Regular or distinctive spatial organization of visual objects: Which improves memory?

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Abstract

How might varying spatial organization improve memory for sets of objects? In this experiment simple line drawings of everyday objects were placed in grids that were regularly or irregularly organized at either a local or a global level, to give 4 layouts of stimuli that varied in the distinctiveness of their spatial organization of objects. Nineteen university students took part in six successive sessions of drawing the stimuli. In the first session they copied (training) the stimuli and then reproduced them from memory (test). In the subsequent sessions at intervals of 24 hours they reproduced the stimuli from memory (test) and then again copied stimuli (further training). Performance measures were response times (pauses whilst drawing), number of objects and transitions between local areas of the stimulus grid. It was found that global regular organization best supported learning.

Keywords: drawing; learning; memory; representation; spatial organization; regularity versus distinctiveness

Introduction

Learning from graphical materials has received attention in the education system (e.g., Samuels, 1970). The use of visual aids as an interactive learning tool can facilitate teaching and learning. The way information is represented has a role in the effectiveness of learning, because it may be conveyed more effectively in a graphical form than textual format. Research on the picture superiority effect (i.e., better memory for pictures than for corresponding words) has been widely attributed to conceptual and perceptual advantages (Madigan, 1983; Paivio, Rogers, & Smythe, 1968; Stenberg, 2006). Furthermore, graphical approaches may enhance learning as interactive effects can reinforce the contents being learned and motivate students to become more involved in their learning. In addition, learning from visual representations may facilitate the integration of new knowledge, help to organize information and facilitate learners to think critically (Fry, 1981; Larkin & Simon, 1987).

Thus, the way in which visual forms organize information has a critical role in determining the success of engaging learning experiences. Organized materials have shown to enhance memory in terms of speed and ease of access to the information (Bower, 1970; Collins & Quillian, 1970; Pollio, Richards, & Lucas, 1969). Mandler and Ritchey (1977) reported that recognition of objects in an unorganized scene is more difficult than recognition of objects in an organized scene. This is because meaningful relationships between the objects are less obvious in the unorganized scene, so provide less effective cues for the activation of the target objects. In a review of visual memory capacity, Brady, Konkle and Alvarez (2011) emphasise the need to focus on how representations are structured in order to understand their impact of the memory visual material.

Thus, it is interesting and worthwhile to investigate how the overall spatial organization, or layout, of objects in a scene affects our memory, going beyond general scenes (Mandler and Ritchey, 1977), fields of objects, to spatial layouts that might be used to presented graphical information for the purpose of learning; for example, in educational material. Here, we use grids to configure different layouts of target objects in the form of simple line drawings. The grids are either regular or irregular, at a global (whole diagram) level or at a local level (Figure 1, described more fully below). The goal of the present study is to investigate how such differences in the spatial layout facilitate learning performance. Which of the grids will best support memorization of the sets objects? Will a more regular layout, whether at global and local levels (or both), improve memory for the set or will greater distinctiveness of the irregular grids, across the levels, be better for memorization? Theoretical arguments can be marshalled in favour of both alternatives.

We may hypothesize that the more regular layouts will be better, from at least two perspectives. First, a regular grid is a table and thus participants' familiarity with tables may enhance memory, because they are used to interacting with such layout. One might contend that our mental representation of tables, which will have been acquired through our daily use of these cognitive artefacts, may serve as a generic memory structure, in that way that individuals trained in the method of loci use a journey or memory palace to serve as an encoding and retrieval device. Second, a regular grid may enhance memory simply because it may be less costly to process cognitively; for instance, visual search for items can potentially proceed in a systematic fashion.

Alternatively, we may argue that the irregular layouts will be better on the grounds of *distinctiveness* (Schmidt, 1991). Von Restorff (1933) reported the effect that now bears her name that began studies of the impact of distinctiveness on memory, which are still on-going today. In general, stimuli items or events that are more distinctive tend to be bettered remembered. Such targets may be distinctive in various ways. Schmidt (1991) identified four classes of these: (a) *emotional distinctiveness* where the participant's emotional response that is unusual; (b) *primary distinctiveness* occurs in situations where the target is differentiated with respect to a conceptual framework that is activated by co-present or recently experienced stimuli; (c) *secondary distinctiveness* occurs when the target is judged with respect to a conceptual framework retrieved from long-term memory and the target is distinctive because it is a peripheral member of some common or natural category; (4) the *distinctive process* class relates to unusual processes invoked by particular task contexts or materials. Unfortunately, there is no single theory that fully explains all the forms of distinctiveness effects (Schmidt, 1991).

