Extent of bilingual experience in modulating young adults' processing of social-communicative cues in a cue integration task: An eye-tracking study

Jia Wen Lee (jiawen_lee@sutd.edu.sg), Xiaoqian Li (xiaoqian_li@sutd.edu.sg), and W. Quin Yow (quin@sutd.edu.sg)
Humanities, Arts and Social Sciences, Singapore University of Technology and Design, Singapore

Abstract

This study investigated whether bilingual experience would influence young adults' integration of multiple cues to infer a speaker's intention. Using a cue-integration task coupled with eye-tracking, we examined the effects of balanced language usage on young bilingual adults' ability to integrate multiple cues in determining a speaker's referential intent. Behavioral and eye-tracking findings indicated that balanced bilinguals were better able than unbalanced bilinguals in identifying a target object in the three-cue condition (i.e., contextual, semantic and gaze cues were shown). However, there were no group differences in the two-cue condition (i.e., only contextual and semantic cues were shown). Our results suggest that the extent of bilingualism could modulate the sensitivity to and integration of multiple cues in the intention-inference process. We argue that balanced bilinguals' greater exposure to complex communicative situations could enhance their ability in utilizing multiple cues to understand a speaker's intention.

Keywords: bilingualism; communicative cues; eye-tracking; cue integration; referential intention

Introduction

Effective communication requires a good understanding of the speakers' intention. To understand a speaker's intention accurately, adults often have to process and integrate multiple social-communicative cues in the communicative context, including linguistic cues such as the semantics of a word or utterance, nonlinguistic cues such as eye gaze, as well as the context of the speaker's situation or perspective to avoid miscommunication (e.g., Epley et al., 2004; Keysar et al., 2000; Nappa & Arnold, 2014; Yow & Markman, 2015). Thus, it is important to examine factors that may influence the processing and integration of multiple cues in communication. One such factor is exposure to diverse linguistic environments (e.g., bilingualism).

Individuals immersed in bilingual environments have greater exposure to speakers from a diverse language background and may face unique communicative challenges. In their conversations, bilinguals would need to regularly track who speaks what language and determine how to respond appropriately to avoid communication failures (Comeau et al., 2007). Bilinguals' extensive experience in coping with challenging linguistic circumstances may result in a heightened sensitivity to the subtle social-communicative cues that are indicative of a speaker's intention (e.g., Brojde et al., 2012; Yow & Markman, 2016). Indeed, there is a large body of evidence suggesting that early exposure to multiple languages enhances children's sociolinguistic sensitivity. Bilingual children are better able than their monolingual peers at detecting violations of conversational maxims (Siegal et al., 2009), recognizing the needs of their communicative partner (Gampe et al., 2019), as well as making use of referential cues such as pointing and eye gaze to figure out a speaker's referential intent (e.g., Yow & Markman, 2011, 2016; Yow et al., 2017).

The increased need in bilinguals to constantly monitor and adapt to the dynamic communicative context may also have positive effects on their ability to integrate multiple cues. Compared to monolingual children, bilingual children appeared to be better able to integrate multiple cues to determine a speaker's intent, especially when these cues have to be construed differently according to the context (Yow & Markman, 2015). For instance, using a Cue Integration Task (see below for more details), Yow and Markman (2015) found that 3-year-old bilinguals were more successful than their monolingual peers in integrating multiple communicative cues (i.e., the context, semantics, and eye gaze cues) to understand a speaker's referential intent. Additionally, a number of studies have provided evidence that bilingual experience can advance social-cognitive skills such as perspective-taking and mental state reasoning, and this bilingual advantage is evident in both children (e.g., Liberman et al., 2017) and young adults (e.g., Ikizer & Ramirez-Esparza, 2017; Rubio-Fernández & Glucksberg, 2012; cf. Cox et al., 2016; Ryskin et al., 2014).

Despite the above-mentioned evidence suggesting that bilingualism could modulate social-cognitive abilities in adulthood, little prior work has examined the effect of bilingual experience on young adults' processing and integration of cues in understanding speaker's intentions. Using a Sally-Anne Task with eye-tracking, a study by Rubio-Fernández and Glucksberg (2012) demonstrated that bilingual adults were less susceptible to egocentric bias than monolinguals in their false-belief reasoning processes. Bilingual adults also showed stronger reliance on nonlinguistic communicative cues (i.e., looking or looking-and-pointing cues) in their interpretations of ambiguous pronouns compared to monolinguals, particularly when listening to a non-native speaker (vs. a native speaker; Contemori & Tortajada, 2020). This suggests that a bilingual experience could lead to a greater sensitivity to nonlinguistic cues that are indicative of the referential intent of a speaker, especially in contexts with greater communication challenges (also see Lorge & Katsos, 2019).

