

Selective attention to the mouth of talking faces in monolinguals and bilinguals aged 5 months to
5 years

MANUSCRIPT IN PRESS, *Developmental Psychology* (2019)

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Author note

This research was supported by grants from the Natural Sciences and Engineering Research Council of Canada awarded to Krista Byers-Heinlein (402470-2011) and Diane Poulin-Dubois (2003–2013), a Seed Funding Team Program grant from Concordia University awarded to Norman Segalowitz and Krista Byers-Heinlein, and a Fonds de Recherche du Québec - Société et Culture Doctoral Fellowship awarded to Elizabeth Morin-Lessard. Special thanks to Nathalie Germain, Alexa Fogel, the teams at the Concordia Infant Research Lab and the Cognitive Language Development Lab, and the parents, children, and adults who participated.

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Abstract

A talking face provides redundant cues on the mouth that might support language learning and highly salient social cues in the eyes. What drives children's looking towards the mouth versus eyes of a talking face? This study reports data from 292 children who viewed faces speaking English, French, and Russian. We investigated the impact of children's age (5 months to 5 years) and language background (monolingual English, monolingual French, bilingual English-French), and the speaker's language (dominant, non-dominant, or non-native) relative to children's native language(s). Data from 129 bilingual adults were also collected for comparison. Five-month-olds showed balanced attention to the eyes and mouth, but children up to 5 years tended to be most interested in the mouth. In contrast, adults were most interested in the eyes. We found little evidence for different patterns of attention for monolinguals versus bilinguals, or to a native versus a non-native speaker. Using percentile scores, monolinguals with larger productive vocabularies looked more at the mouth, while bilinguals with larger comprehension vocabularies looked marginally less at the mouth, although both effects were small and not as robust with raw vocabulary scores. Children showed large but stable individual variability in their face scanning patterns across different speakers. Our results show that the way that children allocate their attention to talking faces continues to change from infancy through the preschool years and beyond. Future studies will need to go beyond looking at bilingualism, speaker language, and vocabulary size to understand what drives children's in-the-moment attention to talking faces.

Keywords: infancy, childhood, bilingualism, audio-visual speech, language development, multisensory perception

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Speech is both an auditory and a visual signal: listeners hear conversational partners and see their face while they are speaking (Yehia, Rubin, & Vatikiotis-Bateson, 1998). Both the eyes and the mouth are highly informative parts of a talking face. The mouth moves in synchrony with speech, and its redundancy with the auditory signal can support speech comprehension (Munhall & Vatikiotis-Bateson, 1998; Summerfield, 1992). In contrast, the eyes of a speaker provide important social and emotional information about a speaker and are important for establishing joint attention and determining what a speaker is referring to (Emery, 2000). It is then unsurprising that, from early in development, the mouth and eyes attract the bulk of attention when listeners gaze at a talking face (Hunnius & Geuze, 2004).

What factors affect how infants and children allocate their attention to the eyes versus the mouth of a talking face? A number of studies have suggested that an infant's age, language background as monolingual or bilingual, and the language being viewed may all contribute to face-scanning patterns (see the Appendix for a table of studies that have investigated these factors). However, a major limitation of these data is that these studies have varied in both stimuli and experimental tasks, which could obscure developmental patterns (Creel & Quam, 2015). Further, while many aspects of language acquisition show a protracted developmental course that continues well into the preschool years (e.g., Brown, 1973), most studies of how children allocate attention to talking faces have focused on infants 12 months and younger.

The goal of this research was to more fully explore children's looking towards a talking face from infancy through the preschool years. Uniquely, we used the same paradigm to test both monolingual and bilingual learners from 5 months to 5 years, as they viewed speakers of three different languages. Below, we review empirical and theoretical work on how different types of

listeners allocate attention to the eyes versus mouth of a talking face at different points across development, which served as the motivation for our study.

Selective attention to the eyes and the mouth in infancy and childhood: The language expertise hypothesis

Listeners' allocation of visual attention to different parts of a talking face changes over the first year of life. At age 4–6 months, infants typically pay more attention to the eyes than the mouth of a talking face (Lewkowicz & Hansen-Tift, 2012; Smith, Gibilisco, Meisinger, & Hankey, 2013). However, interest in the mouth of both native speakers and non-native speakers increases over the first year of life until at least age 10 months (Hunnius & Geuze, 2004; Lewkowicz & Hansen-Tift, 2012; Pons, Bosch, & Lewkowicz, 2015; Wagner, Luyster, Yim, Tager-Flusberg, & Nelson, 2013). Two studies have reported that at age 12 months, monolingual infants become less interested in the mouth of a native-language speaker, but maintain interest in the mouth of a non-native speaker (Lewkowicz & Hansen-Tift, 2012; Pons et al., 2015). This could indicate that 12-month-old infants are on their way to showing an adult-like pattern of greater interest in the eyes than the mouth of a talking face (Lansing & McConkie, 1999; 2003; Méary, Jaggie, & Pascalis, 2018; Vatikiotis-Bateson, Eigsti, Yano, & Munhall, 1998).

What drives these developmental changes? One account is the language expertise hypothesis (Lewkowicz & Hansen-Tift, 2012; Hillairet de Boisferon, Tift, Minar, & Lewkowicz, 2017; 2018). This account posits that early interest in the eyes is driven by infants' status as language novices. With the emergence of babbling in the middle of the first year of life, infants more actively try to process speech, so their interest in the mouth increases. With the onset of production at 12 months, monolinguals no longer need to access redundant visual information from the mouth while listening to speech, and their interest shifts back towards the eyes when hearing a native language as they begin to approach adult patterns of looking. Under this account,

even when infants have become experts in their native language and no longer look towards the mouth, they may do so when viewing a non-native language.

A test of the language expertise hypothesis is whether face-scanning behaviours are related to individual differences in language proficiency. Indeed, there are some reports indicating that, controlling for age, children with better language skills showed greater interest in the mouth than those with poorer language skills (Hoareau, Nazzi, & Yeung, 2017; Tsang, Atagi, & Johnson, 2018; Young, Merin, Rogers, & Ozonoff, 2009; although see Hillairet de Boisferon et al., 2018, who did not observe this relationship). This relationship could be observed if children who are somehow predisposed to look at the mouth are more successful language learners. However, the language expertise hypothesis might also predict the opposite relationship: children who are more successful language learners, and thus have greater language expertise, have less need to look at the mouth. Under this scenario, children with better language skills (e.g., those with larger vocabularies) would show less interest in the mouth – the opposite of what has been reported.

Several other pieces of evidence remain inconsistent with the language expertise hypothesis. First, not all studies have reported that infants' attention to the mouth declines beginning at 12 months (Tenenbaum, Shah, Sobel, Malle, & Morgan, 2013; Fort, Ayneto-Gimeno, Escrichs, & Sebastián-Gallés, 2017; Hillairet de Boisferon et al., 2018), and these results do not support the idea that the onset of speech production leads to changes in face-scanning patterns. Other studies have linked face-scanning behaviour with autism risk status (Merin, Young, Ozonoff, & Rogers, 2007) and clinical outcomes (Pons, Sanz-Torrent, Ferinu, Birulés, & Andreu, 2018; Young et al., 2009), although the direction of the observed relationship has been inconsistent. These findings could suggest that aspects of socio-emotional development may be a concurrent driver of changes in infants' face-scanning patterns.

Data from preschool-aged children could be informative to test the language expertise hypothesis. If interest in the mouth begins to decline at 12 months due to increasing native language expertise, this change should continue in the preschool years until children's gaze patterns match those of adults, who tend to look more at the eyes than the mouth (Lewkowicz & Hansen-Tift, 2012). Studies of preschool-aged children are sparse, however one study that used a variety of different video stimuli reported increases in interest to the mouth relative to the eyes from 5 to 30 months (Frank, Vul, & Saxe, 2012). Moreover, data from other paradigms have indicated that children from age 4 to 14 years benefit from audio-visual speech under difficult listening conditions, and that the ability to leverage redundant visual information improves across these ages (Jerger, Damian, Tye-Murray, & Abdi, 2014). Together, these studies raise the possibility that children's allocation of attention to different parts of a talking face might show important development even beyond infancy.

Effects of bilingualism

Studying bilingual listeners provides an additional test of the language expertise hypothesis. Bilinguals are unique in that they must acquire and use two different languages, and there is evidence that young bilinguals are especially sensitive to visual speech information that could help them tell their languages apart. When the sound of talking faces in French and English is muted, both monolinguals and bilinguals at 4 and 6 months can discriminate between languages based on subtle articulatory variations. However, at 8 months, monolinguals can no longer tell languages apart visually (Weikum et al., 2007), while bilinguals show a continued sensitivity even when the languages are non-native (Sebastián-Gallés, Albareda-Castellot, Weikum, & Werker, 2012). Monolinguals and bilinguals may also differ in their processing of still faces (Kandel et al., 2016).

The language expertise hypothesis predicts that, compared to monolinguals, bilinguals will attend more to the mouth when processing audio-visual speech, due to the more challenging nature of their language-learning context. Indeed, in a study that compared monolingual and bilingual infants at 4, 8, and 12 months, Catalan-Spanish bilinguals looked more at the mouth from 8 to 12 months in both their native and non-native languages, whereas 12-month-old monolinguals replicated the previously-reported pattern of reduced interest in the mouth (Pons et al., 2015). This result was consistent with a study of 8-month-old Spanish-Catalan bilinguals, which showed that they were more interested in the mouth of laughing and crying faces than monolinguals, although no difference was observed at 12 months (Ayneto & Sebastián-Gallés, 2017). In a third study, bilinguals showed continued interest in the mouth at 12 and 18 months, but had difficulty disengaging their attention from the mouth compared to monolinguals (Fort et al., 2017). Together, these results suggest that monolinguals and bilinguals may differ in their patterns of attention to faces. However, all of these studies tested Spanish-Catalan bilingual infants, thus it is not known whether these results generalize to bilinguals learning other language pairs. Indeed, in recent work testing 4- and 8-month-old monolingual English, unimodal bilingual (learning English and another spoken language) and bimodal bilingual (learning English and British Sign Language) infants, monolinguals and unimodal bilinguals infants increased looking to the mouth with age, while bimodal bilinguals did not (Mercure et al., 2018). Here, the modality of the languages being learned appeared to impact attentional patterns more than whether infants were monolingual or bilingual.

The current study

Selective attention to the eyes versus the mouth of a talking face can reveal how listeners prioritize linguistic versus social information in a naturalistic context. While several studies have reported data from monolingual infants and adults, data from preschoolers and from bilinguals in

general are sparse. Thus, we only have an incomplete picture of how selective attention to talking faces operates over the course of development, and how it interacts with characteristics of both the speaker and the listener. In this study, we adopted a developmental, cross-language approach to offer a comprehensive view of selective visual attention to talking faces.

