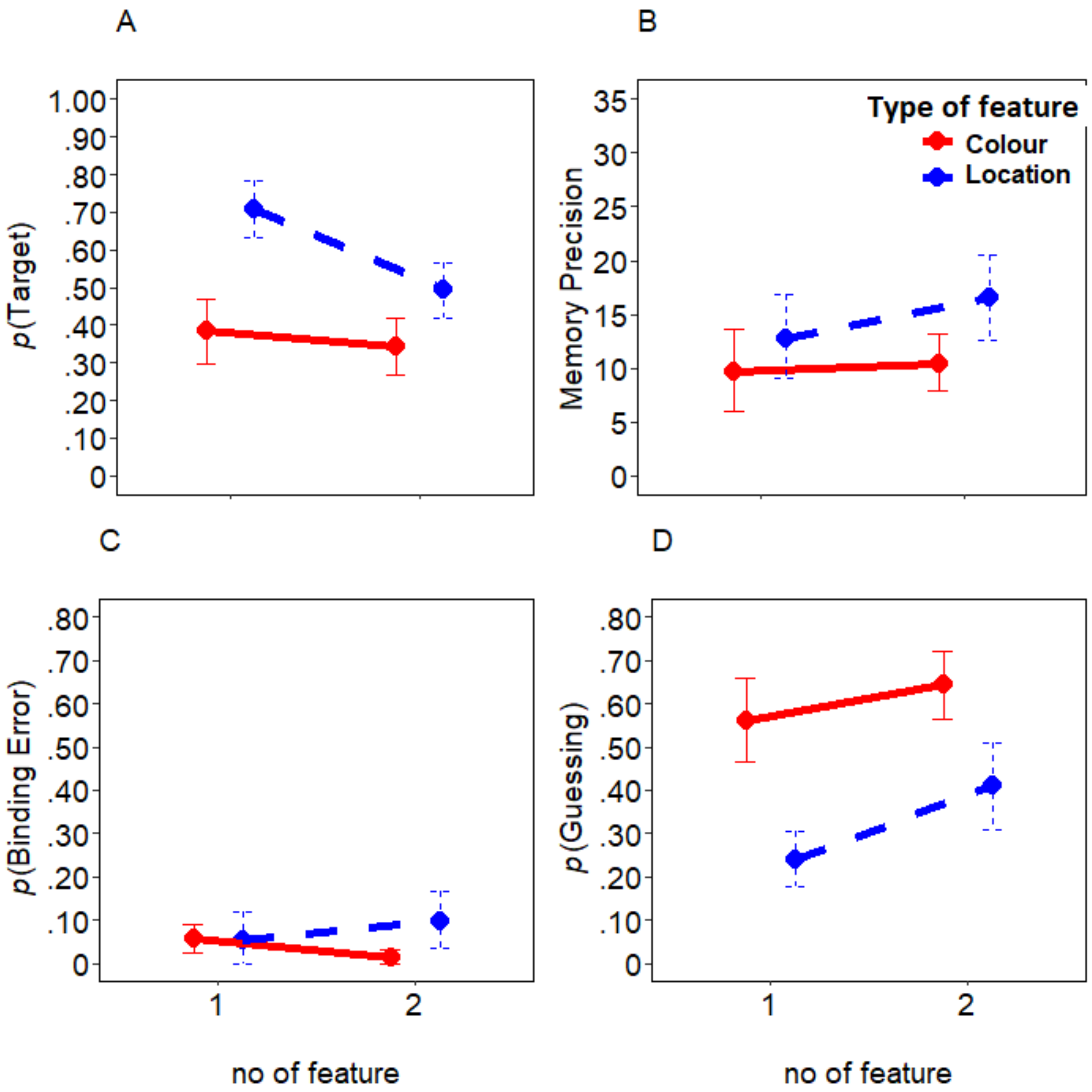
Summary of Mean Parameter Estimates [and 95% Highest-Density Intervals]

