Inhibitory processes in visual perception: A bilingual advantage

Word Count = 4000 (text + references)

Abstract

Bilingual inhibitory control advantages are well established. An open question is whether inhibitory superiority also extends to visual perceptual phenomena that involve inhibitory processes. This research used ambiguous figures to assess inhibitory bilingual superiority in 3-, 4-, and 5-year old mono- and bilingual children (*N* = 141). Findings show that bilinguals across all ages are superior in inhibiting a prevalent interpretation of an ambiguous figure to perceive the alternative interpretation. In contrast, mono- and bilinguals revealed no differences in understanding that an ambiguous figure can have two distinct referents. Together, these results suggest that early bilingual inhibitory control superiority is also evident in visual perception. Their conceptual understanding of figure ambiguity is comparable to their monolingual peers.

Keywords: bilingualism; inhibitory processes; ambiguous figures; reversal; representational development

Inhibitory processes in visual perception: A bilingual advantage

A consistent finding in bilingualism research is that bilingual children are superior in inhibitory executive function (Bialystok & Martin, 2004; Martin-Rhee & Bialystok, 2008; Poarch & van Hell, 2012). Communicating in one language at a time requires managing competition between both languages and inhibition of lexical access of the alternative language. The suggestion is that the inhibitory control advantage is domain-general (Green, 1998). Superiority is already evident in preschool age and is revealed in inhibition tasks requiring conflict resolution of competing responses (Martin-Rhee & Bialystok, 2008; Bialystok, Barac, Blaye, Poulin-Durbois, 2010; Carlson & Meltzoff, 2008).

An open question is whether bilinguals' inhibitory superiority also extends to the visual perceptual domain. The current research uses ambiguous figures to assess inhibitory superiority in bilingualism and investigates when age differences may emerge. Ambiguous figures, such as Jastrow's (1900) duck-rabbit, are pictorial representations that have two possible interpretations. Adult viewers experience switching from their perceived interpretation (e.g., duck) to the alternative interpretation (i.e., rabbit), termed "reversal", underlying interacting bottom-up (low-level) and top-down (higher-level) processes (Long & Batterman, 2012; Long & Toppino, 2004). Developmental findings revealed that *conception* of figure ambiguity precedes its *perception*. Initially, it has been suggested that reversal involves a complex understanding of ambiguity (Gopnik & Rosati, 2001). This claim is based on a relation between reversal and understanding the effect of an uninformative picture-part on a viewer (Gopnik & Rosati, 2001), indexed with the Droodle task (Chandler & Helm, 1984). Direct evidence for a conceptual prerequisite is the understanding that a stimulus can represent two distinct referents (pictorial metarepresentation), developing around 4 years (Doherty & Wimmer, 2005; Wimmer & Doherty, 2011). This has been demonstrated in an ambiguous figure production task requiring reporting both interpretations of an ambiguous figure (see also Beck, Robinson, Ahmed, & Abid, 2011). This conceptual understanding does not underlie memory and executive function developments (Wimmer & Doherty, 2011). Pictorial metarepresentational understanding is further linked to understanding mental states such as false beliefs (Doherty & Wimmer, 2005; Wimmer & Doherty, 2011). However, despite relevant maturity in the visual system (Slater, 1998), children do not perceive reversal until at least 4 ½ years (Doherty & Wimmer, 2005; Gopnik & Rosati, 2001; Rock, Gopnik, & Hall, 1994; Wimmer & Doherty, 2011). Additional developments in inhibitory capacity (i.e., inhibiting a prevalent interpretation) and mental imagery allow reversal around the age of 5 (Wimmer & Doherty, 2011).

An interesting prediction then emerges: If the inhibitory bilingual advantage is domain-general, then we should also find this in visual perceptual phenomena involving inhibitory processes. To date, one study demonstrated that 6-year-old bilinguals require fewer prompts to identify the alternative interpretation of an ambiguous figure when naïve about the interpretations (e.g., duck/rabbit) (Bialystok & Shapero, 2005). The present key question is whether bilinguals are superior in initial reversal *per se*, when being informed of alternative interpretations and thus, know what to inhibit (akin to their dual language use). A further open question is whether differences are evident at the time of reversal emergence after 4 years when inhibitory benefits have been demonstrated (e.g., Carlson & Meltzoff, 2008).