Here, we report data from a total of 292 monolingual and bilingual children aged 5 months to 5 years, and a comparison group of 129 bilingual adults. Monolinguals acquired either English or French as their native language, and bilinguals acquired both English and French. We used an identical naturalistic eye-tracking method at all ages. Participants saw videos of a different native speaker of the following three languages: English, French, and Russian. These languages were chosen because all the participants were learning English and/or French as their native language(s), but none were familiar with Russian.

We tested the language expertise hypothesis, that proficiency in the language being heard is the main driver of attention to the eyes versus the mouth. This hypothesis, together with previous results, generated five main predictions. First, we expect a u-shaped developmental pattern, with initial interest in the eyes at 5 months followed by increasing interest in the mouth, then an ongoing reduction in interest to the mouth beginning around age 12 months for monolinguals (Lewkowicz & Hansen-Tift, 2012; Pons et al., 2015). Second, bilinguals should maintain interest in the mouth at later ages than monolinguals, as they have less exposure to each language, and may need extra support from the information available on the lips and mouth to process their languages (Ayneto & Sebastián-Gallés, 2017; Pons et al., 2015). Third, bilingual children should show less interest in the mouth for the language in which they have more expertise (their dominant language), and more interest in the mouth for the language in which they have less expertise (their non-dominant language). Fourth, regardless of language background, learners should look more towards the mouth when encountering a non-native

language than a native language. Fifth, there should be a correlation between vocabulary size (taken as an index of language expertise) and relative interest in the eyes versus the mouth.

Methods

Participants

A total of 292 children, all healthy and born full term, contributed data for analysis. Most children were from middle-class families. Each child was either monolingual or bilingual, and belonged to one of the following age groups: 5-month-olds, 9-month-olds, 12-month-olds, 14-month-olds, 2-year-olds (range 1.5–2.5 years), 3-year-olds, and 4- to 5-year-olds. Each participant contributed data at a single age. A full breakdown of participants by age group and language group is displayed in Table 1, with detailed information about gender composition, mean age, age range, and the proportion of children who were English dominant (the rest were French dominant). Many of the children were tested following participation in unrelated studies in the lab on the same visit, which yielded somewhat unequal sample sizes across subgroups. None of the other studies involved audio-visual speech perception. Although this minimizes the chance of carryover effects, it does not completely eliminate them, and we acknowledge that these could potentially differ across age and language groups when children participated in different studies. Informal discussions with colleagues suggest that testing children in two studies on the same visit is routine practice in many labs, although we have seldom seen this practice reported in the literature. A main possible concern is that this could fatigue participants, but we note that fussy participants were excluded from the final sample. Children were recruited through a database of interested families in Montréal, Québec, a city where both English and French are spoken widely.

Depending on the participant's age, their language background was measured using the Multilingual Approach to Parent Language Estimates in conjunction with the Language Exposure

Questionnaire, or the Language Experience and Proficiency Questionnaire (see below for a full description of these measures). Monolinguals were exposed to either English or French at least 90% of the time, with no systematic exposure to another language. Bilinguals were exposed to both English and French at least 25% of the time. Note that for simplicity, we use the term “dominant language” to refer to the child’s most-heard language throughout the rest of the paper, whether the child was monolingual or bilingual. The majority of bilinguals were exposed to both languages regularly from birth, although 6 bilinguals began learning their second language sometime after birth but before 12 months. A few bilinguals ($n = 23$) had some exposure to a third language, which ranged up to 10% and averaged 5%. No child was exposed to Russian.

An additional 106 children were tested for the study but excluded from the final sample because of technical difficulties ($n = 41$), fussiness ($n = 40$), reported health or developmental issues ($n = 12$), experimenter error ($n = 8$), failure to meet age criteria ($n = 6$), or parental interference ($n = 2$). Finally, a further 149 children were invited into the lab on the basis of a brief phone screening, but ultimately failed to meet our pre-established language inclusion criteria for either the monolingual or the bilingual group. Data from these children were collected out of courtesy to the families but excluded from analysis.

For comparison to the children’s results, we also report data from 129 bilingual adults tested in the same paradigm. Adults were undergraduate psychology students studying at an English-speaking university, who participated in the study for course credit. We limited our sample to French-English bilinguals given the difficulty of recruiting monolingual participants, as all adults lived in a city (Montréal) where both languages are spoken in the community, and all Canadian children receive instruction in both English and French at school. All participants reported a minimum comprehension score of 4/5 in both languages, according to the Language Background Questionnaire (Segalowitz, 2009). Some adults had proficiency in a third or fourth

language other than English or French, but none were familiar with Russian. Data were collected from a further 11 adults but excluded from analyses due to guessing the purpose of the study ($n = 6$), not reporting sufficient proficiency in English and/or French ($n = 3$), technical difficulties ($n = 1$), or recognizing one of the speakers ($n = 1$).

Table 1

Descriptive statistics for child participants by age group and language background.

Age group	Language group	<i>n</i>	Mean	Min.	Max.	Prop. Eng.-dominant	Prop. female	Avg. # trials /3
			age (days)	age (days)	age (days)			
5m	Monolinguals	25	175	144	197	0.32	0.28	3.0
5m	Bilinguals	15	166	148	191	0.60	0.67	3.0
9m	Monolinguals	22	288	265	308	0.59	0.50	2.9
9m	Bilinguals	20	288	262	322	0.50	0.50	3.0
12m	Monolinguals	17	383	358	405	0.53	0.24	2.8
12m	Bilinguals	17	377	357	401	0.53	0.47	2.9
14m	Monolinguals	20	434	418	453	0.50	0.45	2.7
14m	Bilinguals	18	436	415	462	0.44	0.61	3.0
2y	Monolinguals	31	793	603	1,014	0.61	0.52	2.9
2y	Bilinguals	24	716	605	944	0.29	0.33	2.9
3y	Monolinguals	21	1,295	1,084	1,448	0.57	0.43	2.8
3y	Bilinguals	23	1,319	1,078	1,456	0.70	0.48	2.8
4–5y	Monolinguals	20	1,689	1,497	1,975	0.35	0.35	2.7
4–5y	Bilinguals	19	1,676	1,466	2,107	0.47	0.42	2.6

Questionnaires

Multilingual Approach to Parent Language Estimates (MAPLE). For participants in the 5-month-old to 2-year-old age groups, language exposure was measured with the Language Exposure Questionnaire (Bosch & Sebastián-Gallés, 2001) using MAPLE (Byers-Heinlein et al.,

under review). This was administered by the experimenter as a structured interview and yielded a percentage of the child's exposure to English, French, and other language(s) since birth based on detailed questions about a typical day in the child's life at different ages. The questionnaire also provided information about the age at which children acquired their language(s).

Language Experience and Proficiency Questionnaire (LEAP-Q). For participants in the 3- and 4- to 5-year-old groups, language background and age of acquisition were measured using a modified version the Language Experience and Proficiency Questionnaire (LEAP-Q; Marian, Blumenfeld, & Kaushanskaya, 2007). The LEAP-Q was completed by children's parents in their preferred language (English or French). To assess participants' overall exposure to their language(s), parents were asked to indicate the percentage of time their child was exposed to each of their languages on average, for a total of 100%.

MacArthur-Bates Communicative Development Inventory (MCDI). To assess children's early vocabulary development and its relation to attention to different parts of a face, the MacArthur-Bates Communicative Development Inventory (MCDI) - Words and Gestures was given to children in the 9-, 12-, and 14-month groups in its original English version (Fenson et al., 2007) and in its adaptation for Canadian French in Québec (Trudeau, Frank, & Poulin-Dubois, 1997). This form assesses both comprehension and production. Parents of children in the 2-year-old group completed the Words and Sentences form, which assesses word production only. MCDI vocabulary measures were not obtained for 3-year-olds and 4 to 5-year-olds as the instrument is not normed for these ages.

The parents of monolingual children completed a single questionnaire in English or in French as appropriate, while the parents of bilingual children completed both the English and French versions. To establish comparable vocabulary scores for monolinguals and bilinguals, MCDIs were scored to compute each child's total conceptual vocabulary size for comprehension

(9-, 12-, and 14-month-olds) and production (9-, 12-, 14-month-olds, and 2-year-olds). This measure counts the total number of concepts lexicalized by each child. For monolinguals, this is the same as typical vocabulary size. For bilinguals, this counts translation equivalents (cross-language synonyms) only once. For example, knowing either the word *dog*, the word *chien*, or both words, would count once towards knowing the concept of a dog. Using total conceptual vocabulary size sets the same upper bound for vocabulary words for monolinguals and bilinguals, and research has suggested that the two groups are typically comparable on this metric (De Houwer, Bornstein, & Putnick, 2014; Pearson & Fernández, 1994; although see Core, Hoff, Rumiche, & Señor, 2013 for evidence that bilinguals might have smaller vocabularies on this metric).

We converted raw conceptual vocabulary scores to percentile scores using vocabulary norm data downloaded from the Wordbank database (wordbank.stanford.edu, downloaded on November 29, 2017; Frank, Braginsky, Yurovsky, & Marchman, 2017). One issue is that norms are somewhat different for the American English and Québec French instruments. For example, a 14-month-old who produces 10 words is considered at the 37th percentile if they are an English learner but at the 43rd percentile if they are a French learner. Moreover, there are no established norms for bilingual children. We thus averaged across the percentile values for the American English and Canadian French norms, so that all children could be compared on the same metric. For example, a 14-month-old who produces 10 words was considered to be at the 40th percentile (the average of 37 and 43) regardless of language background.

Stimuli

Stimuli consisted of videos of three women, each speaking in a different language: English, Russian, and French (see Figure 1). English and French were chosen as stimuli languages since all children were learning French and/or English as a native language. Russian

was used as a control language since it is perceptually distinct from both English and French and was unfamiliar to all participants.

Each video was produced by a female native speaker of the language, videotaped in front of a white background from the shoulders up, who recited a neutral passage in infant-directed speech. Passages were translated versions of each other, and were based on those used by Lewkowicz and Hansen-Tift (2012). To control for differences in appearance between the speakers, all speakers had brown hair and brown eyes, tied their hair up, did not wear make-up, wore the same orange T-shirt, and kept their heads still during the recording session. The length of the videos was 55 seconds (English), 66 seconds (French), and 47 seconds (Russian), which varied because of differences in the time it took to recite the passage in each language. To equate the duration of the videos, analyses were limited to the first 45 seconds of each video. Stimulus videos are available at osf.io/ikvyr/.



Figure 1. Screenshots of (A) English speaker, (B) French speaker, and (C) Russian speaker.

Areas of interest for eyes, mouth, and face are outlined in black. The individuals whose faces appear here gave signed consent for their likeness to be published in this article.

Procedure

Parents (children) or participants (adults) provided written informed consent prior to participation in the study. Study protocols were approved by the Human Research Ethics Committee at Concordia University (“Monolingual and Bilingual Language Development”, Certification Number UH2011-041-1). Data were collected between May 2013 and November 2017.

