THE EFFECT OF POINTING GESTURE ON SPATIAL MEMORY

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SUMMARY

Pointing gestures are hand movements that identify references in space. These gestures are either directed to concrete locations where the entities situate (e.g., index finger points to the library) or to virtual locations that represent the entities (e.g., index finger points to an empty space on the left that is associated with the library). Pointing gestures to concrete locations direct listeners' attention to the target objects while pointing gestures to virtual locations help listeners to simulate an image of the spatial layout of the objects. This research aimed to examine whether encoding these two types of pointing gestures enhanced spatial memory in three experiments.

Listeners seldom process pointing gestures alone. There are other sources of spatial information, such as maps and verbal descriptions. Hence, the way pointing gestures influence spatial memory might interact with other spatial cues. Study 1 examined the effect of pointing gestures to concrete locations on spatial memory and explored how such effect interacted with types of speech (spatial or non-spatial). The participants watched the narrator reciting spatial or non-spatial statements about fictitious countries while pointing to their locations on the maps. The findings showed that, when the maps were present, pointing gestures did not aid spatial recall. However, there was a significant interaction between the type of speech and the presence of pointing gesture, which highlights the importance of examining speech content that accompanies pointing. Study 2 manipulated the visibility of maps and examined whether pointing gestures aided spatial memory when the maps were hardly perceived. Pointing gestures aided spatial recall when the map was visually ambiguous, but the effect was marginally significant. Study 3 removed the maps

entirely. The narrator pointed to the virtual locations that represented the countries. The results showed that pointing gestures enhanced location recall regardless of the types of co-occurring speech.

As a result, the effect of pointing gestures on spatial memory interacts with the presence of maps and types of co-occurring speech. Pointing gestures do not always facilitate spatial memory. When the map is clear, pointing gestures appear to be redundant, probably due to the presence of other visual cues that were sufficient for efficient encoding of spatial location. However, pointing gestures are not redundant when directed to an unclear map or to a virtual location. They could serve to clarify reference that is present but unclear. In addition, pointing to a virtual location facilitates spatial memory regardless of the content of the accompanying speech. When the accompanying speech is spatial, pointing to a virtual location provides an alternative source of spatial information that could strengthen memory trace. When the accompanying speech is non-spatial, pointing to a virtual location provides an indispensible, only source of spatial information. These findings have especially relevant implications for classroom use of pointing gestures.

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The Effect of Pointing Gesture on Spatial Memory

CHAPTER 1

Pointing Gesture and its Function

When people speak, they move their hands. A type of hand gestures frequently used in conversation is pointing. Pointing gestures are hand movements that signal out the objects located in space. For example, a speaker uses his index finger to point to the location of a dog while saying, “I saw the dog run away”. Both children and adults use pointing gestures in everyday life. Children have been observed to point to a toy to indicate that they would like to play with it (So, Demir, & Goldin-Meadow, 2010). Adult caregivers have been observed to point to objects in order to prompt their children to label them (So & Lim, in press). In an educational setting, teachers may point at the numbers written on the board while explaining mathematics (Goldin-Meadow, 1999).

The examples above mainly concern pointing gestures directed to concrete objects. Interestingly, we sometimes point to *empty* space as if the abstract location represents an entity (McNeill, 2005), although research on such kind of pointing gesture is relatively scarce. For example, when describing the spatial locations of the Central Library and Computer Center, we say and gesture, “The Central Library is on the left (point to our left) of the Computer Center (point to our right)”.

Both types of pointing gestures (pointing to concrete objects and pointing to empty space) identify referents mentioned in speech. However, they serve different functions. The section below reviews the functions of these two types of pointing gestures and speculates how they are associated with spatial memory.

Pointing Gestures to Concrete Objects Direct Attention in Space

Yamamoto and Shelton (2009) found that directing the attention of participants to targets influenced their spatial memory. In this study, the participants memorized positions of objects and later had to recall the location of each object during the test phase. During the learning phase, the participants were presented with objects either sequentially or simultaneously. They were instructed to remember the location of the objects. During the test phase, the location recall task involved participants pointing to the location of each object. The results showed that the participants were more accurate in their recollection of object location when they had studied the location of the objects sequentially rather than simultaneously. Yamamoto and Shelton (2009) suggested that in the sequential viewing condition, the participants had their attention directed to each object and this directing of attention resulted in better location memory as compared to the simultaneous viewing condition. Thus, if pointing gestures serve to direct attention to concrete objects, then it is likely that the presence of pointing gestures would also result in improved memory for the location of these objects.

Clark (2003) proposed that pointing gestures to concrete objects could draw listeners' attention towards the target entities. Tversky et al. (2009) found that when the participants explained the routes to listeners, they used pointing gestures to indicate the landmarks that were important in the route (e.g., where the route made a turn). In a study done by Bangerter (2004), pointing was shown to help the listeners focus their attention to the referents in speech during a dialogue. For example, the participants used pointing gestures to shift the attention of their partners to the target. In that study, each pair of participants had to match the photos of faces on the arrays mounted on a board placed in front of the pair. The photo arrays were located at varying distances from the two participants. One of the participants in the pair (the “director”) was given a list of target names and photos which were hidden from the other participant (the “matcher”). The director had to identify the targets on the board to the matcher by directing the attention of the matcher to the target, so that the “matcher” could see the target’s name from the array board and write the name in the answer sheet. The matcher then wrote the names of the targets down on an answer sheet. Bangerter (2004) found that the directors tended to use pointing gestures with words such as “there” when the array board was situated close to them. Furthermore, when the current target was further away on the board from the previous target, the participants used pointing gestures more often to indicate the location of the new target, as compared to when the current target was nearer to the previous target. The results also showed that participants who were “directors” used several strategies to direct the attention of the “matcher” to the target. These strategies were pointing while saying deictic words such as “there” or “that”, describing the location of the target and describing features of the target. In view of these results, Bangerter (2004) suggested that pointing gestures function to direct listeners’ attention

Another piece of research also suggests that pointing gestures function to direct attention. Louwerse and Bangerter (2010) examined the direction of eye gaze and its response to the pointing gesture in listeners. In this study, the verbal descriptions that accompanied pointing were either location+feature descriptions (e.g. “in the middle with a happy face”) or feature descriptions only (e.g. “with a happy face”). None of the verbal descriptions contained deictic words that were observed to accompany attention-directing pointing gestures in Bangerter (2004). The participants in this study watched a target face being described (out of 12 faces) with pointing or without pointing. The results showed that the participants made more gaze fixations to the target face when the video clip had pointing in contrast to when it did not contain pointing. The participants also fixated their gaze to the target face earlier when pointing was present. These findings make the case that pointing gestures do not always need to accompany deictic words to direct attention; pointing also serves to direct attention when they are accompanied by verbal description.

Altogether previous findings showed that pointing gestures could direct listeners’ attention to the target referents mentioned in speech. Perhaps encoding pointing gestures would ultimately enhance memory for the location of referents. In a spatial memory task, encoding pointing gestures might arouse listeners’ attention to the accompanying referents that in turn, facilitate spatial processing of referents and strengthen retention.

However, pointing gestures might not facilitate spatial memory even if they confer a benefit to cognitive processing. Yuviler-Gavish, Yechiam and Kallai (2011) found that visual aids in the learning phase may not help subsequent memory for completing the task. In that study, the participants completed a 3D puzzle while guided by instructors over a computer. The participants referred to items on a computer screen while the instructors either gave verbal instructions only, or gave verbal instructions and pointed to items on the computer screen with a mouse pointer. The results showed that while pointing helped to decrease cognitive load during the learning phase, the participants took a longer time to complete the 3D puzzle and were less accurate at the puzzle when they were instructed with pointing as compared to when they were instructed without pointing. Thus, it seems that pointing may not always facilitate spatial memory and its effect depends on the task during the test phase. Since this thesis examines the effect of pointing gestures on location recall, it is likely that pointing gestures enhance spatial memory in terms of location recall (Yamamoto and Shelton, 2009) but not necessarily influencing spatial memory required to solve a 3D puzzle, which involves not just a mental representation of location but also mental rotation.