This paper extends previous research on distinctiveness by focussing on the overall spatial layout of objects to be remembered. Rather than making one target distinctive, say by positioning or orientating it differently to others in a field of objects, we study how memory for a whole field of objects is affected by the distinctiveness of their spatial organization. Thus, distinctiveness here is in relation to the overall organization of the stimuli and distinctiveness is being compared between spatial organizations (stimuli). In terms of Schmidt's (1991) four classes of distinctiveness, spatial organization as considered here is a form of *secondary distinctiveness*, because the grid layouts are not being directly compared with each other in a single trial. So, the grid pattern in each stimuli will be contrasted with spatial layouts that participants will have experienced, of which regular forms are naturally the most common. Therefore, from this perspective irregular layouts will be more distinctive and hence better promote the memory for the sets of objects.

The two alternative perspectives – known regular spatial schemas versus distinctive layouts – give diametrically opposing predictions about the impact on memory of different spatial organizations. The experiment tests which of these contrary positions is valid using the stimuli shown in Figure 1. The stimuli have been designed with grids at two spatial levels: *globally* an overall frame with a grid divides the space into four main areas, using solid lines; *locally* subframe grids sub-divide each main areas into four cells, using dashed lines. A simple line drawing (object) is located in each of the sixteen cells.

The frame and the sub-frames may either be Regular *(R)* or Irregular *(I)*, so four different stimuli are created given the degree of regularity and the two spatial levels. These are labelled *RR*, *RI*, *IR* and *II*, where the letters refer to Regular or Irregular grids and the first letter is for the global level and the second letter is for the local level: for example, RI is a globally regular but locally irregular stimulus. For example, in Figure 1-RR, the cells of the upper left area of the global frame consist of four objects: a '+' sum symbol, a clock, a heart shape and the letter 'A'.

The four stimuli provide a range of regularity/ distinctiveness with the most regular (least distinctive) stimuli being RR and the least regular (most distinctive) being II. Stimuli RI and IR have regular and distinctive aspects at different levels, so we expect that they will impact the memorability in a way that is between RR and II. No particular ordering of RI and IR is predicted. Thus, if regularity determines the ease of learning the stimuli the order of the stimuli on the performance measures will be RR, RI/IR and then II. If distintiveness predominates then order will be II, RI/IR and RR.

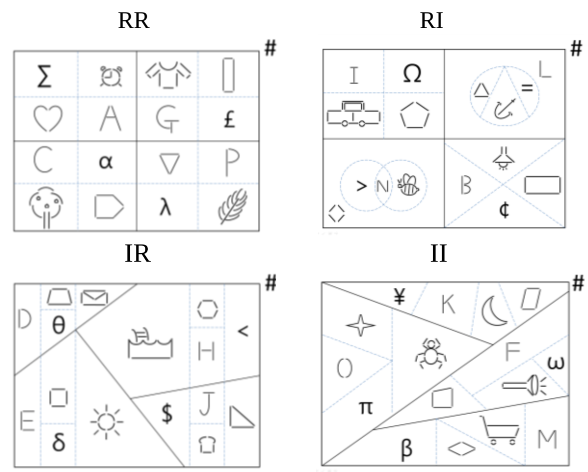


Figure 1: Stimuli
Regular and Irregular at global (1^{st} letter) and local (2^{nd}) levels.

In the test sessions of the experiment participants are present with the stimuli grids and attempt to draw the objects they remember in the correct locations. Thus, four measures of performance are used: the number of objects drawn; number of correct objects in the right location; the response time between objects (inter-stroke *pause*); the order in which objects are drawn, which will be assessed using a *transition count* score (see below). The use of drawings in the study of learning adopts the Graphical Protocol Analysis (GPA) approach of Cheng & Rojas-Anaya (2006), Obaidellah & Cheng (2009), and van Genuchten & Cheng (2010). GPA records pause durations between the pen lifting off the paper at the end of a drawing stroke and pen landing on the paper at the start of the next stroke. These pauses are related to the amount of processing required to retrieve and prepare elements for output and thus provide information about the potential organizational structure of the chunks being mentally processed (Collins & Quillian, 1970).