Participants sat comfortably on their parent’s lap (children) or in a chair (adults) in a dimly-lit sound-attenuated room, approximately 60 cm away from a Tobii T60-XL or a Tobii X300 eye tracker. Parents wore darkened sunglasses and headphones throughout the study, and were asked not to interact with their child. The eye-tracker was calibrated to each participant’s eyes using a 5-point infant calibration routine. Next, participants saw all three videos (in English, French, and Russian) in one of 6 counterbalanced presentation orders. Each video was preceded by an attention-getter presented in the center of the screen, which was a ball stretching and alternating colours. The experimenter pressed a key to begin each trial when the participant fixated the attention-getter. In total, the eye-tracking portion of the visit lasted about 3 minutes. After the study, children were given a T-shirt or a small gift and an honorary degree for their participation, and adults were given course credit. Parents (children) or participants (adults) completed relevant questionnaires either prior to or after the main study.

Results

Data preparation, cleaning, and analysis strategy

Three areas of interest were identified for each speaker: eyes, mouth, and face. The dimensions of the eyes and the mouth areas of interest were equal, and the three areas of interest were chosen such that they could be the same size for all three speakers, while also covering the relevant features (see Figure 1). We initially screened participant data to remove any trial where

participants looked during less than 10% of the video (4.5 seconds). The total number of trials per condition contributed by children in each language group is displayed in Table 1.

Next, because different participants were native in different languages, we recoded the language used by each speaker relative to each participant's language dominance. For all participants, Russian was identified as the control language. French and English were coded as the dominant language or non-dominant language depending on the participant's exposure to each language. For English monolinguals, English was coded as the dominant language and French was coded as the non-dominant language. Conversely, for French monolinguals, French was coded as the dominant language and English was coded as the non-dominant language. For bilinguals, the dominant language was coded as whichever of English or French was heard most, or the maternal language if both languages were heard equally. The non-dominant language was coded as whichever of English or French was heard least.

Preliminary analyses suggested that children spent the vast majority of the time looking towards the face, which averaged 99% of the trial. Thus, following Lewkowicz and Hansen-Tift (2012), the main dependent variable was the proportion of total looking time score (PTLT), which was calculated separately for each trial type (dominant, non-dominant, control). This was calculated by dividing the total looking time to the eyes and mouth respectively by the total looking time to the face. For follow-up analyses, we also calculated a PTLT difference score, which subtracted the PTLT for the mouth from the PTLT for the eyes, such that PTLT difference scores above zero represented greater interest in the eyes, and PTLT difference scores below zero represented greater interest in the mouth.

Following the analytic approach used in previous similar work, we first present ANOVAs in which participants are grouped into age bins. We then model with age as a continuous variable using multilevel orthogonal polynomial regression (Grimm, Ram, & Hamagami, 2011).

Language group was dummy coded with monolinguals as the reference group, and trial type was dummy coded with dominant language as the reference category. All analyses were done in R (R Core Team, 2018), and scripts are available at osf.io/ikvyr/.

ANOVA models: Effects of age group, language group, and speaker language

We began our analysis of children's data by conducting an omnibus 2 (AOI: eyes, mouth) x 7 (age group: 5m, 9m, 12m, 14m, 2y, 3y, 4–5y) x 2 (language group: monolingual, bilingual) x 3 (speaker language: dominant, non-dominant, control) ANOVA. Our focus was the main effects and interactions with AOI, as these tested our main research question of differences in attention to the mouth versus the eyes. We found a significant three-way interaction between AOI, age group, and trial type, as well as several significant lower-order effects, $ps < .05$. Importantly, there were no interactions involving both AOI and language group, suggesting that monolinguals' and bilinguals' interest in the mouth versus the eyes was similar.

We observed a few other statistically significant effects that did not involve AOI. As these effects do not interact with AOI, they reflect overall differences in looking to the two AOIs combined. Since both of these are measured in proportion to looking at the entire face, they can be interpreted in terms of interest in looking at areas other than the eyes and the mouth. There was a statistically significant effect of trial type, qualified by a significant trial type by age group interaction. This was due to less overall interest the eye and mouth AOIs combined (indicating greater interest in other parts of the face) for control trials relative to other trials. This effect was particularly pronounced for younger infants. We also observed an interaction of language group with age group. At most ages, monolinguals and bilinguals showed highly similar overall interest in the eyes and mouth combined. However, at 14 months bilinguals appeared more interested in other regions of the face than monolinguals, while at 3 years monolinguals were more interested

in other regions than bilinguals. The lack of developmental continuity in this effect suggests that it might be spurious.

To follow up on the three-way interaction we observed in the omnibus ANOVA, we conducted separate 2 (AOI: eyes, mouth) x 7 (age group: 5m, 9m, 12m, 14m, 2y, 3y, 4–5y) x 2 (language group: monolingual, bilingual) ANOVAs with PTLT as the dependent variable, for each speaker language: dominant, non-dominant, and control. Although our omnibus ANOVA had not found any relevant effects of language group, we decided to nonetheless include this factor to again test for any effects of children's language background. Next, for each child in each language, we calculated a PTLT difference score, and then compared each combination of age and language group's looking to chance (0, i.e. similar looking to the eyes versus mouth). We also conducted a series of pairwise *t*-tests across age groups to investigate potential developmental differences. PTLT difference scores by age group, language group, and speaker language are plotted in Figure 2, with bilingual adults' results also plotted for comparison (note that monolingual adults were not tested).

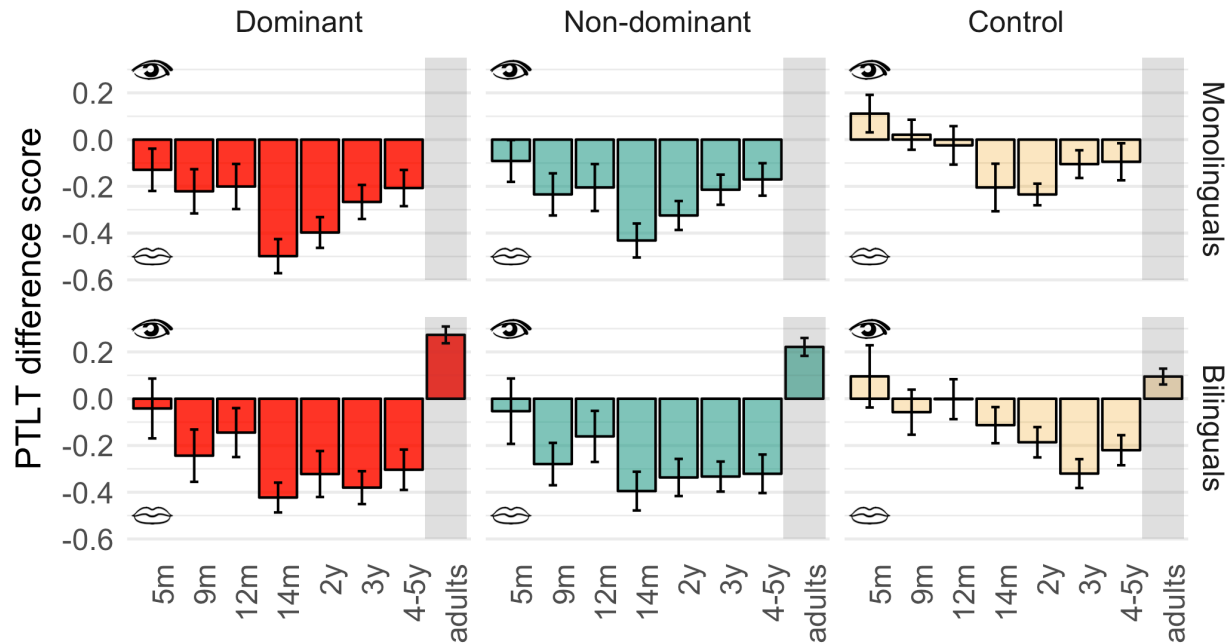


Figure 2. PTLT difference scores by age group, language group, and speaker language. Scores above zero indicate greater interest in the eyes than the mouth, while scores below zero indicate greater interest in the mouth than the eyes. Error bars represent the standard error of the mean. Data from adults are plotted against a grey background for reference, although note that no data were collected from monolingual adults.

Dominant language trials. In the main ANOVA for dominant language trials (Table 2), we found a statistically significant main effect of AOI, driven by more looking towards the mouth than towards the eyes. This was moderated by an AOI by age interaction, suggesting that the preference for the mouth differed by age. However, there were no other statistically significant effects nor interactions, indicating that this interest in the mouth when hearing the dominant language was similar across monolinguals and bilinguals.

To more clearly understand which age and language groups preferred looking at the mouth, we conducted a series of single-sample *t*-tests for each language group at each age

comparing PTLT difference scores against chance (0). Out of the 14 *t*-tests performed, 10 groups showed significantly more interest in the mouth than in the eyes ($p < .05$). The exceptions were 5-month-old monolinguals ($p = 0.17$), 5-month-old bilinguals ($p = 0.75$), 12-month-old monolinguals ($p = 0.054$), and 12-month-old bilinguals ($p = 0.19$), who did not show a statistically significant difference in looking to the mouth versus the eyes.

Our final analyses attempted to more precisely describe age-related changes in looking patterns in the dominant language. We collapsed across language group, as neither of our ANOVAs found evidence for an effect of this variable, and conducted a series of *t*-tests across the different age groups with PTLT difference scores as the dependent variable. As 14-month-olds showed the numerically highest interest in the mouth compared to the eyes, we focused on comparisons relative to this group. Tests uncorrected for multiple comparisons indicated that 14-month-olds showed significantly greater interest in the mouth than 5-, 9-, and 12-month-olds ($p < .05$), who were not significantly different from one another. There was no statistical difference between 14-month-olds and the 2- and 3-year-old groups. Fourteen-month-olds were significantly more interested in the mouth than the 4 to 5-year-olds ($p = 0.03$). The older groups were not significantly different from each other in their looking patterns. However, when we applied the Holm-Bonferroni correction for multiple comparisons (Holm, 1979), only the difference between 14-month-olds and 5-month-olds, as well as between 14-month-olds and 2-year-olds, remained statistically significant. Finally, a *t*-test comparing adults with our oldest age group (4–5 year-olds) showed a statistically significant difference ($p < .001$), suggesting that children's looking patterns were not adult-like even by this age.

Overall, our results show a pattern of increasing interest in the mouth of a dominant-language speaker from 5 to 14 months, which is relatively constant throughout the preschool years, although it may begin to decline somewhat by 4–5 years of age. Results from 5-month-

olds were congruent to those previously reported for 4- to 6-month-olds in this paradigm (Lewkowicz & Hansen-Tift, 2012; Pons et al., 2015). However, results from 12-month-olds were not consistent with what has previously been reported. Whereas Pons et al. (2015) found that bilinguals, but not monolinguals, preferred the mouth at 12 months when hearing their native language, we found a similar pattern for our two groups of 12-month-olds (neither showed a statistically significant preference for the mouth versus eyes), and no statistically significant difference between the two groups, $t(32) = -.039, p = .698$. Even up to age 5 years, children's overall interest in the mouth contrasts markedly with adults', who looked significantly more to the eyes than to the mouth.

