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Verbal Fluency Development Across Childhood: Normative Data from Brazilian–Portuguese Speakers and Underlying Cognitive Processes

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Abstract

Objective: Verbal fluency (VF) tasks are widely used to investigate children's lexical knowledge and executive functions skills. Consistency of measurement of the strategic retrieval components is still an issue and performance of Brazilian–Portuguese speaking children are currently not available. A cross-sectional study investigated the effects of age, school type (public × private) and the influence of language, memory and inhibitory control on VF.
Method: We assessed 414 Brazilian children, aged 6–12, in the number of words produced and both clustering and switching components, with two measures of VF: letter (LVF) and semantic (SVF).
Results: Analysis of the number of words produced showed a significant increase between 6–8-year-olds, 9–10-year-olds and 11–12-year-olds in SVF, while in LVF, the differences were significant only in the later age group. In SVF, the numbers of clusters and switches increased with age, whereas in LVF, the number of switches increased in all age groups, but clusters increased only in the older group. Structural equation model analyses showed that oral and written language, verbal memory and inhibitory control are associated with VF performance and IQ, while age mediated VF performance.
Conclusions: The results indicate a different development pattern between LVF and SVF in the number of words produced and in clustering and switching, with the latter predicting VF performance in words produced. VF development is shown to depend on language, memory and inhibitory control. Our results have important implications to clinical neuropsychology.

Keywords: Verbal fluency; Clustering; Switching; Executive functions; Children

Introduction

Verbal fluency tasks (VF) are widely used in the neuropsychological assessment of children to investigate the development of components of three neuropsychological domains: (a) memory (verbal semantic memory and verbal episodic memory) (Chami et al., 2017); (b) language (phonological awareness, lexical-semantic processing) (Tallberg, Carlsson, & Liberman, 2011); and (c) Executive Functions (EF) (updating and monitoring of working memory representations, shifting and inhibitory control). The rationale for using this task is based on two complementary models of EF development (Brocki & Bohlin, 2004; Miyake & Friedman, 2012; Miyake, Friedman, Emerson, Witzki, & Howerter, 2000) and on the two-component model of VF, described later (Troyer, 2000; Troyer, Moscovitch, & Winocur, 1997). VF tasks consist in generating as many words as possible according to a letter (letter verbal fluency—LVF), to a semantic criterion (semantic verbal fluency—SVF) or no criterion, often for 60 s (Strauss, Sherman, & Spreen, 2006). Usually, the score on VF tasks is the number of correct words produced. In LVF tasks, all words must begin with a certain letter, such as "M" (Charchat-Fichman, Oliveira, & Silva, 2011; Salles et al., 2011); or with one letter from a set, for instance, "F," "A," and "S" (Fonseca, Salles, & Parente, 2009; Toazza

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et al., 2016). In SVF tasks, the produced words must belong to a specific category, such as fruits, clothes, or animals, the latter being the category most frequently used (Chami et al., 2017; Tallberg et al., 2011). Deficits in VF performance in children have been observed to be negatively associated to academic achievement and learning of everyday activities (Tallberg et al., 2011) and to be clinically informative for developmental disorders and neuropsychiatric disorders such as Down syndrome (Nash & Snowling, 2008), oral language disorders (Henry, Messer, & Nash, 2012), and anxiety disorders (Toazza et al., 2016).

Studies in children and adults report that age and educational level have a strong impact on overall performance in SVF (Brucki & Rocha, 2004; Chami et al., 2017; Tallberg et al., 2011; Troyer, 2000) and LVF tasks (Anderson, Anderson, Northam, Jacobs, & Catroppa, 2001; Sauzéon et al., 2004; Tallberg et al., 2011; Troyer, 2000). The number of words produced increases throughout childhood and adolescence, but the developmental peak varies according to type of task (Koren, Kofman, & Berger, 2005; Sauzéon et al., 2004; Tallberg et al., 2011). Performance in SVF is higher in 9–10-year-olds compared to 7–8-year-olds, while in LVF, the amount of words produced increases significantly after the age of 11–12 (Sauzéon et al., 2004; Tallberg et al., 2011). Studies with Brazilian–Portuguese speakers (Charchat-Fichman et al., 2011; Hazin et al., 2016; Malloy-Diniz et al., 2007) have found differences in LVF task performance between 7-year-olds and 9–10-year-olds, with an advantage for the latter, but not between 7- and 8-year-olds or between 8- and 9-year-olds. Nevertheless, differences in number of words produced exist across languages, suggesting a need for collecting language-specific data and establishing norms (Oberg & Ramírez, 2006; Tallberg et al., 2011).

It is important to notice that the overall score (number of words produced) is uninformative regarding specific cognitive mechanisms underlying test performance. To investigate these underlying cognitive processes, Troyer et al. (1997) proposed a VF model based on two cognitive components: clustering and switching. The former consists in the ability to produce words beginning with a letter or belonging to a semantic subcategory (letter clusters and semantic clusters, respectively) and is associated with semantic memory and word storage. Clustering is usually measured by cluster size, starting with the second word in each cluster (see the methods section for details about scoring rules). The second component is the ability to switch between subcategories and is therefore associated with the shifting and inhibitory control components of EF (Troyer et al., 1997; Troyer, 2000). Switching is usually measured by the number of clusters and the number of switches between clusters (Hurks et al., 2010; Troyer et al., 1997). According to these authors, switching is more important for overall performance than clustering (Troyer et al., 1997; Unsworth, Spillers, & Brewer, 2011), which suggests that the ability to self-generate category cues (switching) is more important than the total number of items under a cue (clustering). Studies with adult samples with acquired neurological lesions corroborate the hypothesis that the clustering component depends on semantic memory and that the switching component is dependent on EF (for a review see Donovan, Siegert, McDowall, & Abernethy, 1999; Raoux et al., 2008; Rich, Troyer, Bylsma, & Brandt, 1999; Troyer, Moscovitch, Winocur, Alexander, & Stuss, 1998; Troyer, Moscovitch, Winocur, Leach, & Freedman, 1998).

Similar to the case of overall performance, effects of age and schooling on clustering and switching measures have been observed. Studies show an increase in the number of clusters and switches in LVF tasks after ages 7–8, and a decrease in cluster size with increasing age, particularly in 9–10-year-olds (Sauzéon et al., 2004; Tallberg et al., 2011). In SVF tasks, the decrease in cluster size occurs earlier, in the 7–8-year-old group compared with 9–10-year-olds, with a resulting increase in the number of clusters and switches in older children (Sauzéon et al., 2004; Tallberg et al., 2011).