With regard to conceptual differences, the predictions for a bilingual advantage are less clear. There is limited indication of a conceptual advantage in bilingual preschoolers' appearance-reality distinctions and visual-perspective taking abilities (Goetz, 2003; but see Greenberg, Bellana, & Bialystok, 2013 for differences in mid childhood). Further, Goetz (2003) revealed no advantage in the standard unexpected transfer false belief task (Wimmer & Perner, 1983) and performance has been attributed to executive control processes rather than conceptual superiority (Kovács, 2009). That is, bilingual superiority was found in 3-year-olds and emergence models, suggesting certain level of executive function is required to develop mental state concepts, may explain this finding (Carlson & Moses, 2001). It is clear from developmental research above that the conceptual aspect of understanding ambiguous figures develops independently of inhibitory processes. Thus, focusing on the understanding that there can be more than one stimulus (conception) versus the spontaneous perception of alternative interpretations (reversal) should provide us with novel insights into bilinguals' advantages in the visual perceptual domain.

To measure children's conception that one stimulus can have two interpretations 3- to 5-year-olds received an ambiguous figures production task (Doherty & Wimmer, 2005; Wimmer & Doherty, 2011), requiring acknowledging both interpretations of an ambiguous figure. This conception was directly compared to understanding the effect of visual ambiguity on another person (Droodle task) and mental metarepresentational understanding (false belief task). To assess reversal, the ambiguous figures Feature Identification task (Wimmer & Doherty, 2011) was administered, requiring perception of both interpretations of an ambiguous figure.

Method

Participants

In total 141 children, 71 monolinguals (38 boys, 33 girls) and 70 bilinguals (32 boys, 38 girls) from four nursery and two primary schools with a variety of socioeconomic backgrounds participated. Children were divided into three age groups; monolinguals: 25 3-year-olds (*M* = 3.5, *SD* = 4 months), 20 4-year-olds (*M* = 4.4, *SD* = 3 months), 26 5-year-olds (*M* = 5.5, *SD* = 4 months); bilinguals: 19 3-year-olds (*M* = 3.6, *SD* = 3 months), 30 4-year-olds (*M* = 4.4, *SD* = 3 months), 21 5-year-olds (*M* = 5.6, *SD* = 3 months).

Both language groups were comparable in their receptive vocabulary ($t(139) = 1.49$, p =

.139, two-tailed), indexed by the British-Picture-Vocabulary Scale (BPVS-III) (Dunn et al., 2007).

Monolinguals were English native speakers. Bilinguals spoke English at school and another language at home on a daily basis. Second languages included French (38.6%), Italian (20%), Arabic (8.6%), Polish (7.1%), Kurdish (4.3%), Spanish (4.3%), Russian (4.3%), Swedish (2.9%), Chinese (1.4%), Czech (1.4%), Dutch (1.4%), German (1.4%), Malayalam (1.4%), Romanian (1.4%) and Slovakian (1.4%).

Children participated following parental consent and their own assent on the day of testing.

Design

Children were seen in a quiet area attached to the classroom and received four tasks lasting approximately 15 minutes: ambiguous figures (AF) Production plus Feature Identification task, False Belief and Droodle tasks. Aditionally, the BPVS-III was administered in the end.

Materials and Procedure

AF Production plus feature identification. Three ambiguous figures (duck/rabbit, man/mouse and seal/donkey) each with two corresponding interpretations were used (see Wimmer & Doherty, 2011). The task consisted of three phases and was run on an electronic device (iPad 2; 24 x 18.5 cm).

