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Using latent variable analysis to capture individual differences in bilingual language experience

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Research Article

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Abstract

Bilingualism is an experience that varies across a continuum and can change across the lifespan. Psychometric research is an underexplored avenue with the potential to further our understanding of the mechanisms and traits underlying bilingual experiences. Here, we developed and validated a social network questionnaire to measure sociolinguistic features in 212 individuals via personal social network. Confirmatory factor analysis examined the measurement structure of the variables. Compared to a one-factor model, the best fitting model was a two-factor model in which the language experience of the individual (i.e., ego) and the language experience of the individual's network (i.e., alters) were correlated latent factors under which aspects of the bilingual experience loaded. Additional analyses revealed other potential ways to examine the data in future analyses. These results provide the first measurement model of bilingual experiences, and provide support for theoretical accounts suggesting differential neuropsychological outcomes based on individual bilingual variability. The results also support the use of social network tools to capture differences in bilingualism.

Introduction

The ability to communicate is a ubiquitous experience for humans, from childhood to older age. Societies are increasingly multilingual, with most of the world's population using more than one language (Grosjean, 1982, 2010; Grosjean & Li, 2013). Societies are also increasingly mobile and people often migrate to a different country at different stages of life, with the need to quickly acquire the new community language or culture. Given these statistics, it is expected that a large part of the world has been exposed to more than one language to some degree. For example, today there are 55 countries that have two or more official languages; about two thirds of the world's children are estimated to have grown up in bilingual environments (Crystal, 1997); and there is growing evidence that even those who consider themselves monolinguals often have knowledge of, experiences, and encounters with other languages (Castro et al., 2022). For this reason, recent research has focused on describing bilingualism as a variable experience that adopts different forms (Bialystok, 2010) and that can also change across the life span (Navarro et al., 2022). Specifically, some aspects of the bilingual experience seem to affect different outcomes. For example, Navarro et al. (2022) found that second language use, but not language fluency, is more relevant for performance in a perspective-taking measure. Similarly, Del Maschio et al. (2020) found that the time spent using a second language, but not age of acquisition or language fluency, modulated white matter microstructure in brain structures primarily related to language control.

Despite the ubiquity of bilingualism in our society, most research examining bilingual experiences has traditionally divided samples into monolinguals and bilinguals, ever since bilingualism began to be examined using sound methodology (Peal & Lambert, 1962). Before this, bilingualism was thought to have deleterious effects for intelligence, mostly the result of poor sample matching and language of task administration. The dichotomization of bilingualism was necessary to explore differences between groups, but led to the conceptualization of bilingualism as an all-or-none trait, with little room for variability (Surrain & Luk, 2019). However, the definition of bilingualism has begun to shift in light of recent neurobehavioral models of bilingual language that consider bilingualism as a dynamic trait that varies along a continuum based on traits like use and purpose (Green & Abutalebi, 2013), sociolinguistic diversity, context, background, and culture (DeLuca et al., 2019; Gullifer et al., 2018; Khodos et al., 2021; Marian & Hayakawa, 2021; Navarro et al., 2022).

Critically, to better understand the dynamic nature of bilingualism, it is important to examine the underlying structure of the bilingual experience. Psychometric modeling provides an optimal tool to describe and model individual differences in bilingual experiences. Just like individual differences in cognitive abilities and personality traits are largely studied by creating

and comparing latent variable models (e.g., Engle & Kane, 2004; Kovacs & Conway, 2016; McCrae & Costa, 1997), bilingualism research can benefit from exploring individual variation within the construct. In fact, there have been recent calls to create psychometric models of the bilingual experience to better capture its individual variability (Kašćelan et al., 2022; Kremin & Byers-Heinlein, 2021).

The goal of this study was to describe and compare latent variable models of bilingual experience based on both the speakers' background and that of the individuals who form the immediate personal social network of the speakers, with the goal of empirically testing whether a two-factor model of bilingual experience (where corelated latent factors represent distinct dimensions) was a better representation of the data than a single-factor model. We expected the findings to show how an individual's experience with language(s), and the experiences gathered from their close family environment can be empirically captured by overarching latent factors and provide direct support for a conceptual definition of bilingualism that includes multiple variables related to and involved in an individual's bilingual experience. In addition, we aimed to provide psychometric and theoretical evidence for how social network science can be used to assess and measure bilingual experiences.

Bilingualism as a spectrum

Bilingualism has been traditionally conceptualized as a dichotic phenomenon contrary to monolingualism, especially in fields like neurolinguistics, psycholinguistics, and cognitive science. Most research in these areas compares performance between bilingual and monolingual samples, considering monolingualism largely as a default state and bilingualism an extension of this experience (Hartanto & Yang, 2020). This view largely differs from many areas of psychology (e.g., personality, intelligence, emotion regulation) that study individual differences in performance by examining variance between and within participants. The limited research available examining the extent to which bilingual experiences affect cognitive and neural outcomes hinders the applicability of findings about multilingual speakers.

Largely because of this impediment, in recent years researchers have begun to study bilingual experiences as a multicomponent construct, considering bilingualism as a spectrum (Leivada et al., 2023), and focusing on the degree of variability across language experiences and how that variability influences other linguistic, social, and cognitive abilities (DeLuca et al., 2019; Gullifer et al., 2018; López et al., 2021; Ramírez-Esparza et al., 2020; Tiv et al., 2020b). For example, the well-known Adaptive Control Hypothesis (ACH; Green & Abutalebi, 2013) proposes that neurocognitive engagement depends on the different conversational contexts that bilinguals can engage in. That is, in a single-language context, the two languages are kept separate, while in a dual-language context, the speaker might switch between languages in the course of a conversation, but not necessarily switch within a sentence. Thus, in a dual-language context, the ACH predicts the engagement of neural circuits needed for conflict monitoring and interference suppression. In a dense code-switching context, instead, bilinguals switch languages fluidly within the same sentence. In this context, the ACH predicts an adaptation involving neural regions necessary to mediate the late retrieval and activation of both languages at the same time. Thus, the interactional context of the speaker is thought to adaptively engage different neurocognitive demands.

Some of the predictions made by the ACH model have been validated by studies showing that differential interactional contexts and environments shape bilingual executive functions' recruitment (Beatty-Martínez et al., 2020; Hartanto & Yang, 2020). Following the same trend, multiple studies have also examined the effect of variability in language experience on a number of outcomes. Specifically, work by Tiv et al. (2022a) found that the extent to which someone was a connector among language communities influenced mentalizing performance for individuals who come from highly linguistically diverse regions, but not for those coming from less diverse ones. This suggests that living in areas where bilingualism is commonplace aids individuals exercise their mentalizing ability by constantly tracking others' beliefs (Tiv et al., 2022a). Similarly, Gullifer and Titone (2020) found that individual differences in language experience were related to second language abilities, and these differences were variable among an otherwise homogeneous bilingual group, suggesting that language use and experience can influence commonly studied linguistic outcomes that would not be perceived in traditional groups comparisons. Further, researchers have also found that differences in cognitive control and second language proficiency can influence reading ability differently based on individual differences (Pivneva et al., 2014). Overall, the existing evidence suggests that the bilingual experience and its effects on other neurocognitive outcomes cannot be adequately identified without measuring individual differences in bilingual experiences.