Pointing Gestures to Virtual Locations Convey Spatial Information

People do not point to concrete objects only. They also point to empty space. Few studies have specifically examined whether pointing gestures to virtual locations convey spatial information. The possibility of this function of pointing gestures to virtual locations can be deduced by considering the findings of studies with general hand gestures in empty space and the analysis of McNeill (1992) of pointing gestures to empty space.

Two lines of previous research suggest that pointing gestures to virtual locations convey spatial information. In the study conducted by Lavergne and Kimura (1987), the participants were instructed to talk about topics that contained either spatial or non-spatial information. Spatial topics included route descriptions and room layout descriptions, while non-spatial topics included descriptions of a typical day and descriptions of family members. The participants produced more gestures in general when talking about spatial topics. Furthermore, people locate their hand gestures in a particular area of empty space to refer to the spatial location of a specific object (So, Kita, & Goldin-Meadow, 2009). In this study, the participants retold a story to the experimenter. The participants would sometimes produce a hand gesture in a specific area of empty space to refer to a character in the video and subsequently refer to that character in their descriptions again by producing hand gestures in the same location as before. Considering these two studies in particular, the tendency to produce hand gestures in empty space when talking about spatial information and the link between gesture locations in space with the identity of the referent hint that the function of hand gestures in empty space to convey location information. However, speakers could have produced more hand gestures when speaking about spatial information due to these gestures helping them in the process of speech (Krauss, 1998; Rauscher, Krauss & Chen, 1996; Alibali, Kita, & Young, 2000; Kita, 2000) and not because these gestures conveyed spatial information to the listener.

The second line of past research shows that hand gestures produced in empty space indeed conveys spatial information to the listener (Beattie & Shovelton, 1999; Alibali, 2005). In the study by Beattie & Shovelton (1999), there were two groups of participants. The participants in one group ("the informant") watched clips of a cartoon story and were filmed as they recalled the events in the cartoon. The resulting videos were shown to the participants in the other group ("the respondent"), who had to answer questions about the narrated events after viewing the video featuring the informant. The answers from the respondent were then compared with the original cartoon video. Beattie & Shovelton (1999) found that the informants received more accurate spatial information (e.g., relative location and size) about the events and objects in the cartoon when the respondents gestured in the video. This finding supports the idea that gestures in empty space convey spatial information, especially location information.

Even though these studies did not examine pointing gestures specifically, the function of conveying spatial information can be generalized to pointing. McNeill (1992) observed that pointing gestures that are produced in the absence of visible entities represent the spatial locations of those entities. For example, one may point to different areas on a table to indicate the locations on a map from memory (e.g., pointing to the left part of a table to indicate Portugal and pointing to the right part of the table to indicate Spain.). In this context, these two pointing gestures convey spatial information about the location of Portugal and Spain, even though the map is not physically available. In fact, without the visible referent, pointing gestures simulate an *image* of location of countries in a listener's mental representation (McNeill, 1992). Such simulated image, derived from the gestures, provides an additional source of location information besides the verbal description in speech (e.g., saying, "Country X is to the right of Country Y").

Would this source of spatial information improve recollection of location? As cited in the studies above, gestures that occur in empty space are commonly accompanied by speech (and are called "co-speech gestures") (McNeill, 1992). This is true of pointing gestures as well (McNeill, 1992). According to the Dual-Coding Theory (Paivio, 1971), encoding semantic information in both modalities (i.e., visual and verbal modalities in the above example) leads to a stronger memory trace and better location recall. Considering the prediction of this theory, pointing gestures may improve spatial memory because encoding these gestures in the absence of an external referent means that there is now a visual source of spatial information, thus spatial information is more likely to be recalled and less likely to be interfered with.

Pointing Gesture and its Interaction with other Sources of Information

As discussed in Chapter 1, pointing gestures (either pointing to concrete objects or empty space) identify referents and these gestures could be expected to facilitate spatial processing of referents. However, individuals develop spatial representation from various informational sources. In fact, they are rarely exposed to one source of information, e.g., pointing gesture, at a time. Rather, they experience multiple sources of information simultaneously such as verbal descriptions of space, information from maps and first-person experience (Brunyé, Rapp, & Taylor, 2008; Lee & Tversky, 2001; Levine, Marchon & Hanley, 1984; Lloyd, 2000; Taylor, 2005; Tversky, 1992). Abundant work has been done on how encoding information in map and/or verbal description shapes spatial representation (Hirtle & Jonides, 1985; Tversky, 1992, 2000; Shelton & McNamara, 2004; Lee & Tversky, 2005; Noordzij & Postma, 2005; Brunyé, Rapp, & Taylor, 2008). For example, Noordzij and Postma (2005) examined whether spatial descriptions influenced how people think about location. They found that the participants mentally organized the information from the verbal descriptions into spatial representations that resembled mental maps. In addition, Shelton and McNamara (2004) examined how verbal descriptions or viewing virtual environments affected subsequent scene recognition. The results of their study showed that the participants recognized scenes more quickly when the tested scene matched the perspective of the studied scene, suggesting that people form spatial representations from viewing visual scenes as well as from verbal descriptions of those scenes.

Despite much research done on retention of spatial information from studying maps and/or verbal descriptions of maps, little is known about the role of gesture in the retention of location memory from maps, let alone the interplay of pointing gestures and other sources of spatial information. It is possible that the pointing gesture interacts with other sources of spatial information, which in turn, either interferes or facilitates spatial processing.

Imagine a scenario in which the listener is presented with a map and watches a narrator describe the spatial locations of countries while pointing to those regions on the map. For example, the narrator says, “Austria is to the right of Switzerland” while pointing to Austria on the map. In another scenario, the narrator does not point to Austria but produces the same spatial statement. Since pointing could direct the listener’s attention to the target region of the map while the spatial statement is processed, the listener may be expected to have a better spatial memory of the location of Austria in the first scenario than in the second scenario.

However, in reality, the narrator might convey non-spatial features of the countries while pointing to them on the map. For instance, the narrator may say, “Austria has more concert halls than Spain” while pointing to Austria on the map. Does the pointing gesture facilitate spatial processing in this example? Following the reasoning in the previous paragraph, it appears that pointing gestures direct attention to location. Since directing attention has been shown to improve spatial layout memory (Yamamoto & Shelton, 2009), then they would help spatial memory even when accompanied by non-spatial speech. An objective of this thesis is to determine whether pointing gestures directed to visible referents aid spatial memory, since previous studies have only looked at the effect of pointing gestures on directed attention. Since a prior study has suggested that directed attention can improve spatial location recall, it is possible that pointing gestures can aid spatial memory by directing attention. This thesis also seeks to investigate the relationship between the presence of pointing gesture and the type of accompanying speech on location recall, which has not been examined by previous studies.