The pauses were coded into two levels and are defined as: *L1-within object pause* – the time before drawing elements within an object, calculated for every transition occurring between the previous line and the current line that belongs to the same object; 2) *L2-between object pause* – the time before drawing elements between objects within the same area of a grid, calculated for every transition between the last drawn line of an object and the first line of the following object in different areas. The L1 pauses establish the amount of processing associated with producing an element from within a chunk (object), whereas the L2 pauses reflect all the processing needed to prepare to produce a new object. L1 pauses are expected to be shorter than L2 pause, because less processing is involved. Retrieval of an object from with a group will make associated objects with the same group more active and hence easier to retrieve. So, if spatial organization facilitates the grouping of objects and as this supports the retrieval of the objects, then the L2 pauses will be relatively shorter than when layout does not support retrieval.

The *transition count* measures then extent to which drawing of all the objects in an area is done all at once, or otherwise interspersed between drawing in other areas, which indicates the coherence of grouping of objects by area. It is defined as the number drawing returns to an area, not including the first visit. When the number of objects drawn is large (approaching 16) but the transition count is small, the participant appears to be treating all the objects in a local area as a group. When the high transition count is high, this implies that participants are not treating objects within an main area as group, which may suggests that they are not using global spatial structure to aid their memorization. If all the objects are completely drawn in each area on the first visit to the area the transition count will be zero.

Method

Participants. Nineteen voluntary participants aged 19-25 years (*Mean* age = 21.2 yr.; *SD* = 1.87) were recruited. The participants, who were all university students (20 female and 7 male), received a small monetary reward for their participation. All of them possessed typical drawing skills demonstrated by their ability drawing simple figures in a practice task prior to the actual experimental task. There was no other specific requirement for their participation.

Design. This study employed a repeated measures within-subject design consisting of two independent variables (i.e., stimulus type, session) and four dependent variables (i.e., total number of items recalled, number of correct items recalled, pause duration, transition count). The independent variables were crossed producing 24 experimental conditions (4 stimuli x 6 sessions). All participants performed all experimental conditions, copying each stimulus and drawing each stimulus from memory, for a total of eight drawings per session.

Materials. Each stimulus has four main local frames that consist of 16 objects; Fig 1. There were 64 different objects for all stimuli (16 objects x 4 stimuli). Each local frame of a stimulus consists of four cells that each contains a common object, a symbol, a shape and an letter. Thus, each stimulus contains four of those items, randomly picked from a pool of these categories as pre-defined by the experimenter. All participants did the same set of stimulus.

Procedure. All drawings were made on empty stimulus layout (i.e., Fig 1 without the objects) taped on the Wacom Intuous graphics tablet using a special inking pen to enable a digital record of the drawing protocols. A special program, TRACE (Cheng & Rojas-Anaya, 2004), was used for the recording. In all drawing tasks, the participants began with writing a hash (#) to ensure that drawing was well underway before the first stroke of the first object, so that its values are a valid and can be used in the full data set.

Each participant completed two sets of drawings in copying and recall from memory modes in each session. In the first session, the participants first copied all four stimuli individually as training before they drew again from memory when represented with an empty grid as a test. From the second session onwards, all participants initially drew the stimuli from memory as tests given empty grids and then copied the given stimuli as further training. The given order of the stimuli was randomized in each drawing task in each session. There was a gap of at least 24 hours, but no longer than 48 hours between each session. During copying (training), participants were allowed to view the target stimulus throughout the drawing process. In both tasks, the participants were encouraged to only reproduce items they saw. No study time was allocated prior to drawing. Participants were reminded to draw as fast as possible when instructed to begin drawing. No specified duration was allocated to complete their drawings. However, the participants were asked if they had anything else to draw after a pause longer than a minute. Majority of them decided to stop after this duration.

Results

We conducted a repeated measures analysis of variance (ANOVA) with stimulus type (RR, RI, IR, II) and session (1-6) on the total number of items recalled, number of correct items recalled, pause duration and transition count of slot usage. Only drawings from recall task were analysed, as data obtained from the copying task do not contribute to the research questions of the present study. Data were screened for extreme or missing values and statistical assumptions for ANOVA were addressed. The degrees of freedom for a particular effect were adjusted if the data violated the sphericity assumption. In this case, the Greenhouse-Geisser correction was applied when the estimate of sphericity was found smaller than .75. The Alpha level was set at .05 for the evaluation of statistical significance. All pairwise comparisons were conducted using Bonferroni adjustments. Table 1 shows the mean scores and standard deviations for the four stimuli showing shorter L1 pauses than the L2 pauses in all cases, as expected.