Probe	No. of feature	*P*(Target)	Precision	*P*(Binding Error)	*P*(Guessing)
Colour	1	0.38 [0.30, 0.46]	9.59 [5.93, 13.63]	0.06 [0.03, 0.09]	0.56 [0.47, 0.66]
	2	0.34 [0.27, 0.42]	10.35 [7.88, 13.15]	0.01 [0.00, 0.03]	0.64 [0.57, 0.72]
No. of Feature Effect		-0.04 [-0.15, 0.08]	0.77 [-4.14, 5.75]	**-0.04 [-0.08, -0.01]**	0.08 [-0.04, 0.20]
Location	1	0.71 [0.63, 0.78]	12.75 [9.01, 17.91]	0.05 [0.00, 0.11]	0.24 [0.18, 0.30]
	2	0.49 [0.42, 0.57]	16.49 [12.65, 20.46]	0.09 [0.04, 0.17]	0.41 [0.32, 0.51]
No. of Feature Effect		**-0.21[-0.32, -0.11]**	3.73 [-1.88, 9.41]	0.04 [-0.06, 0.14]	**0.17 [0.04, 0.28]**

Note. Boldface indicates a credible effect.

Figure 4.3

Parameters Estimates for the Three-Parameter Mixture Model: (A) The Probability that the Target is in Memory, P(Target). (B) Memory Precision. (C) The Probability that a Response Comes from Memory for an Incorrect Feature Associated with Another Object in Memory, P(Binding Error). (D) The Probability that a Response is a Random Guess, P(Guessing).



4.4 Discussion

Object-based versus feature-based views

Since I did not find any differences in the automaticity between intrinsic and extrinsic features in the first three experiments (see Chapters 2), I was curious to know if other factors (e.g. WM storage) affect the automaticity of feature binding in WM. As I have explained in the Chapter 1 and the introduction of this chapter, there is a controversy about whether the feature-based or object-based view accurately describes how we store information in WM. If the object-based view is correct, then an object is stored as a whole representation, and thus whether the feature is intrinsic or extrinsic should not influence the automaticity of feature binding. This could be one of the possible explanations for the null difference between intrinsic and extrinsic binding that I found in the last two chapters, thus motivating this experiment. However, the result of this experiment did not support either the object-based view or feature-based view; instead, it supported the third view that both object-based and feature-based storage co-exist in WM depending on unitisation.

As explained previously, there is no consensus in the literature whether intrinsic features are more automatically bound together than extrinsic features. Some previous studies have shown that binding extrinsic features is more resource-demanding than binding intrinsic features at encoding (e.g. Ecker et al., 2013; Morey & Bieler, 2013). According to the Type-Token memory model (Zimmer & Ecker, 2010), the intrinsic feature of an object is more automatically bound into the object token (i.e. the basis of item memory), while the extrinsic feature is more effortful to bind into the episodic token (i.e. addition information of the object token, e.g. its encoding context). This is because extrinsic features are considered as additional information of the object token, and thus, it is more effortful to bind extrinsic than intrinsic features. This is the reason why it is possible that how information is stored in WM depends on the unitisation of features, as the mechanism and the cost of binding may differ between intrinsic and extrinsic features.

The results of this experiment are consistent with the fourth hypothesis that whether WM storage is more feature-based or object-based may depend on unitisation, such that intrinsic features are more automatically processed and integrated within objects than extrinsic features. Specifically, there was a credible difference in recall error between single-feature and two-feature conditions in location but not colour. This result suggests that WM storage is more object-based when the features to store are intrinsic, while it is more feature-based when the features to store are extrinsic. The finding of location (extrinsic features) is in line with previous findings which supports feature-based view (e.g. Fougnie & Alvarez, 2011; Wheeler & Treisman, 2002), such that remembering more features is more resource-intensive and will thus lower performance compared to just remembering a single feature. Conversely, the finding that recall error was insensitive to the number of features in the colour (intrinsic) condition aligns with the object-based view (e.g. Luck & Vogel, 1997). Thus, the experiment demonstrates evidence of both feature-based and object-based storage in WM depending on the type of feature.

In addition, the results of the three-parameter hierarchical mixture model showed that there was a credible difference between the single-feature and two-feature conditions in target memory and guessing in location but not colour. Thus, recalling two features is more resource-demanding than one feature during the location trials, leading to reduced recall of the correct feature and increased guessing. Interestingly, binding errors were *lower* when recalling two features versus one feature in the colour condition, but it is not immediately clear why this would be the case. In short, the results of this study supported the fourth hypothesis that both feature-based and object-based co-exist in WM depending on unitisation of the features, such that the storage of intrinsic features is more object-based, while the storage of extrinsic features is more feature-based in WM.

Is location special?