In the current study, we aim to investigate the effects of bilingualism on young adults' multiple-cue integration when understanding a speaker's referential intent. We adapted the Cue Integration Task (Nurmsoo & Bloom, 2008; Yow & Markman, 2015) to examine bilinguals' ability to integrate

contextual, semantic and gaze cues in identifying an object a speaker is referring to. In this task, participants would need to integrate *contextual* cue (i.e., although the speaker knew there were two objects in a box, the design of the box allowed the speaker to see only one of them, while the participant could see both), *semantic* cue (i.e., "*There it is*" or "*Where is it*"), and *gaze* cue (i.e., the speaker looks at the object of mutual focus) to identify the referent object. When the speaker looked at the object of mutual focus and said "there", the contextual, semantic, and gaze cues are aligned to suggest that the object of mutual focus is the one that the speaker was referring to. In contrast, when the speaker looked at the object of mutual focus and asked the question "where", it is inferred that the speaker was referring to the object that she could not see, despite the gaze cue suggesting the object of mutual focus. Therefore, the "where" trials require more nuance interpretation of the cues together. We hypothesize that bilinguals who have more extensive experience in managing two languages will be better able to integrate the multiple cues to identify the referent object, especially on "*Where*" trials than bilinguals with less extensive experience in managing their languages.

To test our hypothesis, we examine bilingualism both as a categorical variable and a continuous variable with a focus on daily practice of bilingualism (i.e., the extent of balanced usage of languages). Previous work studying bilingual effects on adult social-cognitive ability have examined bilingualism as a dichotomous variable, for example, comparing group-level differences between bilinguals and monolinguals (Contemori & Tortajada, 2020; Lorge & Katsos, 2019). However, current propositions argue for bilingualism as a multi-dimensional, continuous construct (Luk & Bialystok, 2013) and that variations in one's bilingual experience, including daily practice of languages and language competence (Bak, 2016), might have different effects on one's social cognitive ability. In particular, compared to bilinguals who use one language more frequently than the other (i.e., unbalanced bilingual), bilinguals who use both languages frequently (i.e., balanced bilingual) are more likely to interact with speakers from diverse language background and may have greater exposure to challenging communicative situations. If such bilingual experience modulates the effects of bilingualism on cue-integration ability, we would expect (1) better task performance in balanced bilinguals compared to unbalanced bilinguals (i.e., group-level differences) and (2) an effect of balanced language usage on task performance (i.e., individual-level differences).

One may argue that participants could succeed in our Cue Integration Task by simply interpreting the semantic cue within the contexts (while ignoring the gaze cue), therefore, balanced bilinguals' better task performance might just reflect their advantage in processing semantic and contextual cues compared to unbalanced bilinguals. To rule out this possibility, and considering that past studies suggest that the effects of bilingualism may be apparent only in more challenging tasks that require more complex skills, we introduced a second condition that has a lesser demand on cue-integration where participants only received contextual and semantic cues but not the gaze cues. We predicted that balanced bilinguals and unbalanced bilinguals would perform similarly in inferring the speaker's intention in this condition and the extent of balanced language usage would not influence bilinguals' performance in this situation.

We also monitored participants' eye movements while participants completed the Cue Integration Task. Eye-tracking provides a non-intrusive way of tracking information and linguistic processing in real-time (Huettig et al., 2011). By analyzing fixations to a target object, one would be able to track in real-time the way individuals process and integrate information in understanding speaker's perspective (Epley et al., 2004; Huettig et al., 2011). If bilingual experience were to modulate adults' integration of cues, we predict that balanced bilinguals would have higher proportion of fixations to the target object than unbalanced bilinguals.

Methods

Participants

Thirty-eight young adult bilinguals (M_{age} = 22.2 years, *SD* = 1.19; 14 females) participated in this study. Participants were students from the university's introduction to psychology course and participated in the study for course credits. All participants were residents in Singapore, a multilingual, multicultural country with English as the official language. The study was conducted in English.

Participants completed a self-report language background questionnaire. All participants reported both English and another language (Mandarin = 31, Malay = 2, Cantonese = 1, Korean = 1, Tamil = 1, Teochew = 1) as the two most-used languages in their daily life. Usage of third and/or fourth languages do not exceed 10%. The average age of acquisition for the second language is 1.05 years (range = 0-7).