Table 2

ANOVA for dominant language trials

Effect	DFn	DFd	SSn	SSd	F	<i>p</i>	<i>p</i> <.05	Ges
(intercept)	1	260	86.37	1.87	12,009.35	<.001	*	0.80
age group	6	260	0.08	1.87	1.89	0.08		0.00
language group	1	260	0.00	1.87	0.15	0.70		0.00
aoi	1	260	9.70	20.14	125.27	<.001	*	0.31
age group x language group	6	260	0.04	1.87	0.92	0.48		0.00
age group x aoi	6	260	1.72	20.14	3.71	<.001	*	0.07
language group x aoi	1	260	0.00	20.14	0.03	0.86		0.00
age group x language group x aoi	6	260	0.21	20.14	0.46	0.84		0.01

Non-dominant language trials. For non-dominant language trials, the main ANOVA (Table 3) indicated a statistically significant effect of AOI: like for dominant language trials, children looked more on average to the mouth than to the eyes. However, this effect was moderated by a statistically significant interaction between age and language group. The age by language group interaction was driven by differences between monolinguals and bilinguals in their overall attention towards the eyes and the mouth as compared to the other parts of the face (i.e., the sum of the PTLT eye and PTLT mouth scores were different from monolinguals as compared to bilinguals, which is attributable to looking towards other areas given these are proportion scores relative to looking at the whole face). We observed differences between monolinguals and bilinguals in overall attention to these two AOIs in the 14-month-old group and the 3-year-old group, although the observed difference between monolinguals and bilinguals was in opposite directions at the two ages. A main effect of language group was not observed at other

ages. These developmentally implausible patterns may indicate that the observed interaction between age and language group was spurious. Moreover, there were no statistically significant two-way or three-way interactions involving bilingualism and AOI, which would have indicated that bilinguals show differential interest to the eyes versus mouth as compared to the monolinguals, at one or more ages. Finally, as with dominant-language trials, there was a statistically significant interaction between AOI and age group, suggesting that patterns of attention to the mouth versus eyes changed with age.

Once again, we conducted a series of two-tailed *t*-tests comparing the PTLT difference scores to chance (0), to examine the age and language groups that showed a statistically significant preference for either the eyes or the mouth for the non-dominant language trials. Very similar to the pattern of results seen for dominant language trials, 10 of the 14 groups showed significantly more interest in the mouth than the eyes ($p < .05$). The exceptions were 5-month-old monolinguals ($p = 0.32$), 5-month-old bilinguals ($p = 0.71$), 12-month-old monolinguals ($p = 0.06$), and 12-month-old bilinguals ($p = 0.16$), who did not show a significant preference for the mouth or eyes. Again, this was a very different pattern from the bilingual adults, who showed statistically significantly greater interest in the eyes than the mouth.

Finally, we conducted pairwise *t*-tests comparing PTLT difference scores across age groups to probe developmental trends, as indicated by the interaction between AOI and age group in the omnibus ANOVA for non-dominant language trials. We once again used 14-month-olds as our reference group, as this group showed greatest relative interest in the mouth. Fourteen-month-old infants showed significantly more interest in the mouth than 5-month-olds and were marginally more interested than 9-month-olds ($p = 0.06$) and 12-month-olds ($p = 0.01$). Amongst this younger group, 5-month-olds were significantly less interested in the mouth than 9-month-olds. There were no statistical differences between 14-month-olds and 2-year-olds or 3-year-olds.

Fourteen-month-olds were marginally significantly more interested in the mouth than 4- to 5-year-olds ($p = 0.05$). The groups older than 14-months were not significantly different from each other. When the Holm-Bonferroni correction was applied, the only statistically reliable difference was between 5-month-olds and 14-month-olds, as well as between 5-month-olds and 2-year-olds. Overall, the patterns are highly similar to those seen with the dominant language, with early attention to the mouth increasing in the first year or so of life and becoming stable thereafter through age 4 to 5 years. A t -test comparing adults with 4–5 year-olds showed that even the oldest children looked significantly more at the mouth than adults ($p < .001$).

Table 3

ANOVA for non-dominant language trials

Effect	DFn	DFd	SSn	SSd	F	p	$p < .05$	Ges
(intercept)	1	264	84.61	1.98	11,256.25	<.001	*	0.80
age group	6	264	0.06	1.98	1.37	0.23		0.00
language group	1	264	0.01	1.98	1.91	0.17		0.00
aoi	1	264	8.60	18.86	120.43	<.001	*	0.29
age group x language group	6	264	0.10	1.98	2.31	0.03	*	0.00
age group x aoi	6	264	1.33	18.86	3.10	0.01	*	0.06
language group x aoi	1	264	0.03	18.86	0.42	0.52		0.00
age group x language group x aoi	6	264	0.17	18.86	0.39	0.89		0.01

Control language trials. On control language trials, the main ANOVA (Table 4) again indicated a statistically significant effect of AOI, where children on average showed greater interest in the mouth than the eyes. We also found a statistically significant main effect of age,

moderated by a statistically significant interaction between age and language group, as we had found for non-dominant language trials. As on non-dominant trials, this was driven by different amounts of overall interest in the eyes and the mouth between monolinguals and bilinguals, particularly at 14 months and 3 years. However, this did not interact with AOI, thus suggesting some different patterns in overall attention towards the eyes and the mouth as opposed to other areas of the face at certain ages. Finally, there was a statistically significant interaction of age and AOI indicating that children's relative interest in the mouth versus eyes changed over time. There were no statistically significant interactions that included AOI and language group, indicating that for control language trials as for the other trial types, monolinguals and bilinguals did not differ in their interest to the mouth versus the eyes.

Two-tailed *t*-tests with PTLT difference scores revealed that only 5 of the 14 groups were significantly different from chance (0) in their looking to the eyes versus mouth of the control language speaker. Neither monolingual nor bilingual children at 5, 9, 12, or 14 months showed a statistically significant difference in interest to the mouth versus the eyes, with the exception of 14-month monolinguals whose preference for the mouth was marginal ($p = 0.06$). In the 2-year-old group, both monolinguals and bilinguals significantly preferred the mouth over the eyes. At 3 years, bilinguals continued to significantly prefer the mouth, and monolinguals showed a marginal preference for the mouth ($p = 0.09$). At 4 to 5 years, bilinguals once again significantly preferred the mouth, while monolinguals did not show a statistically significant preference for the mouth versus the eyes ($p = 0.25$). This differed markedly from patterns seen for the dominant and non-dominant language trials, where greater interest in the mouth was robust in most groups, starting at ages 9–12 months and continuing to age 4–5 years.

Once again, we conducted *t*-tests comparing PTLT difference scores across different ages. As 2-year-olds showed the greatest average interest in the mouth, we report comparisons to this

group as the reference. Two-year-olds showed significantly greater interest in the mouth than 5-, 9-, and 12-month-olds. Amongst these younger groups, only the 5-month-olds and 14-month-olds differed significantly. Two-year-olds were not significantly different from 14-month-olds, 3-year-olds, or 4- to 5-year-olds. After applying a Holm-Bonferroni correction, only the comparison between 5-month-olds and 2-year-olds remained statistically robust. As for the other trial types, these results indicate interest to the mouth which initially increases and then plateaus in the preschool years, despite overall less interest in the mouth for control language trials than for the other trial types. However, even at 4–5 years, children still looked at the mouth significantly more than adults ($p < .001$).

Table 4

ANOVA for control language trials

Effect	DFn	DFd	SSn	SSd	F	p	$p < .05$	Ges
(intercept)	1	265	63.90	2.68	6,317.05	<.001	*	0.78
age group	6	265	0.20	2.68	3.33	<.001	*	0.01
language group	1	265	0.01	2.68	0.70	0.40		0.00
aoi	1	265	1.22	15.63	20.76	<.001	*	0.06
age group x language group	6	265	0.13	2.68	2.16	0.05	*	0.01
age group x aoi	6	265	1.72	15.63	4.86	<.001	*	0.09
language group x aoi	1	265	0.05	15.63	0.86	0.35		0.00
age group x language group x aoi	6	265	0.35	15.63	0.99	0.43		0.02

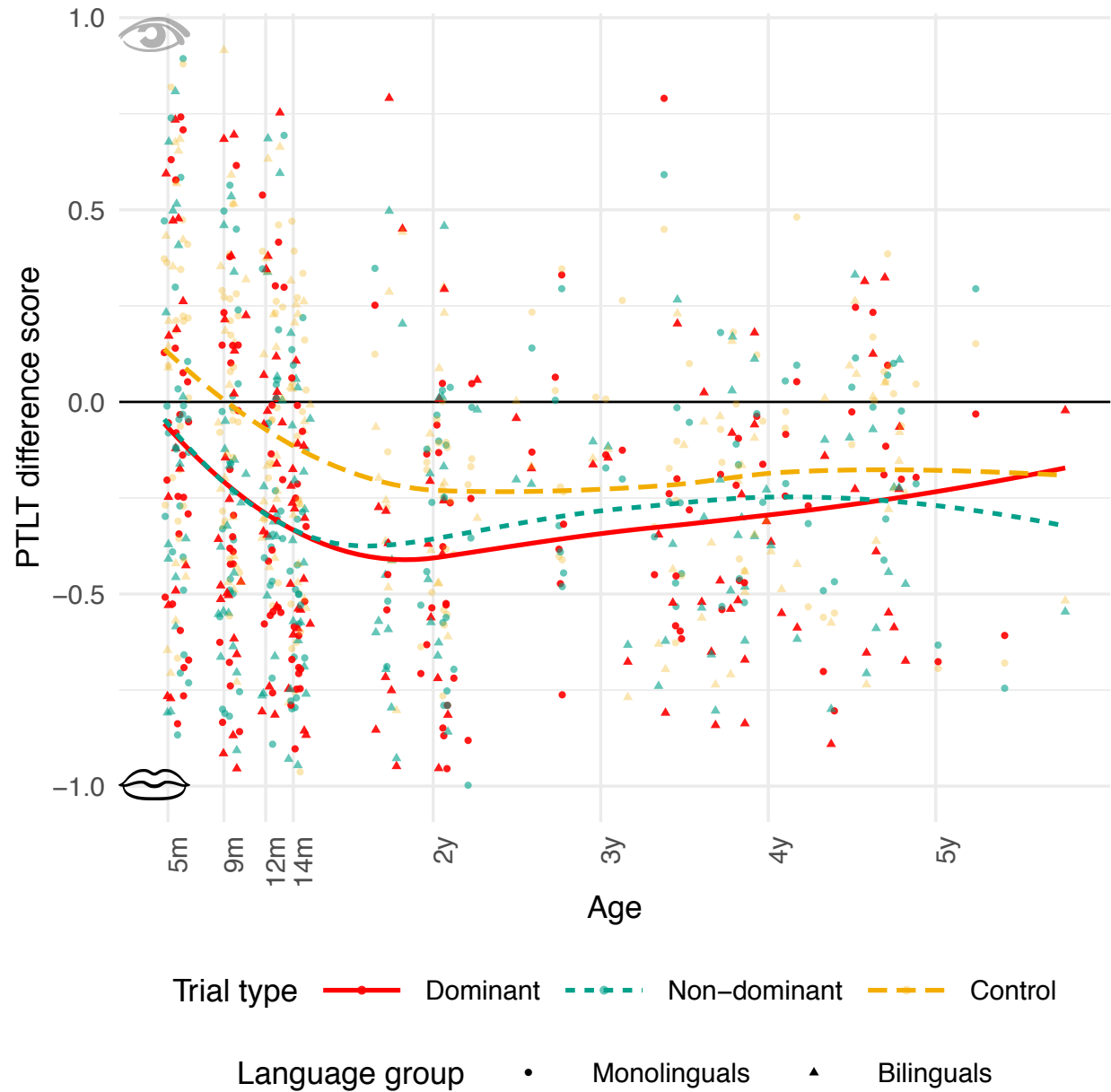


Figure 3. PTLT difference scores by age as a continuous variable. Both individual data points and smoothed lowess curves by trial type are displayed. Ribbons display the standard error of the mean.