Yet another aim of this thesis is to examine the effect that referent visibility has on spatial memory, since pointing gestures are directed to virtual locations at times. What happens then when the map is removed from the scenarios described? When the map is absent, speakers may use pointing gestures to locate a country in space while saying a spatial statement. Imagine a scenario in which the speaker points to a location on a board and says, “Austria is on the right of Switzerland”. In this situation, the pointing gesture might substitute for the map to convey spatial information in the visual modality. Encoding such a gesture thus allows listeners to store spatial information in a nonverbal format. On the other hand, listening to the spatial statement allows listeners to form a spatial memory trace in a verbal format. In another scenario, the narrator produces the same spatial statement but does not point to the empty location on the board. In such a situation, the listener encodes spatial information only in the verbal modality. Comparing the two scenarios above, we expect that the listener should have a better spatial retention in the first scenario than in the second one as dual encoding of spatial information in verbal and non-verbal modalities facilitates one's spatial processing (Kulhavy, Lee & Caterino, 1985). In addition, encoding the pointing gesture to the empty location helps the listener to form a simulated image of the map, which in turn helps the listener to retrieve the spatial memory later (Woodall & Folger, 1985).

When the narrator describes the non-spatial features of the countries while pointing to the empty space, (e.g., pointing to an empty location and saying, "Austria has more towns than Switzerland"), such pointing gesture is the only modality to convey spatial information to the listener. The pointing gesture in this situation could still aid spatial memory, although the beneficial effect would be weaker than in the situation where spatial information is conveyed in both gestural and verbal modalities.

Overall, the experiments in this thesis examined the extent to which the presence or absence of a map and the type of accompanying speech interacts with pointing gestures in enhancing spatial memory. Study 1 investigated the spatial location recall performance of participants after they had watched a video of an actor narrating the descriptions of countries on a map mounted to a board. The narrated descriptions were either the descriptions of spatial location of the countries ("Country X is to the right of Country Y") or of their non-spatial features ("Country X has more trees than Country Y"). The actor either pointed or did not point to each country on the map while narrating a statement. Location memory was assessed by having the participants fill in an empty map with the names of the countries given. If pointing gestures improved location memory regardless of the type of accompanying speech, then participants would generally recall more map locations accurately when the narrator pointed to the map as compared to not pointing to it. Spatial speech was also expected to produce better performance in the location memory task than non-spatial speech. Spatial speech would provide the participants with a verbal source of location information, while non-spatial speech contained information that was redundant to the task of filling in the map. Past studies have shown that information, presented during the learning phase, which is redundant to spatial recall tasks may even result in poorer performance (e.g., Schneider & Taylor, 1999), giving rise to the expectation that non-spatial speech would result in poorer spatial recall in general. Earlier in this section, the hypothesis that pointing gestures would aid spatial memory regardless of the type of accompanying speech was made. In light of the prediction that spatial speech would result in better location recall than non-spatial speech, it is reasonable to expect that location recall is best for the condition with pointing gesture and spatial speech, followed by either pointing gesture and non-spatial speech or spatial speech only, with the condition of non-spatial speech only producing poorest location recall.

Contrary to expectation, the findings showed that pointing gestures did not enhance spatial memory recall. Perhaps when the maps were clearly visible to participants, co-occurring speech containing the country names was sufficient to direct the participants' attention to the target countries. Hence, the participants did not need additional assistance from the pointing gesture. It raises the possibility that the facilitating effect of pointing gestures on memory is only apparent when the maps are difficult to be perceived, e.g., the borders of the maps are not clear. Chapter 3 presents Study 2, which investigated the effect of pointing gestures and spatial speech on location memory when the map was clearly visible as compared to when the map was visually unclear. In Study 2, participants watched videos of a narrator reciting spatial statements while pointing or not pointing to a map that was in high or low contrast with the background. Participants should be able to perceive high contrast maps easily but they should need more effort to perceive the low contrast maps. After watching each video, participants completed the exact same task to recall map locations as in Study 1. If pointing gestures facilitated spatial processing when the targets were not visually unclear, then participants would recall more locations correctly when pointing gestures were accompanying spatial speech than when they were not.

Study 3 (Chapter 4) examined the effect of pointing gestures when the maps were entirely removed. The methods used were exactly the same as in Study 1 (Chapter 2) except that maps were not available. In the video, the narrator either pointed or did not point to the virtual locations that were similar to the real locations on the maps in Study 1 while reciting statements (spatial and non-spatial) about each country. If pointing gestures that conveyed spatial information strengthened spatial memory, the participants would be able to recall more spatial locations when the pointing gestures were accompanying speech than when they were not.

CHAPTER 2

Pointing Gestures, Type of Speech and Spatial Recall of Location

The aim of this study was to investigate the effect of pointing gestures on spatial recall and how such effect interacts with the types of speech (spatial and non-spatial). If pointing gestures facilitated spatial memory by arousing the participants' attention, then participants would recall more country locations when watching the videos in which the spatial speech was accompanied by pointing gestures than when watching the videos in which the spatial speech was not accompanied by pointing gestures. Since past research on the effects of directed attention on memory has been confined to spatial information, it is not clear how pointing gestures would interact with non-spatial speech to influence spatial memory. A possibility is that the attention-directing effect of pointing gestures would prevail, leading to a general improvement in location recall even when pointing gesture occurs with non-spatial speech. If so, then the participants would be expected to recall location of the countries more accurately in the condition with non-spatial speech and pointing gesture as compared to the condition with non-spatial speech only. The participants would also be expected to recall more locations accurately in the condition with spatial speech and pointing as compared to the condition with non-spatial speech and pointing due to the expected effect of spatial speech aiding spatial location recall.

Method

Participants

Sixty-eight undergraduates (34 males and 34 females) from the National University of Singapore participated in this study. All were native English speakers and had normal or corrected-to-normal vision.

Design

This study adopted a 2 x 2 within-subject design. The two independent variables were types of speech (spatial or non-spatial) and presence of pointing gesture (present or absent). Each participant was required to be involved in all the four experimental conditions: spatial speech with pointing gesture (SG), non-spatial speech with pointing gesture (NSG), spatial speech without pointing gesture (SNG) and non-spatial speech without pointing gesture (NSNG).

Materials and Procedure

Participants were tested with four different maps in this experiment. Each map featured a unique spatial layout of eight fictitious countries. The names of the countries were different across the maps (refer to Appendix A). The maps were tested one at a time and they were mounted on a whiteboard in the videos.

For each map, *eight* different sentences were generated describing the spatial locations and non-spatial features respectively of the eight fictitious countries (see Appendix B for an example of the spatial and non-spatial sentences provided for one of the maps). A narrator was asked to produce those sentences in four separate videos for each map. Of the four videos, the narrator was asked to 1) verbally describe the spatial location of the countries while pointing to those countries on the map at the same time; 2) verbally describe non-spatial features of the countries while pointing to them at the same time; 3) verbally describe the spatial location of the countries but not point to them and; 4) verbally describe non-spatial features of countries but not point to them (see Table 1 for an example). Altogether, there were sixteen videos for all the four maps, with each video lasting fifty seconds.

Table 1

Illustrated examples of each condition from screen captures of videos with Map 1

	Pointing gesture	
Type of speech	Present	Absent
Spatial e.g., "Country X is to the left of Country Y."		
Non-spatial e.g., "Country X has more cows than Country Y."		

The narrator was standing to the right of the map when describing the countries in English. He referred to the countries in a bottom-up order (Cabibihan, So, Nazar, & Ge, 2009). Hence, the first country (at the bottom) and the last country (at the top) in each map were mentioned only once but the rest of the countries were mentioned twice or thrice, depending on the shape of the spatial layout.

The participants were tested individually. This experiment adopted a within-subject design in which the participants were tested in all the four experimental conditions (spatial speech with pointing gestures, SG; non-spatial speech with pointing gestures, NSG; spatial speech without pointing gestures, SNG; non-spatial speech without pointing gestures, NSNG). In each condition, the participants watched a corresponding video on a computer screen and put on headphones to listen to the audio output. Each of the four videos presented to the participant featured a *different* map. The orders of the maps and videos were counterbalanced across the participants.