For bilingualism as a continuous variable, we calculated a score of "balanced usage" (in proportion) per participant as the participant's most used language frequency minus second-most used language frequency, serving as a proxy for the extent of bilingual experience. In our sample, the average balanced usage score was 0.64 (range = 0.10-0.98), with lower scores indicating more balanced usage of the two languages. For bilingualism as a category, participants were classified into two groups based on median split in balanced usage (*Mdn* = 0.74): *balanced bilingual* (*n* = 19; mean balanced usage = 0.41) and *unbalanced bilingual* (*n* = 19; mean balanced usage = 0.87). To control for potential covariation with knowledge of English that may affect performance in our task, we also collected information on participants' English proficiency in terms of listening and speaking via self-report using a Likert scale (1 = *not proficient at all* to 10 = *very proficient*). There was no significant difference in English proficiency between balanced bilinguals (*M* = 9.11) and unbalanced bilinguals (*M* = 9.34), $t(36) = -0.70$, $p = .49$.

Apparatus and Procedure

The experiment used a Tobii TX300 eye-tracker to record participants' looking behavior. Participants were seated 60cm away from a 23-inch widescreen monitor, which was mounted on the eye-tracker. Stimuli were presented on the screen (1920 x 1080) from a computer with Tobii Studio. Before beginning the experiment, the eye-tracker was calibrated for each participant using a five-point calibration.

Cue Integration Task Participants were presented with pre-recorded video clips of the task, in which a female speaker was seated behind a table with a cardboard box placed on it throughout. The box had two compartments with two cut-out windows. A movable screen covered one of the windows (see Figure 1). The box was placed in such a way that participants could see through both compartments, while the speaker could only see through the uncovered compartment. The task consisted of three phases presented in this order: familiarization phase, three-cue experimental phase, and two-cue experimental phase. In each experimental phase, there were two "*There*" trials and two "*Where*" trials, identical except for the test question.

In the familiarization phase, the speaker introduced the box to the participants. Two familiar objects were placed into the box, one in each compartment. Participants were asked to identify which object the speaker could see and which she could not see. The box was then rotated 180 degree. Participants were asked to identify which object they now could and could not see to ensure that they understood the speaker's perspective.

In the three-cue experimental phase, participants were to identify the referent object by integrating three cues (i.e., context, semantic, and gaze) presented in this situation. On each trial, two novel objects were introduced to the participants. The speaker then turned around, with her back facing the participant, while a puppet placed the novel objects the box, one in each compartment. When the speaker turned back around, she fixed her gaze at the object of mutual focus (see Figure 1) and asked the test question. On "*There*" trials, the speaker said, "Oh! There is the [novel label]! There it is!" On "*Where*" trials, she said, "Oh! Where is the [novel label]? Where is it?" On both types of trials, the speaker then looked up at the participant and asked, "Can I have the [novel label]?" Participants were to respond by pressing the "A" key to select the object on the left of the screen and the "L" key to select the object on the right side of the screen. No feedback was given. The order of the test trials, the target object, and its location (left/right) were counterbalanced across participants.

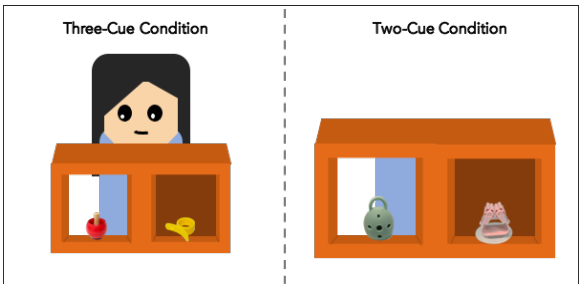

Figure 1: Illustration of the three-cue experimental phase (left) and the two-cue experimental phase (right).

In the two-cue experimental phase, participants were to identify the referent object by considering only the context and semantic cues. The procedure was identical to the three-cue experimental phase except for the omission of the gaze cue when the speaker asked the test question. After the speaker turned back around, the scene was zoomed in such that the speaker's face was not shown while she asked the question (see Figure 1).

In both three-cue and two-cue conditions, the target object was the object of mutual focus (i.e., *visible object*) for "*There*" and the object hidden from the speaker's perspective (i.e., *hidden object*) for "*Where*" trials.

Results

To examine participants' overall performance in the Cue Integration Task, we derived two measures: (1) the number of times that participants chose the target object (behavioral task response), and (2) the proportion of looking time directed to the target object during the response interval (eye tracking data; see below). We also analyzed the looking behavior during the test question interval (see Pre-Naming and Post-Naming Window below) to investigate how participants' attention was distributed when processing multiple social-communicative cues.

Behavioral Performance

A summary of participants' behavioral performance is shown in Figure 2. We conducted a 2 x 2 ANOVA on the number of correct response (max=2) with Group (balanced vs. unbalanced) as the between-subjects variable and Question (there vs. where) as the within-subject variable for three-cue and two-cue conditions separately. We also fitted a mixed effects logistics regression on correct responses with Question (there vs. where), Balanced Usage (continuous), and the interaction term as the predictors for each condition.