Interestingly, the calibrated set size was larger for location than colour, and recall error was still better for colour than location despite the calibration procedure. These results of the calibration phase go against my first hypothesis and do not align with previous findings that binding is more automatic for intrinsic (colour) than extrinsic (location) features (e.g. Ecker et al., 2013). Specifically, location seems to be an easier detail to remember than colour, which is consistent with some other prior research (e.g. Rajsic & Wilson, 2014).

One of the possible explanations of this result is that binding location is different from binding other extrinsic surface features (e.g. the background colour of a shape, as in the previous chapters). Many studies have shown that binding locations is different from binding colours and shapes (Cowan et al., 2006; Mitchell et al., 2000). This may be because content-location binding is relatively automatic than colour-shape binding. For example, some work suggests that cued object location was attended regardless of location was task-relevant, whereas the surface features (e.g. colour) were attended only when they were task-relevant (Lamy & Tsal, 2000; Tsal & Makovski, 2006). Postma and De Haan (1996) also found that, when comparing to the colour changes alone, it was not much more resource-demanding for detecting colour-location binding changes. It seems it is relatively automatic or cost-free to maintain the combination of simple features and their locations with sufficient precision for recognition.

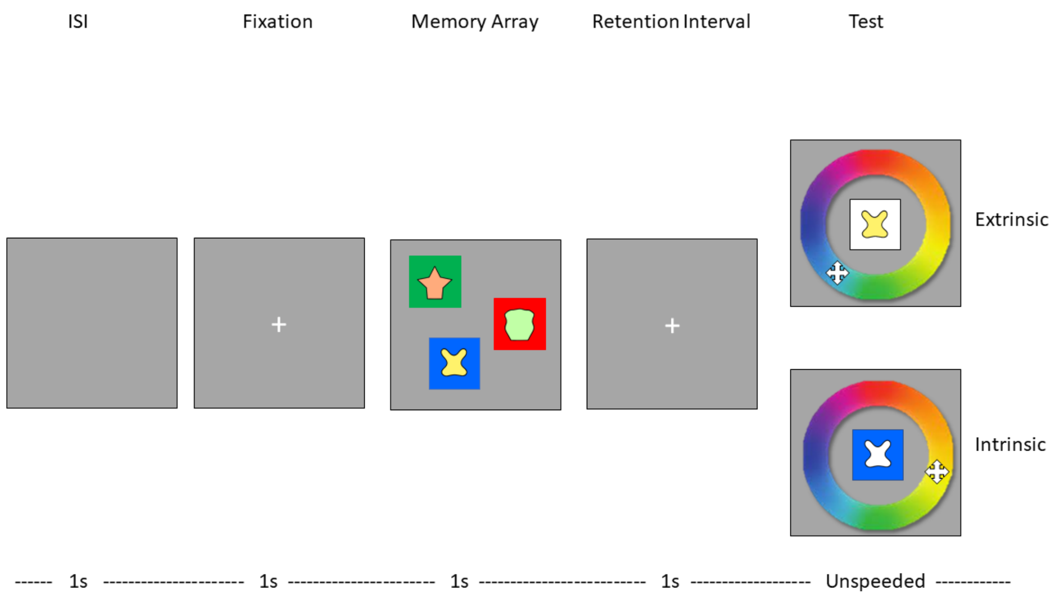
In addition, Loaiza and colleagues (2023) showed that participants preferred to use the location of the probe to guide their recall rather than other features. Participants were asked to recall the colour of either a concrete (i.e. real life) or abstract shape, and in two of the supplemental experiments, the shapes were presented in their original locations from the encoding stage. Surprisingly, recall error was similar between the abstract and concrete conditions; if prior knowledge in LTM facilitates memory formation, then recall error should have been reduced in concrete versus abstract conditions. These results indicated that participants ignored the shape in these two experiments and instead used the location to help them to recall the colour.

This evidence suggests that the mechanism of binding location may be different from binding other features. This is consistent with the object file framework (Kahneman et al., 1992) that proposes that when an individual pays attention to a visible object, its perceptual features (e.g. its colour and shape) are retained briefly in memory. The spatial index is recruited and thus marks the location of the object, but only serves as a pointing device. Therefore, those perceptual features are bound to the spatial index marking that object and forming the object file. Thus, location is having a special role in feature binding and therefore, binding location is more automatic than binding other surface features. The process of object file formation suggested by the object file framework indicates that the mechanism of binding location is different from binding other surface features.