First, during disambiguation children were presented with the ambiguous figure (e.g., duck/rabbit) and asked what it was. After the child’s response (e.g., “duck”) the corresponding disambiguating context was added (i.e., the duck’s body) and the child was asked to point to a feature (e.g., “eye”). Then, the experimenter introduced the alternative interpretation by adding the other disambiguating context (i.e., the rabbit’s body) (“But look, it can be something else too, what is it now? . . . Yes, you are right, it’s a rabbit.”). Again the child was asked to point to a feature (e.g., “ears”). In case of a child failing to point out the feature, the experimenter would point out other features of this interpretation (e.g., top of head, body), before asking the child again for the same feature (i.e., “ears”). At this stage all participants were able to point out features. The disambiguating drawing was removed and the experimenter said: “So this picture can be two different things, it can be a duck and a rabbit.”

The *Production* test-phase followed immediately. The ambiguous duck/rabbit figure was presented and to check whether a child had changed interpretation, it was asked again, “What’s this?” … (child’s response, e.g.) “It’s a duck!” Then the Production test-question followed: “I say it’s a duck, what else can it be?” The child’s task was to produce the alternative interpretation (i.e., “rabbit”). If the child repeated the experimenter’s label (i.e., “duck”) the test-question was repeated once: “But I’ve already said it’s a duck, what *else* can it be?” If the child continued to repeat the experimenter‘s label the alternative was produced for them (“I know, it can be a rabbit, can’t it?”). Children who produced the alternative interpretation passed *Production*.

Immediately after producing the alternative interpretation, the *Feature Identification* test-phase followed. Children had to indicate features of the alternative interpretation (e.g., “Can you point to the mouth of the rabbit?”). Indicated features were distinct from the ones during disambiguation. Children who indicated features of the alternative interpretation passed *Feature Identification*.

These three phases were continued with the remaining two ambiguous figures. Children scored from 0 to 3 in each of Production and Feature Identification.

False belief task. A story was acted out with two play people dolls, a boy (Tony) and a girl (Sally), a yellow box, a black box, and a marble. Tony hid his marble (e.g.) in the yellow box and left. In his absence, Sally moved the marble to the black box and left. Tony returned and children were asked these three questions.

Belief question: “Where will Tony first look for the marble?”

Reality question: “Where is the marble really?”

Memory question: “Where did Tony put in the marble in the beginning?”

Children passed the task if they answered all questions correctly.

Droodle task. The Droodle involved two pictures, one of a flower and one of an elephant. Each picture was covered with a non-transparent overlay (29.7cm x 21cm), with a 3 cm^2 hole revealing a small unidentifiable part of the picture (“Droodle”). During the test phase a doll (Sandy) acted as protagonist.

Children were first shown the Droodle, and asked what it was. After the child’s incorrect guess the full drawing was revealed. Then the overlay was replaced, Sandy appeared, and the test question followed: “Sandy has never seen this picture before. If she comes in and sees just this bit, will she know that this is a flower/an elephant?” (Correct answer: “No”). In a control condition, the other drawing was fully visible from the start, and children were asked the same test question (Correct answer: “Yes”). Children passed the task if they answered both questions correctly.

Results

Mean task performances as a function of age- and language group are presented in table 1.

Task performances

AF production plus feature identification. Numbers of alternative interpretations produced and features indicated were subjected to a repeated measures ANOVA with age and language group as independent variables.

Children's performance increased with age, $F(2, 135) = 46.16$, $p < .001$, $\eta p^2 = .41$, where improvements occurred between all adjacent age groups, 3- ($M = 1.05$) and 4 years ($M = 1.79$, $p < .001$), and 5 years ($M = 2.48$, $p < .001$) (Bonferroni post-hoc).

It was easier to produce alternative interpretations ($M = 2.08$) than to indicate features ($M = 1.46$), $F(1, 135) = 54.74$, $p < .001$, $\eta p^2 = .29$. However, both effects were qualified by an age x task interaction ($F(2, 135) = 7.58$, $p = .001$, $\eta p^2 = .10$) that occurred because of equal performance in 3-year-olds ($p > .05$) in contrast to better production performance than feature identification in 4- and 5-year-olds (all $p < .001$).