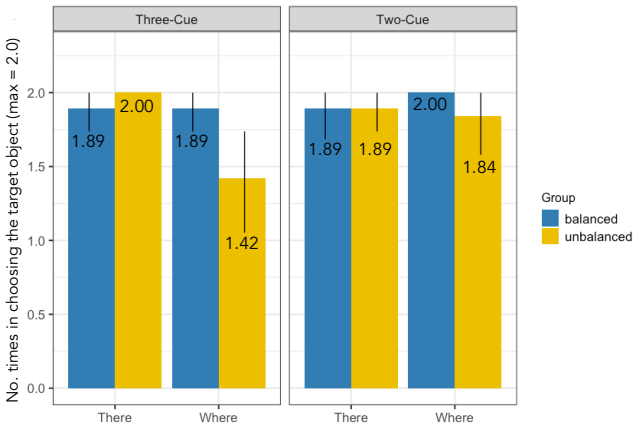

Figure 2: Group means for choosing the target object by experimental condition and language group. Error bars represent 95% confidence intervals.

Three-Cue Condition Results from the ANOVA revealed a significant main effect of Question, $F(1, 36) = 37.84$, $p = .008$, partial $\eta^2 = 0.18$, and a marginally significant main effect of Group, $F(1, 36) = 3.37$, $p = .075$, partial $\eta^2 = 0.09$). Importantly, there was a significant Question x Group interaction effect, $F(1, 36) = 7.84$, $p = .008$, partial $\eta^2 = 0.18$. A similar significant interaction of Question x Balanced Usage emerged in the mixed logistic regression where we considered balanced usage as a continuum ($b = -0.11$, $p = .036$, OR = 0.89), but not for the main effects of Balanced Usage or Question, $ps > .14$.

To interpret the interaction, we compared balanced and unbalanced bilinguals' performance in choosing the target object on each question. We found that balanced bilinguals were more accurate than unbalanced bilinguals in choosing the target object only on "*Where*" trials, $F(1, 36) = 6.18$, $p = .018$, partial $\eta^2 = 0.15$, but not on "*There"* trials, $F(1, 36) = 2.12$, $p = .154$, partial $\eta^2 = 0.06$. One-sample *t*-test revealed that both groups of participants were above chance (=1) on both "*There*" and "*Where*" trials, all *p*s <.001.

Two-Cue Condition Results from the ANOVA showed no significant main effects of Question and Group, both *F*s < 1, and no significant Question x Group interaction, $F(1, 36) = 1.27$, $p = .268$, partial $\eta^2 = 0.03$. One-sample *t*-test revealed that both groups of participants performed above chance on both "*There*" and "*Where*" trials, all *p*s < .05. Results from mixed effects logistic regression also revealed no significant effects, all *ps* > .17.

In sum, these results show that both groups of adult participants, regardless of the degree of bilingualism, were able to integrate the different cues in identifying the referent object in our task. However, the balanced bilinguals appeared to be more accurate than the unbalanced bilinguals in identifying the target object when there was a relatively high demand in integrating multiple cues that conflict with each other (i.e., "*Where*" trials in three-cue condition). In other situations (i.e., both "*There*" and "*Where*" trials in two-cue condition and the "*There*" trials in three-cue condition), the balanced and unbalanced bilinguals performed equally well.

Eye Tracking Data

Data Preprocessing and Analysis Eye-tracking data was pre-processed and analyzed using the eyetrackingR package in R. Area of Interests (AOIs) were drawn by a human coder for the two novel objects and the speaker's face (only for three-cue conditions). Individual test trials with more than 50% track-loss were excluded from analysis (about 8.1% of all trials). We first analyzed participants' looking behavior during a "response interval" as a second measure of task performance. The response interval consisted of a 900ms window of analysis (i.e., Response Window) after the offset of the speaker's request for the target object ("Can I have the [novel label]?"). Next, we examined looking patterns during a "test question interval" where the speaker asked the test question ("There/Where is the [novel label]") to gain insight into participants' processing of multiple cues in the task. The test question interval consisted of two windows of analysis: (1) an 800ms window that started from the offset of the disambiguation label and ended on the offset of the novel label (i.e., Pre-Naming Window) and (2) a 900ms window after the offset of the novel label and until the onset of the following sentence (i.e., Post-Naming Window).

For each window of analysis, the average proportional looking time toward the target object was calculated with respect to the total amount of time spent looking at the two objects. We then fitted a mixed effects logistic regression model predicting the proportional looking time to target with Group, Question, and Group x Question as the predictors (*Model 1*). Proportion of looking at the target was compared against chance (.50) to examine whether participants successfully identified the target object by showing a preferential looking to the target over the non-target. We also fitted a similar mixed effects logistic regression model (*Model 2*) as per Model 1 but with the categorical variable of Group replaced with the continuous variable of Balanced Usage.