While the emerging research has started to address differences in linguistic contexts and their differential demands on neurocognitive adaptation, less research has focused on the social context and varying functional demands of language use as a relevant source of differences for the bilingual experience (e.g., Marian & Hayakawa, 2021). More concretely, the Complementary Principle (Carroll & Luna, 2011; Chiaro, 2009; Grosjean, 1985, 1997, 2010, 2015) states that bilinguals use their languages for various purposes, across various domains of life, and with various people (Gasser, 2000; Jaccard & Cividin, 2001; Kupisch & Rothman, 2018; Luk & Bialystok, 2013), supporting research that indicates that bilinguals can vary consistently, including the age of acquisition, proficiency, number of languages, frequency of language use, tone, and context, among others (Marian & Hayakawa, 2021). Along these lines, there has been increasing interest in understanding the influence of sociolinguistic experiences derived from one's background on neurocognitive outcomes. In other words, researchers are focusing on the extent to which different factors of a speaker's sociolinguistic background influence performance in behavioral and linguistic tasks, regardless of whether they consider themselves to be bilingual or fully proficient in a second language. There have been promising findings in this area regarding the role of sociolinguistic context for bilingual outcomes, including language use patterns (Titone & Tiv, 2022), language use and engagement (Castro et al., 2022), neurocognitive outcomes (Bice & Kroll, 2019; Gullifer & Titone, 2020), and social cognition (Navarro et al., 2022; Tiv et al., 2022a). This suggests that individual differences in bilingual experience can be relevant for functional language engagement, and therefore that it could be a critical factor in assessing other linguistic (see Cuartero et al., 2023), neurolinguistic, and behavioral outcomes (Titone & Tiv, 2022). Therefore, clearly defining and measuring sociolinguistic factors can provide a broader conceptualization of individuals' bilingual experiences that can reflect more nuanced research findings.

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Social network science approaches to bilingualism

In the methodological realm, efforts have been made to create extensive language and language use experience questionnaires to capture self-reported measures of bi-multilingual experience (e.g., Li et al., 2014; Marian et al., 2007; Rodriguez-Fornells et al., 2012). These widely used and validated tools have provided a foundation for collecting in-depth profiles of bilinguals and their language use and experiences across life stages and social contexts. However, the focus of these instruments is largely on the individual's experience with language, with little information about how they function with those around them This creates a void of information regarding how the different sociolinguistic contexts influence the bilingual experience, including communication behaviors between the individuals and their interlocutors, and/or linguistic and communicative behaviors of interlocutors who interact with the speaker. To address these aspects of the bilingual experience, there has been an increase in the use of network science tools to assess factors involved in language and communication behavior among individuals.

Network science is the study of the pattern of relationships, behaviors, and experiences among social actors. Personal or social network methodologies fall under this broader field. In a social network study, an individual's network refers to a set of actors (or nodes) in their life and the relationships among them (or edges) (McCarty et al., 2019). In PERSONAL social networks, the relationships among an individual (i.e., ego), their personal connections (i.e., alters), and the relationships among them (alter to alter ties) can be examined and compared. Recently, researchers have started to explore how speakers use their languages in different social settings and with different interlocutors (Gullifer et al., 2018; Lanza & Svendsen, 2007), trying to understand variability beyond the individual level. Early on, Milroy (1987) and Milroy and Wei (1995) found that close-knit social networks were related to higher language maintenance in most cultures. Other researchers have since reported some exceptions. For example, David (1996) found that close and dense networks of the Sindhi people in Malaysia showed that language tendencies were moving away from ethnic language. Similarly, Govindasamy and Nambiar (2003) reported that immigrant Malayalee communities with dense networks were nonetheless communicating in English, the language of the host country. Lanza and Svendsen (2007) propose a similar challenge to the importance of dense social networks for multilingual maintenance as a way to preserve identity in multilingual immigrant communities. These studies are a reminder of the strong effect that Western cultural influences have in minority languages and cultures where social networks might not provide sufficient means to preserve language diversity.

In the realm of bi/multilingualism, notably, Tiv et al. (2022b) developed the Systems Framework of bilingualism to understand the bilingual experience from the lens of interpersonal, individual, and social variability. The researchers use social network analysis to identify interpersonal and ecological language dynamics. Using this approach, the researchers found that aspects related to general language use were predicted by the characteristics of the personal networks' language and the linguistic environment of the individuals' neighborhood, while specific language aspects, such as vocabulary proficiency, were predicted by interpersonal networks. In another recent study, Kutlu et al. (2022) used social network analysis to examine how bilinguals' race and ethnicity affect accent perception and speech comprehension for non-standard language speakers. These findings showed that those with less racially diverse social networks were more likely to indicate that an accent was stronger, overall suggesting that attitudes towards bilingualism can be strongly influenced by one's immediate network. Social network analysis has also been used to examine general language skills. For example, Lev-Ari (2022) found that people with larger social networks had more difficulty learning to recognize voices speaking in familiar languages, suggesting that social network size can impact the level of attention paid to the linguistic (as opposed to non-linguistic) markers that differentiate speakers. Other uses of social networks have been directed to examining second language learning in study abroad and mobility contexts (e.g., Paradowski et al., 2021) and the effect of networks for second-language communication stress among migrants (Doucerain et al., 2015).

However, to date, psychometric work examining personal social network analysis applied to the bilingual experience has been scant and is only recently emerging in the literature. Social network research has been traditionally implemented in sociology, linguistics, and economics, among others, while other types of network science, such as psychometric networks are common in the fields of clinical and cognitive psychology. For example, personal social network analysis has been used to examine topics that vary from relationships in the workplace (Van de Bunt & Groenewegen, 2007), to migration flows and processes (Danchev & Porter, 2018; Lubbers et al., 2021), and maintenance of cognitive functioning in aging (Ellwardt et al., 2015). However, there has been little exploration regarding the extent to which social network tools can be used to explore theoretical aspects of the bilingual experience using psychometrically sound approaches. This lack of psychometric work should be addressed to further support emerging evidence from network science for the area of bilingualism.

Psychometric approaches to bilingualism

Research in bilingualism has largely utilized psychometrics to develop and validate tools that assess bilingualism, such as questionnaires and tests (e.g., Anderson et al., 2018; Gollan et al., 2012; Marian et al., 2007) as well as to assess the effect of sociolinguistic background for linguistic knowledge (Wigdorowitz et al., 2020). These are fundamental tools to understand different aspects of being bilingual. However, little to no research has focused on using psychometric approaches to study bilingual models from a theoretical perspective to quantify the knowledge and traits that these tests and surveys measure more broadly. This is possibly related to the fact that bilingualism has not been understood as a psychological trait, but rather an ability or skill that one develops. In other words, it is evident that bilingualism does not CAUSE behaviors like language use or switching. However, the fact that bilingualism is not a psychological trait does not mean that it cannot be studied as an index of one's bilingual experience using latent variable analysis.

A majority of latent variable research of psychological traits focuses on understanding the structure of a given ability based on scores on a given test or tests. The models defined by these analyses are thought to represent a biological system to some extent, such as intelligence, personality, or language ability. However, there are multiple examples of research that uses psychometric techniques to study a psychometric trait, rather than a psychological trait, and many researchers have called for a distinction to be made between the two; a psychometric model that

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explores a certain psychological trait does not necessarily represent a given biological system. A clear example is the field of cognitive ability, where general intelligence or *g* has been the center of investigation for over 100 years. *g* emerges as a result of the shared variance among tasks of cognitive ability when using factor analysis. For this reason, researchers have long considered *g* the root of all cognitive abilities scores and therefore a specific psychological entity. More recently, however, an increasing number of researchers have called into question this assumption by proposing that the psychometric *g* exerted from factor analysis models does not necessitate that a psychological trait *g* exists, but rather that it should be considered an index of ability (e.g., Kovacs & Conway, 2016; van der Maas et al., 2006). In the same way, a factor analysis model of bilingualism could be understood as an index of bilingual experience, but does not imply the existence of a psychological trait. While some research has been conducted using latent variable analysis to explore how different bilingual skills interact with latent factor models of executive functions (e.g., Sanchez-Azanza et al., 2020; Hartanto & Yang, 2020), a theoretical model of bilingual experience that identifies individual differences has not been defined using latent variable analysis. This is not surprising, since bilingualism has been long conceptualized as a dichotomous trait; if a person is either bilingual or monolingual, then any variability is considered noise and not variance within a given ability. The new approaches to understanding individual differences in the bilingual experience described above allow for a psychometric examination of the construct that can support emerging theoretical frameworks.