There was no effect of language group ($F(1, 135) < 2$) but a language group x task interaction, $F(1, 135) = 6.94$, $p = .009$, $\eta p^2 = .05$. This interaction emerged because bilinguals outperformed monolinguals in feature identification ($p = .006$) whereas no group difference emerged in producing alternative interpretations ($p > .05$) (Bonferroni post-hoc).

False belief task. Children's performance improved with age, Kruskall- Wallis $\chi^2 = 21.55$, $df = 2$, $p < .001$, between 3- ($M = .34$) and 4-year-olds ($M = .66$, $p = .004$), who in turn did not differ from 5-year-olds ($M = .80$) (Fisher's Exact, two-tailed). There was no difference between the two language groups (Mann-Whitney U, $p > .05$) (Table 1).

Droodle task. Again, children's performance improved with age, Kruskall-Wallis $\chi^2 = 45.21$, $df = 2$, $p < .001$. Improvements occurred between all adjacent age groups; 3-year-olds ($M = .14$) and 4-year-olds ($M = .32$, $p = .05$) and in turn 5-year-olds ($M = .81$, $p < .001$) (Fisher's Exact, two-tailed). Language groups did not differ (Mann-Whitney U, $p > .05$).

Table 1: Summary of mean performance on ambiguous figures production and feature identification, false belief, and Droodle tasks for monolinguals and bilinguals (standard deviation in parenthesis).

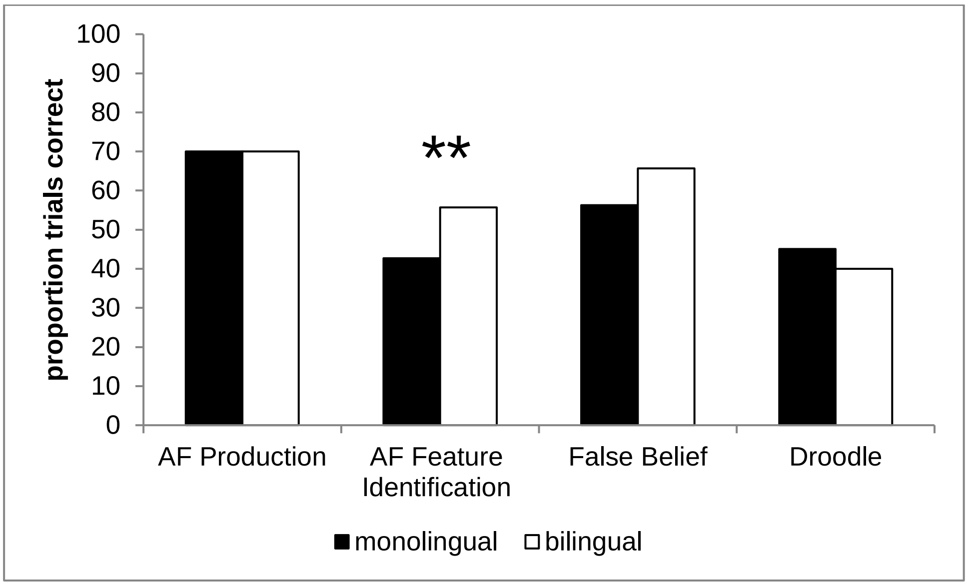
	Production (range 0-3)	Feature Identification (range 0-3)	False Belief (range 0-1)	Droodle (range 0-1)
3 years				
Monolinguals (*N* = *25*)	1.12 (1.01)	.88 (.88)	.24 (.44)	.20 (.41)
Bilinguals (*N* = *19*)	1.16 (.90)	1.05 (.85)	.47 (.51)	.05 (.23)
4 years				
Monolinguals (*N* = *20*)	2.30 (.92)	1.05 (.11)	.70 (.47)	.25 (.44)
Bilinguals (*N* = *30*)	2.23 (1.0)	1.57 (.82)	.63 (.49)	.37 (.49)
5 years				
Monolinguals (*N* = *26*)	2.88 (.33)	1.85 (.73)	.77 (.43)	.85 (.37)
Bilinguals (*N* = *21*)	2.81 (.68)	2.38 (.74)	.86 (.36)	.76 (.44)