Given this evidence that binding location may be different from binding other surface features, I suggest that future research be conducted to confirm the result of this experiment that WM storage depends on unitisation and as well as to investigate whether binding location is really different from binding other extrinsic features (see Figure 4.4). This suggested experiment is very similar to the colour-only condition of the current experiment, with the exception that it uses coloured shape as intrinsic features and coloured background as extrinsic features as in the experiments in the previous chapters. Participants would be required to recall either the colour of the shape (intrinsic) or the colour of the background (extrinsic) during retrieval stage. If intrinsic features are more automatic than extrinsic features, then the calibrated set size will be greater in the intrinsic binding condition than extrinsic binding condition. In addition, the recall error in the test phase will be either similar in the 1-feature and 2-feature condition if the object-based view is the case; greater in the 2-feature condition than 1-feature condition if feature-based view is the case and intrinsic and extrinsic binding are similarly automatic; or greater in the 2-feature than 1-feature in extrinsic condition but not intrinsic condition if feature based-view is the case and intrinsic binding is more automatic than extrinsic binding.

Figure 4.4

An illustration of a new experiment trial sequence



To conclude, the result of this experiment suggested that both object-based and feature-based storage co-exist in WM, but whether WM storage is more object-based or feature-based may depend on unitisation. However, this study cannot rule out the possibility that binding location, this extrinsic feature, is different from binding other extrinsic features. Therefore, a subsequent study has been proposed to investigate further whether using another type of extrinsic feature would yield the same result.

Chapter 5: General Discussion

This thesis investigated the factors that may influence the automaticity of feature binding. Several factors presented themselves in the literature, such as unitisation (e.g. Ecker et al., 2013), prior knowledge (e.g. Bartsch & Shepherdson, 2020; Mizrak & Oberauer, 2020; Oberauer et al., 2017), culture (e.g. Masuda & Nisbett, 2001; Nisbett et al., 2001; Nisbett & Miyamoto, 2005), basic unit of storage in WM (e.g. Oberauer & Eichenberger, 2013; Vergauwe & Cowan, 2015; Xu & Chun, 2006), etc. These factors have been examined in different chapters in this thesis.

5.1 Summary of research

Chapter 2

Chapter 2 examined the role of culture, prior knowledge and unitisation in the emergence of colour-shape binding in visual working memory (WM). On the basis of previous theorising (Ecker et al., 2013; Masuda & Nisbett, 2001; Nisbett et al., 2001; Nisbett & Miyamoto, 2005), Easterners should be more automatic in binding extrinsic features than their Western counterpart. But both Easterners and Westerners should be similarly automatic in binding intrinsic features. For the role of prior knowledge in the feature binding of visual WM, prior studies proposed that prior knowledge in long-term memory (LTM) facilitated the WM formation (e.g. Brady & Störmer, 2022; Loaiza & Srokova, 2020). Therefore, recalling an object related to the information in your LTM is easier than a novel object with no information stored in your LTM. For the key findings of this thesis, I found that culture (Experiment 1 and 2), unitisation (Experiment 1 and 2) and prior knowledge benefits (Experiment 2) may not be the factors which influence the automaticity of feature binding.

In addition, this thesis used a variety of different analytical techniques, such as the Multi-nominal Processing Tree (MPT) model, to replicate the processes of feature binding in WM. The Independence model proposed that individuals can recognise an object correctly if they have the correct binding memory (i.e. remembered the combination of features). On the other hand, the Dependence model proposed that if individuals can correctly recognise a presented object, they need to have both item memory and binding memory. The result of MPT models in both Experiments 1 and 2 did not show a significant difference between these two models. This ambiguous result cannot confirm whether the Dependence or Independence model shows the correct underlying processes of feature binding.

Chapter 3

Chapter 3 is a confirmation experiment, which re-examined the role of culture and unitisation in the colour-shape binding with an additional independent measure of cultural differences. Since I did not find any cultural and binding differences in Experiments 1 and 2, I was not sure if those null effects in Experiments 1 and 2 were because of the failure to detect the cultural and binding effects or just because there were no true cultural and binding effects at all in feature binding. Based on this background, I tried to replicate the Experiment 1 of Ecker and colleagues (2013) in Chapter 3, as they found the differences between intrinsic and extrinsic features in Western participants. In addition, I have added an additional Cognitive Attribution task to confirm whether the null effect in cultural differences in this experiment is due to no cultural differences in this group of participants or failure to detect the cultural effect. The result of this experiment is consistent with Experiments 1 and 2; I found that intrinsic and extrinsic binding are similarly automatic; therefore, binding an extrinsic feature is not more resource-demanding than an intrinsic one.