Indeed, there have been calls for a comprehensive modeling approach to bilingualism. Kremin and Byers-Heinlein (2021) proposed possible models of bilingualism that researchers in the field could explore using psychometrics, including models that combine categorical and continuous representations of bilinguals (e.g., grade of membership models). The researchers also questioned the lack of psychometric research of the theoretical construct of bilingualism and discussed how developing psychometric models of bilingualism can help integrate empirical work on continuous and categorical aspects that have not been addressed before, allowing for a more comprehensive understanding of this complex construct. Similarly, Marian and Hayakawa (2021) proposed the creation of a Bilingual Quotient (BQ) to identify a generalizable and valid index of multilingual experience assessing multiple factors related to it. Understanding the underlying structure of bilingual experiences is especially relevant as some research shows that factor scores derived from bilingual questionnaires present different results than composite scores when predicting neurocognitive task performance (e.g., Champoux-Larsson & Dylman, 2021). Overall, the lack of psychometric modeling work in bilingual experiences is detrimental for understanding the components tapped by bilingual tests and surveys that could be better studied as separate constructs, and for developing accurate theoretical models of bilingual experience that can be used to support existing accounts.

Current study

In this study, we described measurement models of the bilingual experience using latent variable approaches, capturing social and linguistic differences among the participants and the personal social networks collected from members of their immediate family. We expected the model to show how an individual's experience with language as well as the experiences of their family members can be empirically captured by overarching latent factors. In addition, we attempted to provide evidence showing that using social network science for assessing and measuring bilingual experiences is a psychometrically valid and reliable assessment method. Finally, we explored the data collected by framing them within current theoretical perspectives that propose that bilingualism is influenced by multiple factors that can vary and affect outcomes differently. For this, we compared latent variable models to understand whether these data could provide some support for said theoretical frameworks.

Method

Design and participants

An online sample of participants was recruited via email diffusion through colleagues and researchers working across areas of the United States with high linguistic diversity. Over 200 participants completed the survey. The final sample size was N = 212. The participants were part of undergraduate courses at various higher education institutions in Southern California, Texas, and Florida, who completed the study online in exchange for course credit. All participants were invited to participate regardless of bilingual identification to increase diversity. Over 85% of participants reported English as their dominant language, with 9% of participants reporting Spanish as their dominant language, and around 5% reported other languages. Over 43% of participants reported Spanish as their second language, about 13% reported English and 11% reported other languages. About 32% of participants did not report a second language. None reported being color blind and all participants reported having normal or corrected-to-normal vision. Details about the sample are summarized in Appendix A. All participants completed a social network questionnaire tool. Part of the sample completed the questionnaire as part of a study that included other tasks of language and social cognition.

Measures

In this study, a social network questionnaire was constructed following rigorous social network analysis methodology (McCarty et al., 2019) to examine the language experience properties of the participants and their networks. The questionnaire was built using validated language tools available in the literature (i.e., Anderson et al., 2018; Marian et al., 2007; Rodriguez-Fornells et al., 2012), as well as newly developed items, to gather as much information as possible about the language experience, switching tendencies, context, use, and childhood experiences with languages of the participant or *ego*, the members or ALTERS of the ego's immediate family and of the relationships among these alters. The complete survey can be found here: https://osf.io/azmpk/.

Each participant first responded to short demographic questions, including age, gender, and education. Next, participants completed the survey (adapted from LEAP-Q, Marian et al., 2007; and from Anderson et al., 2018), by naming first, second, and other (if applicable) language(s) they know based on dominance and average use, the age(s) at which they began speaking those languages, their cultural identification, and the number of years they have lived in a country where the languages are spoken. Next, they provided percent estimates (on a scale from 0 to 100) of the average use for each reported language among

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different groups (family, friends, etc.) and for different contexts (shopping, work). They then rated their fluency in each language (on a scale from 0–10) and provided information about the languages they used in different life stages, including infancy, high school, and college. Finally, they reported their engagement in language switching across different groups and contexts (adapted from Rodriguez-Fornells et al., 2012). After the participants completed the Ego section of the survey, they began answering the questions regarding the alters and their relationships. The participants were asked to provide the names of up to five members of their family with whom they interact often and were then asked questions about each of them, as well as about each of the relationships among them. As mentioned above, the reasoning for this choice was to gather information about how family relationships with bilinguals can vary and how they may influence bilinguals' language use in childhood and adulthood. For example, if a participant named an alter as "Mom", they were then asked to provide the language(s) they speak with "Mom", the language(s) they spoke with "Mom" as a child, and whether they switch languages when speaking with "Mom". After the participant answered all questions about each of their alters, they were asked questions about the alter ties. For example, a participant would be asked to indicate whether "Mom" and "Dad" talk to each other in the present and during the participant's childhood, what language(s) they use, and whether they switch languages now and in the past. The participants answered these questions for each alter pair available (e.g., "Mom and Dad", "Mom and Sister", "Dad and Sister"). Responses to these questions were then grouped and aggregated based on themes, following a composition approach to social network analysis. In personal network research, we can talk about network composition and network structure. Network composition are the characteristics or attributes regarding the members of a given network, such as the family members of the participants. On the other hand, network structure refers to elements regarding the network itself, such as size. Two different networks can differ in either structural and/or compositional features depending on the subject of study (McCarty et al., 2019). To estimate compositional characteristics of a network, we can group questions regarding a specific topic (e.g., language switching). For this, we summarize characteristics depending on the research questions and interests. For example, in their guidelines for conducting network research, McCarty et al. (2019) propose averaging continuous or discrete variables (e.g., age) based on mean or median, estimate relationships among alters based on a given characteristic (i.e., ego correspondence) by examining the mean difference between an alter and the ego, or summarizing groups of variables that target the same topic to obtain the overall score of a compositional attribute. Depending on the goal of the analysis, multiple variables can be combined. For example, McCarty et al. propose calculating the average "closeness to one's network" by combining two variables (the reported closeness of an alter and the ego and the alter's place of residence) to study a migrant's level of acculturation. In this sense, compositional variables are a way to understand the effect of related alter-level variables with a given outcome, such as estimating childbearing intentions among young married women by calculating the total or average number of friends, the number of contacts of the same sex as the ego, and reported childbearing intentions of an ego's network. Other compositional variables that can be obtained include ego correspondence or geographical dispersion, among others.

Another set of outcome variables that are commonly studied in network science are structural variables. As mentioned, structural variables can help create variables that quantify aspects related to the connectivity among network members and are extracted from alter ties. These metrics are designed to capture specific aspects of the network structure, including density (i.e., how many ties exist out of all possible ties) or other more specific metrics, such as degree of centrality, closeness, betweenness, among others (for a complete review, see McCarty et al., 2019). These metrics are calculated using specialized software and can be used to answer questions related to aspects of a network for a certain behavioral or social outcome.

In this study, we focused on extracting and examining compositional variables of the members of the network. The reasoning behind this decision was based on the original conceptualization of the study: to understand whether attributes of someone's bilingual experience (number of languages, proficiency, number of bilingual relationships…) adequately load on a specific bilingual factor. In other words, whether these aspects of one's experience are related to the same overarching factors. In addition, because our focus was on relationships among family members with whom the participants have contact relatively often (i.e., there is active communication) as well as understanding these relationships in childhood (i.e., what the structures of bilingual communication in childhood and at present look like), the survey items were constrained to the extent of the research question and were less exploratory than other personal networks. For this reason, structural variables are less likely to be informative in this case. For example, network size and density will be rather homogenous, as we required participants to come up with members of a specific subgroup of their network and had an upper limit to control length/time of the survey, but also to ensure reliability of responses (how many family members one talks to on a regular basis).

Along these lines, we calculated multiple variables based on the questions asked in the survey, and grouped those variables based on their belonging to overarching topics or themes. The questions included in each variable can be found in Appendix B. By collecting the responses from different sociolinguistic levels, we expected to capture different aspects that can influence an individual's experience, above and beyond information regarding their individual current language use. As mentioned, the focus of this analysis was on immediate family members with whom the participants maintain communication so as to look at relationships among people with whom they may speak in different languages, code switch, and have encountered since childhood. However, note that including additional social groups may result in additional latent variables which may be of interest for future research. This approach has the potential to provide a deeper understanding of the dynamics of bilingual experience from an individual differences perspective that does not dichotomize participants based on any given variable. The complete survey included over 100 items asking questions about the ego, alters, and alter ties and is available here: https://osf.io/azmpk/

Procedure

Over 200 participants were invited to participate in the study via recruitment emails sent to researchers and professors in the United States. A subset also completed other cognitive and linguistic tasks as part of a wider study (N = 89). A total of 225 participants were offered course credit in exchange for participation.