After watching each video, the participants were then asked to recall the spatial location of eight fictitious countries by filling in the names of countries in their corresponding locations on an empty map (spatial recall task). All the names were given so that the participants did not have to remember the spellings of the countries.

Since the maps laid out the spatial locations of all the countries, it raised the possibility that the participants ignored the co-occurring speech while strategically paying attention *solely* to the maps. In order to minimize such strategic encoding, the participants were told at the beginning of the experiment that they had to do both the spatial recall task and the recognition task. In the recognition task, they were presented with eight statements. Of all the statements, four of them were the same as the sentences narrated in the video and another four, different. The participants were asked to decide whether these statements were previously heard in the video. By doing so, the participants ought to pay attention to the speech produced by the narrator.

Altogether, the participants completed both spatial location recall and recognition tasks after each condition. The recall task was prior to the recognition task in order to prevent the participants from being primed from the statements in the recognition task. The accuracy rates of both tasks were then calculated for each participant.

Results

Three participants (2 males and 1 female) who did not complete the tasks in one of the conditions (one male missed the NSG condition while the other two missed the SNG condition) due to technical error automatically had their data for the particular condition excluded during analysis. On the whole, participants paid attention to the narrated statements in the video (refer to Chapter 5 for the analyses).

Figure 1 reports the means and standard deviations of the number of locations recalled in the spatial recall task in each condition. A 2 x 2 fully within ANOVA, with the types of speech (spatial, non-spatial) and pointing gesture (present, absent) as within-subject independent factors, found a significant main effect of speech, $F(1,66) = 17.9$, $p < .001$, partial eta squared = .21, no effect of pointing gesture, $F<1$, and a significant interaction between type of speech and presence of pointing gesture, $F(1,66) = 6.50$, $p = .013$, partial eta squared = .089. The participants recalled more spatial locations of the countries when encoding spatial descriptions than when encoding non-spatial descriptions. Interestingly, encoding pointing gestures did *not* enhance overall memory recall. The participants recalled a comparable number of the spatial locations of the countries when pointing gestures were present than when they were absent.

The interaction between the type of speech and presence of pointing gesture was further analyzed by a test of simple main effects. Significantly fewer locations were recalled in the SG condition than in the NSG condition, $t(67) = 5.0$, $p < .001$, $d = .71$ but there was no significant difference between the SNG and NSNG conditions, $p > .05$. These findings imply that the type of speech affected spatial recall only when pointing gesture was present. Non-spatial speech hindered location recall in the presence of pointing gestures, as compared to spatial speech.

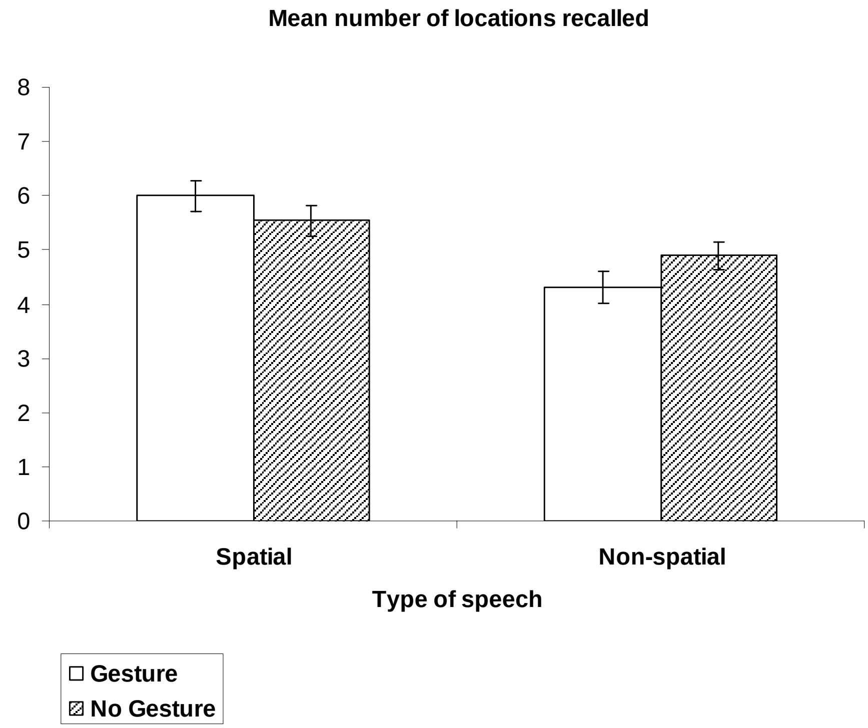

Figure 1. Means and standard deviations of the number of locations recalled for each condition in Study 1.

The results of the recognition task were analyzed by computing *d'* for each participant by subtracting the normalized false alarm rate from the normalized hit rate. Data from the three participants mentioned earlier who did not complete all the conditions were automatically excluded during analysis of this secondary task. The mean *d'* values and standard deviations (in parenthesis) for each condition were: SG: 0.62 (0.9); NSG: 0.33 (0.9); SNG: 0.49 (0.9) and NSNG: 0.23 (0.9). The *d'* values were analyzed in a 2 x 2 fully within ANOVA, with the types of speech (spatial, non-spatial) and pointing gesture (present, absent) as within-subject independent factors. There was a significant main effect of the type of speech, with secondary task performance significantly better in the presence of spatial speech than in the presence of non-spatial speech, $F(1,65) = 6.06$, $p = .017$, partial eta squared = .085. Participants recognized the narrator's exact statements from the video more often when those statements contained spatial than non-spatial information. There was no significant main effect of gesture on mean accuracy of statements recognized (*d'*), $p > .05$ and no significant interaction between the type of speech and the presence of gesture on mean accuracy of statements recognized (*d'*), $p > .05$.

Note that the number of times the countries were mentioned varied in each map. For example, in a particular map, the name Zuga was mentioned only once in the eight statements but the name Wabo was mentioned three times. Would the countries that were mentioned more often result in better spatial recall than those mentioned less often? Correlation analyses showed that the number of times the countries mentioned was not significantly correlated with the likelihood of the countries recalled in all the four conditions, SG: $r = .10$, $p = .60$; NSG: $r = .11$, $p = .55$; SNG: $r = .02$, $p = .90$; NSNG: $r = .14$, $p = .46$. Thus, the frequency of country names being mentioned in speech did not influence spatial recall.

Interim Discussion

The results supported the hypothesis that the presence of spatial speech resulted in better recall of spatial information than the presence of non-spatial speech. This finding is not surprising, given the wealth of literature of the effect of spatial speech on the construction of mental models of spatial representation (e.g., Shelton & McNamara, 2004). However, contrary to expectations, encoding pointing gestures in general did not enhance memory for location. It appears that pointing gestures do not contribute to the retention of location in memory when they accompanied speech. Instead, the combined presence of pointing gesture and spatial speech resulted in significantly better location recall as compared to the combined presence of pointing gesture and non-spatial speech, unexpectedly illustrating the importance of the speech content that co-occurs with pointing gestures.

The expectation behind this study was that watching the narrator point to a map would direct the attention of the participants to the locations that they had to remember (Goldin-Meadow, 2003; Hanna & Tanenhaus, 2004; Louwerse and Bangerter, 2005; Marslen-Wilson, et al., 1982), thereby strengthening the processing of location and hence retention of information. However, this hypothesis was not supported. Perhaps listening to the verbal labels of the countries (e.g., “Fago”) could also guide the participants’ attention to the target regions, thus making the pointing gestures redundant in this situation. Yet previous research showed that listeners rely on pointing gestures to identify referents when the speech was ambiguous (So and Lim, in press). Thus, participants might make use of the pointing gestures when the spatial / non-spatial speech is ambiguous. In order to explore this possibility, participants would have to be presented with ambiguous speech (e.g., lowering the volume of speech when the narrator was verbally labeling the country names).