Because VF is a multidimensional construct, factors other than age and education might be related to its development, such as socioeconomic status (SES). A positive association between SES and development of language, memory, and EF (skills that are directly related to VF) has been consistently observed in studies with different populations (Brito, Piccolo & Noble, 2017; Corso, Sperb, & Salles, 2013; Piccolo et al., 2012; Piccolo, Arteche, Fonseca, Grassi-Oliveira & Salles, 2016). However, a specific association between SES and VF performance has not been established. For example, Spanish children aged 8–12 belonging to low-SES families have been shown to perform worse than their high-SES peers in words produced in both LVF and SVF tasks (Arán-Filippetti, 2011). Conversely, Prigatano, Gray, and Lomay (2008) found no SES-related differences (private vs. public schools) in LVF performance in Hispanic children. Other findings suggest that, around age six, scores on SVF are more affected by the child's environment rather than by genetic factors (Kavé, Shalmon, & Knafo, 2013). According to the studies above (Arán-Filippetti, 2011; Kavé et al., 2013; Prigatano et al., 2008), it seems that the effects of environmental variables, such as SES, are moderated by the type of VF and the children's ages.

In studies on childhood and adolescence, SES is often measured by family income and parental education (ABEP, 2010). In Brazil, the variable school type is strongly associated with SES, with children from lower-SES families often attending public schools (INEP, 2006). In a Brazilian study with adolescents aged 12–18, after controlling for age and SES, school type did not have an effect on performance in LVF (words produced); however, other related tasks (e.g., phonological working memory) displayed an effect of school type (Casarin, Wong, Parente, Salles, & Fonseca, 2012). This suggests that the association between SES-related variables (i.e. school type) and the development of VF needs to be further investigated, especially in Brazil, where large differences exist between public and private school environments (Miranda et al., 2007; Piccolo et al., 2016; Sbicigo, Abaid, Dell'Aglio, & Salles, 2013). In this sense, it is important that, when establishing Brazilian norms for VF clustering and switching measures, school type is taken into account.

A large body of research has demonstrated that VF performance is dependent on important cognitive domains such as oral language, orthographic development, semantic verbal memory, lexical-semantic processes, and executive functions (Brocki & Bohlin, 2004; Sauzéon et al., 2004; Tallberg et al., 2011; Toazza et al., 2016; Unsworth et al., 2011). The influence of each different cognitive domain on performance varies according to the type of VF task and to the clustering and switching components. Unsworth et al. (2011) investigated in adults how overall performance in VF, clustering and switching were related to working memory, vocabulary, processing speed and inhibition control through several confirmatory factor analyses and structural equation models (SEM). The authors found main contributions of working memory to overall performance, clustering and switching; and main contributions of vocabulary for overall performance and clustering, but not for switching. These results suggest that each VF component has a specific relationship to other cognitive processes. However, to our knowledge, no studies investigating VF SEM in children have been performed.

Overall, both switching and clustering have demonstrated significant positive correlations with number of words produced (Hurks et al., 2010; Unsworth et al., 2011). Additionally, both SVF and LVF have proven to be valid assessments of both EF and lexical-semantic skills in adult and children (Chami et al., 2017; Sauzéon et al., 2004). However, several methodological discrepancies exist between studies, which leads to a lack of validity of the VF model (Abwender, Swan, Bowerman, & Connolly, 2001; Ross et al., 2007). Furthermore, the specific cognitive processes that influence VF performance and its multidimensionality remain elusive, since no studies so far have investigated VF with SEM in child samples. This scarcity of studies, coupled with methodological discrepancies across studies, complicates the use and interpretation of published data. First, the age at which significant improvements are reported vary across studies. One possible explanation is the difference in age groups employed across studies (Chami et al., 2017; Hurks et al., 2010; Koren et al., 2005). Moreover, the clustering and switching measures employed, as well as their scoring methods, also vary across studies (Chami et al., 2017; Sauzéon et al., 2004; Tallberg et al., 2011). Second, the development of mean cluster size remains unclear, with some studies reporting mean cluster size to increase with age (Hurks et al., 2010; Sauzéon et al., 2010), while others have found no significant difference across age groups (Bertola et al., 2014; Brucki & Rocha, 2004; Koren et al., 2005; Tallberg et al., 2011). Third, regarding normative data specifically for clustering and switching scores for Brazilian children, as far as we know, there are no studies published using this scoring method in LVF and SVF tasks. Clarifying these issues is important not only for theory but may also allow clinicians to use clustering and switching scores to dissociate the two cognitive components of VF and understand the cognitive processes underlying overall performance.

The investigation of the retrieval strategies underlying VF performance may clarify the issues mentioned above as well as the hypothesis of LVF reliance on EF and of SVF reliance on lexical-semantic processes. In this study, we investigated the performance in VF tasks according to age group (6–8-years old, 9–10-years old and 11–12-years old), school type (public vs. private) and task type (LVF vs. SVF) in Brazilian–Portuguese speaking typically developing children aged 6–12, aiming to provide Brazilian norms for clustering and switching. We also aimed to test a structural model for VF including the variables age, nonverbal IQ, verbal memory, oral and written language. and EF (inhibitory control). This study contributes to the field by providing Brazilian clustering and switching norms by age and school type and has implications to the theoretical model of VF through the use of SEM. The hypotheses summarized below concern the effects of age (Hypothesis 1) and school type (Hypothesis 2) on overall performance and retrieval strategies. Hypothesis 3 concerns the effects of type of task (LVF vs. SVF) on overall VF performance. Finally, Hypothesis 4 concerns the effects of organization strategies on LVF and SVF performance, and Hypothesis 5 tests a structural model for VF.

- Hypothesis 1. We expect an increase with age in overall performance in both VF tasks. Performance differences in SVF may occur between younger groups; in LVF, differences should occur only between older groups (Sauzéon et al., 2004). The variables number of clusters and number of switches will probably increase with age, while mean cluster size will likely decrease.
- Hypothesis 2. We anticipate that participants from private schools will outperform those from public schools, especially in LVF tasks, where there is greater EF recruitment (Arán-Filippetti, 2011; Piccolo et al., 2012, 2016).
- Hypothesis 3. Performance in the SVF task will likely be higher than performance in LVF tasks for all ages (Charchat-Fichman et al., 2011; Sauzéon et al., 2004; Zimmermann et al., 2014).