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The study was conducted fully online and asynchronously as it was shared across states with high linguistic variability in the United Stated in an attempt to obtain as wide a range of responses as possible in terms of bilingual experiences. The students were largely based in higher education institutions in Southern California, Texas, and Florida. The students were first directed to a landing page created by the researchers to explain the purpose of the study, as well as provide instructions on how to complete the study. Participants completed the network questionnaire via links available on the website. At the end of the study, participants were directed to a separate survey where they entered their personal information to obtain credit. Data from 209 participants were included in the study. All responses were anonymized and de-identified. The approximate time commitment was 30 minutes.

Analysis

In this study, we sought to examine COMPOSITIONAL aspects of the personal social network of individuals. As mentioned, compositional variables refer to items that assess participants' attributes or characteristics. In this study the goal was to examine, from a theoretical perspective, the extent to which meaningful attributes of an individual's network can be represented using theoretically sound constructs. However, note that structural aspects of the network may be more suitable to answer a different research question or when used to examine a network with different constraints.

The calculated scores (see Appendix B) were entered in the analysis. The variables included at the ego level were: the number of cultures, the total number of languages, the average use of the second language, the total number of languages reported throughout the lifespan, and the average time spent switching between languages when speaking with others. For the alters, the variables included: the number of languages among alters and ego, the languages spoken between ego and alter in childhood, the average amount of language switching when speaking with alters, the number of languages the alters speak among themselves presently as well as in the ego's childhood, and how often the alters switch languages with each other (see Table 1).

Confirmatory factor analysis (CFA) is a technique used to test and estimate relationships among observed and unobserved variables to construct a measurement model. The measurement model can be used to assess whether tests that measure a construct are consistent with the theoretical definition of the construct of interest. To examine whether a construct is adequately being measured, the fit of the model to the data can be tested. The measurement model tests whether the observed variance-covariance matrix is equal to the variance-covariance matrix implied by the model. To decide whether a model fits the data, multiple fit indices are observed. Fit indices consider the fit of the model relative to the saturated model (where all relations are specified) or the null model (where no relations are specified). According to Kline (2015), adequate models should have a chi-square to degrees of freedom ratio lower than 2, a Comparative Fit Index (CFI) greater or equal to .90, a Standardized Root Mean Square Residual (SRMR) lower or equal to .08, and a Root mean square error of approximation (RMSEA) between .05 and .10 (Kline, 2015). In addition, factor loadings should also be examined. Factor loadings represent the relationship between the manifest variable and the latent factor. Although ideally factor loadings should be above .60, most psychological tests tend to present loading values of between .30 and .60. When several models are being compared, model comparison indicates whether the models are significantly different, indicating that one of the models represents the data more adequately. CFA also requires the selection of an estimation algorithm to compare iterated sets of values. This allows to minimize the difference between the observed and implied correlation matrix. The robust maximum likelihood (RML) algorithm was used in this study, as it is a conservative estimator recommended for multivariate non-normal data. Empirical evidence has shown that RML leads to higher numerical robustness and can naturally and easily estimate non-zero initial conditions with low computational cost (Gibson & Ninness, 2005).

Table 1. Descriptive statistics ($N = 209$)

	Mean	SD	Median	Min	Max	Skew	Kurtosis
Ego Cultures	1.68	0.84	1.00	0.00	4.00	1.03	0.50
Ego Languages	1.79	0.68	2.00	1.00	4.00	0.83	1.38
L2 AoA	2.99	4.04	2.00	0.00	28.00	2.46	8.98
Ego L2 Use	31.76	33.32	19.14	0.00	100.00	0.57	−1.19
Ego Languages Lifespan	1.12	0.42	1.00	0.00	3.57	2.16	9.80
Ego Switching	1.03	0.82	1.00	0.00	3.18	0.45	−0.58
Alter Languages	1.06	0.35	1.00	0.00	2.00	0.00	0.83
Alter Languages Childhood	0.81	0.43	0.80	0.00	1.80	-0.05	−0.46
Alter Switching	0.39	0.37	0.40	0.00	1.00	0.38	−1.33
Alter Ties Languages	0.91	0.38	1.00	0.00	2.00	-0.28	1.02
Alter Ties Languages Childhood	0.59	0.36	0.60	0.00	1.50	0.15	−1.02
Alter Ties Switching	0.19	0.22	0.10	0.00	0.90	1.20	0.71

Note. Ego Cultures = Culture(s) reported by participant; Ego/Alter Languages = language(s) spoken by participant and participant's alter respectively; L2 AoA = age of acquisition of reported second language; Ego L2 Use = average use of reported second language; Ego/Alter Switching = average language switching by participant and participant's alter respectively; Alter Languages Childhood = languages spoken by alters during participant's childhood; Alter Ties Languages/Languages Childhood = languages spoken among alters presently and during participant's childhood respectively; Alter Ties Switching = language switching among alters.

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Results

Data cleaning procedures

No missing data were identified. Multivariate outliers were identified by generating Mahalanobis distance terms for each case (Tabachnick et al., 2013). In total, 2 cases were identified as having a Mahalanobis distance greater than the associated critical value, (e.g., χ 2 (31) = 61.09) and were deleted list-wise. Univariate and multivariate normality were assessed by examining skewness and kurtosis values and conducting tests designed to assess multivariate normality. No measures in the original dataset demonstrated violations to univariate normality due to extreme values of skewness (more extreme than ±3.00) and kurtosis (more extreme than ±10.00) (see Table 1); nevertheless analysis showed that the variables did not present multivariate normality based on Mardia test (Mardia, 1970) and q-q plots. For this reason, all analyses were conducted using an estimator that does not require the normality assumption and is most adequate for survey data (i.e., weighted least squares). Finally, variance inflation factors (VIFs) for all of the variables were less than 5, indicating that there was no problematic multicollinearity (James et al., 2013).

In this study, CFA was used to a) assess the construct validity of the survey, and b) to examine whether a single-factor model compared to a two-factor model better explained variance among tasks, by comparing model fit and loading paths. Data from 212 participants were used. Descriptive statistics and correlations are presented in Tables 1 and 2. Data and scripts are available at: https://osf.io/9hjkm/. The reliability of the social network tool was assessed using Cronbach's *alpha* (Cronbach, 1951) for internal consistency. Cronbach's alpha is a function of the number of test items and the average inter-correlation among the items. Overall, the higher the inter-item correlation, the higher alpha if the number of items stays constant. In most social science research, a reliability coefficient of .70 is considered acceptable, but attention must be paid to each individual instrument. The test indicated that the reliability of the questionnaire was moderate to high (alpha = .82, 95% CI =.78, .86). However, Cronbach's alpha has received criticism because it can be influenced by the number of items on a scale and is subject to multiple assumptions, including using continuous items with normal distributions, equal item contribution to the overall test, and uncorrelated errors, often rendering lower estimates than in reality among other methodological issues (for a detailed review, see McNeish, 2018). For this reason, we also conducted an Omega (ω) composite reliability (McDonald, 1970, 1999), a recommended measure of composite reliability where items vary in terms of the strength of the relationship to the overall construct being measured, avoiding the assumptions of Cronbach's alpha. The Omega total score produced a similar estimate to Cronbach's alpha (ω = .88), suggesting an overall adequate reliability of the instrument.

Main analyses

Two CFA models were specified. The first model, Model 1, was a one-factor model where all manifest variables were predicted by a single general bilingual experience construct. Model fit indices are presented in Table 3. Generally, Model 1 presented poor fit based on Kline's fit indices described above, with no indices within standard ranges. While the fit indices presented a poor model (see Table 3), the standardized factor loadings were overall adequate (see Figure 1a). This indicates that, as expected, a model with a single factor does not adequately represent the data and therefore a single bilingual ability is not a good fit for the measures collected.