Looking During Response Interval Both models did not find any significant effects in predicting participants' proportional looking time directed to the target object during the response window in both three-cue condition and two-cue condition, all *p*s > .52. Follow-up comparisons to chance confirmed that both balanced and unbalanced bilinguals were above chance in their proportion of looks to the target object on both there and where trials, and in both three-cue and two-cue conditions, all *ps* < .01 (see Figure 3). Although there was no evidence that the balanced and unbalanced bilinguals performed differentially in terms of their looking pattern during the response window, these results, in fact, complemented the above-chance performance of both groups of participants as revealed by their behavioral data. Specifically, young adults in our study demonstrated successful multiple-cue integration not only in their explicit selection of the target object but also in their implicit looking time toward the target object.

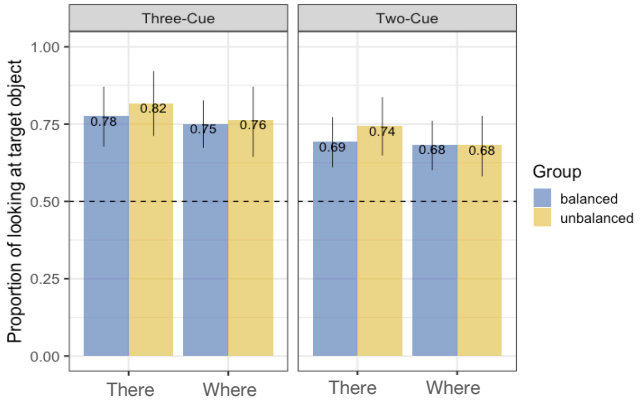

Figure 3: Results for looking during response interval. Mean proportional looking time toward the target object by experimental condition and language group. Error bars indicate the 95% confidence intervals

Looking During Test Question Interval The group means for proportional looking toward the target object in each window of analysis are presented in Figure 4a-b. We also plotted the time course of looking proportions toward the different AOIs (see Figure 4c-d) to illustrate the dynamic changes of looking across the test question interval.

Three-Cue Condition: For Pre-Naming Window, results of Model 1 showed a significant main effect of Question (b = -1.26, p = .001, OR = 0.28), but not for Group and Group x Question interaction, ps > .54. Furthermore, both groups of bilinguals looked toward the target object above chance on "*There*" trials, ps < .008, but at chance on "*Where*" trials, ps > .16. The same pattern of results emerged when we fitted Model 2 with Balanced Usage as a continuous variable: there was a significant main effect of Question (b = -2.28, p = .045, OR = 0.10), but not for Balanced Usage and Balanced Usage x Question, ps > .14. In sum, participants were more likely to look at the target object on "*There*" trials than "*Where*" trials during the pre-naming window, regardless of their degree of bilingual language usage.

For Post-Naming Window, Model 1 revealed a significant effect of Group (b = -0.79, p = .031, OR = .45), a marginal effect of Question (b = -0.63, p = .074, OR = .53), and no significant interaction (b = -0.23, p = .78). Overall, balanced bilinguals were more likely to look at the target object than unbalanced bilinguals. Results from Model 2 revealed a significant main effect of Balanced Usage (b = -0.49, p = .015, OR= 0.95), Question (b = -4.17, p = .027, OR = 0.02), and a marginal Question x Balanced Usage interaction (b = 0.042, p = .07, OR= 1.04). Participants were more likely to look at the target object on "*There*" trials than "*Where*" trials. Similar to the results from Model 1, participants with more balanced language usage were more likely to look at the target object than those with less balanced language usage.

Follow-up chance comparisons indicated that all participants looked toward the target object more than chance (ps < .005), except for the unbalanced bilingual group in the "*Where*" trials, which did not differ from chance (p = .68). As illustrated in the time course plot for "*Where*" trials (Figure 4c), while the balanced bilinguals clearly looked more toward the hidden object than the visible object, the unbalanced bilinguals spent equal time looking at the two objects over the post-naming window.

Two-Cue Condition: We did not find any significant effects from mixed effects logistic regression on proportional looking toward the target object in both Pre-Naming and Post-Naming Window, all ps > .13. Overall, participants' fixations to the target object did not differ between "*There*" and "*Where*" trials, or between balanced and unbalanced groups during this test question interval. However, comparing the proportion of looking against chance level revealed some nuanced differences in terms of the nature of performance between "*There*" and "*Where*" trials. On "*There*" trials, both balanced and unbalanced bilinguals were above chance in their proportion of looks at the target object, ps < .005. On "*Where*" trials, in contrast, the looking time directed toward the target object was above chance level for the unbalanced bilingual group during Pre-Naming Window, p = .014, but not for the same unbalanced group in Post-Naming Window or the balanced bilinguals' performance in both windows, ps > .07.