- Hypothesis 4. The number of switches and clusters will probably be related to overall performance in VF in both tasks, but cluster size will not (Bertola et al., 2014; Brucki & Rocha, 2004; Koren et al., 2005). Clustering and switching scores will likely exhibit high correlations, explaining much of the variance in overall VF performance, along with age.
- Hypothesis 5. High correlations are expected between VF variables, and the best adjusted model will include all VF variables in one endogenous VF variable. This will likely be influenced by exogenous cognitive variables, namely memory, language ,and EF (inhibitory control), required to perform the VF tasks (Brocki & Bohlin, 2004; Charchat-Fichman, et al., 2011; Sauzéon et al., 2004; Tallberg et al., 2011; Toazza et al., 2014, 2016). We expect that IQ and age will moderate the effects of language, memory, and inhibitory control on VF, since the first two influence the development of the other cognitive functions. We predict that to perform VF tasks, children must develop first language, memory, and inhibitory control.

Materials and Methods

Participants

This is a secondary data analysis using a database comprising 414 children aged 6–12, of both genders, from first to the seventh grade of elementary public ($N = 3$) and private schools ($N = 2$) in urban communities in Southern Brazil, selected by convenience. All children attending the participant schools were invited to join the investigation via parent informed consent. In Brazil, children begin formal school at 6 years old (Grade 1). The children were divided into three age groups: (a) 6–8-years old; (b) 9–10-years old; and (c) 11–12-years old. All participants were native speakers of Brazilian–Portuguese, monolingual, and had no history of neurological or psychiatric disorders, learning disabilities, school failure or uncorrected hearing, or visual impairments (reported by parents/guardians in a structured interview questionnaire). The participants' characteristics are described in Table 1.

According to a Chi-square analysis ($p < .05$), there were no differences in the distribution of gender and school type between age groups (Table 1). The socioeconomic survey from the Brazilian Association of Education and Research (ABEP, 2010) showed that the age groups did not differ in SES ($\chi^2(12) = 11.37$, $p = .49$). Each group included children in A, B, C, and D status, in a scale where A represents the most advantaged and D the most disadvantaged socioeconomic group. Families categorized as A have higher scores in an index combining parental education and existence or non-existence of household goods as an estimation of purchasing power. Since the groups did not differ in SES, we chose to investigate SES impact using school type, as in Brazil they are extremely related to each other (Corso *et al.* 2013; Piccolo et al., 2012).

Table 1. Participants' characteristics for each age group

	6–8 ($n = 180$)	9–10 ($n = 120$)	11–12 ($n = 114$)	p
Gender Female/Male (n)[a]	97/83	66/54	60/54	.936
Age (years) $M \pm SD$[b]	7.0 ± 0.8	9.5 ± 0.5	11.5 ± 0.5	<.001*
Grade (n)[a]				<.001*
First grade	89	–	–	–
Second grade	57	–	–	–
Third grade	34	25	–	–
Fourth grade	–	77	1	–
Fifth grade	–	18	40	–
Sixth grade	–	–	73	–
School type Pb/Pr (n)[a]	88/92	60/60	63/51	.549
Raven percentile $M \pm SD$[b]	83.7 ± 16.4	79.5 ± 16.4	76.9 ± 21.6	.93
CATRS-10 $M \pm SD$[b]	4.1 ± 4.8	3.3 ± 4.6	2.7 ± 3.0	.97

Note. Pb = Public; Pr = Private; CATRS-10 = Score on the Abbreviated Conners Teacher Rating Scale; M = Mean; SD = Standard Deviation.
*$p < 0.01$.
[a]Analysis with Chi-square to test the association between variables.
[b]Analysis of Covariance (ANCOVA) to determine differences between groups controlling for age.

Measures and Procedures

This study was approved by the university's Ethics Research Committee under the protocol number 2008/067. The children were volunteers with parental consent. The exclusion criteria were symptoms of Attention Deficit Hyperactivity Disorder (ADHD), measured by the Abbreviated Conners Scale for Teachers (Abbreviated Conners Teacher Rating Scale—CATRS-10) (Brito, 1987) and intellectual deficit indicated by a percentile below 25 in the Raven's Colored Progressive Matrices (Angelini, Alves, Custódio, Duarte, & Duarte, 1999). The parents or guardians of each participant filled out a socio-demographic and health information form. All children were evaluated in two, 1-h sessions—one collective and one individual—at school and all measures and instructions were written and presented in Portuguese.

Raven's Colored Progressive Matrices. The Brazilian standardization (Angelini et al., 1999) of this nonverbal fluid intelligence measure was applied during the collective session. Children were presented with an incomplete set of eight abstract figures that combined solid shapes inside outlines (e.g., a solid diamond inside a square outline) and that followed certain sequences from right to left (e.g., no outline, oval outline, square outline) and from top to bottom (e.g., hollow bar, striped bar, solid bar). The task was to identify which figure from among eight options completed the pattern shown. The previously reported reliability for this measure with a sample of 9,929 Brazilian students was .87 (Cronbach's alpha) for a general factor (Pasquali, Wechsler, & Bensusan, 2002).