Model 2 was conducted next to examine whether, as hypothesized, a two-factor model of bilingual experience with two latent factors (ego experience and alter experience) provided an adequate fit for the data. The items corresponding to questions about the ego's language experience were loaded onto a latent factor "Ego" and the items about the ego's experience with their network were loaded under a latent factor "Alter".

Table 2. Bivariate correlations (N = 209)

	1	2	3	4	5	6	7	8	9	10	11	12
1. Ego Cultures	–											
2. Ego Languages	**0.22**	–										
3. L2 AoA	−0.06	**0.37**	–									
4. Ego L2 Use	**0.14**	**0.49**	**0.31**	–								
5. Ego Languages Lifespan	**0.12**	**0.24**	0.01	0.04	–							
6. Ego Switching	**0.28**	**0.58**	**0.32**	**0.55**	**0.16**	–						
7. Alter Languages	**0.24**	**0.31**	0.03	**0.26**	**0.25**	**0.43**	–					
8. Alter Languages Childhood	**0.25**	**0.26**	−0.01	**0.20**	**0.17**	**0.27**	**0.51**	–				
9. Alter Switching	**0.30**	**0.51**	**0.12**	**0.47**	**0.19**	**0.73**	**0.58**	**0.40**	–			
10. Alter Ties Languages	**0.17**	**0.16**	−0.04	0.10	**0.28**	**0.19**	**0.64**	**0.40**	**0.31**	–		
11. Alter Ties Languages Childhood	0.09	0.03	−0.04	0.00	**0.12**	0.02	**0.46**	**0.63**	0.09	**0.53**	–	
12. Alter Ties Switch	**0.20**	**0.34**	0.03	**0.38**	**0.18**	**0.52**	**0.51**	**0.42**	**0.70**	**0.41**	**0.33**	–

Note. Ego Cultures = Culture(s) reported by participant; Ego/Alter Languages = language(s) spoken by participant and participant's alter respectively; L2 AoA = age of acquisition of reported second language; Ego L2 Use = average use of reported second language; Ego/Alter Switching = average language switching by participant and participant's alter respectively; Alter Languages Childhood = languages spoken by alters during participant's childhood; Alter Ties Languages/Languages Childhood = languages spoken among alters presently and during participant's childhood respectively; Alter Ties Switching = language switching among alters. Bold indicates a significant correlation.

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Table 3. CFA Fit Indices.

Fit Indices	χ^2	*df*	x^2/ *df*	CFI (TLI)	RMSEA	SRMR
Recommended fit (Kline, 2015)			≦2	≧.90	≦.08	.05 – .10
Model 1: One factor	388.13	54	7.18	0.63 (.55)	0.180	0.127
Model 2: Two-factor model	175.86	45	3.91	0.86 (.79)	0.124	0.10
Model 3*: Hierarchical model	171.96	44	3.91	0.86 (.78)	0.125	0.11
Model 4*: Uncorrelated two-factor model	388.93	48	8.10	0.65(.51)	0.188	0.23
Model 5*: Three-factor model	165.89	43	3.86	0.87(.80)	0.119	0.099

Note. * = additional models.

Both latent factors were allowed to correlate as they were expected to be related. Fit indices for Model 2 are summarized in Table 3. Overall, Model 2 presented an excellent fit to the data (Table 3). Factor loadings ranged between good to excellent values (see Figure 1b). All indices were within or close to excellent fit. Compared to Model 1, Model 2 presented a better fit across all indices. The correlation between Ego and Alter latent factors was strong (.81). These results indicate that a two-factor solution presents an overall adequate fit to the data. Model comparison between Model 1 and Model 2 revealed that Model 2 was indeed significantly better than Model 2 (X^2 (45,54) = 216.56, p = <.001).

Overall, the results suggest that a two-factor model of bilingual experience was the best fit for the data collected by the social network tool. These results align with our original hypothesis that proposed that bilingual experience is better represented by related but distinct aspects of one's sociolinguistic network.

Additional analyses

While our goal was to compare measurement two models theorized *a priori*, after specifying the two models above, we considered additional models as potential explanation for the structure of the data. First, a hierarchical model (Model 3) with Bilingualism was estimated as a different approach to understanding the variance shared by the Ego and Alter latent factors. Theoretically, this model could indicate that while in our survey there are two latent factors representing the bilingual experience of the Ego and the Alters, the variance shared by these two sets of measures could be explained by an overarching general factor of bilingual experience and therefore suggest that both of these sets of manifest variables could be explained by a third-tier factor. We therefore specified a model where a hierarchical Bilingual Experience factor was the cause of the shared variance among Alter and Ego, which at the same time were specified as in the

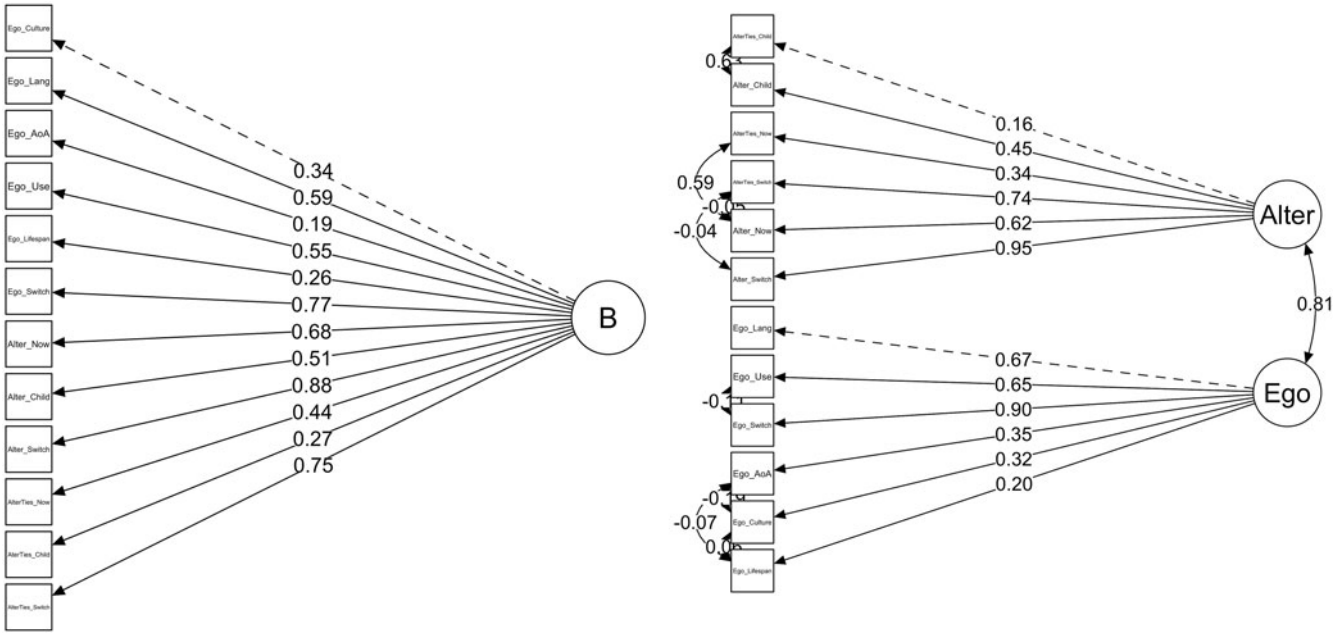

Figure 1. Main models. (a) One-factor model (Model 1). Standardized factor loadings are presented. All loadings were within adequate range (>.30) All variables load onto the same Bilingual latent factor (B). (b)Two-factor model (Model 2). Standardized factor loadings are presented. Most loadings were within adequate range (>.30. Variables were loaded either onto an *Ego* latent factor or *Alter* latent factor.

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bi-factor model. The results of Model 3 showed adequate fit indices (Table 3), similar to those of the bi-factor model; however, there was not a statistical difference between the bi-factor and hierarchical model ($p > .05$). Since the bi-factor model was the most parsimonious of the two, we favor the bi-factor model over the hierarchical when comparing the two (Figure 2a).