Discussion

Using a Cue Integration Task coupled with eye-tracking, we examined the effects of bilingualism (as both a categorical variable and a continuous variable) on bilingual young adults' ability in integrating multiple cues when understanding a

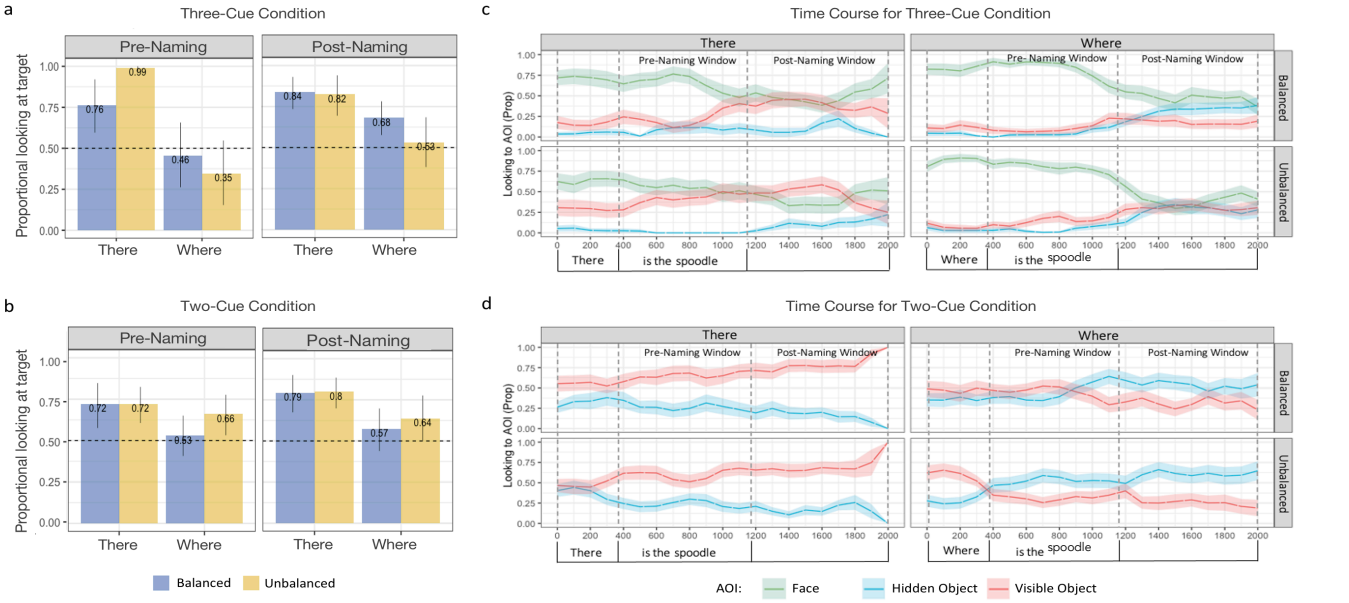

Figure 4: Results for looking during test question interval. a-b: Mean proportional looking time toward the target object in three-cue and two-cue conditions (error bars indicate 95% confidence intervals). c-d: Time course plots of proportionate looking toward the respective area of interest (AOI) across the test question interval (shaded regions indicate standard error).

speaker's referential intention. Our behavioral and eye-tracking results revealed similar findings whether comparing balanced and unbalanced bilingual young adults or examining the effects of bilingualism as a continuous variable. We found that the balanced bilinguals (or young adults with more balanced bilingual usage) were more adept than the unbalanced bilinguals (or young adults who used one language more frequently than the other) in integrating semantic, gaze, and contextual cues when understanding the speaker's referential intention. On the other hand, bilingual young adults performed similarly when only semantic and contextual cues were provided, regardless of their language experience. This excludes the possibility that balanced bilingual adults' better performance in integrating semantic, gaze, and contextual cues is due to their better processing of semantic and contextual cues. To sum up, results from our study suggest that more balanced language usage enhances bilingual young adults' ability to integrate multiple cues in the intention-inference process.

In line with previous studies (e.g., Yow and Markman, 2015), our study revealed a bilingual advantage on multiple cue integration. Bilinguals who use two languages more frequently could have greater exposure to complex communicative situations as they are more likely to interact with speakers from diverse language background, and with multilingual speakers who mixed languages in conversations. To avoid communication failure, balanced bilinguals could be more accustomed in detecting and processing subtle cues, such as gaze cues, according to the contexts in conversations. They could also be more experienced in integrating cues of different modalities in understanding the speaker's intention.