Chapter 4

In addition to culture, prior knowledge and unitisation, Chapter 4 has moved further to examine how the basic unit of storage in WM influences the automaticity of feature binding. Based on previous theorising, the basic unit of storage in the WM can be feature-based (e.g. Fougnie & Alvarez, 2011; Experiment 4 of Olson & Jiang, 2002; Wheeler & Treisman, 2002), object-based (e.g. Delvenne & Bruyer, 2004; Luck & Vogel, 1997; Experiment 3 of Olson & Jiang, 2002; Stevanovski & Jolicœur, 2011; Vogel et al., 2001) or a third option; more specifically, both object-based and feature-based storages co-exist in the WM (e.g. Oberauer & Eichenberger, 2013; Vergauwe & Cowan, 2015; Xu & Chun, 2006). As I mentioned above, Ecker and colleagues (2013) found that intrinsic binding is more automatic than extrinsic binding; therefore, if what Ecker and colleagues (2013) found is the case, and both feature-based and object-based storage co-exist in the WM, then, I proposed that whether the WM is more feature-based or object-based may depend on unitisation. Furthermore, I have also fitted the data of Experiment 4 into the Mixture model to find the contribution of guessing and binding errors into the accuracy data. The key findings of Experiment 4 are (1) intrinsic binding is more automatic than extrinsic binding and (2) both feature-based and object-based storage co-exist in WM. Therefore, the result of Experiment 4 concluded that whether WM is more feature-based or object-based storage may depend on whether the to-be-bound feature is intrinsic or extrinsic to the object.

Taken all together, these findings show that culture and prior knowledge are not the factors influencing the feature binding. However, unitisation and the basic unit of storage in WM are the factors affecting the automaticity of feature binding. Such that whether WM is more feature-based or object-based storage may depend on the unitisation of the to-be-bound information.

5.2 Methodological and theoretical contributions

Different results in cultural differences

This study investigated different factors that potentially influence the automaticity of feature binding in WM between Eastern and Western participants. The results of the WM task in Experiment 1 and 2 showed that there are no cultural differences at all between Chinese and British participants in WM. However, the result of the Cognitive Attribution task in Experiment 3 reported the cultural differences in cognitive style between Eastern and Western populations. The results of Chapters 2 and 3 show that there are cultural differences in cognitive style but not feature binding. It seems like the Analytic and Holistic thinking style framework applies to the cognitive style of Eastern and Western participants but not feature binding in WM.

Differences in the measurement of attention. Since this study has linked cultural psychology and cognitive psychology together and this study aims to investigate feature binding. Based on this background, the design of this study is more similar to WM studies, and thus, several significant deviations exist between this study and previous cross-cultural studies, such as, differences in the measurement of attention and experimental design.

For the differences in the measurement of attention, attention means focusing on a specific item and ignoring all the other distractors in the environment (e.g. Chun et al., 2011; Desimone & Duncan, 1995). The WM task of Experiments 1 and 2 in this thesis measured the prioritisation of participants' attentional preferences in this study, which means that I measured whether Eastern and Western participants prioritise their attention to foreground objects or background in that 1 second during encoding. However, those previous cross-cultural studies measured the differences in attention allocation between Eastern and Western participants. That means they measured whether Eastern and Western participants spent more time encoding foreground objects or background during the encoding stage (e.g. Masuda &

Nisbett, 2001). Therefore, the presentation time of previous cultural studies is usually much longer than 1 second as they measure participants' attention allocation (e.g. Gutchess et al., 2006; Nisbett et al., 2001). For example, Masuda et al. (2001) showed 10 animated underwater scenes to their participants twice and participants had 20 seconds to encode those stimuli on the screen for each scene. Such differences in the measurement of attention between the current studies and previous cross-cultural studies resulted in several theoretical concerns, and thus, the results of previous cross-cultural studies may not apply to this study.