The goal of the study was to confirm the measurement model of the personal network survey and compare measurement models to explore theories of bilingual experience that consider individual differences. Thus, the analyses were based on the assumption that a two-factor model would be different from a one-factor model. However, because the personal network survey used in this study has only been applied in one other study (Navarro et al., 2022), it is also possible that the underlying structure may fit the data differently than hypothesized. This can be exploratorily examined via Exploratory Factor Analysis (EFA). EFA is a technique used to understand whether data are indeed a good representation of the measurement model constructed in the CFAs. Ordinarily, an EFA could be constructed to estimate whether the questions or items in a survey or task are measuring the same underlying dimension by examining to what extent groups of items share the same variance. Just like CFA, EFA requires a large sample size; nevertheless, it is not considered good practice to first conduct EFA on the same data that will next be introduced in a CFA (Kline, 2015). This is because data that have been exploratorily tested using EFA will likely provide a good fit to the measurement CFA model constructed based on that same EFA. Instead, latent variable guidelines indicate that CFA should be conducted on a different data set or that data should be divided into two sets (an exploratory set and a confirmatory set). Because the sample size in this study did not include sufficient data points to split the data sets while retaining sufficient power to conduct the CFA, we instead decided to conduct one *post hoc* EFA to examine potential incongruencies in our original hypothesis that could explain how to improve the fit of the models.

Parallel analysis, elbow plot, and eigenvalues were used to determine the number of factors that should be retained. Parallel analysis creates a random data set with the same number of observations and variables as the original data and eigenvalues are computed for the randomly created dataset. Then, the randomly generated eigenvalues are compared to the observed eigenvalues. Because the random eigenvalues mostly represent random noise, only those factors that fall outside the random eigenvalues are retained. The solution provided by the parallel analysis should be followed to avoid biased generation of factors when exploring the data. The parallel analysis suggested that two factors should be retained (eigenvalue for factor 1 = 3.49, eigenvalue for factor 2 = 2.26, eigenvalue 3 = 0.165) (see Appendix C). Thus, we conducted the EFA with two specified factors using an Oblimin rotation.[1] As is customary, all variables with loadings greater than 0.30 were considered to load on a given factor. Weighted least squares was used as the factoring method. The results showed that all alter-related variables loaded onto Factor 1 and all ego-related variables loaded onto Factor 2. However, two variables (Alter Languages and Alter Switching) presented loadings over .30 on the Ego Factor, suggesting some overlap between the two factors. This could indicate that a third factor (Switching) could be measured separately if more switching manifest variables are collected, and that bilingual switching experiences as a whole can potentially represent a latent factor of their own. Overall, the results of the EFA largely support the structures compared in the CFAs.

Based on the results of the EFA, we decided to conduct two additional models. While we believe these models can be informative of the structure of the data obtained from the social network questionnaire, we are cautious to make strong claims from these findings, as these were not models originally hypothesized. The two models tested are a two-factor model with uncorrelated latent factors (Model 4), and a three-factor model with a language switching latent factor (Model 5). Model 4 could help further understand the relationship between the Ego and Alter factors while Model 5 could show whether language switching variables should in fact be considered separately from Ego and Alter factors, as hinted by the EFA.

Model 4

The two-factor solution with uncorrelated factors provided a poor fit to the data (Table 3). In addition, multiple manifest variable path loadings presented Heywood cases (Figure 2b), overall indicating model misspecification (Farooq, 2022). This suggests that the strong correlation between latent factors likely represents the expected shared variance among manifest variables that overall belong to the same survey themes. While strongly correlated, both fit indices in Model 2 and EFA show the independence of the factors, indicating highly related (bilingual traits) that are nonetheless separate sets of experiences. This instance is exemplified by the well-known relationship between general intelligence (*g*) and SAT/ACT scores. While these indices of mental ability have shown strong correlations with *g* in latent variable and experimental analyses, they are not considered interchangeable and they are thought to represent different aspects of cognitive ability that share domain-general sampling processes but tap different domain-specific processes (Coyle & Pillow, 2008; Kovacs & Conway, 2016).

Model 5

The three-factor solution included the Ego and Alter factors, as well as a third Switching latent factor made of the Ego Switching, Alter Switching, and Alter Ties Switching variables. The model presented overall adequate fit indices (Table 3) and model comparison indicated a small significant difference from Model 2 (X^2 (43,45) = 8.76, $p = .012$). However, the model presented a Heywood case (Figure 2c), possibly indicating the need to include more manifest variables or a model misspecification (Farooq, 2022). These models are further discussed below.

Discussion

The goal of this study was to examine the structure of bilingual experience from a psychometric modeling perspective to understand the structure of bilingualism as a construct. More specifically, we had three goals: first, we attempted to describe the first psychometric measurement model of bilingual experience using advanced psychometric modeling based on language experiences from speakers as well as their immediate personal social network; second, we presented the first piece of evidence showing that using social network science for assessing and measuring bilingual experience is a psychometrically valid and reliable assessment method; and third, we compared psychometric models of bilingual experience to explore the increasingly common claim that bilingualism is better understood as a multicomponent variable trait, rather than a dichotomous outcome.

The results of this study have multiple implications. First, this study presents the first psychometric model of bilingual experience that represents a theoretical model of bilingualism. In the future, this two-factor model can be further improved and used in combination with other tasks of neurocognitive and linguistic

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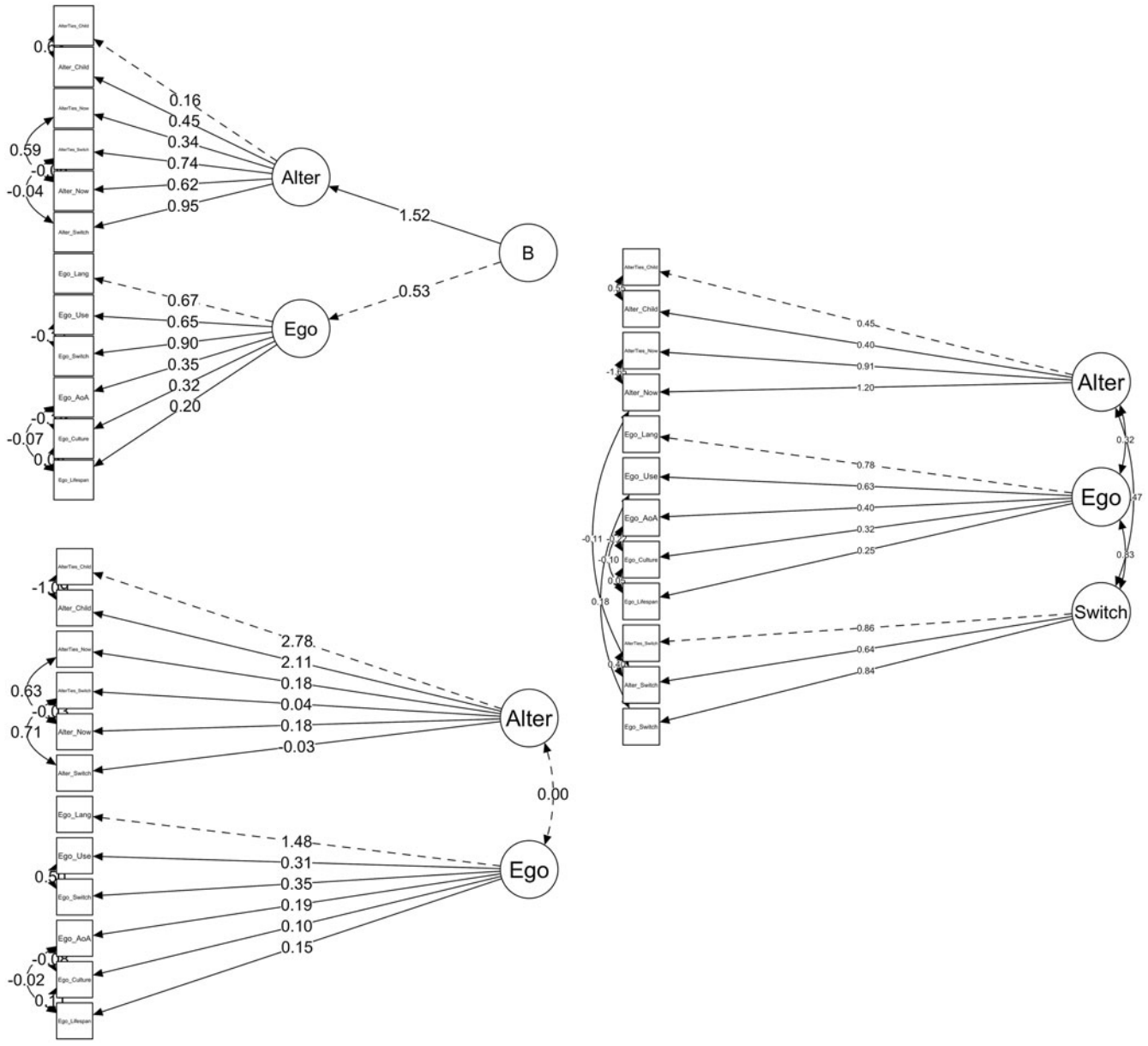