Alternatively, unbalanced bilinguals' worse performance may stem from an overreliance on gaze cues. Unbalanced bilinguals, who might be less comfortable and less proficient in their less-used language, are more accustomed to using gaze cues heuristically in conversations, to compensate for their weaker proficiency when conversing in their less-used language. While it is possible that unbalanced bilinguals had difficulty in processing semantic cues, we caution against this possibility as both balanced and unbalanced bilinguals were capable of identifying the referent object in the two-cue condition where semantic and contextual cues were provided.

It could also be argued that balanced bilinguals' better performance is due to the cognitive advantages associated with bilingualism. To succeed in the "Where" trials, where the speaker's gaze cues could have conflicted with the semantic cues, participants would have to ignore irrelevant information (i.e., conflicting gaze cues) and attend to the relevant cues. General cognitive control processes could thus play an important role. Balanced bilinguals who control and negotiate their two languages frequently could have more enhanced cognitive control processes than bilinguals with less balanced usage (e.g., Abutalebi & Green, 2016), which in turn benefitted cue integration. It would be interesting for future studies to investigate the mediating role of cognitive processes on bilingualism and multiple cue integration.

Surprisingly, in the two-cue condition, we found that unbalanced bilinguals, but not balanced bilinguals, were above chance in looking at the target object during the Pre-Naming window on "Where" trials. It should be noted that the two groups of bilinguals performed similarly in identifying the target object in terms of their behavioral choice as well as the looking pattern during the response interval. The current finding likely reflected different strategies that the unbalanced and balanced bilinguals used in processing semantic and contextual cues in this condition, especially in the early stage of the intention-inference process. Unbalanced bilinguals appeared to take a reactive approach and would readily use the semantic cue "Where" once it became available, whereas balanced bilinguals might take a proactive approach to monitoring and evaluating all potential cues before making their interpretation of the speaker's intention ~~clearly~~.

Our study contributed to the literature by examining the effects of bilingual language experience as a categorical variable and as a continuous variable. Our results suggest that balanced usage, defined as the daily practice of two languages in social interactions is critical in modulating the young adults' utilization of cues when determining a speaker's referential intent. It should also be noted that our participants were residing in a multilingual environment where dual language use is highly prevalent in everyday life (Bokhorst-Heng & Caleon, 2009). The mere exposure of and interaction with individuals who use both languages in the same conversations could have an influence on adults' processing and integration of cues as well. Future studies could include bilingual adults living in mostly monolingual environment to better understand the effects of bilingual experience on multiple cue integration.

Most prior work on bilinguals' cue integration has focused on children. Our study contributes to existing literature by demonstrating that the effects of bilingual experience on multiple cue integration are extended in young adulthood. Nevertheless, it should be noted that the young adult bilinguals in our study were still capable of integrating multiple cues in determining the speaker's intentions regardless of their bilingual experience. There is considerable evidence that aging is accompanied by decline in social cognition and perspective taking (e.g., Henry et al., 2013). Thus, older adults may experience difficulty in integrating cues required for effective communication. It would be useful for future studies to examine older adults' ability in integrating multiple cues, and whether bilingual experience would be a protective factor against a decline in multiple cue integration in older adulthood (Chan et al., 2020).

In conclusion, our study provided both behavioral and neurocognitive evidence that regular usage of two languages could positively affect adults' ability to process and utilize multiple linguistic and non-linguistic cues in understanding speaker's referential intent. We argue that the complex communicative experience that balanced bilinguals have to face regularly enhances their ability to integrate cues. The

extent of the bilingual experience thus likely modulates multiple cue integration in the intention-inference process.

Acknowledgments

This research is supported by the SUTD Growth Plan Grant for Healthcare (SGPHCRS1902) to the last author. We are grateful to all participants who participated in this study.

References

Abutalebi, J., & Green, D. W. (2016). Neuroimaging of language control in bilinguals: neural adaptation and reserve. *Bilingualism: Language and cognition, 19*(4), 689-698

Bak, T. H. (2016). The impact of bilingualism on cognitive ageing and dementia: Finding a path through a forest of confounding variables. *Linguistic Approaches to Bilingualism, 6*(1-2), 205-226.

Bialystok, E. (2017). The bilingual adaptation: How minds accommodate experience. *Psychological Bulletin, 143*, 233–262.

Bokhorst-Heng, W. D., & Caleon, I. S. (2009). The language attitudes of bilingual youth in multilingual Singapore. *Journal of Multilingual and Multicultural Development, 30*(3), 235-251.

Brojde, C. L., Ahmed, S., & Colunga, E. (2012). Bilingual and monolingual children attend to different cues when learning new words. *Frontiers in Psychology, 3*, 1–11.