Child Brief Neuropsychological Assessment Battery (NEUPSILIN-INF). This instrument (Salles, Miranda, Fonseca, & Parente, 2016; Salles et al., 2011) assesses the components of eight neuropsychological functions in school-age children: orientation, attention, visual perception, memory, arithmetic abilities, language (oral and written), visuospatial abilities, and executive function administered individually. Given that the literature shows a consistent association between VF and performance in memory, language and EF tasks (Brocki & Bohlin, 2004; Charchat-Fichman et al., 2011; Sauzéon et al., 2004; Tallberg et al., 2011; Toazza et al., 2014, 2016), in this study, we used only tasks that measure memory (episodic memory, semantic memory and working memory—forward and backward digit span and nonword span), oral language (phonemic elision and rhyme) and written language (reading, spelling, and spontaneous writing) and EF, specifically inhibitory control (go/no go auditory task, LVF and SVF). Verbal episodic memory was investigated with a task consisting of the immediate recall of a nine words list (test–retest reliability, r = .428). Verbal working memory was assessed with three simple span tasks: nonword span (test–retest reliability, r = .681) forward-order digit span (test–retest reliability, r = .632) and reverse-order digit span (test–retest reliability, r = .568). Semantic memory was evaluated with four questions about general knowledge (e. g. *What do we celebrate on December 25th?*) (test–retest reliability, r = .680). Oral reading was assessed with a list of six syllables, six words and five nonwords (test–retest reliability, r = .757). In the spelling task, children were requested to spell 14 words and five nonwords (test–retest reliability, r = .941). The rhyme task consisted of four items containing three words each, from which children must discriminate two words that rhyme (test–retest reliability, r = .504). Phonemic elision was assessed with a list of six words; children had to delete phonemes and say the new word aloud (test–retest reliability, r = .616). Spontaneous writing consisted in asking the children to write a statement (test–retest reliability, r = .536). Finally, executive functions were assessed with three tasks: a computer-administered go/no-go response inhibition task ("respond yes to all numbers you hear except for the number 8," test–retest reliability, r = .560) and the VF tasks described below. Most of the correlations for the test–retest reliability were average (.301–.59) or strong (.60–.79); with one of them (spelling) being very strong (over .80) (Levin, Fox, & Forde, 2014). The average test–retest correlations exhibited by four of the tasks could be due to the low range of variability and to ceiling effects of the normative data performance (Fonseca, Prando, Esteves, & Miranda, 2016). Previous studies demonstrated a good fit of the same NEUPSILIN-INF factorial model and its construct validity (Piccolo et al., 2016; Salles et al., 2016; Salles, Sbicigo, Machado, Miranda, & Fonseca, 2014). In the LVF task, participants were asked to retrieve from memory and produce as many words as they could starting with the letter M, excluding names and words derived from the same root (e.g. mean, meaning, meant) for 60 s. In the SVF task, participants were asked to retrieve from memory and produce animal names starting with any letter, also for 60 s.

Clustering and switching measures. Four scores were generated for each of the VF tasks, including number of clusters, mean cluster size, number of switches, and number of words produced. The scoring was performed using criteria proposed by Troyer et al. (1997) and by Lopes, Brucki, Giampaoli, and Mansur (2009). Detailed rules to score cluster size and switches for letter and semantic fluency in Brazilian–Portuguese are available in Becker and Salles (2016) (published in English). Briefly, clusters are defined as successively generated words belonging to the same subcategory (Troyer, 2000; Troyer et al., 1997), and must contain at least two words. In the LVF task, words form a cluster if they begin with the same two first letters, if they rhyme or if they differ only by a vowel sound. In the SVF task, clusters are successively generated words that belong to the same semantic category, such as wildlife, aquatic animals, pets, farm animals, birds, and insects. For the LVF task, only letter clusters were scored, whereas for the SVF task only semantic clusters were scored, in accordance with previous studies (Brucki & Rocha, 2004; Sauzéon et al., 2004; Troyer et al., 1997; Troyer, 2000). Errors and repetitions were considered for the variables of clustering and switching, as they provide information about retrieval strategies:

- *number of clusters:* the sum of each participant's clusters. Single words were not counted as clusters.
- *mean cluster size:* cluster size was computed starting from the second word in each cluster. The mean cluster size was calculated by summing the size of each cluster and dividing by the number of clusters.
- *number of switches:* the number of transitions between clusters, including single words (which are not counted in Scores a and b).
- *words produced:* all words retrieved during the 60 s, excluding errors (words beginning with another letter, names and derivations from the same roots for LVF; and words other than animal names for SVF) and repetitions (gender and plural derivations were counted as repetitions).
- *Discrepancy between LVF and SVF:* number of words produced in the SVF minus number of words produced in the LVF (SVF–LVF). This score was based on the study of Zimmermann et al. (2014).

All protocols were scored by three independent judges following the process described by Becker and Salles (2016). Intraclass correlation analyses were performed on the performance of all children to verify the reliability between judges, yielding results greater than 0.9. These values are considered excellent agreement (Shrout & Fleiss, 1979).

Statistics

First, we analyzed the differences between ages by comparing $6 \times 7 \times 8 \times 9 \times 10 \times 11 \times 12$ in each dependent variable. Since we did not find differences across all age groups and in order to increase power in the multivariate analysis, we grouped the subjects into three similar age groups, in accordance with previous studies (Sauzéon et al., 2011; Tallberg et al. 2011). The same was done with socioeconomic class. We investigated the normality and homogeneity of the dependent variables with a Kolmorogov–Smirnov test ($p > .05$) and histograms. To obtain normative data in the LVF and SVF tasks by age group and school type, descriptive analyses were conducted for each dependent variable.

Two-way multivariate analysis of variance (MANOVA) tests were employed to test for effects of age and school type on all VF task dependent variables simultaneously. We chose to perform a MANOVA because the dependent variables of each task are correlated and share a common conceptual meaning, as described in the instruments. We report the Pillai's Trace multivariate test because covariance matrices were unequal across groups (Meyers, Gamst, & Guarino, 2006). Analyses of variance (ANOVA) were employed to test for the same effects on the LVF–SVF-dependent variable. Depending on the outcomes of these tests, additional analyses were performed and are described in the Results section. The Bonferroni post hoc was used for multiple comparisons in MANOVA and ANOVA when a *p*-value below .05 was observed. Effect sizes are presented as Partial Eta Squared (η^2).

A multiple regression analysis using the stepwise method investigated the influence of age (as a continuous variable), clustering and switching variables (predictors) on the words produced (predicted variable) in each VF task. The analyses were performed using the IBM SPSS 20.0 statistics software, with an alpha of 5%. Lastly, we used the Mplus software (version 6) to run a SEM analysis to determine the relationships between age, nonverbal IQ, language, memory and EF (inhibitory control) in VF performance. Multigroup models were also tested by school type, using multiple-group confirmatory factor analysis (CFA). To test for differences between the school groups (public and private), we built a model in which each parameter was forced to be the same for both groups (fixed parameters), and then this first model was compared with a second model in which the association between the variables evaluated were not restricted. Model adjustment indices were considered as suggested by Byrne (2011).

Results

The global score (words produced), along with cluster, switch, and discrepancies scores are presented first, followed by the results for effects of age and school type (Hypotheses 1–3). We then present the results for the multiple regressions (Hypothesis 4) and, finally, the structural model of VF built with SEM (Hypothesis 5).