Figure 2. Additional models. (a) Hierarchical model (Model 3). Standardized factor loadings are presented. Manifest variable loadings were within adequate range (>.30), however the path between the hierarchical factor and the Ego factor was > 1. Variables load onto second-order factors that in turn load onto a hierarchical factor. (b) Uncorrelated two-factor model (Model 4). Most variable presented either low loadings or path loadings >1. (c) Three-factor model (Model 5). Variables were loaded onto Ego, Alter or Switch latencies. Manifest variable loadings were within adequate range with the exception of *Alter Now* (>1).

ability to create predictive models that assess bilingual experience using, for example, structural equation modeling. The model also provides a theoretically meaningful representation of the structure underlying bilingual experience, which is key to understanding variations in bilingual experience, and its effects on other cognitive and social outcomes. The model demonstrated that an individual's bilingual experience is better represented by their linguistic experience in combination with the linguistic experience of their personal social network. In fact, this model presented a good fit to the data and was superior to a single-factor model. This has implications for theoretical accounts of bilingualism and current research using social networks as a proxy of bilingual experience.

Further, additional models corroborated these findings and provided an avenue for future modeling research. Specifically, the *post hoc* EFA suggested that some switching variables loaded on both factors, which may indicate that Switching-related variables may be more adequately measured as a separate factor. This was supported by Model 5. Although Model 5 presented a Heywood case that should be addressed in future research, the model seemed to present a slight improvement to Model 2. Generally, it seems likely that switching between languages in itself is not an innately person-specific or family-specific quality of bilingualism but rather an altogether separate dimension of being bilingual whose use may affect specific linguistic and psychological outcomes that other Ego/Alter items aren't necessarily involved in. Future research should further investigate this possibility with additional switching variables and a larger sample size.

In terms of its impact for bilingualism theory, these findings add to a growing body of literature indicating that there is

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specificity of neurocognitive adaptations to different language experiences or subcomponents of bilingualism that in turn affect domain-general cognitive outcomes. For example, the ACH model of bilingualism described above (Green & Abutalebi, 2013) proposes that neurocognitive engagement depends on the different conversational contexts in which bilinguals can engage. These findings suggest that there are individual differences in conversational partners and styles that form someone's bilingual experience. Thus, a person who has a specific bilingual profile along the variables measured in this study could present different neurocognitive performance compared to a person with a different bilingual profile. By studying bilinguals along their individual profiles, the predictions made by the ACH can be studied in more detail. The predictions made by the ACH are also partly supported by the model comparison conducted in this study. The models tested and compared show that when a model is specified where a single latent factor (i.e., bilingualism) is estimated as the source of variance among all items, the model does not provide a good fit to the data compared to a two-factor model where separate components account for the variance among the latent factors. The significant difference between the models indicates that considering bilingualism as a single trait does not adequately capture the nature of the construct. This indicates that unlike other constructs in psychology that do fit a single-factor model, such as intelligence or personality, bilingual experience as measured in our study was not better represented by an overarching bilingualism construct. These findings are also in line with the UBET framework (DeLuca et al., 2020). The UBET framework posits that two subcomponents of bilingual experience (intensity and diversity of language use and language switching) contribute to greater requirements of executive control systems/processes to handle the associated cognitive load with these experiences. While this study did not examine the relationship of the model to neurocognitive tests, the emergence of the two-factor model as the best fit for the data, suggests that there are individual differences in language switching and use, and these traits are subcomponents of an overarching latent factor.

In addition to their contribution to theoretical perspectives on bilingualism, these findings also support new methodological approaches to studying bilingual experience. First, the findings of this study align with calls for validation of an index of multilingual experience that accounts for bilingual variability within and between participants (Baum & Titone, 2014; Kaushanskaya & Prior, 2015; Luk, 2015; Marian & Hayakawa, 2021). Specifically, these results present the first index of bilingual experience accounting for individual differences in items that assess bilingual use, performance, and experiences across linguistically diverse speakers. The results of the model support the possibility of a Bilingual Quotient as proposed by Marian and Hayakawa (2021) that could potentially be used as a predictor of performance in subsequent models. Further, by examining differences in item responses using latent variable analysis, the findings show that there are individual differences in bilingual experiences whereby aspects of someone's language experience (e.g., language use with relatives, language switching, or multicultural experience) can be linked to an overarching construct of familiar experiences with language. This further supports models like the ACH model discussed above. Specifically, by proposing that differences in the degree and manner of engagement with a language can have different outcomes at the behavioral level, the ACH model implies a certain degree of individual variability must exist to observe differing consequences of bilingual experiences. In addition, measurement techniques constitute an avenue to advance theoretical accounts that have been underexplored in bilingual research. Unlike fields like cognitive and social psychology, little research has used this approach to study bilingualism and neurocognitive outcomes, despite its potential to help inform future research (Kremin & Byers-Heinlein, 2021).

Another methodological contribution of this study is the validation of network science as a tool to identify variability in bilingual experience, beyond the speakers themselves. A growing body of research examines how social networks are related to different socio-linguistic and cognitive outcomes. For example, Tiv et al. (2020) identified differences in language use and topic selection based on linguistic and communicative context among bilinguals in Montreal. Similarly, Tiv et al. (2022b) used personal social networks to identify differences in a mentalizing task between bilinguals living in socio-linguistically diverse settings and Navarro et al. (2022) found that variables derived from this social network differentially predicted performance in a perspective-taking task. The findings of the current study show that the present personal social network questionnaire is a valid and reliable measure to explore the overarching latent construct of bilingual experience, providing support for the methodologies used in these studies and the findings derived therein. Of course, in order to apply the present social network questionnaire to other bilingual contexts or specific bi/multilingual environments, ad-hoc modifications will be needed, depending on the specific research questions.

This study is not without limitations. Since this psychometric study of bilingual experience is the first to our knowledge, the results of the current models should be further validated in new datasets and with additional tests that have been shown to be relevant for bilingualism, such as language proficiency. In addition, the current model should be further tested in predictive techniques, using tools such as structural equation modeling, to understand if this model supports predictions made by theoretical models of bilingualism, such as the ACH. In addition, in this study we tested a two-factor model that contained questions that were largely divided into two categories (alter-focused questions and ego-focused questions). This original division of the instruments may influence the model fit of the two-factor model, not because the bilingual experiences of the participants can be explained as a bidimensional construct, but because the questions were pre-determined to focus on two different dimensions of bilingualism. We believe that the additional EFA conducted shows that while these items belong to two different factors, there is overlap among some of them (e.g., switching), thus possibly indicating that the division in two constructs is not fully due to the design of the instrument. Further, it should be reiterated that limiting social network alter generation may constrain the collection of information of the participants' experience. While the goal of this study is to focus on the effects of one's family on the bilingual experience from childhood to early adulthood, the upper limit on the number of alters likely reduces the potential experiences of the participants with other members of the community that should be further studied in models of bilingual experience.