Chan, C. G., Yow, W. Q., & Oei, A. (2020). Active bilingualism in aging: Balanced bilingualism usage and less frequent language switching relate to better conflict monitoring and goal maintenance ability. *The Journals of Gerontology: Series B, 75*(9), e231-e24.

Comeau, L., Genesee, F., & Mendelson, M. (2007). Bilingual children's repairs of breakdowns in communication. *Journal of Child Language, 34*, 159–174.

Contemori, C., & Tortajada, F. (2020). The use of social–communicative cues to interpret ambiguous pronouns: Bilingual adults differ from monolinguals. *Applied Psycholinguistics, 41*(1), 51-77.

Cox, S. R., Bak, T. H., Allerhand, M., Redmond, P., Starr, J. M., Deary, I. J., & MacPherson, S. E. (2016). Bilingualism, social cognition and executive functions: A tale of chickens and eggs. *Neuropsychologia, 91*, 299-306.

Epley, N., Morewedge, C. K., & Keysar, B. (2004). Perspective taking in children and adults: Equivalent egocentrism but differential correction. *Journal of Experimental Social Psychology, 40*(6), 760-768.

Gampe, A., Wermelinger, S., & Daum, M. M. (2019). Bilingual children adapt to the needs of their communication partners, monolinguals do not. *Child Development, 90*(1), 98–107.

Henry, J. D., Phillips, L. H., Ruffman, T., & Bailey, P. E. (2013). A meta-analytic review of age differences in theory of mind. *Psychology and Aging, 28*(3), 826.

Huettig, F., Rommers, J., & Meyer, A. S. (2011). Using the visual world paradigm to study language processing: A review and critical evaluation. *Acta Psychologica*, *137*(2), 151-171.

Ikizer, E. G., & Ramírez-Esparza, N. (2018). Bilinguals' social flexibility. *Bilingualism: Language and Cognition*, *21*(5), 957-969.

Keysar, B., Barr, D. J., Balin, J. A., & Brauner, J. S. (2000). Taking perspective in conversation: The role of mutual knowledge in comprehension. *Psychological Science, 11*(1), 32-38.

Liberman, Z., Woodward, A. L., Keysar, B., & Kinzler, K. D. (2017). Exposure to multiple languages enhances communication skills in infancy. *Developmental science, 20*(1), e12420.

Long, M. R., Horton, W. S., Rohde, H., & Sorace, A. (2018). Individual differences in switching and inhibition predict perspective-taking across the lifespan. *Cognition, 170*, 25-30.

Lorge, I., & Katsos, N. (2019). Listener-adapted speech: Bilinguals adapt in a more sensitive way. *Linguistic Approaches to Bilingualism*, *9*(3), 376-397.

Luk, G., & Bialystok, E. (2013). Bilingualism is not a categorical variable: *Interaction between language proficiency and usage. Journal of Cognitive Psychology, 25*(5), 605-621.

Nappa, R., & Arnold, J. E. (2014). The road to understanding is paved with the speaker's intentions: Cues to the speaker's attention and intentions affect pronoun comprehension. *Cognitive Psychology*, *70*, 58–81.

Nurmsoo, E., & Bloom, P. (2008). Preschoolers' perspective taking in word learning: Do they blindly follow eye gaze? *Psychological Science*, *19*(3), 211-215.

Rubio-Fernández, P., & Glucksberg, S. (2012). Reasoning about other people's beliefs: Bilinguals have an advantage. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *38*(1), 211.

Ryskin, R. A., Brown-Schmidt, S., Canseco-Gonzalez, E., Yiu, L. K., & Nguyen, E. T. (2014). Visuospatial perspective-taking in conversation and the role of bilingual experience. *Journal of Memory and Language*, *74*, 46-76.

Siegal, M., Iozzi, L., & Surian, L. (2009). Bilingualism and conversational understanding in young children. *Cognition*, *110*(1), 115-122.

Yow, W. Q., Li, X., Lam, S., Gliga, T., Chong, Y. S., Kwek, K., & Broekman, B. F. (2017). A bilingual advantage in 54-month-olds' use of referential cues in fast mapping. *Developmental Science, 20*(1), e12482.

Yow, W. Q., & Markman, E. M. (2011). Young bilingual children's heightened sensitivity to referential cues. *Journal of Cognition and Development, 12*, 12–31.

Yow, W. Q., & Markman, E. M. (2015). A bilingual advantage in how children integrate multiple cues to understand a speaker's referential intent. *Bilingualism: Language and Cognition, 18*(3), 391–399.

Yow, W. Q., & Markman, E. M. (2016). Children increase their sensitivity to a speaker's nonlinguistic cues following a communicative breakdown. *Child Development, 87*(2), 385–394.