Comparisons of Performance in VF between Age Groups, School Type and Task Type

Descriptive analyses of VF by age group and school type are presented in Table 2. There was a statistically significant effect of age in LVF, with performance increasing with age, F (8, 812) = 7.674, p < .001; Pillai's V = .141, partial η^2 = .07. No statistically significant effects of school type (F (4, 405) = 1.353, p = .250; Pillai's V = .013, partial η^2 = .01) or its interaction with age (F (8, 812) = .704, p = .688; Pillai's V = .014, partial η^2 = .07) were observed. The group of 11–12-year-olds produced a larger number of words (M = 9.61, SD = 3.81, p < .001) and a larger number of clusters (M = 2.05, SD = 1.21, p = .002) compared to the younger groups, between which there were no significant differences (p = .23 and p = 1.00, respectively). For mean cluster size, there were differences only between the two extreme age groups (6–8-years old [M = 1.91, SD = 1.47] and 11–12-years old [M = 1.50, SD = 1.08], p = .04), with cluster size decreasing with increasing age. Finally, performance was significantly higher for number of switches in the 11–12-year-old group (M = 5.96, SD = 2.63, p < .001), followed by the 9–10-year-old group (M = 4.24, SD = 2.9, p < .001), followed by the 6–8-year-old group (M = 3.38, SD = .20, p < .001).

The MANOVA for the SVF task also showed significant effects for age only, F (8, 812) = 7.739, p < .001, Pillai's V = 0.142, partial η^2 = .07. There were no significant effects of school type (F (4, 405) = .882, p = .47, Pillai's V = 0.009, partial η^2 = .009) or its interaction with age (F (8, 812) = .920, p = .49, Pillai's V = 0.018, partial η^2 = .009). Post hoc Bonferroni analyses showed distinct results for the effects of age on the SVF task, compared to the LVF task, for all dependent variables. There were significant differences in words produced between the three age groups, with the 11–12-year-old group performing better than the other two (M = 16.70, SD = 5.34, p < .001), followed by the 9–10-year-old group (M = 14.74, SD = 4.76, p < .001). The number of clusters also displayed an age-related increase. As in the case of LVF, the 11–12-year-old group (M = 4.72, SD = 1.78) outperformed the two younger groups (p < .001 and p = .001, respectively), which did not differ from each other (p = .25). The number of switches was smaller for the 6–8-year-old group (M = 4.84, SD = 2.60) when compared to the 9–10-year-old group (p = .001) and to the older group (p < .001), which did not differ from the 9–10-year-olds (p = .19).

Regarding the discrepancy score between SVF and LVF, the ANOVA showed main effects of age (F(2) = 4.50, p = .01, partial η^2 = .022), and school type (F(1) = 3.58, p = .05, partial η^2 = .009), but no interactions between them (F(2) = .66, p = .51, partial η^2 = .003). Discrepancy tends to be higher for the group of 9–10-year-olds (M = 7.26, SD = 4.67) compared to 6–8-year-olds (M = 5.76, SD = 4.73) (p = .02), but there were no significant performance differences between these two groups and the 11–12-year-olds (p = .06 and p = 1.00, respectively). Moreover, private school children exhibited greater discrepancy compared to those from public schools (M = 6.99, SD = 5.00 and M = 6.15, SD = 4.74, p = .001, respectively).

Table 2. Means and standard deviations (SD) of words produced, number of clusters, cluster size and number of switches by age and school type

Tasks		Groups					
School type		Public			Private		
Age group		6–8 (n = 88)	9–10 (n = 60)	11–12 (n = 63)	6–8 (n = 92)	9–10 (n = 60)	11–12 (n = 51)
LVF							
Words Produced	*M*	6.6	7.3	9.9	6.8	7.6	9.2
	SD	3.1	3.5	3.5	3.2	3.3	4.1
Number of Clusters	*M*	1.46	1.51	1.96	1.60	1.68	2.15
	SD	0.11	0.13	0.13	0.10	0.13	0.14
Mean Cluster Size	*M*	1.9	1.7	1.4	1.9	1.6	1.7
	SD	1.5	1.5	0.9	1.4	1.0	1.2
Number of Switches	*M*	3.4	4.1	6.2	3.4	4.4	5.2
	SD	2.5	3.0	2.9	2.3	3.0	3.3
SVF							
Words Produced	*M*	12.1	13.7	16.8	12.9	15.7	16.5
	SD	4.3	4.5	5.3	4.7	4.0	5.6
Number of Clusters	*M*	3.11	3.23	4.36	3.41	3.88	4.25
	SD	0.16	0.20	0.19	0.16	0.20	0.21
Mean Cluster Size	*M*	2.7	2.4	2.4	2.4	2.5	2.5
	SD	1.9	1.3	1.1	1.4	1.5	1.2
Number of Switches	*M*	4.5	5.6	6.7	5.1	6.3	6.4
	SD	2.4	2.6	2.4	2.8	2.6	2.7
SVF–LVF	*M*	5.44	6.40	6.90	6.06	8.13	7.31
	SD	4.25	4.73	5.30	5.15	4.47	5.08

Effects of Clustering and Switching on the Words Produced

The results for the LVF task indicate a predictive model in which all independent variables included explain 88% ($p < .001$) of the variance in overall performance (words produced) (Table 3). The model produced good adjustment indices, with a Durbin–Watson of 1.65. The variable with the greatest explanatory power was the number of switches, which explained 75% of the variance.

Table 3. Multiple regression for words produced in the LVF task

	β	R	R^2	t	p
Step 1		.791	.625		
Number of switches	0.791			26.21	<.001
Step 2		.884	.781		
Number of switches	0.903			37.65	<.001
Mean cluster size	0.411			17.12	<.001
Step 3		.942	.887		
Number of switches	0.766			41.02	<.001
Mean cluster size	0.353			21.10	<.001
Number of clusters	0.352			19.56	<.001
Step 4		.943	.889		
Number of switches	0.752			−39.14	<.001
Mean cluster size	0.355			20.36	<.001
Number of clusters	0.347			19.38	<.001
Age	0.047			2.65	.008

With respect to SVF, the final model explained 83% of the variability in words produced (again keeping all the variables in the analysis as predictors—Table 4). The Durbin–Watson value was 1.71, indicating good model adjustment. In this case, the variable with the greatest explanatory power was number of clusters, accounting for 63% of the variance.