Presentation time. The presentation time is another significant deviation between this study and previous cross-cultural studies. There is a controversy in the WM literature about whether a longer presentation time will yield a performance improvement. Some WM studies reported that longer presentation time did not yield performance improvement in encoding those simple meaningless stimuli (e.g. Experiment 2 of Luck and Vogel, 1997; Brady et al., 2016). On the other hand, some researchers argued that a longer presentation time might improve the performance (e.g. Brady et al., 2016; Cowan et al., 2005). For example, Cowan and colleagues (2005) presented lists of words to their participants. Each list contains 3, 4, 6 or 8 words, and each word was presented for 1.5 seconds, which is considered longer than the usual presentation time in WM studies. Such long presentation time may allow participants to rehearse what they have seen. Therefore, it is argued that those stimuli in the encoding stage may not be established as WM; instead, they may be established as stable items in LTM. This argument is supported by Keppel and Underwood (1962). They showed that participants could retain more items if they were allowed to rehearse for 2 seconds before the retention interval. Lin and Luck (2012) also found that the memory performance could be facilitated if the presentation time is longer and those to-be-encoded stimuli are complex and meaningful stimuli, as a longer presentation time allows participants to access the LTM system. Brady and colleagues (2016) found a similar result. They tested their participants in three different conditions (they are required to remember six (1) colours, (2) real-world objects or (3) detailed real-world objects) for three different presentation times (200 seconds, 1000 seconds and 2000 seconds). In the object condition, participants will see six distinct objects (e.g. biscuit, mud, map, car, pen, shoes), while, in the detailed object condition, participants will see six objects from the same category (e.g. 6 different muds). They found that the longer presentation time did not improve participants' performance for meaningless stimuli regardless of whether those stimuli were simple or complicated, as those meaningless stimuli are too fast to be encoded. However, longer encoding time resulted in more real-world objects are being remembered, especially those detailed real-life objects. It may be possible that longer encoding time allowed participants to access their LTM, and thus, more real-world objects are being remembered.

Taken together, if cultural differences only happen in a longer presentation time, then it may be possible that cultural differences only influence LTM but not WM, as what participants have encoded during a longer presentation time is established as a stable item in LTM instead of WM. This may explain why there is no cultural effect in this study and also, to the best of my knowledge, there is extensive evidence showing that there are cultural differences in LTM in the literature but not in WM so far.

Originally, this argument can be confirmed by the result of Experiment 3. However, because of the poor performance of Chinese participants in Experiment 3, I cannot conclude that the null cultural effect in Experiments 1 and 2 is because of the differences in the measurement of attention or there are no true effects in cultural differences in feature binding. Therefore, further research may need to confirm whether the significant differences in the design between this study and previous cross-cultural studies is one of the possible explanations for the null cultural effect.

Different results in the automaticity between intrinsic and extrinsic features

The results of Experiments 1, 2 and 3 of this thesis showed that intrinsic and extrinsic bindings are similarly automatic, while the result of Experiment 4 showed that intrinsic binding is more automatic than extrinsic binding. The results of Experiments 1 to 3 go against the Type-Token memory model (Zimmer & Ecker, 2010). The Type-Token memory model suggested that the intrinsic features of an object are automatically bound into the object token (i.e. the basis of item memory), while its extrinsic features are more effortful to bind into the episodic token (i.e. additional information of the object token, e.g. its encoding context). Therefore, extrinsic features are considered as additional information of the object token, and thus, it is more effortful to bind extrinsic features than intrinsic features. Different results obtained between Experiment 1 to 3 and Experiment 4 may be due to the fact that I am using different intrinsic and extrinsic feature combinations in Experiment 1 to 3 (Coloured shape versus Coloured background combination) and Experiment 4 (Colour versus Location combination). There are two possibilities for having such results.