Another possibility was that the visual cues provided on the maps were too salient such that the listeners did not have to rely on the pointing gestures to direct their attention to the target regions. Previous research showed that pointing gestures facilitate referential identification when there were multiple visible references (Bangerter, 2004). Therefore, when references are ambiguous (e.g., there are multiple references or the references are difficult to be visually perceived), listeners might need an assistance of pointing gestures to guide their attention. In order to explore this possibility, Study 2 (in Chapter 3) manipulated the clarity of the map.

CHAPTER 3

Pointing Gestures, Visual Ambiguity and Spatial Recall of Location

The aim of this study was to investigate how the effect of pointing gestures on spatial memory recall interacts with the clarity of the maps. Pointing to a country on a visually unclear map could play a substantial part in directing the listeners' attention to the target country (and disambiguating the country from the others as well). If so, the participants should recall more locations when a visually ambiguous map was accompanied by pointing gestures than when it was not. This study examined spatial speech only.

Method

Participants

Fifty-six undergraduates (17 males and 39 females) from the National University of Singapore participated in this study. All were native English speakers and had normal or corrected-to-normal vision.

Materials and Procedures

The maps used for this study were identical to those in Study 1. However, the visual clarity of each map was manipulated by varying the contrast of the borders with the background. The smaller the contrast of the borders with the background, the more difficult the maps were visibly perceived. The grey shades were denoted by their RGB number (the lower the RGB number, the darker the shade). The clear maps had a border shade of RGB 128 and a background of RGB 192. The ambiguous maps had a border shade reduced from 128 to 188, thus reducing the contrast of the borders with the background. See Appendix C for examples.

All the four maps that were tested in Study 1 were used. Note that each map has four versions of videos (spatial speech with pointing; non-spatial speech with pointing; spatial speech without pointing; and non-spatial speech without pointing). Altogether, there were 16 videos created in Study 1. Since the focus was on spatial speech in Study 2, eight videos were filmed in which the narrator recited eight spatial statements. Of the eight videos, the narrator pointed to the maps in four of the videos but did not point to them in another four videos. All the videos contained the clear maps.

For the ambiguous maps, the same narrator was filmed reciting the spatial statements in another eight videos. The ambiguous maps had a smaller color contrast with the background. The narrator recited the same eight spatial statements for each map in each video. Of the eight videos, the narrator pointed to the maps in four of the videos but did not point to them in another four videos.

The experimental procedure in Study 2 was exactly the same as in Study 1. It was a 2 x 2 fully within experiment in which the participants were tested in all the four experimental conditions (clear map with pointing gestures, CG; ambiguous map with pointing gestures, AG; clear map without pointing gestures, CNG; ambiguous map without pointing gestures, ANG).

In each of the four experimental conditions, the participants watched a corresponding video on a computer screen and put on headphones to listen to the audio output. Each of the four videos presented to the participant featured a *different* map. The orders of the maps and videos were counterbalanced across the participants.

As in Study 1, the participants in Study 2 completed both spatial location recall and recognition tasks after each condition. This study only consisted of spatial speech, which would be helpful for completing the main task of location recall. Hence there was no longer a need to administer the secondary recognition task to ensure that the participants paid attention to the narrator's speech in all conditions, as was done for Study 1. However the secondary recognition task was given so that the experimental procedure and requirements for this study would be as similar to Study 1 as possible.

Results

Data from 13 participants (3 males and 10 females) were excluded from analysis due to participants not adhering to instructions. Figure 2 reports the means and standard deviations of the number of locations recalled in the spatial recall task in each condition. A 2 x 2 fully within ANOVA, with map clarity (clear, ambiguous) and pointing gesture (present, absent) as the within-subject independent factors was conducted. There was a significant main effect of clarity on the mean number of locations recalled, $F(1,42) = 81.88$, $p < .001$, partial eta squared = .661. Participants recalled more locations correctly in clear maps than in ambiguous maps. There was no significant main effect of pointing on the mean number of locations recalled, $p = .29$, however, there was a marginally significant interaction between the pointing gesture and map clarity, $F(1,42) = 3.44$, $p = .071$, partial eta squared = .076. Due to the marginal nature of these results, the interaction effects of pointing gesture and map clarity are not conclusive.

As in the previous experiment, the results of the recognition task were analyzed by computing *d’* for each participant by subtracting the normalized false alarm rate from the normalized hit rate. Data from the participants mentioned earlier who did not follow instructions were automatically excluded during analysis of the secondary task. The mean *d’* values and standard deviations (in parenthesis) for each condition were: CG: 0.63 (1.0); AG: 0.32 (1.1); CNG: 0.72 (0.9) and ANG: 0.21 (0.8). The *d’* values were analyzed in a 2 x 2 fully within ANOVA, with map clarity (clear, ambiguous) and pointing gesture (present, absent) as within-subject independent factors. There was a significant main effect of map clarity, with secondary task performance significantly better when the map was clear than in the map was ambiguous, $F(1,42) = 11.2$, $p = .002$, partial eta squared = .21. Participants recognized the narrator’s exact statements from the video more often after viewing a clear map than after viewing a visually ambiguous map. There was no significant main effect of gesture on mean accuracy of statements recognized (*d’*), $p > .05$ and no significant interaction between the clarity of the map and the presence of gesture on mean accuracy of statements recognized (*d’*), $p > .05$.

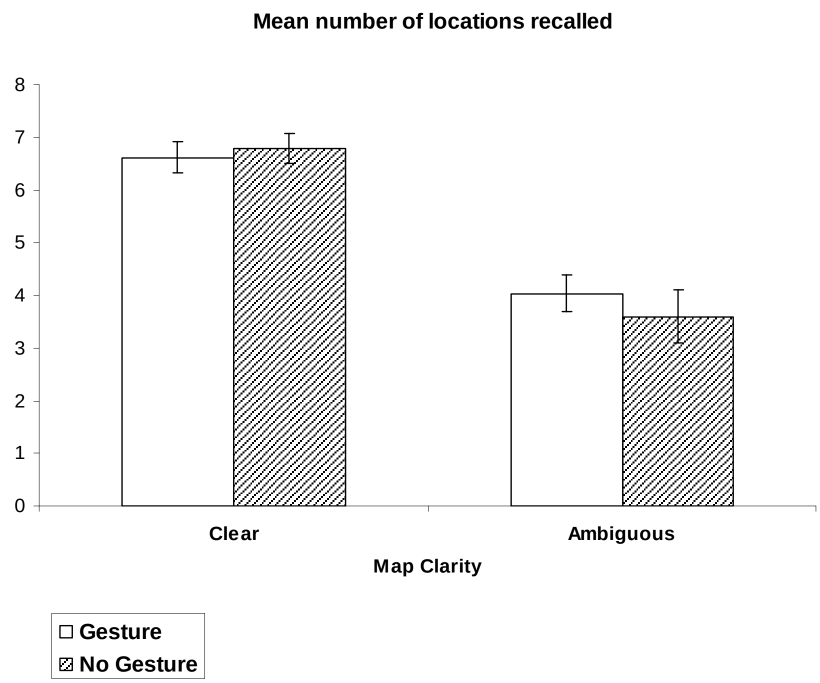

Figure 2. Means and standard deviations of the number of locations recalled for each condition in Study 2.