Comparison of tasks

Comparing all performances directly, tasks were rescored in proportion of trials correct [e.g., false belief task scores were either 0% (failed) or 100% (passed) whereas production task scores ranged from 0% (0 alternatives produced) or 33% (1 alternative produced) or 67% (2 alternatives produced) or 100% (all 3 alternatives produced)] (Figure 1).

For *monolinguals* the feature identification question was harder than both false belief, $z = -2.38$, $p = .017$, and production tasks, $z = -4.98$, $p < .001$ (Wilcoxon Signed Ranks test). Moreover, the false belief and droodle tasks were both harder than the production question, $z = -2.51$, $p = .012$; $z = -3.75$, $p < .001$, respectively (Figure 1). A slightly different pattern emerged for *bilinguals*. The Droodle task was harder than all other tasks; false belief, $z = -3.67$, $p < .011$, production, $z = -4.69$, $p < .001$, and feature identification, $z = -3.12$, $p = .002$. Additionally, feature identification was harder than production, $z = -3.12$, $p = .002$ (Wilcoxon Signed Ranks test) (Figure 1).

Figure 1: Task performances re-scored into proportion of trials correct for each language group (Note. ** $p < 0.01$ performance difference between mono- and bilinguals).



Process predictors. Two linear regressions with backward elimination method examined the relation between task performances, chronological age and verbal mental age

(BPVS-III score), and language group performance on production and feature identification performance.

For *production* the model was significant $R^2 = .53$, F (3, 140) = 52.21, $p < .001$ where age ($\beta = .23$, $p = .01$), verbal mental age ($\beta = .42$, $p < .001$) and feature identification ($\beta = .18$, $p = .008$) best predicted the ability to produce alternative interpretations of ambiguous figures. For *feature identification* the model was also significant $R^2 = .40$, F (4, 140) = 21.83, $p < .001$ where language group ($\beta = .24$, $p = .001$), Droodle performance ($\beta = .25$, $p = .002$) and production performance ($\beta = .25$, $p = .014$) significantly predicted the ability to perceive alternative interpretations of an ambiguous figure.

Discussion

The aim was to examine bilingual advantages in conception of ambiguous figures and their perceptual reversal. The present findings revealed a clear bilingual advantage in reversal but none in ambiguous figure conception. Bilinguals performed equally well as monolinguals in producing the alternative interpretation of an ambiguous figure (production task). Thus, pictorial metarepresentation - understanding that one pictorial stimulus can represent two distinct referents - is similar in mono- and bilingual children. Further, both groups were equal in mental metarepresentation, as in the unexpected transfer false belief task (see also Goetz, 2003). There was also no difference in understanding the effect of an uninformative picture-part on a viewer (Droodle task). Overall, there are no conceptual pictorial and mental representational advantages in bilingualism. Previous evidence of conceptual superiority is sparse and has mainly been associated with inhibitory processes. Children’s ability to distinguish between appearance and reality (e.g., a sponge that looks like a rock) (Flavell, Flavell, & Green, 1983) shows some bilingual advantages compared to Chinese monolinguals but not clearly to English ones (Goetz, 2003). Further, group differences were only found in a reality question (“What is it really?”) as a result of superior inhibition of current reality, but none in appearance questions (“What does it look like?”) (Bialystok & Senman, 2004). Similarly, perspective taking, such as understanding that a picture of a turtle can be standing on its feet from one perspective and lying on its back from the opposite (Flavell, Everett, Croft, & Flavell, 1981) only differs between bilinguals and Chinese monolinguals but not compared to English monolinguals (Goetz, 2003). The current findings add that pictorial metarepresentation is similar in mono- and bilingual preschoolers. Success in the production task is independent of inhibitory processes. Therefore, this finding of equal production performance strengthens evidence for absence of conceptual representational advantages.