It is worth noting that the models where the latent factors were allowed to be correlated presented pretty high correlations. Theoretically, the two exogenous factors were expected to be correlated. On the one hand, as mentioned above, the items of the survey represent responses to questions regarding language use and tendencies among members of a family and within an individual so it is to be expected that they correlate pretty strongly. However, multicollinearity and diagnostic tests did not show

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problematic values that could be responsible for the correlation. In this study, we were interested in trying to show that both of these bilingual dimensions are not necessarily captured by just targeting one dimension (Ego) as has been traditionally done in bilingualism research. While related, there are aspects of language use, acquisition, performance, proficiency, and tendencies that may be similar across individuals (Ego) but different among the individuals' family units. This entire other realm of what it entails to be bilingual in a social context and how that realm can influence other psycholinguistic outcomes is largely unknown. By emphasizing the difference between both the individual (Ego) and family-context (Alter) factors, despite being strongly correlated, we aim to bring attention to the need to include the Alter dimension in research and theory. This is not dissimilar from approaches in traditional research on intelligence, where the well-known strong relationship between general intelligence (*g*) and SAT/ACT scores is not thought to represent an interchangeable index of mental ability but rather that they represent different aspects of cognitive ability that share domain-general sampling processes, but tap different domain-specific processes (Coyle & Pillow, 2008; Kovacs & Conway, 2016).

Overall, the current findings provide evidence for theoretical models of bilingualism that propose differences in performance outcomes based on a speaker's bilingual variability by using a psychometric approach to modeling bilingual experience. The study also provides evidence for multivariate methodological approaches to bilingualism, such as network science, providing support for this increasingly popular tool for assessing bilingual experience. Finally, the study provides empirical evidence for the current trend among researchers of bilingualism that increasingly considers the variability within bilingualism as a way to understand performance in sociolinguistic and cognitive outcomes.

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Competing Interests Declaration. The authors declare none.

Note

1 Extraction techniques produce factors that are orthogonal and atheoretical. Rotation allows the transformation of the factor loadings, so they become more interpretable. Oblimin is an oblique (as opposed to orthogonal) rotation technique, therefore it allows the factors to be correlated (which is often the case in psychological studies.

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APPENDIX. A Sample Demographic Details ($N = 209$).

	Mean	SD	Frequency
Age	25.26	6.95	
Female			85%
Male			14%
Third gender/non-binary			1%
Some college/high school diploma			43%
Associate Degree			51%
Bachelor's Degree			6%
AoA L1	1.26	1.35	
AoA L2	4.56	4.21	
Speaks only L1			6.5%
Speaks L2			85.7%
Speaks > L2			7.8%
Years living in L1 country	19.49	9.63	
Years living in L2 country	18.9	10.69	
Single Culture			49%
Multicultural			51%

Note. L1 = reported first language. L2 = reported second language, AoA = age of acquisition.

APPENDIX. B Description of items derived from survey.

Variable	Survey Items	Computation
1. Ego Cultures	Name the culture(s) you identify with […]	Total reported
2. Ego Languages	List all the languages you know in order of dominance	Total reported
3. L2 AoA	At what year did you begin acquiring your second language?	Total reported
4. Ego L2 Use	What time do you spend using Language 2 on average in the next contexts: Friends, Family, Coworkers, School mates/roommates, Extracurricular activities, Religious activities, Shopping/ restaurants	Average across all contexts
5. Ego Switching	[…] Please indicate how often you engage in language-switching […]: With parents (Never-Always), With siblings (Never-Always), Other family members (Never-Always), With friends (Never-Always), With coworkers (Never-Always).	Average across all groups
6. Alter Languages	What language(s) do you speak with [Alter] every time you speak? Please list all the languages if more than one.	Average across all alters
7. Alter Languages Childhood	If you did speak with [Alter] as a child, what language(s) did you speak with him/her?	Average across all alters
8. Alter Switching	[…] Do you switch between the languages you speak while talking to [Alter]?	Average across all alters
9. Alter Ties Languages	[…] Think of the times (if any) that you have seen Alter1 and Alter2 speak to each other: what language(s) where they speaking?	Average across all alters
10. Alter Ties Languages Childhood	[…] in what language did Alter1 and Alter2 talk to each other when you were younger?	Average across all alters
11. Alter Ties Switch	[…] Think of the times (if any) that you have seen Alter1 and Alter2 speak to each other. Do they ever switch between languages?	Average across all alters

Note. For the full version of the items, see the complete survey available at: https://osf.io/azmpk/

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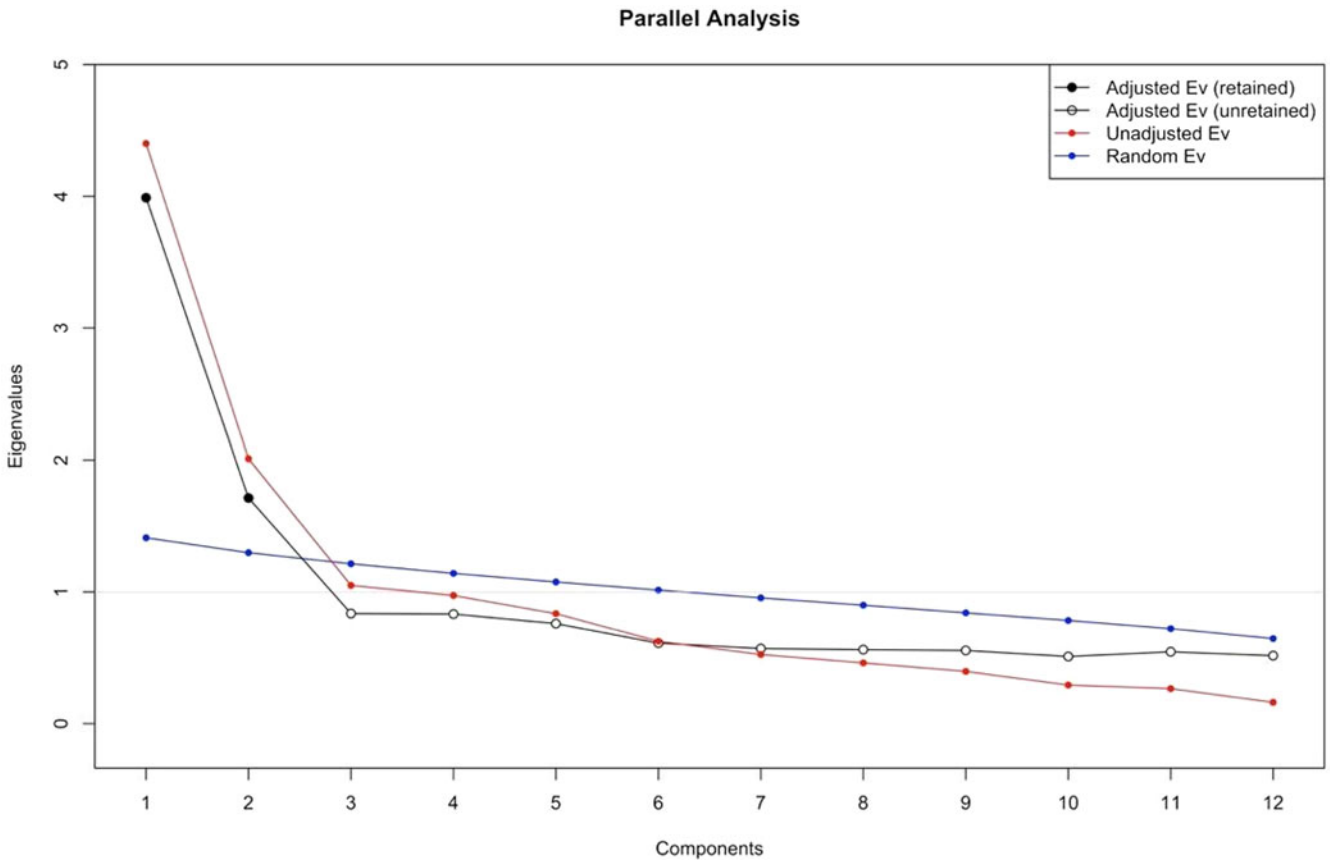
APPENDIX. C Results of *post hoc* parallel analysis.



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