Table 4. Multiple regression for words produced in the SVF task

	β	R	R^2	t	p
Step 1		.753	.567		
Number of clusters	0.753			23.23	<.001
Step 2		.821	.674		
Number of clusters	0.858			29.01	<.001
Mean cluster size	0.344			11.61	<.001
Step 3		.912	.831		
Number of clusters	0.649			27.18	<.001
Mean cluster size	0.472			21.16	<.001
Number of switches	0.484			19.52	<.001
Step 4		.836	.835		
Number of clusters	0.636			26.68	<.001
Mean cluster size	0.464			20.97	<.001
Number of switches	0.466			18.67	<.001
Age	0.076			3.59	<.001

Effects of Age, IQ, Memory, Language and Executive Functions in VF

A SEM analysis was conducted to examine the relationship of VF with age, IQ (percentile on Raven's Colored Progressive Matrices) (Table 1), language, memory, and EF (inhibitory control) (Table 5). The measurement models, specifically the latent variables of language and memory, were based on the confirmatory factor analysis of the NEUPSILIN-Inf instrument (Salles et al., 2014), using maximum likelihood (ML) as an estimation method. We used as predictors the latent variables of language and verbal memory and the observed variables of IQ, age and go–no go task (EF—inhibitory control). The tasks rhyme, letter elision, word reading, spelling and spontaneous writing (write a sentence) were indicators of "oral and written language" latent variable. The tasks digit span (forward and backward), nonword span, semantic memory, and episodic memory (immediate recall of word list) composed the latent variable "verbal memory". Working memory was included

Table 5. Means and standard deviations for oral and written language, verbal memory and executive function tasks

NEUPSILIN-INF tasks ($M \pm SD$)	6–8 (n = 180)	9–10 (n = 120)	11–12 (n = 114)
Oral Language			
Rhyme	3.45 ± 0.59	3.74 ± 0.42	3.88 ± 0.31
Phonemic Elision	5.11 ± 0.09	5.65 ± 0.07	5.88 ± 0.03
Oral Reading	5.22 ± 0.10	5.95 ± 0.21	5.96 ± 0.18
Written Language			
Spelling	14.65 ± 0.31	17.92 ± 0.10	18.46 ± 0.07
Spontaneous Writing	1.34 ± 0.05	1.79 ± 0.03	1.90 ± 0.03
Verbal Memory			
Digit Span	16.11 ± 0.41	19.77 ± 0.35	21.47 ± 0.35
Nonwords Span	11.47 ± 0.25	13.28 ± 0.29	14.61 ± 0.28
Semantic Memory	3.65 ± 0.03	3.93 ± 0.02	3.94 ± 0.02
Episodic Memory	4.68 ± 0.09	5.04 ± 0.10	5.64 ± 0.10
Executive Functions			
Go/No Go	51.09 ± 0.51	55.84 ± 0.40	58.12 ± 0.26

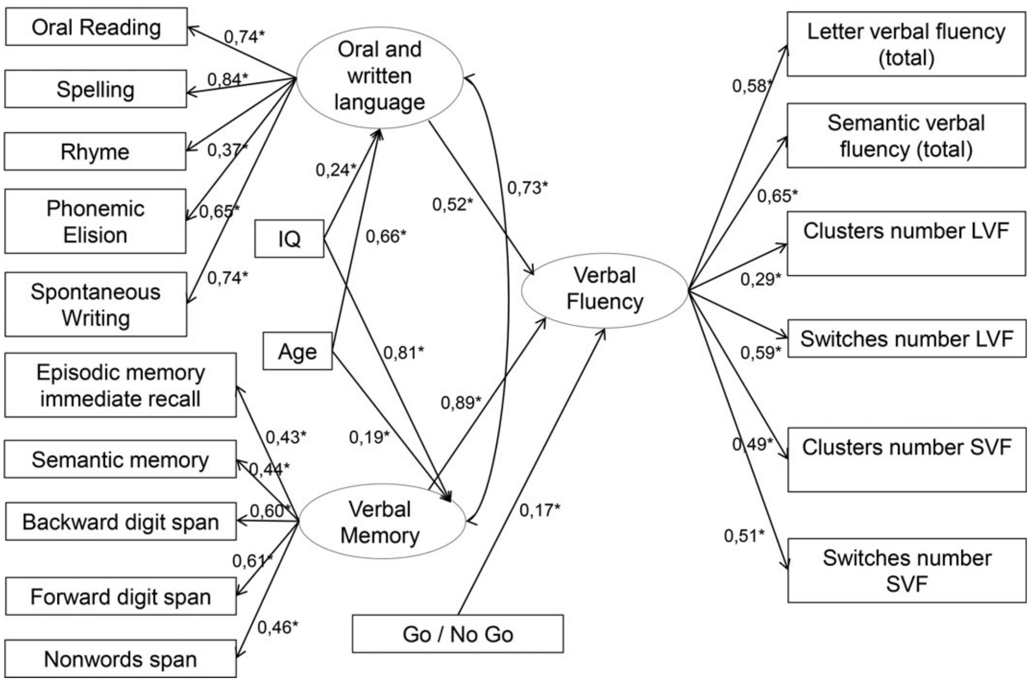

Fig. 1. Structural model (Oral and written language, Verbal memory, Go/No go, IQ and Age as predictors) for verbal fluency latent variable.

in the verbal memory latent variable, since we used confirmatory factor analysis of the NEUPSILIN-Inf instrument (Salles et al., 2014). The inclusion of working memory as a subtype of verbal memory is based on Baddeley's (2000) working memory framework, and in other studies with children that separate working memory measures from EF measures (Bull, Espy, & Wiebe, 2008). An auditory go–no go task was used as indicator of executive functioning (inhibitory control component). The outcome variable, VF, was composed by the numbers of clusters and switches and total scores (number of words) in both tasks, LVF and SVF. We did not include mean cluster size due to an absence of significant correlations with the total number of words retrieved in each task, as stated before.

The estimated coefficients of the final structural model are shown in Figure 1 (STDYX standardization method). In general, a ratio $\chi^2/df > 2$ is commonly found in large samples, as the Chi-square statistic is very sensitive to the number of participants. However, the other fit indices were satisfactory, as recommended by Byrne (2011): $\chi^2(133) = 285.96$ ($p < .01$); CFI = 0.949; TLI = 0.936; RMSEA = 0.053 (IC 90%: 0.045–0.062); SRMR = 0.050. In order to test for differences between public and private schools, we performed a multigroup comparison by school type between the models, but no significant differences were observed (χ^2 (10) = 27.9, χ^2/gl = 2.79; $p < 0.05$).