Interim Discussion

In general, the participants recalled more country locations correctly when they viewed a clear map than an ambiguous map, which is not surprising since encoding a clear map required less effort and thus generated better performance. There was a marginally significant interaction between the presence of pointing gesture and map clarity. However, these results do not provide conclusive evidence that directing a pointing gesture aids memory when the references are visually ambiguous.

Previous literature (e.g., Bangerter, 2004) suggested that pointing gestures benefit referential identification when the target referent is surrounded by distracters. The results of Study 2 hint at this effect by the marginal findings, suggesting that a stronger function of pointing gestures on spatial memory could lie in maps that are even more difficult to detect visually, or ultimately, absent.

In light of these findings, do pointing gestures have any beneficial effect on spatial recall when the visible references are entirely removed? McNeill (1992) observed that people produce pointing gestures even in the absence of a visible referent (e.g., pointing to a space on the left part of the table to convey the location of Portugal relative to Spain). When the reference is absent, pointing gestures are the only source of location information that listeners can process. Thus, pointing gestures are expected to have a strong influence on spatial recall of location when the referent is absent, in contrast to when the reference is present as in Studies 1 and 2. To investigate this hypothesis, Study 3 was conducted.

CHAPTER 4

Pointing Gestures, Type of Speech and Spatial Recall of Location without a Visible Reference

The aim of this study was to investigate the effect of pointing gestures on spatial recall and how such an effect interacted with the types of speech (spatial and non-spatial) when the map was absent. Pointing gestures could substitute the maps in conveying spatial information to listeners. Thus, the participants would recall more country locations when the narrator's spatial speech was accompanied by pointing gestures then when it was not. When the speech conveyed non-spatial speech, pointing gestures became the only source of spatial information.

Method

Participants

Sixty – two undergraduates (31 males and 31 females) from the National University of Singapore participated in this study. All were native English speakers and had normal or correct-to-normal vision.

Design

This study was a 2 x 2 fully within experiment. The two variables of interest were type of speech (spatial or non-spatial) and presence of pointing gesture (present or absent). The 4 conditions were: spatial speech with pointing gesture (SG), non-spatial speech with pointing gesture (NSG), spatial speech without pointing gesture (SNG) and non-spatial speech without pointing gesture (NSNG).

Materials and Procedure

The materials and procedure were the same as those in Study 1 except that the maps were removed from the videos in this study. In the videos, the narrator pointed to the *virtual* locations of the countries on a white board in the SG and NSG conditions. The virtual locations of the countries on the whiteboard were the same as their real locations shown on the maps in Study 1. In the SNG and NSNG conditions, the narrator recited the statements while standing next to an empty whiteboard. Sixteen videos were created for this study using the same spatial and non-spatial statements as in Study 1. Four different videos were used in four conditions. The order of the maps and videos were counterbalanced across the participants. The participants completed two tasks that were the same as in Study 1 – the spatial recall task followed by the verbal recognition task.

Results

Seven subjects (5 males and 2 female) were excluded due to the technical error. Figure 3 shows the mean number of spatial locations accurately recalled in each condition. A 2 x 2 fully within ANOVA, with type of speech (spatial, non-spatial) and pointing gesture (presence, absence) as within-subject independent factors, found a significant effect of the type of speech on the mean number of locations recalled, $F(1,60) = 5.07$, $p < .028$, partial eta squared = .044, a significant effect of pointing gestures on the mean number of locations recalled, $F(1,60) = 27.7$, $p < .001$, partial eta squared = .32, and no interaction between the presence of pointing gestures and type of speech, $F < 1$.

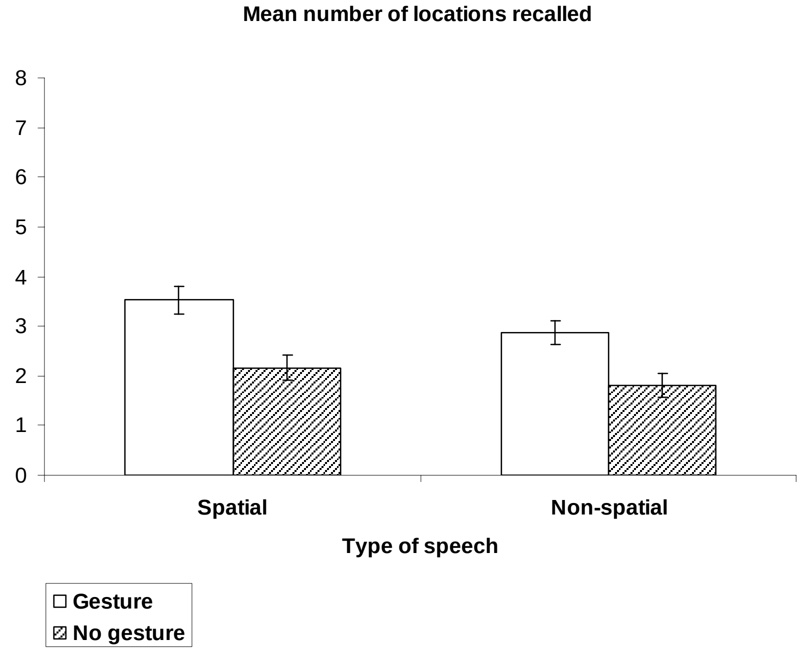

Figure 3. Means and standard deviations of the number of locations recalled for each condition in Study 3.

Comparing the participants' performance in Study 1 and Study 3, the findings showed that they recalled more spatial locations in Study 1 than in Study 3 in all the four conditions, SG: $t(135) = 5.79$, $p < .001$, $d = 1.00$; NSG: $t(128) = 3.76$, $p < .001$, $d = 0.66$; SNG: $t(136) = 7.87$, $p < .001$, $d = 1.35$; and NSNG: $t(136) = 9.38$, $p < .001$, $d = 1.61$. In fact, less than three countries were successfully recalled by the participants when the pointing gesture was the only cue providing spatial information (as compared to five countries recalled in Study 1 when the map was the only cue providing spatial information). Yet, the findings did suggest that when pointing gesture was the *only* source of spatial information, the participants processed the spatial information conveyed in gestures and retained it for subsequent recall.

As mentioned in the methods section of Chapter 3 (Study 1), the recognition task was created to minimize the possibility that the participants encoded the information presented on the maps but ignored the narrator's speech. Recognition task performances in Studies 1 and 3 were compared in order to examine whether the recognition task was effective in ensuring that the participants paid attention to the speech. Note that the maps were present in Study 1 but removed in Study 3. If the participants in Study 1 ignored the narrator's speech and pay attention on the maps only, they should recognize significantly fewer statements than the participants in Study 3. The findings showed that the participants recognized comparable numbers of statements in both Study 1 (map present; $M = 4.56$, $SD = 1.5$) and Study 3 (map absent; $M = 4.51$, $SD = 1.5$), $t(518) = 0.35$, $p = .72$. Hence, the participants did pay attention to the speech regardless of the presence or absence of the maps.

Interim Discussion

These results supported the hypothesis that pointing gestures aided spatial memory even though they were not directing to the maps. The participants recalled more spatial locations when encoding pointing gestures than when not encoding them in both types of spatial and non-spatial speech. It is possibly because the pointing gestures to virtual locations simulated the images of locations in the participants' mental representation (McNeill, 1992; Kita, 2000), and in turn, those images facilitated retrieval of locations.

CHAPTER 6

General Discussion

In order to create a mental representation of space, we usually extract information from multiple sources such as verbal description, maps, and gestures (e.g., Brunyé, Rapp, & Taylor, 2008). This research attempted to investigate how multiple information sources interact in spatial cognition. Specifically, it explored the circumstances in which pointing gestures influence spatial memory, by manipulating the availability and clarity of maps and types of speech. The findings showed that pointing gestures do not facilitate spatial memory when the maps are perceptually available and that the accuracy of spatial recall depends on the type of speech accompanying the pointing, with spatial speech content interacting with pointing to result in better location recall than non-spatial speech interacting with pointing. In contrast, pointing gestures clearly enhance spatial memory when the maps are not perceptually available.