Table 1: Mean scores for pauses

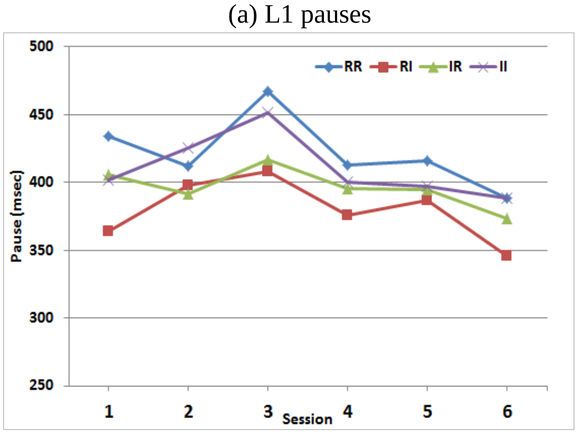
		L1 pauses		*L2 pauses*	
Stimulus	*N*	*M*	*SD*	*M*	*SD*
RR	19	422	27	6736	4663
RI	19	380	23	6277	4504
IR	19	395	15	7235	3889
II	19	411	24	9676	5397

Amount of processing – L1 and L2 pauses

The amount of processing is measured using the pauses. Figure 2a shows that the (within object) L1 pauses are relatively constant across sessions, but there are overall various in L1 pauses across the stimuli. An ANOVA for the L1 pauses revealed significant main effect for stimulus type, $F(3,54)=4.76$, $p<.05$, $\eta^2=.50$ using sphericity assumed. The contrast test showed that significant differences were large between RR and RI.

Figure 2b shows a substantail decline the the L2 pauses across sessions for all the stimuli and also a difference between some the stimuli. There is a significant main effect for stimulus type, $F(3,54)=4.25$, $p<.05$, $\eta^2=.19$ using sphericity assumed. The pairwise comparison showed large difference between RR and II. Significant main effect was also found for session, $F(2.57,46.24)=15.64$, $p<.001$, $\eta^2=.47$ using Greenhouse-Geisser estimates of sphericity ($\varepsilon=.51$).

(a) L1 pauses



(b) L2 pauses

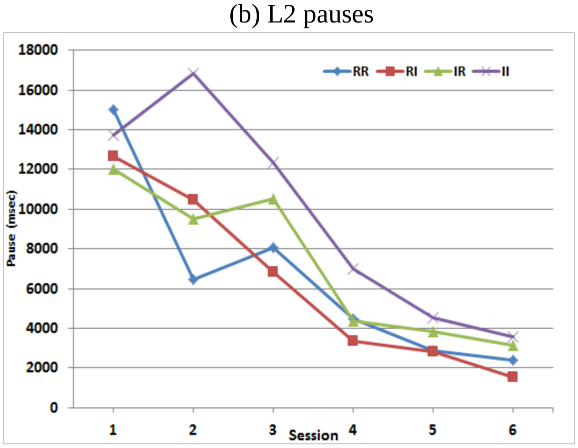


Figure 2: L1 and L2 pauses for all stimuli

Table 1 and Figure 2 together show that L2 pauses are shorter for the more regular stimuli: as significant differences overall; as a significant pairwise difference (RR<II); and as trends (RR<IR, RR<II, IR<II).

Total number of items recalled

Figure 3 shows the total number of objects drawn, which increase over the sessions to approaching the maximum of 16. Again there are differences between stimuli. In the initial stage of drawings, participants drew incorrect items, either errors or commissions or omissions of objects. Commissions are drawn items which are not defined in Figure 1 and also includes items drawn in the wrong stimulus. Omissions are items which are shown in the actual stimulus, but the participants did not draw them in their drawings. We report the total number of objects, correct or not (Fig 3) and correct entries drawn (no figure presented here). Considering the total number of items drawn per stimulus, the ANOVA showed a significant main effect for stimulus type, $F(3,54)=8.45$, $p=.000$, $\eta^2=.32$ using sphericity assumed ($\varepsilon=1.00$). Pairwise comparison between the stimuli showed large difference all at $p<.05$ for the following: 1) RR>II, 2) RI>IR, 3) RI>II. The ANOVA also reported a significant main effect for session, $F(1.65,29.68)=56.27$, $p=.000$, $\eta^2=.76$ using Greenhouse-Geisser estimates of sphericity ($\varepsilon=.33$).