First, previous studies consistently reported that location may be a special extrinsic feature than other extrinsic surface features, and thus, binding location is more automatic than binding other surface features. According to the Object file framework (Kahneman et al., 1992), the mechanism of binding location is different from binding other surface features as those perceptual features (e.g. its colour and shape) of a visible object are bound to the spatial index marking that object and forming the object file. Therefore, binding location is more automatic than binding other surface features. This is consistent with some other prior research (e.g. Cowan et al., 2006; Mitchell et al., 2000; Rajsic and Wilson, 2014; Postma and De Haan, 1996). For example, Rajsic & Wilson (2014) found that location seems to be an easier detail to remember than colour or other surface features. This may be due to the fact that content-location binding is relatively more automatic than colour-shape binding. Postma and De Haan (1996) also found that, when comparing to the colour changes alone, it was not much more resource-demanding for detecting colour-location binding changes. It seems it is relatively automatic or cost-free to maintain the combination of simple features and their locations with sufficient precision for recognition. The above empirical evidence suggests that the mechanism of binding location may be different from binding other surface features; therefore, different combinations of intrinsic and extrinsic features between Experiments 1 to 3 and Experiment 4 may be one of the possibilities of having different results.

Another possibility of having different results between the first 3 experiments of this thesis and Experiment 4 is that both intrinsic and extrinsic features use colour in Experiments 1 to 3. Previous studies reported that encoding colour is fast and automatic; therefore, it may be possible that the automaticity of encoding intrinsic and extrinsic colour features is similar. For example, Brady et al. (2016) asked participants to encode colour, real-world objects or real-world objects with details in their Experiment 1. They found that participants could encode colour within 200ms, which is more automatic than encoding real-world objects. Also, the Experiment 5 of Luck and Vogel (1997) tested participants to recall the colour in the small inner square, large outer square or the combination of the small inner and large outer squares. Their results showed that the accuracy of response in these three conditions are similar. In addition, the Experiment 1 of Delvene and Bruyer (2004) also reported a similar result with Luck and Vogel (1997). They asked their participants to recall the colour of the small inner square, large outer square or the combination of the inner small and large outer squares. Their result showed that the accuracy of recalling the colour of the inner small squares and outer large squares is similar, but the performance in the conjunction condition (i.e. recalling the colour of both inner and outer squares) are significantly worse. These studies showed that encoding the intrinsic colour (i.e. the inner square) and extrinsic colour (i.e. outer square) are similarly automatic. In this case, since encoding colour is fast and automatic regardless of intrinsic and extrinsic features, therefore, encoding intrinsic and extrinsic colours in Experiments 1 to 3 may also be similarly automatic. Based on this background, further studies may need to investigate the effect of unitisation on feature binding with more variations in the combinations of intrinsic and extrinsic features.

Online studies

All the experiments in this thesis are online studies because of the Covid-19 pandemic. There is a controversy over whether online studies can replicate the results of a traditional lab-based study. For example, it may be hard for the participants to pay full attention for one hour in an online study, and many factors are out of researchers' control if this is an online study, such as the monitor size, speed of the internet, machine performance may vary among participants. Most of the previous studies in WM analysed accuracy, while as Vergauwe and Cowan (2015) mentioned, accuracy data could not provide a strong indication of the underlying process. Therefore, it may be a good idea to analyse both the accuracy data and response time (RT) of correct responses. There are couple previous studies (conducted before or after pandemic) found that there is not a significant difference in the result between online studies and lab-based studies in accuracy data (Buso et al., 2021; Del Popolo Cristaldi et al., 2022; Gould et al., 2015; Prissé & Jorrat, 2022; Sauter et al., 2020; Schidelko et al., 2021; Semmelmann & Weigelt, 2017). For example, Prisse and Jorrat (2022) reported there are no differences in RT between the data collected in the lab and online; therefore, they concluded that the RT would not be influenced even if the research environment were not being controlled. However, some studies reported that the RT collected during online studies had a significant delay (between 20ms to 60ms; e.g. Del Popolo Cristaldi et al., 2022; Sauter et al., 2020; Semmelmann & Weigelt, 2017) due to different reasons (e.g. differences in set-up, speed of internet etc. among participants). For example, Del Popolo Cristaldi and colleagues (2022) tested a group of 255 participants (aged between

19 and 69 years old) in the lab (N = 129) or online (N = 126). They found a significant delay (about 20ms) in RT but no issues with the accuracy data.