Regression model: Effects of age as a continuous predictor, language group, and speaker language

In the above ANOVAs, we treated age as a categorical variable by grouping participants into age bins, in order for results to be more easily comparable to previous research. However, given the nature of our sample, we were also able to analyze age as a continuous variable. In Figure 3, children's age was plotted as a continuous variable against individual-level PTLT difference scores for each trial type. We also included loess curves, which provide a smoothed average over age. The relationship between age and looking patterns appeared to be polynomial (rather than a simple linear increase or decrease), so we modeled the effects of age (measured in days) on PTLT difference scores using an orthogonal polynomial regression approach. Orthogonal polynomial regression can fit complex curves, by including linear, quadratic, cubic, and higher order polynomial terms in the model. Moreover, in these types of models, the polynomial terms are uncorrelated, and so may be interpreted independently. Because trial type was a repeated measure across participants, all models were fit in a multilevel framework using the `lme4` package in R (Bates, Maechler, Bolker, & Walker, 2015), with random intercepts and slopes by participant and trial type.

Exploratory models indicated that third-order polynomials were necessary and sufficient to model the effects of age on PTLT difference scores, thus all models included linear, quadratic, and cubic terms. We initially fit a full model that included interactions between the third-order polynomial function of age, trial type (dominant, non-dominant, control), and language group (monolingual, bilingual). We then fit simpler models, and iteratively compared whether the removal of higher-order terms significantly changed model fit. Terms that were statistically significant in one model were retained in subsequent models.

In our final model, the linear effect of age was not statistically significant, but there were statistically significant quadratic and cubic effects of age. This reflected the steep initial decline in interest to the eyes, followed by a slow subsequent increase in attention to the eyes. We identified an inflection point for each trial type, to determine the age at which children's looking at the mouth was greatest. Under the model, interest in the mouth peaked at 28 months for dominant language trials, 25 months for non-dominant language trials, and 24 months for control language trials. Trial type did not show a statistically significant main effect, however there was a significant interaction between the linear age term and the control trial type. This pattern indicated that control trials had a different age slope compared to dominant language trials, but dominant and non-dominant language trials had a similar age slope. In the series of models we tested, we found no statistically significant main effects or interactions with language group. Moreover, there were no significant main effects or interactions in the dominant versus non-dominant language trials.

Overall, these results echo the findings from the ANOVAs, showing that a) Children's allocation of attention to the mouth versus the eyes varies with age such that children show the greatest interest in the mouth around their second birthday, b) The pattern of performance on control language trials differs from that of dominant or non-dominant language trials, which did not differ from each other, and c) Monolinguals and bilinguals have a similar developmental trajectory. Finally, it is important to note that our final model accounted for only 8.60% of the variance (for a summary of the fixed effects, see Table 5), suggesting that the vast majority of variance across infants was unexplained by the factors we investigated. This finding is also apparent from a visual inspection of Figure 3, which illustrates the high dispersion of data points around the mean at each age.

Table 5

Fixed effects for final orthogonal polynomial model.

Effects	Estimate	Std. Error	df	<i>t</i> value	<i>p</i>	<i>p</i> < .05
(intercept)	-0.27	0.15	0.00	-1.78	1.00	
age	-0.61	0.63	399.74	-0.96	0.34	
age2	1.95	0.58	288.27	3.34	<.001	*
age3	-1.46	0.59	287.00	-2.48	0.01	*
trial type (non-dominant)	0.02	0.21	0.00	0.08	1.00	
trial type (control)	0.17	0.21	0.00	0.80	1.00	
age x trial type (non-dominant)	0.31	0.42	540.66	0.72	0.47	
age x trial type (control)	-1.49	0.42	544.26	-3.53	0.00	*

Individual differences

Using our final regression model, we calculated the intraclass correlation (ICC) by participants as a measure of how strongly individual children's relative attention to the eyes versus the mouth was related across the three trial types. We observed a moderately high ICC = 0.68. To visualize this relationship, we plotted children's PTLT difference score for their dominant language against that for their non-dominant language in Figure 4. We complemented our ICC analysis by calculating Pearson's correlations between PTLT difference scores across the different languages. Correlations were very high and statistically significant (p 's < .001): r (dominant, non-dominant) = 0.86, r (dominant, control) = 0.76, r (non-dominant, control) = 0.77. Indeed, 74% of the variance in children's looking patterns when hearing their non-dominant language could be accounted for by their pattern of looking when hearing the dominant language.

This indicates that there are large and stable individual differences in how children allocate their attention to faces speaking different languages.

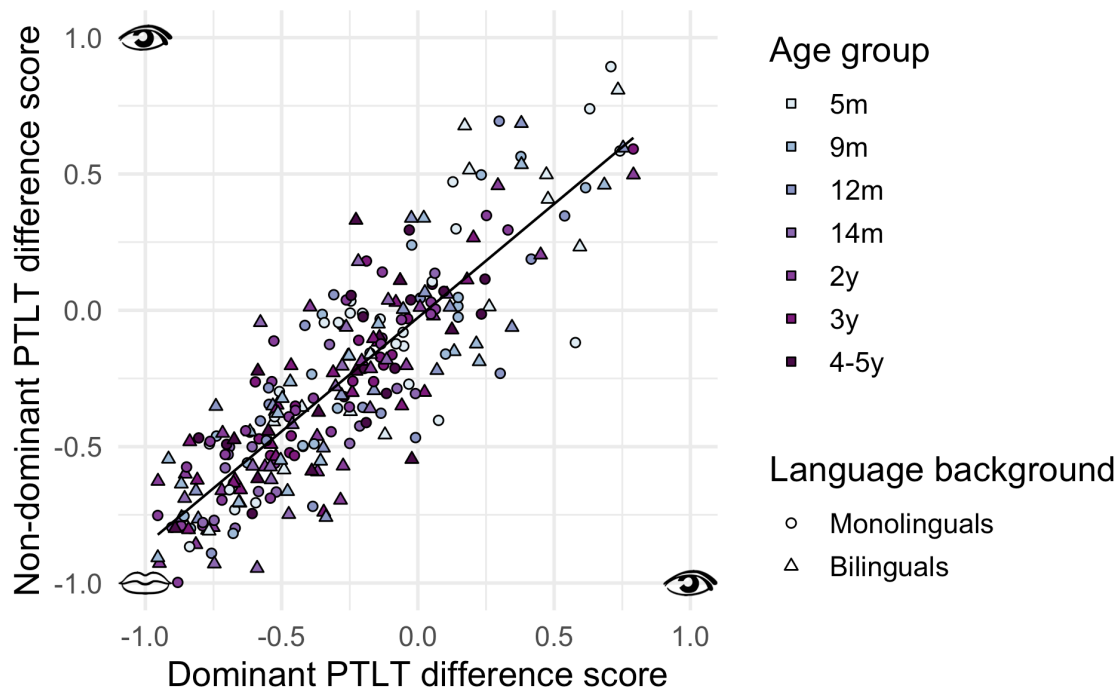


Figure 4. Individual stability in looking to dominant versus non-dominant language speaker. In black is the line of best fit.

One possible source of individual differences could be children's vocabulary size. Thus, our final set of analyses tested whether children's PTLT difference scores were related to their total conceptual vocabulary size. Given strong individual stability of looking patterns across different trial types, we computed the Pearson's correlations with each participant's average PTLT difference score. We investigated relationships both to raw total conceptual vocabulary, as well as percentile scores (which control for age-related changes). We report analysis first for comprehension vocabulary, and then production vocabulary.

For comprehension scores, we found no correlation for monolinguals in either raw vocabulary scores $r(56) = -0.18, p = 0.18$, or vocabulary percentile $r(56) = -0.02, p = 0.89$, or percentile vocabulary size. For bilinguals, we found no relationship with raw vocabulary size $r(53) = 0.08, p = 0.58$. However, there was a marginally significant positive correlation such that bilinguals with higher vocabulary percentile scores in comprehension vocabulary spent relatively more time gazing at the eyes, $r(53) = 0.25, p = 0.07$.

For production scores, bilinguals showed no evidence of a link with either raw vocabulary size $r(73) = -0.06, p = 0.62$, or percentile scores $r(73) = 0.07, p = 0.53$. However, monolinguals showed a negative relation, indicating that children with larger vocabulary percentile scores spent relatively more time gazing at the mouth. This correlation was marginally significant for raw vocabulary size, $r(80) = -0.19, p = 0.09$ and statistically significant for percentile scores, $r(80) = -0.25, p = 0.02$. Note that even for monolinguals' productive vocabulary percentile scores – the strongest relationship we observed – vocabulary accounted for only 6% of the variance in PTLT scores. Figures 5 (comprehension) and 6 (production) illustrate the relationships between average PTLT difference scores and vocabulary percentile for each group, plotted both across all ages measured (solid black line) and within each age group (dashed grey lines).

Overall, this analysis found limited evidence for links between vocabulary size and children's allocation of attention to a talking face. Out of the eight correlations that we computed, one was statistically significant, and two were marginally significant. None of the correlations remain statistically significant when corrected for multiple comparisons. Moreover, the nature (i.e., whether the correlation was with comprehension or production) and direction (i.e. whether children with larger vocabularies looked more at the eyes or more of the mouth) of the correlations was inconsistent. For monolinguals, there was a negative correlation with vocabulary production percentile, with a marginally significant correlation with raw scores. For bilinguals,

there was a marginally significant correlation with vocabulary comprehension percentile, with no statistically significant relationship with the raw scores. Thus, we observed no clear or consistent relationship of how vocabulary size might relate to children's looking patterns.