The overall shape of the data for numbers of correct objects is similar as that shown in Fig 3. The ANOVA results for correctly drawn objects showed a significant main effect for stimulus type, $F(3,54)=14.00$, $p=.000$, $\eta^2=.44$ using sphericity assumed ($\varepsilon=1.00$). The pairwise comparison between the stimuli further showed that RI>IR and RI>II. Similarly, significant main effect was reported for session, $F(1.55,27.83)=145.22$, $p=.000$, $\eta^2=.89$ using Greenhouse-Geisser estimates of sphericity ($\varepsilon=.31$). The mean scores for the number of correct items drawn increased over the sessions.

Thus, for both total number of objects and numbers of correct objects there was better performance with the more regular stimuli.

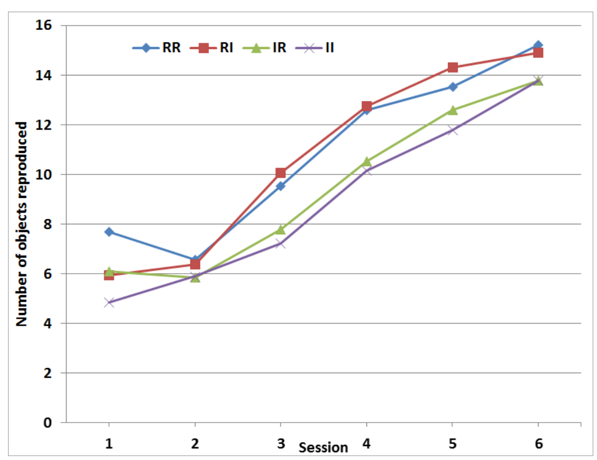


Figure 3: Total number of objects recalled for all stimuli

Transition between the areas

This analysis reports on the number of occurrences of participants returning for a second or subsequent time to draw further items in a particular frame, which indicates the extent to which objects within an area are treated as a group. Figure 4 shows the transition counts for the stimuli across the sessions. The minimum score is zero. The transition count increase for over the sessions for all stimuli with the exception of RI, which is relatively constant.

The ANOVA revealed significant main effects for both stimulus type and session, respectively, $F(3,54)=14.30$, $p=.000$, $\eta^2=.44$ using sphericity assumed ($\varepsilon=1.00$) and $F(1.92,34.62)=15.13, p=.000$, $\eta^2=.46$ using Greenhouse-Geisser estimates of sphericity ($\varepsilon=.39$). A significant interaction effect is also found for stimulus type x session, $F(6.42,115,60)=3.70$, $p<.05$, $\eta^2=.17$ using Greenhouse-Geisser estimates of sphericity ($\varepsilon=.43$).

Clearly RI differs from the other stimuli. As the number of objects drawn increases with session (see Figure 3) there is no increase in the number of moves between areas, which is consistent with the objects in each area being treated as a group. For the other stimuli, as the number of objects increases, from approximately 6 to 14, the transition count only increases by three, so the order of drawing is not random with respect to the areas. This suggests some grouping with RI, IR and II by area but less so than for RI.