Discussion

The results showed main effects of age on the performance in the VF tasks, supporting the hypothesis of an increase in words produced in both VF tasks with age (Hypothesis 1). Performance differences in SVF were observed between younger groups, while differences in LVF occurred between older groups, as expected (Sauzéon et al., 2004). Improvement in VF task performance with age has been reported for other languages, such as French (Sauzéon et al., 2004), Italian (Riva, Nichelli, & Devoti, 2000), Hebrew (Koren et al., 2005), Spanish (Arán-Filippetti & Allegri, 2011), Dutch (Hurks et al., 2010) and Swedish (Tallberg et al. 2011). The performance on the VF tasks (quantitative and qualitative variables) described in this study were very similar to what was observed in other Brazilian studies (Charchat-Fichman et al., 2011; Hazin et al., 2016). However, those Brazilian studies employed the letter *F* instead of *M* in the LVF, and the performance of the Brazilian children in those studies was quite different from that of Hebrew, Dutch, Swedish, and French children. This highlights the importance of obtaining specific scores for each language/culture.

In this study, there was a significant increase in the number of words produced in LVF in the group of 11–12-year-olds compared with 9–10- and 6–8-year-olds, while the latter two groups did not differ significantly. However, different patterns in the developmental trajectory of clustering and switching were observed. The number of switches increased significantly among the three age groups and the mean cluster size, which is related to semantic memory, decreased significantly in the 11–12-year-olds, compared with 6–8-year-olds. Additionally, the increase in the number of clusters (which is related to strategic retrieval of words and to components of EF) was also significant for the older group when compared to younger groups, which exhibited no significant differences. Taken together, these results show that younger children (around 6–10-years old) use fewer but larger letter clusters (with more items), and it is possible that this age group benefits from strategies related to semantic memory through letter strategies.

Our results in LVF also corroborate previous findings that both clustering and switching are important for the number of words produced but switching seems to make a larger contribution than clustering (Koren et al., 2005; Unsworth et al., 2011). These results might be related to the peak of frontal lobe maturation, which starts at around 11–12 years of age (Anderson, 2002; Brocki & Bohlin, 2004; Jurado & Rosselli, 2007) and is associated with the developmental trajectory of EF (cognitive flexibility and retrieval strategies) (Miyake & Friedman, 2012; Miyake et al., 2000), resulting in switching strategies being employed more often. It is noteworthy that, in the Brazilian educational system, important changes occur after the fifth year of Elementary School, including an increase in the number of school subjects, teachers and hence in spelling and orthographic knowledge. Thus, it seems that LVF improves significantly during preteens, coinciding with the attendance of children in their fifth/sixth year of Elementary School. Another possible explanation is that, due to cognitive flexibility and orthographic knowledge, subjects at this age and grades can use more orthographic combinations that are not limited to initial syllabic combination, thus requiring less support from memory. Additionally, there is an increase in vocabulary, spelling knowledge, phonological awareness and lexical access, aspects related to the development of language (Levelt, Roelofs, & Meyer, 1999). This study's LVF results support Hypothesis 1, as well as findings of previous studies (Sauzéon et al., 2004), suggesting that switching strategies were used more frequently after 11–12 years of age, with a decrease in cluster size and a significant increase in overall LVF performance.

In the SVF task, performance differences appeared earlier (between the 6–8- and 9–10-year-old groups), indicating that this ability develops before LVF, also in accordance to Hypothesis 1. These results corroborate theories of lexical semantics, in which semantic relationships begin to be established at around 5 years of age and take a long time to fully develop, increasing with the child's age and experience (Assink, Bergen, Teeseling, & Knuijt, 2004). Our results are also in accordance with an Italian study that found similar results regarding a linear increase in SVF from first grade to fifth grade, but not in LVF (Riva et al., 2000). Additionally, the results for the discrepancy score (SVF–LVF words produced) are consistent with Hypothesis 3, which predicted that the difference between SVF and LVF would decrease with increasing age, as observed in previous studies with children (Charchat-Fichman et al., 2011; Riva et al., 2000; Sauzéon et al., 2004). These results can be explained by an earlier development of semantic relationships, in contrast to the later development of the prefrontal cortex and EF, which accounts for LVF performance improvement. According to EF models (Brocki & Bohlin, 2004; Miyake & Friedman, 2012), EF development is dimensional and relies on three components: inhibition, speed/arousal, and working memory/VF. The latest component appeared to increase significantly at two points during development. The first developmental spurt (age 8) may be interpreted as reflecting the developmental change in the encoding of nonverbal stimuli and working memory, while the later (age of 10–12) might be related to a greater inclination in those children to use a more phonological approach to nonverbal stimuli (Brocki & Bohlin, 2004). Because younger children are just beginning to become phonologically aware, they may use mental imaging strategies, i.e., imagining scenarios from the criterion category, related to the development of lexical-semantic memory (Charchat-Fichman et al., 2011), which occurs before the development of the working memory/VF dimension (Miyake & Friedman, 2012). On the other hand, older children do not have any difficulty coming up with words starting with a certain letter and are likely to be more competent using clustering and switching strategies. This might explain why improvements in SVF performance are observed earlier in childhood than in LVF.

Regarding clustering and switching in SVF, the number of switches increased significantly after ages 9–10, remaining stable in 11–12-year-olds. The development of SVF also appears depend on the development of EF (Hurks et al., 2004). Thus, the increase in the number of clusters for the 11–12-year old-group when compared to younger groups, as well as the increase in the number of switches, can be associated with the development of retrieval strategies, probably related to the maturation of the frontal lobe (Koren et al., 2005). Cluster size in SVF was the only variable not affected by age. This topic will be discussed along with Hypothesis 4.