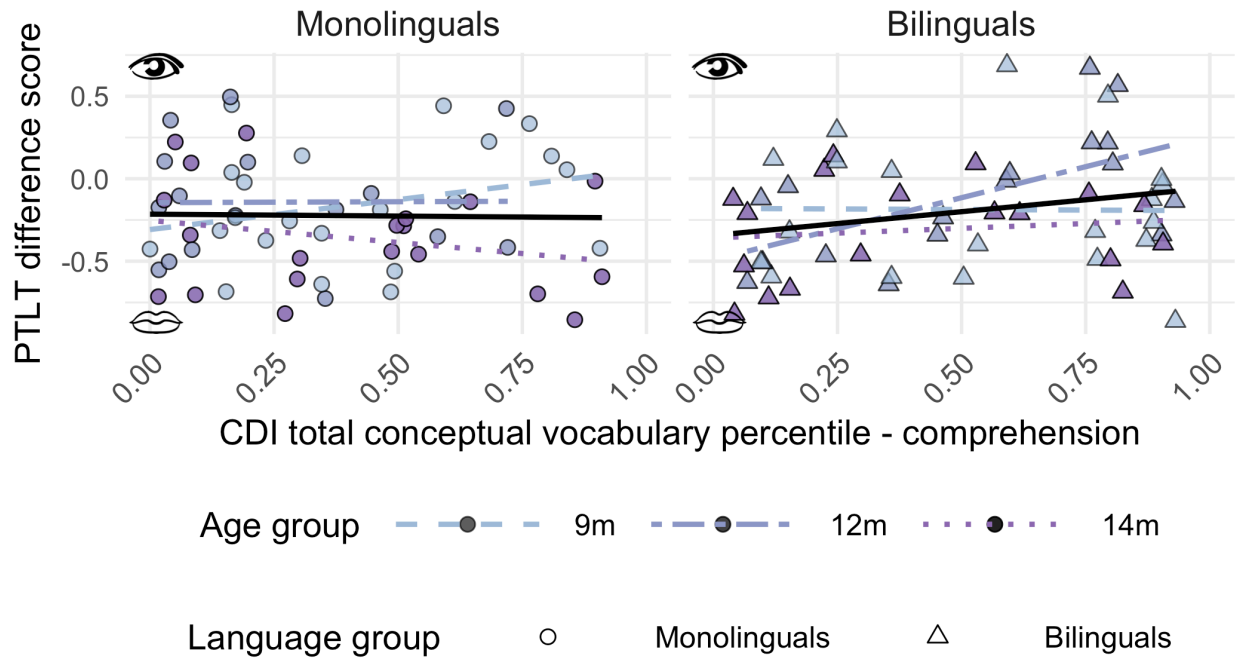


Figure 5. Correlations between PTLT difference score and CDI total conceptual vocabulary percentiles (comprehension) for monolinguals and bilinguals. The solid line represents the overall average, and dotted/dashed lines represent the average for each age group.

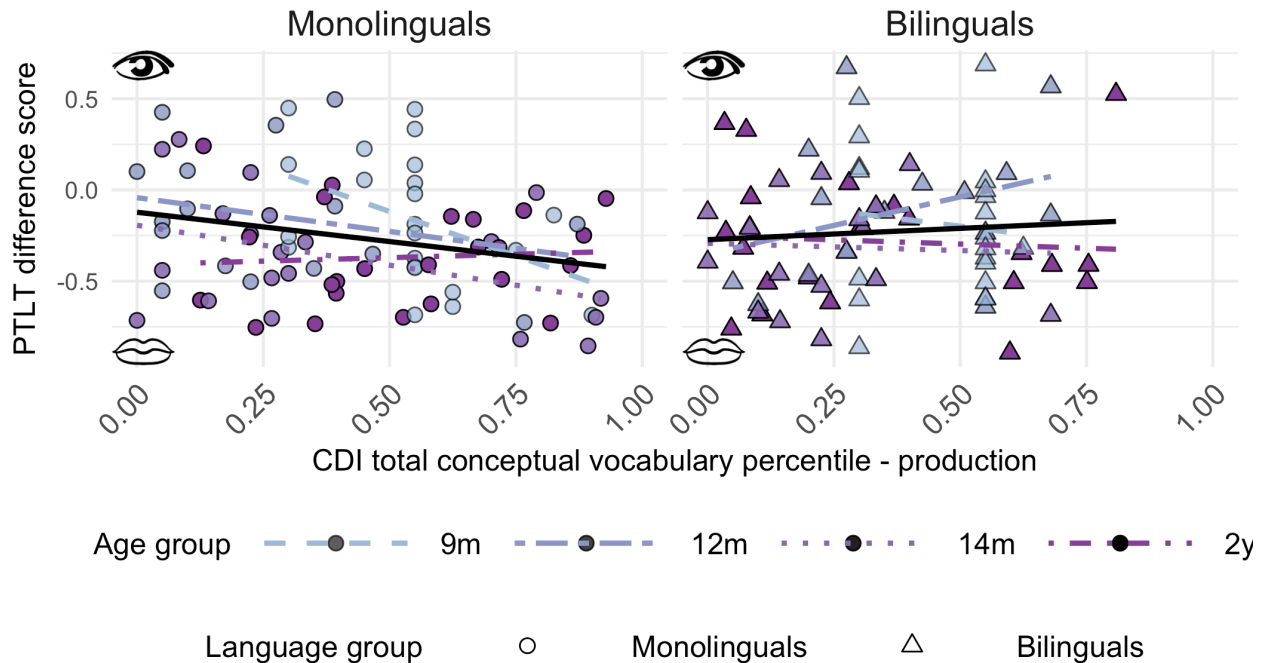


Figure 6. Correlations between PTLT difference scores and CDI total conceptual vocabulary percentile (production) for monolinguals and bilinguals. The solid line represents the average, and dotted/dashed lines represent the average for each age group.

Discussion

What affects how young listeners direct their visual attention towards different parts of a talking face? This study investigated potential impacts of age, bilingualism, the language of the speaker, and children's vocabulary size on children's attention to the mouth versus the eyes. Children from ages 5 months to 5 years from both monolingual and bilingual backgrounds, as well as a comparison group of bilingual adults, saw three videos of speakers using native and non-native languages. When viewing English and French (which were dominant/native for some participants, and non-dominant/non-native for others), 5-month-olds spent equal time gazing at the eyes and mouth, whereas children from ages 9 months to 5 years showed a persistent interest in the mouth relative to the eyes. When viewing Russian, children showed a more balanced

pattern of attention to the eyes versus mouth across all ages. Adults were more interested in the eyes than the mouth while viewing all languages. Averaging across languages, an association with productive vocabulary percentile (although not raw scores) was observed for monolingual infants but not bilingual infants. Overall, we did not find strong support for the language expertise hypothesis, which posits that the main driver of attention to the mouth of a face is limited expertise in a language. Below, we provide a detailed review of our findings in the context of the five predictions generated by the language expertise hypothesis identified in the introduction.

First, under the language expertise hypothesis, we predicted a *u*-shaped developmental pattern, whereby children would show initial interest in the eyes, followed by greater interest in the mouth, and then an increase in interest to the eyes again around age 12 months (Lewkowicz & Hansen-Tift, 2012; Pons et al., 2015). Instead, we observed more of an asymptotic pattern, which confirmed an initially stronger interest in the eyes at 5 months relative to older ages (Ayneto & Sebastián-Gallés, 2017; Frank et al., 2012; Hillairet de Boisferon et al., 2017; Hunnius & Geuze, 2004; Pons et al., 2015; Tenenbaum et al., 2013; Wagner, Luyster, Yim, Tager-Flusberg, & Nelson, 2013), followed by an increase in attention to the mouth (Frank et al., 2012; Hillairet de Boisferon et al., 2018; Pons et al., 2018; Tenenbaum et al., 2013) that persisted until age 5 years. While 12-month-olds' interest in the mouth was not always as robust as at adjacent ages (see also Lewkowicz & Hansen-Tift, 2012; Pons et al., 2015), we did not find statistically significant differences with adjacent age bins, and thus our data lack support for a developmental shift at 12 months as has been previously reported (Lewkowicz & Hansen-Tift, 2012; Pons et al., 2015).

Instead, we observed a peak in attention to the mouth around children's 2nd birthday, although even children as old as 5 years continued to be more interested in the mouth than in the

eyes. Children's persistent interest in the mouth contrasts sharply with our and others' findings that adults tend to look more to the eyes than the mouth in this paradigm (Lewkowicz & Hansen-Tift, 2012). What can explain these developmental patterns? Some researchers have attempted to link developmental trends to the emergence of babbling around 8 months (Hillairet de Boisferon et al., 2017) and word production at 12–18 months (Lewkowicz & Hensen-Tift, 2012; Hillairet de Boisferon et al., 2018). However, these explanations would not predict our pattern of continued interest in the mouth throughout the preschool years. Interestingly, studies in which children saw still faces have indicated that basic face-processing abilities continue to be refined throughout childhood and into adolescence (Pascalis et al., 2011). One study that showed participants still emotional faces found that children's strong interest in the mouth persists through ages 5–10 years, only declining towards adult levels around age 11–12 years (Birmingham et al., 2013). It may be that children's immature gaze patterns towards talking faces are strongly influenced by how they process faces in general, rather than being tightly coupled with language abilities (see also Xiao et al., 2015, for evidence that infants' interest to the mouth increases across the first year of life when viewing faces with non-linguistic motion such as chewing). It will be important for future studies to directly compare how children attend to different types of dynamic and still faces, and to include children older than 5 years to understand when gaze patterns towards talking faces become adult-like.

An important consideration in interpreting age effects is that, in the current paradigm, children did not receive any explicit task instructions. It may be that children at different ages have different goals as they gaze at a talking face. Adults show different scanning patterns if asked to free-view a talking face than when given a specific task that requires processing (Barenholtz, Mavica, & Lewkowicz, 2016). Other studies have similarly found greater attention to the eyes during tasks related to judging emotion or intonation and greater attention to the

mouth during speech processing tasks (Lansing & McConkie, 1999; 2003; Vatikiotis-Bateson et al., 1998; Worster et al., 2017). Thus, future studies might assess the degree to which children are processing linguistic information as they are looking at talking faces, and how this interacts with their developmental level, to better understand what drives the age effects that we observed.

The second prediction was that bilinguals would maintain interest in the mouth at later ages than monolinguals, given that they face a more challenging language acquisition task, and might especially seek redundant cues available on the lips and mouth (Pons et al., 2015). However, we found no evidence for an effect of bilingualism at any of the ages we tested. Instead, bilinguals showed a developmental pattern that was highly similar to monolinguals. Our finding adds to a currently mixed literature, with some studies reporting differences between monolinguals' and bilinguals' face-scanning behaviours (Ayneto & Sebastián-Gallés, 2017; Pons et al., 2015), other studies reporting very similar patterns across the two groups (Tsang et al., 2018; Atagi et al., 2017). One key difference across these sets of studies might be the particular language pair being learned by bilingual children. Our study tested bilingual children learning English and French, two rhythmically and perceptually distinct languages (Ramus, Nespor, & Mehler, 1999; Weikum et al., 2007; 2013). Studies to date that have found that bilinguals show greater interest in the mouth than monolinguals have focused on infants learning Spanish and Catalan (Pons et al., 2015, Ayneto & Sebastián-Gallés, 2017). Spanish and Catalan are both Romance languages, which share many perceptual and linguistic similarities. It may be that patterns observed in Spanish-Catalan bilingual infants do not extend to children learning other less similar language pairs. Indeed, several preliminary reports and recently published work support the hypothesis that the effects of bilingualism on infants' attention patterns might be modulated by language pair (Birulés, Bosch, Brieke, Pons, & Lewkowicz, 2018; Pejović, Yee, & Molnar, 2017; Pons, Bosch, & Lewkowicz, 2015; Mercure et al., 2018). Together, these results

suggest that it might be particularly challenging bilingual situations, rather than bilingualism per se, that leads to differences in face-scanning patterns.