Additionally, Semmelmann and Weigelt (2017) tested five famous experiments in psychology (Stroop, Flanker, visual search, attentional blink and masked priming) in three conditions (lab, web-in-lab and web). The first condition is 'lab', which is testing in a quiet research booth with computers conducted locally without using the internet; the second condition is 'web-in-lab', which asks participants to complete an online study in the lab setting. Lastly, the third condition is 'web', which asks participants to complete an online study at home. Their results found that there are no differences in the error rates and behavioural data; however, as expected, there is an RT offset in 'web-in-lab' and 'web' conditions. In addition, Buso and colleagues (2021) conducted a similar experiment with three conditions (Physical lab, Online with monitoring and Online without monitoring). In the online without monitoring condition, participants completed an online study at home, while, in the online with monitoring condition, participants not only completed an online study at home but also a researcher was present via webcam. That means they are being monitored over webcam and able to communicate with the researchers during the study. Their results show that participants are performing similarly across three conditions. These results showed that the accuracy data collected online is reliable, but the RT may need further verifications. Based on this background and avoiding concerns about RT collected online, this thesis only included the results of accuracy data, but not RT. Additionally, as I have mentioned in Chapter 3, I have analysed the RT of all the Experiments in this study; however, the RT showed the same results as accuracy; therefore, it is not necessary for us to report RT in this thesis.

5.3 Limitations and Future Directions

For the limitation of this study, first, this study and also traditional cross-cultural studies investigated the differences between the Eastern and Western world (e.g. Kitayama et al., 2006). However, some recent studies proposed that, in addition to the Eastern and Western divisions, there is an under-investigated population between the Eastern and Western world (e.g. Uskul et al., 2023). Future studies may also include this group of people, so as to have a more concrete understanding of how culture influences WM.

Second, this study has only analysed the accuracy but not RT due to the technical difficulties of collecting accurate RT data in the online setting. Future studies may test in the traditional lab setting with a more accurate measure of RT or having more control in the online setting (e.g. asking all the participants to use the same browser) to collect a more accurate RT data.

Third, since Experiments 1 and 2 in this thesis could not confirm whether the Independence or Dependence models correctly show the underlying processes of feature binding, therefore, further experiments are needed to distinguish the underlying process of feature binding proposed by the Dependence model.

Fourth, Takano and Osaka (1999, 2018) reviewed 35 studies (11 Behavioural and 24 Questionnaire studies) published between 1970 and 2016 that compared the differences between Japanese and American participants. They found that most of the studies did not find any cultural differences between American and Japanese at all. Therefore, it is possible that what the Analytic and Holistic thinking style framework proposed may not be the case. However, those studies included in Takano and Osaka (1999, 2018) used very different tools to measure the holistic and analytic thinking styles when compared to this thesis. Therefore, the results of this thesis may not be comparable to those studies. In addition, I am not only relying on what the Analytic and Holistic thinking style proposed, but also, I have added an additional Cognitive Attribution Task to the Experiment 3 to confirm the Eastern participants included in this thesis are more holistic and Western participants are more analytic in thinking style. As I mentioned in Chapter 3, the data collection of Experiment 3 terminated before reaching the target number of participants, therefore, it is not possible to confirm whether there are no true differences between the two cultural groups at all or just failed to detect the cultural differences. However, it is still a good starting point for future studies to confirm whether the cultural differences proposed by the Analytic and Holistic framework are the case.

Fifth, one of the criticisms about the generalisability of the result of this thesis may be limited. This is because participants included in this thesis are more educated, industrialised and younger than the average population in the UK, Hong Kong or mainland China. Therefore, they may not represent all the “Easterners” and “Westerners”. First, according to the previous studies (e.g. van de Vijver & Leung, 2000), cross-cultural comparison studies tend to select more homogenous participants in two cultural groups (e.g. participants in both cultural groups are university students), and thus, it will be more accurate about what is the cause of such differences. For example, previous studies showed that older adults show a significant decline in their cognitive abilities compared to young adults (e.g. Loaiza and Souza, 2019). Therefore, if I recruited participants with mixed age groups, it would prohibit me from understanding whether differences in performance reflect cultural differences or age differences. In short, the sampling of this study tends to be homogenous, and qualified participants in this study should be able to represent a particular group of “Easterners” and “Westerners”. Based on this background, this study focused on young adults only as a starting point to investigate cultural differences in WM. Future studies may need to examine whether such cultural differences exist in the older generation as well, so as to increase the generalisability of the result.

5.4 Concluding remarks

To conclude, the main finding of this thesis is that the automaticity of feature binding may not be influenced by culture and prior knowledge. But unitisation and the basic unit of storage in the WM may influence the automaticity of feature binding. This thesis confirmed that both feature-based and object-based storage co-exist in the WM, and how we store features in WM may depend on the unitisation.

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