Hypothesis 2 of this study was not fully corroborated, although some studies have provided evidence that children from private schools display better academic performance and outperform their peers from public schools in language, memory and complex EF tasks (Brito et al., 2017; Casarin et al., 2012; Corso et al., 2013). In the present study, no differences were observed between type of school in most analyses, except for the discrepancy score, where private school children exhibited greater discrepancy compared to those from public schools. The lower discrepancy between LVF and SVF exhibited by children from public schools is probably due to environmental influences in SVF development. As demonstrated in a study with twins, parental education and length of stay at day-care accounted for 30% of the variance in SVF in preschool children (Kavé et al., 2013), indicating that environment plays an important role in lexical-semantic organization and memory development. Since Brazilian children from lower SES tend to attend public schools, their cognitive development is initially worse than that of private school children. When the LVF peaks at around 10 and 12 years of age, all children are receiving stimuli from school and other environments besides home.

As predicted by Hypothesis 4, multiple regressions indicated that the clustering and switching variables, along with age, were the best predictors (88.9% for LVF and 83.5% for SVF) of variance in words produced in both VF tasks. However, this influence varies according to the type of task (SVF or LVF), as observed previously in adults (Tallberg et al., 2008; Unsworth et al., 2011). In LVF, the number of switches made the greatest contribution to the variability in task performance. This indicates that even in childhood, the EF components of flexibility, strategic retrieval, and inhibition, which are related to the switching component and the number of clusters, are better predictors of LVF performance than those components associated with semantic memory and lexicon size. Additionally, in the SVF task, variables related to the clustering and switching components contributed to the variability in words produced (with a greater contribution from number of clusters). Although in English language studies, both clustering and switching components are highly correlated with overall VF performance (Troyer et al., 1997; Troyer, 2000), no significant results for cluster size were found in this or in other Brazilian studies (Bertola et al., 2014; Brucki & Rocha, 2004). Linguistic and cultural differences between Brazilian–Portuguese and English may explain those differences, but studies in other languages have not found any significant associations between cluster size and number of words produced in children either (Koren et al., 2005; Tallberg et al., 2011). It is important to observe that, although age contributes to overall performance in VF, its weight ranged from 4.5% to 7% in LVF and SVF, respectively. This indicates that other factors also contribute to the overall performance of VF.

In this regard, in order to test Hypothesis 5, we attempted to structure a VF model with the effects of age, IQ and cognitive processes of language, memory, and EF (inhibitory control). In the regression models, the number of clusters and the number of switches were the variables that contributed the most to overall performance in both VF tasks, exhibiting strong relationships. The proposed SEM showed good adjustment indices, with the latent variables of language and memory and the observable EF variable of go/no go task being positively associated with VF, thus corroborating Hypothesis 5. It is important to observe that both age and nonverbal IQ moderated VF performance, suggesting that development of previous skills (i.e., memory and language) is required for VF. These results corroborate other findings in this study regarding a greater role of memory and language for lexical retrieval during early development (Assink et al., 2004), with a posterior influence of EF dependent on the later maturation of the frontal lobes (Bohlin & Brocki, 2004; Miyake & Friedman, 2012; Miyake et al., 2000).

Limitations and Future Directions

It is important to notice that each fluency component depends on several factors. For instance, if a child says fewer words, he/she will cluster fewer words and will switch less often. Consequently, the number of switches depends on the number of clusters. These problems are inherent in the analysis of switching and clustering and should be taken into account as a limitation when interpreting the data. Future studies could include additional variables in the VF model, such as the semantic clusters in LVF, letter clusters in SVF (Tallberg et al., 2011) and return strategies (re-use of words of a previous cluster) (Jones & Golonka, 2012) to overcome the scoring limitations of this study, since these variables were not computed in our scoring system. Furthermore, performance could be investigated by time interval (a measure of the use of automated and controlled process that contributes to the understanding of the VF model [Hurks et al., 2004]). Another suggestion is to include a measure of verbal IQ, or at least vocabulary, since the literature shows a contribution of vocabulary measures to overall VF performance (Koren et al., 2005) and we could not include it in here, because in this study we analyzed a pre-existing database which did not contain those measures.

We observed that, for the measures of number of switches and mean cluster size, the standard deviation values were large, sometimes close to the mean value. Standard deviation is a measure of data spread, so we speculate that one possible explanation for this result is that both number of switches and mean cluster size have a large variability across each age groups in the study. Because of this, we assumed that our results for most analyses did not support our hypotheses. Studies have suggested that other measures for scoring clustering and switching could index EF processes more precisely (Abwender et al. 2001). Finally, future studies might investigate clustering and switching processes by other methods, such as those employed by Abwender et al. (2001), to assess the validity of the model. Including more measures in the structural model, as well as other strategy scores should help to clarify the impact of different cognitive measures in VF performance across age groups and across different backgrounds, as different SES. Moreover, this would contribute to the clinicians investigating underdevelopment of VF and associated cognitive processes.

Conclusions

The present study sought to investigate the effects of age and school type on the development of SVF and LVF; to establish Brazilian norms for clustering and switching for future research and clinical purposes in the Brazilian context; and to show a dissociation of VF components and their underlying cognitive processes with SEM. As expected, we found that VF improves with age, but there were no differences between public and private schools. SVF seems to develop earlier than LVF regarding the number of words produced, and the cognitive processes underlying VF performance are distinct for each task. This study also corroborates the hypothesis of two dissociate components of VF developed by Troyer et al. (1997). Additionally, we have shown an influence of different neuropsychological functions on the development of VF in a structural model.

Both letter and semantic verbal fluency were found to rely on different cognitive and linguistic processes: inhibitory control, semantic and working memory, oral and written language, and speed of processing (Anderson, 2002; Chami et al., 2017; Koren et al., 2005). As also demonstrated by the current study, VF performance should not be assessed only by calculating a child's overall fluency score or in isolation as a diagnostic tool. Considering our findings, it would be beneficial to analyze children's responses with respect to number of clusters, clusters size and the switches between clusters. Poor performance in the total words generated either in LVF or SMV could inform about poor different cognitive underlying processes performance. Hence, it should be a clear indication for further testing including a combination of tests recruiting specific cognitive processes. Besides, while VF tasks may appear to be simple in nature, their potential lies in what they can reveal about the nature of EF organization, orthographic and semantic organization, and lexical-semantic processes in clinical populations. For instance, Toazza et al. (2016) observed a significant association of anxiety with poor LVF performance in children, and this association seems to be explained by children with anxiety producing a smaller number of clusters than control children. Anxiety in children is associated with lower EF performance, rather than memory or lexical-semantic processes. Accordingly, the investigation of the clustering and switching scores could also play an important role in the neuropsychological assessment of Brazilian typical and clinical child populations.

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Conflict of interest

None declared.

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