Our third and fourth predictions related to the language of the speaker. Under the language expertise hypothesis, we predicted that bilingual children would show greater interest in the mouth of the non-dominant language speaker than the dominant-language speaker, and that all children would look more towards the mouth of a non-native language speaker. Our results were not consistent with these predictions. With regards to French and English stimuli (all children were learning one or both of these languages), we did not find an effect of whether these stimuli were children's dominant or non-dominant language. However, we observed a different pattern of results for children's attention to the Russian speaker, a language which was non-native for all children. Surprisingly, children showed *less* interest in the mouth of our Russian speaker compared to our French and English speakers. One possible explanation is that English and French are more visually similar to each other than to Russian. While we know of no metric to directly compare the visual similarity of two languages, rhythmically, English and Russian both belong to the class of stress-timed languages, whereas French is syllable-timed (Ramus et al., 1999; Roach, 1982). Based on rhythmicity alone, English and Russian, rather than English and French, would be expected to pattern together, which is contrary to our findings.

Another explanation for our results is that children's attention was impacted by unmeasured characteristics of our speakers. Similar to previous work (e.g., Lewkowicz & Hansen-Tift 2012; Pons et al., 2015), children in our study saw only one speaker per language, and thus speaker and language were confounded. The difference in gaze patterns to Russian as opposed to the other language suggests that idiosyncrasies of our particular speakers might have contributed to participants' gaze patterns to their faces. Despite attempting to match our speakers on physical characteristics, we cannot rule out influential idiosyncrasies of each speaker, for

example that the Russian speaker's eyes were particularly attractive or expressive, potentially drawing children's attention more to her eyes than those of the English or French speakers. We did look at blinking behaviour as one possible explanation, because blinks could serve to increase attention to the eyes. Our Russian speaker did blink more often (25 blinks) than the English speaker (15 blinks) and French speaker (4 blinks, 3 twitches), which could be a partial explanation for our pattern of results. Another potential issue is that, for the Russian speaker, children spent relatively more time exploring areas of the face other than the eyes and mouth, compared to other speakers. It may be that one or more other areas of this speaker's face was particularly attractive, or that somehow her eyes and mouth were less attractive than the other speakers' eyes and mouths. One way for future studies to overcome the confound between speaker and language would be to record several bi/multilingual speakers such that the particular language used by a speaker could be counterbalanced across children (see Hoareau et al., 2017). However, in our case, this would have necessitated locating trilingual speakers who could produce native-like Canadian English, Québec French, and Russian (or another unfamiliar language), which would have been extremely challenging, if at all possible. Future research will need to explore the effects of individual speaker characteristics more systematically to understand how this might interact with development.

Our fifth prediction was that vocabulary size would be related to children's relative interest in the mouth versus eyes. We tested links with comprehension vocabulary size at 9-, 12-, and 14-months, and productive vocabulary size at 9-, 12-, 14-months, and 1.5–2.5 years, focusing on total conceptual vocabulary size which provides a common metric for monolinguals and bilinguals. Consistent with some other reports (Hoareau, Nazzi, & Yeung, 2017; Tsang et al., 2018; Young et al., 2009), we did find some moderate evidence for links with productive vocabulary size: monolinguals with higher productive vocabularies relative to their age mates

showed significantly more interest in the mouth (note that this was observed for percentile scores; the relationship with raw vocabulary scores was marginally significant). This relationship was small to medium in magnitude ($r = -0.25$), and only accounted for 6% of the variance. Yet, in bilinguals, there was no link between looking patterns and productive vocabulary size. For bilinguals but not monolinguals, we observed a marginally significant relationship with comprehension vocabulary percentile (although not with raw vocabulary scores), but it was in the opposite direction as what was observed for production – bilinguals with larger vocabularies looked less at the mouth (and hence more at the eyes). Thus, as predicted, some links between vocabulary size and looking patterns were observed. However, their nature and direction were inconsistent, and thus inconclusive with regards to the language expertise hypothesis.

Overall, in seeking to identify factors that might predict children's looking patterns towards a talking face, we observed small to medium effects of age, vocabulary size (although inconsistent in direction), and the particular stimuli (e.g. whether participants saw the English/French versus the Russian speaker, although effects were not as a function of whether that language was native/dominant for children), and no effect of whether children were monolingual versus bilingual. Instead, what was striking about our data was the large individual variability that we observed at each age, with some children focusing almost solely on the mouth, others largely attending to the eyes, and the rest dividing their attention between these two regions (see also Tenenbaum et al., 2013). A surprising finding was that individual children's patterns of attention were extremely stable across different speakers. Indeed, the majority of the variance across children's looking patterns to one speaker could be accounted for by their looking patterns to another speaker. Again, the stability of looking patterns for individual children across speakers illustrates that the language a speaker uses (native or foreign) may play a relatively minor role in driving children's in-the-moment looking patterns. What remains unclear is the

stability of these individual differences over time, beyond back-to-back trials in a single testing session. Future research could use a longitudinal design to address this question.

More generally, our results illustrate the sometimes forgotten “long tail” of perceptual development. Infants are remarkable language learners, and make astonishing progress in language acquisition in the first months and years of life. It is therefore not surprising that research on native language perception has focused largely on very young learners (Stoel-Gammon, 2010). However, our finding that even 4- to 5-year-olds were not adult-like in their gaze patterns provide an example of how tuning of the native language and perceptual systems continues well past infancy. For example, other recent work has shown that even children aged 3–6 and 7–9 years are not yet adult-like in their perception of the McGurk effect, an illusion where a visual mouth movement changes a perceived speech sound (Hirst, Stacey, Cragg, Stacey, & Allen, 2018). Our findings raise the possibility that even children aged 5 years and older benefit from the redundant information available from the mouth of a speaker. A challenge for future research will be to develop additional experimental tasks that are appropriate across the lifespan, which will provide a more complete picture of language development.

To conclude, we sought to understand the factors that contribute to infants’ and children’s allocation of attention to the eyes versus mouth of a talking face. Our study investigated the role of age, bilingualism, familiarity with a speaker’s language, and vocabulary size, reporting data from 292 monolingual and bilingual children aged 5 months to 5 years. We found little, if any, effect of these factors, with the exception of somewhat more attention to the eyes at the youngest age tested than at older ages, and potential links with vocabulary size in monolinguals (production) and bilinguals (comprehension) that were small to moderate in size and inconsistent in direction. Instead, our results point to considerable but stable individual variation in face-scanning patterns, characterized by an overall interest in the mouth that persists through the

preschool years, contrasting with adults' interest in the eyes. Our results call for a greater exploration of individual and situational factors that drive children's in-the-moment looking patterns towards a talking face.

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Supplemental Materials

Studies examining effects of language group, age, and speaker language on attention to the eyes vs. mouth of a talking face.

Reference	Participants					Methods		Results				
	Monol.	Biling.	Infants (age mos)	Children (age yrs)	Adults	Stimuli	Trial length	Lang. group	Age	Speaker lang.	Eyes/mouth	Link with outcomes
Current study: Morin-Lessard, Poulin-Dubois, Segalowitz, & Byers-Heinlein	English, French	English, French	5, 9, 12, 14 (n = 154)	2, 3, 4-5 (n = 138)	YES: biling. English-French (n = 129)	Videos of speakers: English, French, Russian	47-66s	NO	YES: mouth more with age	YES: Russian patterned differently from English/French	5m eyes = mouth; older infants and children eyes < mouth; adults eyes > mouth	Monol.: more mouth looking predicts larger production vocabulary percentile Biling: more eye looking predicts larger comprehension vocabulary percentile
Atagi, Tsang, & Johnson (2017; Conf.)	English	English-Other (no Armenian)	15-24 (n = 18)	-	-	Videos of dyads: English, Armenian	20-24s	NO	NO	YES: Infants attend more to speaker of a familiar language overall than an unfamiliar one	-	None with vocabulary, socialization skills, visual attention.
Ayneto & Sebastián-Gallés (2017)	Catalan, Spanish	Catalan - Spanish	8, 12 (study 1 n = 88; study 2 n = 44)	-	-	Video: Emotional faces (neutral, cry, laugh) of infants and adults	30s	YES: Infant faces: biling.. more mouth than monol. for 8m and 12m Adult faces: biling.. 8m more	YES: Adult faces: biling. 8m more mouth compared to monol., 12m biling.. and monol. Mouth > eyes	-	YES: Biling.. more mouth than monol., except at 12m both biling. and monol. mouth > eyes	-

Reference	Participants					Methods		Results				
	Monol.	Biling.	Infants (age mos)	Children (age yrs)	Adults	Stimuli	Trial length	Lang. group	Age	Speaker lang.	Eyes/mouth	Link with outcomes
								mouth compared to monol., 12m biling.. and monol. mouth>eyes				
Birmingham et al. (2013)	Unspecified (English implied)	-	-	5–6, 7–8, 9–10, 11–12 (n = 104)	YES (n = 25)	Images of facial expressions (grayscale)	Up to 15s	-	YES: Less mouth starting at 11-12 and in adults compared to younger age groups	-	YES: Overall attention mouth > eyes, nose, face, head All children except 11-12 and adults mouth > eyes Mouth more for disgust, left eye more for anger and fear	-
Birulés et al. (2018; Conf.)	-	Spanish - Catalan Spanish -Other	15 (n = 38)	4–6 (n = 32)	-	Video of speaker: Spanish, Catalan, English	45s (infants); 10s (children)	YES: Infants mouth > eyes Infants close languages mouth > eyes compared to infants distant languages Only close	YES: Infants overall mouth > eyes Only close languages children mouth > eyes	YES: Infants attend overall more to the mouth of a speaker of a non-native language	YES: Overall mouth > eyes for close languages	-