When pointing gestures interact with speech content to influence memory

When the maps were present, non-spatial speech in combination with pointing gestures actually hindered memory, as compared to when these same gestures accompanied spatial speech. This finding highlights the importance of the interaction between gesture and speech content. In the presence of pointing, speech content affects subsequent recall of location information. When non-spatial speech was accompanied by pointing gestures, the participants were in the midst of processing two pieces of conflicting information – spatial information extracted from the maps and non-spatial information derived from the speech, as suggested by the Competition

Hypothesis (Kirby, 1993) and the Cognitive Load Theory (Sweller, 1988; Chandler & Sweller, 1991). One might contend that the participants could choose not to attend to the pointing gestures. However, pointing gesture automatically attracts attention (Langdon & Bruce, 2000; Ariga & Watanabe, 2009). Thus, it is nearly impossible for the participants to selectively avoid cognitively processing a pointing gesture. Since pointing gestures automatically capture attention, it is interesting to note that the type of speech that accompanies this gesture affects spatial recall.

Since there was no significant difference between the SNG and the NSNG conditions in Study 1, it appears that the content of the narrator’s speech on location memory was only important when the narrator also pointed to the map. The contrasting effects of pointing gestures accompanying spatial speech versus non-spatial speech is possibly an illustration of the Cognitive Load Theory or the Competition Hypothesis, which predict that retention of information is adversely affected if, during learning, cognitive resources are spent on processing multiple cues before the information is committed to memory (Sweller, 1988; Chandler & Sweller, 1991; Kirby, 1993). Thus, the more similar the multiple sources of information in the learning phase are to each other, the easier learning can occur. Conversely, if the sources of information are different from each other or extraneous to the task, then learning suffers. From this perspective, the more similar the narrator’s speech content to the pointing gesture and the layout of the map, the easier the participants would learn about the locations on the map. The spatial speech that accompanied pointing gestures in these studies also contained information that was helpful to the participants for completing the spatial recall task. In contrast, the non-spatial speech that accompanied pointing gestures in the studies did not contain information that was helpful for the spatial recall task. Therefore, when the participants were processing the visual and aural contents of the video, more effort had to be spent in the NSG condition than in the SG condition, leading to poorer spatial recall task performance for the former condition.

Yet some individuals might handle multiple information sources better than the others. Simultaneous processing of information engages cognitive resources such as attention (Allport, Styles, & Hsieh, 1994) and by extension, working memory (Engle, Kane, Tuholski, 1999). Past research has found that an individual’s working memory capacity is linked to the ability to simultaneously process information effectively (Conway & Engle, 1995). Hence, listeners with a higher working memory capacity might be less affected by pointing gestures accompanying non-spatial speech than listeners with a lower working memory capacity. Further research should investigate this possibility.

Indeed, the findings from Study 1 have implications for teaching. In an educational setting, teachers gesture when they talk (Goldin-Meadow, Kim & Singer, 1999; Flevares & Perry, 2001). They may refer to regions or landmarks on a map by pointing but their accompanying speech may not necessarily describe the spatial location of those regions or landmarks. Rather, they may describe non-spatial features, such as history or culture. Yet pointing gestures produced along with non-spatial speech might have an adverse effect on students’ spatial memories. Thus, it is perhaps prudent for instructors not to point to the map while reciting a statement that does not convey location information, if they wish that students remember the spatial information on a map.

When pointing gestures do not influence spatial memory

When the reference is perceptually visible, pointing gesture accompanying spatial speech seems not to add incremental gain on spatial memory (Study 1). Such a finding is contrary to the hypothesis predicting that pointing gestures directed the listeners' attention to the target regions of the spatial locations on the maps, thereby facilitating spatial memory. It might imply that pointing gestures are redundant when the maps are present and speech conveys spatial information (Verdi & Kuhlavy, 2002). The participants would be able to locate the country by listening to the narrator's speech and simultaneously referring to the maps that contained clear labels. As a result, pointing gestures may not offer any ultimate benefits for spatial memory.

This raises the possibility that pointing gestures facilitate spatial memory when accompanying speech is unclear and/or when maps are perceptually unclear. Previous research found that listeners rely on pointing gestures to identify referents when speech was ambiguous (Thompson & Massaro, 1994; So & Lim, in press). Hence, if the narrator recited the statements softly, pointing gestures could substitute speech to guide the listeners' attention to the target regions on the maps. Alternatively, pointing gestures might facilitate spatial memory when reference (i.e., the map) is ambiguous. The findings of Study 2 showed that the participants recalled marginally more spatial locations when the spatial speech was accompanied by pointing gesture then when it was not. Although the results were not conclusive, they might suggest that under the circumstance in which the maps are perceptually unclear, pointing gestures accompanying spatial speech could direct the listeners' attention to the ambiguous regions on the maps.

The lack of evidence that pointing gestures influence spatial memory when the referent is present does not mean that pointing gestures do not facilitate cognitive processing during learning. The findings from Yuviler-Gavish, Yechiam and Kallai (2011) imply that directed attention during the learning phase may not carry over to an improvement on later memory tasks even though the directed attention may confer cognitive processing benefits during learning, which are in line with the findings in this thesis that pointing gestures do not enhance spatial memory when the referent is present. Earlier, the hypothesis was that pointing gestures to concrete objects would enhance spatial memory in terms of location recall, since directed attention during learning was shown to enhance location recall (Yamamoto & Shelton, 2009) and pointing gestures were shown to direct attention (e.g., Louwerse & Bangerter, 2010). Yet the learning phase during the experiment in Yamamoto & Shelton (2009) did not contain speech that accompanied the presentation of objects. The objects were presented to the participants, either sequentially or simultaneously, in silence. On the other hand, the learning phase in Yuviler-Gavish, Yechiam and Kallai (2011) always occurred with speech, which reflected the procedure used in this thesis. This implies that the relationship between pointing gestures and spatial memory may depend on whether the pointing is accompanied with speech, rather than on the nature of the spatial memory task (e.g., location recall versus 3D puzzle). Further study is required to establish the contribution of speech during the learning phase to the relationship between pointing gestures (or more generally, directed attention) and spatial memory.

When do pointing gestures facilitate spatial memory?

The findings showed that when the spatial reference was completely removed, pointing gestures offered crucial help to strengthen the listeners' spatial memory. Visual cues, such as maps and pointing gestures, are the most straightforward source for creating spatial representation in the mind (Kosslyn, 1994). When the maps are removed, pointing gestures to virtual locations become the *sole* visual cue. Hence, the participants had to depend on pointing gestures to process spatial information. While maps offer concrete spatial information, pointing gestures can help listeners to simulate an image of spatial locations of countries in their visual modality. However, our findings showed that the participants recalled fewer spatial locations when using pointing gestures than when using maps, implying that while pointing gestures reliably provide spatial information, they do not convey such information as effectively as the visible referents themselves.

Interestingly, the beneficial effect of pointing gestures did not interact with the types of accompanying speech when the map was absent. When the map was absent, the participants had to rely on pointing gestures to process the spatial locations of countries and such reliance was necessary regardless of the type of accompanying speech. One might contend that the spatial locations of countries could be conveyed by spatial speech, and thus, pointing gestures to virtual locations were redundant. However, the findings showed that spatial information offered by the visual cue (i.e., pointing gesture) was helpful for spatial memory. The participants recalled more spatial locations when they processed spatial speech with pointing gestures than when they did not. Perhaps spatial speech alone did not allow the participants to pinpoint or visualize the location of each country in their mental representation.