In contrast, the present findings clearly indicate that bilingual inhibitory superiority facilitates ambiguous figures reversal, shown by their better performance in feature identification. Moreover, this advantage is already evident at preschool age as there was no interaction between age and feature identification. Previous findings showed that 6-year-old bilinguals require fewer prompts to identify the alternative interpretation of an ambiguous figure when naïve about alternative interpretations (Bialystok & Shapero, 2005). The current research demonstrates that bilinguals are superior in initial reversal *per se*, when they know what to inhibit. This is further strengthened by the finding that for bilinguals, reversal was significantly easier than understanding the effects of partial-view on a viewer (Droodle) whereas both processes were equally difficult for monolinguals. Moreover, the effect of bilingualism is independent of chronological and verbal mental age as revealed in the regression analysis. Together, these findings demonstrate that bilinguals’ inhibitory superiority occurs in ambiguous figure reversal.

To our knowledge the present research is the first to directly demonstrate how superior bilingual inhibitory processes are brought to bear in a visual perception task. Previous research shows that reversal requires inhibiting the prevalent perceived interpretation (e.g., duck), in order to perceive the alternative (i.e., rabbit) (Wimmer &

Doherty, 2011). Bilingual superiority has been demonstrated in inhibiting a prevalent motor response (such as Luria's tapping task, where a model's opposite action has to be performed) (Bialystok, et al., 2010) but not in all tasks requiring response inhibition (such as responding "day" to a night scenario and vice versa - day-night Stroop task) (Martin-Rhee & Bialystok, 2008). Theoretical considerations follow from this: Is there a domain-general inhibitory control advantage (Green, 1998)?

Recent theoretical analysis suggests that rather than direct inhibitory control, a central executive system drives the bilingual advantage "that regulates processing across a variety of task demands" (Hilchey & Klein, 2011, pp. 654). This idea is derived from the context of interference (i.e., between a stimulus and an appropriate response) where performance comprises several trials. Bilinguals exert cognitive control to focus on relevant task factors rather than demonstrating inhibitory control *per se* (Hilchey & Klein, 2011). Although this suggestion may be applied to interference tasks, it is unlikely that the current findings could be explained by a central executive regulation system. The ambiguous feature identification task has only one trial, allowing no adaption time to relevant task factors. On the other hand, there are special cases showing that reversal can be achieved through different strategies. For example, children with autism, despite showing intact reversal abilities (Ropar, Mitchell, & Ackroyd, 2003; Wimmer & Doherty, 2010), may reverse via different perceptual processing as reversal is not always preceded by pictorial metarepresentation (Wimmer & Doherty, 2010). However, it is unlikely that current bilinguals approached the task differently. Both groups performed equal in production, production was easier than reversal, and production predicted feature identification. Thus, as for monolinguals, conception precedes ambiguous figure perception.

Rather, the current findings contribute to the traditional view of a domain-general inhibitory control mechanism in bilinguals (Green, 1998). Broadly, bilinguals' supervisory attentional system (SAS), a conflict-resolution system, inhibits stimuli in the non-required language to retrieve the currently relevant one. The stronger the activation of the concept in the irrelevant language, the more inhibitory capacity is required. Ambiguous figure reversal is an analogous phenomenon. Reversal requires inhibitory insight and inhibitory strength (Wimmer & Doherty, 2011). Inhibitory insight (conceptual factor) concerns knowing what to inhibit and when and develops around the age of 4 (see also Perner & Lang, 1999). Knowing what to inhibit is not sufficient to achieve reversal. Gradual changes in inhibitory strength, arising from the maturity of the dorso-lateral pre-frontal cortex (DLPFC) (Diamond, 2002) allow reversal to emerge. Thus, present findings provide specific evidence in bilinguals' superior inhibitory strength.

In conclusion, early bilingual inhibitory control superiority is also revealed in visual perception.

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