Reference	Participants					Methods		Results				
	Monol.	Biling.	Infants (age mos)	Children (age yrs)	Adults	Stimuli	Trial length	Lang. group	Age	Speaker lang.	Eyes/mouth	Link with outcomes
								languages children mouth > eyes				
Fort, Ayneto-Gimeno, Escrichs, & Sebastián-Gallés (2017)	Catalan, Spanish	Catalan - Spanish	15, 18 (study 1 n = 40; study 2 n = 20)	-	-	Video of sentence (native language) followed by non-speech movement (eyebrow raise or lip protruding)	3-4s	YES: Mouth > eyes for 15m monol. and biling., and for 18m biling.. during speech 15m biling.. more difficulty disengaging attention	YES: 15m biling.. did not anticipate eyebrow raise because mouth looking, 18m did anticipate eyebrow raise	NO	YES: 15m biling.. and monol., and 18m biling.. mouth > eyes during speech 15m biling. continue looking at mouth	-
Frank, Vul, & Saxe (2012)	English	-	3-30 (n = 129)	-	-	Videos: Face only, whole person, multiple people, objects, with unsynchronized classical music	20s	-	YES: mouth more with age, especially for face talking or expressing emotion	-	YES: Younger infants eyes > mouth; older infants mouth > eyes	-
Hillairt de Boisferon, Tift, Minar, & Lewkowicz (2017)	English	-	4, 6, 8, 10, 12 (n = 93)	-	-	Videos of speakers (from Lewkowicz & Hansen-Tift, 2012): English (native) vs. Spanish (non-	30s	-	YES: 4, 6, 10mo mouth = eyes. 8m only mouth > eyes. 12mo mouth = eyes (native), mouth > eyes (non-native)	YES: 12mo mouth = eyes (native), mouth > eyes (non-native)	YES: 4, 6, 10mo mouth = eyes. 8m only mouth > eyes. 12mo mouth = eyes (native),	-

Reference	Participants					Methods		Results				
	Monol.	Biling.	Infants (age mos)	Children (age yrs)	Adults	Stimuli	Trial length	Lang. group	Age	Speaker lang.	Eyes/mouth	Link with outcomes
						native), desynchronized, audio in IDS vs ADS					mouth > eyes (non-native)	
Hillaiet de Boisferon, Tift, Minar, & Lewkowicz (2018)	English	-	14, 18 (n = 91)	-	-	Video of speaker (from Lewkowicz & Hansen-Tift, 2012): English, Spanish passages, audio in IDS vs. ADS	50s	-	YES: 14m mouth > eyes in IDS but not ADS 18m mouth > eyes in both IDS and ADS	NO	YES: Overall looking mouth > eyes More mouth > eyes in IDS vs. ADS	Attention to mouth not associated with vocabulary size
Hoareau, Nazzi, & Yeung (2017; Conf.)	French	-	4, 8, 12 (n = 40) 18mo (productive vocabulary; n = 16)	-	-	Videos of speaker: English, French passages	45s	-	YES: mouth more with age (4, 8, 12m)	YES: Mouth more when non-native language presented first	YES: Overall eyes > mouth, but mouth increases with age Mouth more when non-native language presented first	More mouth looking associated with more parental speech input in younger infants Longer mouth looking related to more language proficiency by 12mo
Hunnius & Geuze (2004)	Unspecified (Dutch implied)	-	1.5–6.5 (longitudinal; n = 20)	-	-	Video of mother: looking, smiling, nodding	30s	-	YES: mouth > eyes with age	-	YES: mouth > eyes with age	-
Lansing & McConkie (2003)	English	-	-	-	YES (n = 16)	Video of speaker: Low-intensity sound (speech) or	sentences	-	-	-	YES: More eyes when no speech, more mouth during speech	-

Reference	Participants					Methods		Results				
	Monol.	Biling.	Infants (age mos)	Children (age yrs)	Adults	Stimuli	Trial length	Lang. group	Age	Speaker lang.	Eyes/mouth	Link with outcomes
						no sound					More lower face overall (primarily mouth)	
Lewkowicz & Hansen-Tift (2012)	English	-	4, 6, 8, 10, 12 (study 1 n = 89; study 2 n = 90)	-	YES (study 1 n = 21; study 2 n = 19)	Video of speaker: English, Spanish passages in IDS and ADS	50s	-	YES: 4m: eyes > mouth 6m: eyes = mouth 8m & 10m: mouth > eyes 12m: mouth = eyes (native), mouth > eyes (non-native) adults: eyes > mouth	YES: Mouth > eyes at 12 m when speaker is non-native	YES: “U-shaped” pattern (native): more eyes(4m); equal mouth-eyes(6m) more mouth (8-10m); more eyes (12m & adults) More mouth in IDS, more yes in ADS	-
Mercure et al. (2018)	English	English –Other (unimodal) English – British Sign Language (bimodal)	4–8 (n = 73)	-	-	Video of speaker: repeated productions of /ba/ and /ga/; audiovisual congruent, audiovisual incongruent, or silent articulation	7.6s	YES: mouth > eyes with age for monolinguals and unimodal biling. No age-related scanning patterns for bimodal biling.	YES: mouth > eyes with age for monolinguals and unimodal biling. No age-related scanning patterns for bimodal biling.	-	YES: mouth > eyes with age for monolinguals and unimodal bilinguals No age-related scanning patterns for bimodal biling.	
Merin, Young, Ozonoff, &	English	-	6 (typically developing,	-	-	Live, <i>Still Face</i> procedure	30-60s	-	-	-	YES: Mother’s mouth >	Link between features of broader

Reference	Participants					Methods		Results				
	Monol.	Biling.	Infants (age mos)	Children (age yrs)	Adults	Stimuli	Trial length	Lang. group	Age	Speaker lang.	Eyes/mouth	Link with outcomes
Rogers (2007)			and at-risk for autism) (at-risk n = 31; typically dev. n = 24)								eyes in infants at risk for autism More eye looking in typically developing infants	autism phenotype and face-scanning patterns
Méary, Jaggie, & Pascalis (2018)	Unspecified (French implied)	-	9–12 mo infants (n = 31)	-	YES (n = 33)	Video of speaker reciting a French nursery song, audiovisual congruent vs. incongruent	14.2s	-	YES: Infants more mouth than eyes compared to adults for dynamic face Adults more mouth in silent condition vs dynamic face	-	YES: Adults more mouth for silent dynamic face Infants overall more mouth than adults for dynamic face No gazing difference for audiovisual congruent vs. incongruent	-
Pejović, Yee, & Molnar (2017; Conf.)	Basque, Spanish	Basque - Spanish	4, 8 (n = 166)	-	-	Video of speaker producing vowels	30s	NO	YES: Mouth more with age	-	YES: 4m (all groups): eyes > mouth; 8m (all groups): eyes = mouth	-
Pons, Bosch, & Lewkowicz (2015)	Catalan, Spanish	Catalan - Spanish	4, 8, 12 (n = 60)	-	-	Video of speaker: Catalan/Spanish (native), English	45s	YES: Differences monol. and biling. at 4m and 12m	YES: Monol. 4 m eyes > mouth, Biling. 4m eyes = mouth Monol. and biling. 8m	YES: Monol. 12m eyes = mouth in native language, mouth > eyes in non-native	YES: Monol. 4 m eyes > mouth; Biling. 4m eyes = mouth	-

Reference	Participants					Methods		Results				
	Monol.	Biling.	Infants (age mos)	Children (age yrs)	Adults	Stimuli	Trial length	Lang. group	Age	Speaker lang.	Eyes/mouth	Link with outcomes
						For bilinguals: Native-language video in dominant language			mouth > eyes Monol. 12m eyes = mouth (native), mouth > eyes (non-native), biling. mouth > eyes (native and non-native)	language, Biling. mouth > eyes native and non-native languages	Monol. and biling. 8m mouth > eyes Monol. 12m eyes = mouth (native), mouth > eyes (non-native), biling. mouth > eyes (native and non-native)	
Pons et al. (2018)	Spanish	-	-	5–9: typically developing and diagnosed with specific language impairment (SLI) (typically dev. n = 18; SLI n = 18)	-	Video of female speaker: Spanish (native) monologue	45s	-	-	-	YES: TD children mouth > eyes SLI children mouth = eyes	In SLI children: more mouth related to better phonological skills
Smith, Gibilisco, Meisinger, & Hankey (2013)	English	-	5–8 (n = 34)	-	YES (n = 24)	Video of speaker: English (native) passages in IDS and ADS	30s	-	NO	-	YES: Eyes > mouth for all ages More R than L eye looking during IDS	-
Tenenbaum, Shah, Sobel, Malle, &	English	-	6, 9, 12 (longitudinal) (n = 97)	-	-	Video of female speaker: English	8s	-	YES: mouth more with age 9 and 12m mouth > eyes	-	YES: Mouth more with age More mouth	-

Reference	Participants					Methods		Results				
	Monol.	Biling.	Infants (age mos)	Children (age yrs)	Adults	Stimuli	Trial length	Lang. group	Age	Speaker lang.	Eyes/mouth	Link with outcomes
Morgan (2013)						sentences, speaking vs. smiling					when female speaking vs. smiling 9 and 12m mouth > eyes	
Tsang, Atagi, Johnson (2018)	Mostly English, some other	English -Other	6–12 (n = 60)	-	-	Video of woman's face: English spoken in IDS	17-23s	NO	NO: when age analyzed as categorical variable YES: More mouth with age when analyzed as continuous variable YES: More non-English exposure related to less mouth looking with age	-	YES: Increasing looking mouth > eyes with age	Mouth looking associated with expressive language skills
Vatikiotis-Bateson, Eigsti, Yano, & Munhall (1998)	English, Japanese	-	-	-	YES (n = 10)	Video of speaker: English, Japanese, with different levels of masking noise	35-45s	YES: English monol. more variability in gaze patterns than Japanese monol.	-	NO	YES: More mouth when masking noise levels increased	-
Wagner et al. (2013)	Unspecified (English implied)	-	6, 9, 12 (eye-tracking) and 18 (measure of social outcome; longitudinal ; n = 117)	-	-	Still photo images of faces, mother (familiar) vs. stranger (unfamiliar)	10s	-	YES: mouth more with age	-	YES: Eyes = mouth at 6m & 9m More mouth at 12m	Relationship looking to mother's eyes at 6m and measure of social outcome at 18m

Reference	Participants					Methods		Results				
	Monol.	Biling.	Infants (age mos)	Children (age yrs)	Adults	Stimuli	Trial length	Lang. group	Age	Speaker lang.	Eyes/mouth	Link with outcomes
Worster et al. (2017)	English (hearing), British Sign Language (deaf)	-	-	5–8 yrs (hearing n = 29, British Sign Language n = 29;)	-	Videos of speaker (males & females): Single-word, speech vs. no speech	~1s	NO	-	-	YES: More mouth with higher speech reading accuracy More mouth during speech, more eyes when silent	Correlation between social tuning pattern (eyes when silent, mouth during speech) and speech reading accuracy
Young, Merin, Rogers, & Ozonoff (2009)	English; at risk for ASD vs. low risk for ASD	-	6, 12, 18, 24 (longitudinal) (at-risk n = 33; low-risk n = 25)	-	-	Video: Spontaneous face-to-face interaction, <i>Still Face</i> procedure, re-engagement with infant	60s	-	-	-	YES: Less mouth at 6m does not predict development of autism at 24m	More looking to mouth predicts higher expressive language and more growth