On the other hand, pointing gestures that co-occurred with non-spatial speech also helped spatial memory because these gestures were the only source of location information. Previous research found that when a gesture conveys additional information that was not present in the communicative context, the participants subsequently recalled that piece of information (Goldin-Meadow & Sandhofer, 1999; Goldin-Meadow, Kim & Singer, 1999). When pointing gestures co-occurred with non-spatial speech, the gestures conveyed location information that was not presented in speech. With pointing gestures, the participants were able to bind the country's name to the corresponding location in space, thereby enabling them to create a mental representation of the map. This finding was in contrast to the different effects of the interaction between pointing gestures and co-occurring speech when the maps were present. This implies that the participants greatly relied on the spatial information conveyed in the pointing gestures and such reliance might conquer the competition effect that stems from processing two pieces of conflicting information.

Overall, the findings provide an empirical psychological perspective on the function of pointing gestures that are aimed at empty space. Past researchers have provided qualitative accounts of the function of pointing to space to indicate the metaphorical location of a referent in conversation (e.g., Kita, 2000; McNeill, 1992). The accounts suggested that pointing to space is a useful way to convey spatial information when the actual referent is absent. This research provides empirical support for the hypothesis that watching a person communicating spatial information by pointing to space enhances the listener's memory for location even when the accompanying speech is spatial in nature.

In a classroom setting, if a diagram is missing, teachers may point to space while describing the location of places or objects to better facilitate students spatial recall. For example, during a geography or history lesson, if a map is not available, the teacher can still enhance students' recollection of the location of countries by pointing to virtual locations to indicate the countries' locations, while describing the location in speech. Similarly, in a science lesson, the teacher can enhance the students' recollection of how to set up an experiment by pointing to the virtual location of where the objects are supposed to be. This method of instruction is especially useful when the teaching tools (e.g., maps or science apparatus) are not available.

Conclusion

Pointing gestures identify referents in speech. This thesis builds on previous research on visible referents to demonstrate that the content of the speech (spatial or non-spatial) that accompanied pointing gesture affects subsequent spatial recall. This thesis also presents evidence for the causal effects of pointing gestures on spatial memory, especially when the referent is absent.

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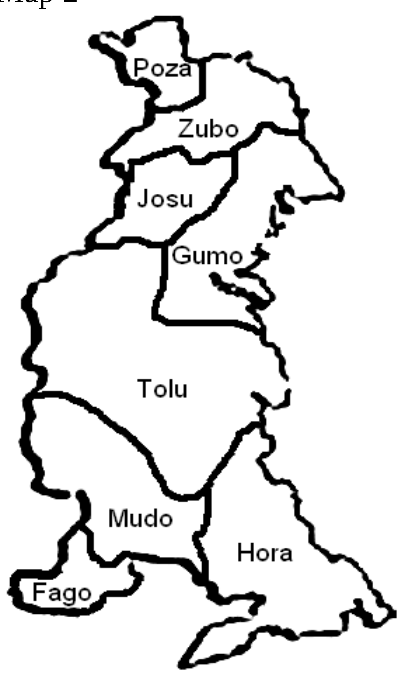
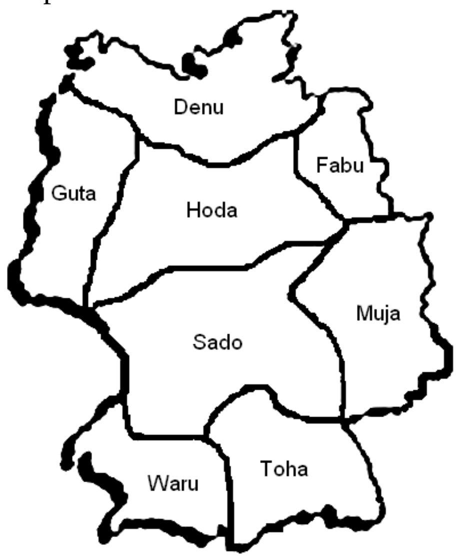
Appendix A: Maps and country names

Map 1

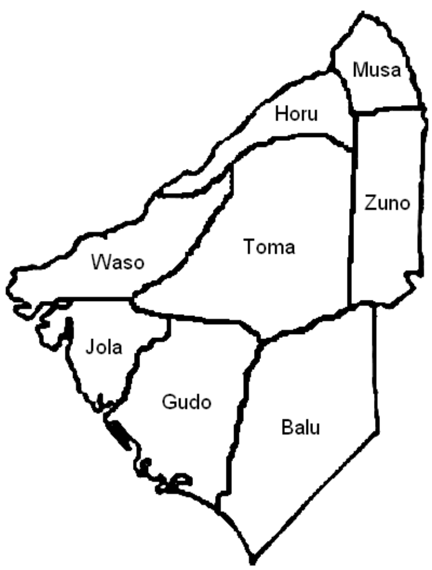
Map 2



Map 3


Denu
Fabu
Guta
Hoda
Muja
Sado
Toha
Waru

Map 4


Musa
Horu
Zuno
Toma
Waso
Jola
Gudo
Balu

Appendix B: Example of spatial and non-spatial statements used for Map 1

Spatial Descriptions:

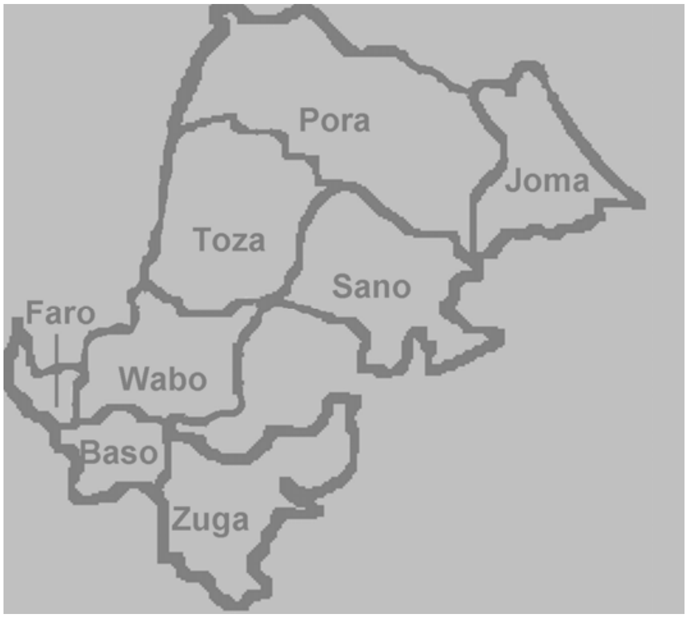
1. Country Zuga is to the right of Country Baso.
2. Country Baso is below Country Wabo.
3. Country Faro is to the left of Country Wabo.
4. Country Wabo is below Country Toza.
5. Country Toza is below Country Pora.
6. Country Sano is to the right of Country Toza.
7. Country Pora is above Country Sano.
8. Country Joma is to the right of Country Pora.

Non-Spatial Descriptions:

1. Country Zuga has the same amount of people as Country Baso.
2. Country Baso has a younger president than Country Wabo.
3. Country Faro experiences the same intensity of storms as Country Wabo.
4. Country Wabo grows less rice than Country Toza.
5. Country Toza has fewer farms than Country Pora.
6. Country Sano was colonized at the same time as Country Toza.
7. Country Pora exports more milk than Country Sano.
8. Country Joma has a flag with the same colours as that of Country Pora.

Appendix C: Examples of clear and ambiguous maps used in Study 2

Clear



Ambiguous