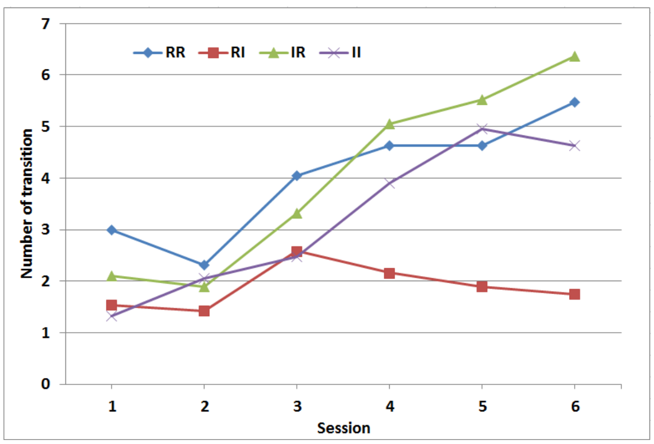


Figure 4: Number of transitions between the overall slots of the stimulus

Discussion

Does the regularity or the distinctiveness of the spatial organization of a grid of objects better support the memorization of a set of objects? Collectively, the results show that more regular layout gives better memory performance. A greater total number of objects is recalled in both globally regular stimuli, RR and RI, over globally irregular stimuli, IR and II. For correct objects, more were drawn under RI than IR and II. With respect with the L2 pauses, RR is less than II and trends are apparent for RR<IR, RR<II, IR<II. At least with respect to RI the transition counts indicate that objects were being group by area, whereas for the other stimuli there was less of an impact, as inferred from the relatively slower increase in transition count compared to total number of objects.

These findings supports the idea that organized visual materials may assist memory, as proposed by Mandler and Ritchey (1977). Findings from this study extend prior studies about the effects of organization on memory (Bower, 1970; Collins & Quillian, 1970; Pollio, Richards, & Lucas, 1969), by addressing spatial layouts as might be found in instructional contexts.

One interpretation of the results is that participants' familiarity with table-like organisations of information may have provided them with a ready encoding and retrieval structure for storing and recalling the objects. This may tap in to mechanisms similar to those that underpin the success of the method of loci as a memorization technique. That approach favours a linear structure, whereas as both RR and RI are 2D, so it is an open question whether the nested frames in the stimuli are being used as hierarchical structures or whether participants are imposing a linear path through the cells of their own devising. Further, analysis of individual paths through the stimuli over successive sessions could be revealing. If the order of the production of objects in the cells of each area were arbitrary this would indicate a hierarchical interpretation, whereas if the order were the same each time that would suggest a more linear interpretation. Understanding the strategy by which each stimulus is processed is important, because if one were different this would be a form of process distinctiveness, as per Schmidt's (1991) fourth category. In other words, if different strategies are used for alternative stimuli this would be an experimental confound.

The transition counts suggest that the approach for remembering RI may, overall, be more hierarchical than for the other stimuli, because the low count implies each area is processed relatively independently of the others. RI also stands out because the majority of significant results apply to it rather than RR. This suggests that the facilitation of memory may not be solely due to regularity, because RR is both regular at both global and local levels, whereas RI is lacks regularity at the local level. Thus, a straightforward contrast between regularity and distinctiveness may be over simplistic. Further, close comparison of the stimuli shows a flaw in the design of the stimuli, as RI at a local level is not irregular in the same way as II at a local level, and IR and II at a global. II at a local level is subdivided in a relatively arbitrary manner, and similarly with both IR and II at the global level. In contrast, RI uses regular and often familiar grids patterns for its cell divisions: two are simple double bi-sections (Figure 1, top-left and bottom right), one is like a Venn diagram (bottom-left), and the fourth is symmetric (top-right). So, on the one hand, it could be argued that at the local level each area is regular or lacking secondary distinctiveness, in Schmidt's (1991) terms; but, on the other hand, at a global level each areas is distinctive, relative to each other, in Schmidt's (1991) primary distinctiveness sense. Depending on one's perspective, what counts as distinctive (or regular) will differ, which only further supports Schmidt's (1991) comments that distinctiveness may have limited value as theoretical construct.

Both IR and II are irregular, or distinctive, at the global level. One reason they may not have facilitated memorization is that their distinctiveness is judged on perceptual grounds. They are both unusual and relatively unique in comparison to a regular rectangular grid; so the participant faces an extra task of learning the global grid pattern over and above the task of remember the objects. Participants may have to correctly differentiate between IR and II before they can begin to remember objects without suffering from between stimuli interference. So, there is a sense in which IR and II are not actually distinctive, at least with respect to each other.

The experiment is a further demonstration of the use of graphical protocol analysis (GPA) in the study of chunking effects. Short L1 pauses (350-470ms), which are fairly constant for all stimuli, is compatible with previous findings about processing used to produce elements signifying within chunk. As expected, the long L2 pauses (1700-1800ms) indicates that more processing is required to begin a new chunk than for intra-chunk elements. These findings are consistent with the prior studies using GPA (Cheng & Rojas-Anaya, 2006; Obaidellah & Cheng, 2009; van Genuchten & Cheng, 2010).

A limitation of the present study the lack of counterbalancing between the conditions of the design. This may explain why L1 pauses varies between stimuli.

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