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Effects of age of acquisition and category size on signed verbal fluency

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ABSTRACT

Using a free-recall paradigm, we explored the effects of age of acquisition and category size on verbal fluency in Turkish Sign Language (Türk İşaret Dili [TİD]). We studied the semantic and phonological fluency task performances of deaf native and deaf late adult signers. We measured the number of correct responses and performed a time course analysis to observe how signers engage in lexical retrieval. Each task parameter had three difficulty settings corresponding to the size of the selected phonological and semantic categories. The results show that native TİD signers produced more correct responses. However, the results reveal no relation between the age of acquisition and the retrieval rate since participants maintained close subsequent response times. This indicates that participants had similar lexical access. Furthermore, the number of signs that the participants produced decreased as the level of difficulty (as a function of category size) increased. Therefore, phonological and semantic category size was found to be a suitable measure for categorical difficulty in TİD. We conclude that both groups of signers update information in the working memory and engage in lexical access similarly, but delayed acquisition of TİD results in a smaller search set in the mental lexicon.

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1. Introduction

Over 90% of all deaf children are born into hearing families where caregivers have little or no prior knowledge of any sign languages, which are the natural languages of many deaf populations (Mitchell & Karchmer 2004; Weaver & Starner 2011; Woll 2013). Given that cochlear implementation (CI) even in early ages does not guarantee a typical (spoken) language acquisition (see Hall, Hall & Caselli 2019 for an evaluation of the possible problems with CI), recent reports have suggested that an early and systematic exposure to sign language provides a more reliable means of ensuring the retainment of future language skills for these children. Furthermore, even if deaf children are implanted with cochlear implants, early exposure to sign language helps to improve their productive spoken language skills such that they rank on a par with normally hearing children (Davidson, Lillo-Martin & Pichler 2014). However, the social and cultural circumstances in the upbringing of deaf children of hearing parents (DCHP) cause a delayed exposure to a fully-fledged linguistic system, regardless of how caring their home environment might be (Trovato2013). In the context of Turkey, an initial attempt at communication by DCHP is made possible with the emergence of home sign.[1] This follows from the fact that an overwhelming majority of early intervention programs available for DCHP in Turkey give greater prominence to the development of spoken language abilities (see Kemaloğlu & Yaprak Kemaloğlu 2012). As a result, many DCHP are deprived of frequent conventional language exposure

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[1]A gestural system that resembles natural languages in terms of its internal consistency but also deviates from them in other aspects (Brentari & Goldin-Meadow 2017).

Supplemental data for this article can be accessed on the publisher's website until they proceed to formal education in a deaf school starting from age 4 and onward (Mayberry 2007). Although the most recent report issued by the Turkish Ministry of National Education (2020:40–41) identifies 72 deaf schools for grades 1 to 12, most of the teachers in Turkey have rudimentary knowledge of a sign language, and they proceed with an oralist approach (i.e., most of the lesson is carried out in Turkish). Moreover, since there is not a set curriculum for teaching TİD, schools for the deaf in Turkey fail to mitigate concerns about professional teaching standards and good quality education. Therefore, for late signers, an essential part of the learning process is achieved by peer learning in and out of the classroom. The resulting dearth of accessible conventional linguistic input in the early few years is claimed to have various detrimental biological and psychological consequences for the child (Humphries et al. 2016, 2019).

Comparatively, 5%–10% of deaf children grow up with deaf parents. There, the presence of one or multiple deaf caregivers brings in the necessary conditions for the native acquisition of a sign language. The onset of linguistic and cognitive development of deaf children of deaf parents (DCDP) takes off from birth onwards, similarly to that of hearing peers (Chamberlain, Morford & Mayberry 2000; Lyness et al. 2013; Petitto 1997). Considering the long-lasting effects of delayed sign language acquisition, it is well documented that DCHP lag behind DCDP in standardized tests and general academic achievement (Lieberman, Volding & Winnick 2004; Ritter-Brinton & Stewart 1992). This finding has important implications for late-signing deaf children since high sign language proficiency is strongly correlated with other academic measures like reading comprehension, mathematical knowledge, and language skills (Hrastinski & Wilbur 2016). Late-signing deaf children also have less developed linguistic abilities especially concerning the domains of morphology, morphosyntax, and phonological processing in both L1 (Boudreault & Mayberry 2006; Emmorey & Corina 1990; MacSweeney et al. 2008; Newport 1990) and possibly in other languages that may follow (Mayberry, Lock & Kazmi 2002).

Research on DCHP has also revealed that a relatively reduced lexicon might emerge because of limited word learning opportunities. Unless an early sign language intervention is provided for these children, DCHP will be mostly unable to benefit from conversations as a word-learning strategy with other family members in environments where only speech is used (Marshall et al. 2013). Other studies also reported less developed vocabulary (Cuetos et al. 2004; Jones et al. 2019). It is also claimed that these gaps in vocabulary will be greater compared to matched hearing peers as DCHP get older (Anderson 2006). One important caveat here is that these findings are difficult to generalize to other late signers given the high variability in age of acquisition. In extreme cases where deaf late adolescents were exposed to their first sign language following age 13, Ramírez, Lieberman & Mayberry (2013) observed that their initial rate of vocabulary acquisition was faster compared to typically developing children. However, the effects of these linguistic differences seem to last, no matter how long a person is exposed to a sign language after a certain threshold (Mayberry & Eichen 1991; Newport 1990). In addition to poor sign language input that DCHP receive, cognitive deficits are reported to gradually emanate in the early years of life and contribute to the slow pace of vocabulary development. An early disadvantage at socialization as well as setbacks experienced in many domains of language coincides with and negatively affects the development of a theory of mind (ToM) (Richardson et al. 2020; Woolfe, Want & Siegal 2002) and executive functioning (EF) among DCHP (Figueras, Edwards & Langdon 2008; Jones et al. 2019). The adverse effects (of late language acquisition on cognitive measures that DCHP experience) have not been observed for DCDP (Hall et al. 2017; Marshall et al. 2015; Meristo & Hjelmquist 2009). These findings suggest a delay in the cognitive development of deaf individuals with limited access to language. Supporting possible resolution of such deficits, some studies comparing deaf late adult signers to matched native adult signers found insignificant differences in tests that measure higher cognitive skills and ToM (Clark et al. 1996; Parasnis 1983). Similar results were observed for deaf adolescents who use a cochlear implant compared to individuals with typical hearing levels on memory tasks (Chandramouli, Kronenberger & Pisoni 2019). These findings suggest that increasing peer communication and social interaction in an accessible modality during the early years of formal education contribute to the development and ultimately the retainment of cognitive skills for DCHP. Still, this observation contrasts with some of the more recent studies (Lecciso et al. 2016; Marschark et al. 2019), which report that late-signing adults still perform poorly particularly on the social-perceptual and social-cognitive components of ToM when compared to the matched native group. Given the complex interplay between cognition and language, it is also important to highlight the possibility that the performance in some cognitive tasks may be masked by the present linguistic demands (Woolfe, Want & Siegal 2002). This would mean that if such linguistic demands were removed in these tasks, late signers' performance might be comparable to matched hearing speakers and native deaf signers. In light of this assumption, we will refrain from making any conclusions about the retainment or resolution of any cognitive deficits in adulthood observed for deaf children.

2. Verbal fluency tests

Verbal fluency tests (VFTs) are measures of verbal ability, consisting of vocabulary knowledge and lexical access, and executive functions (EF) that help update and store information in the working memory (Shao et al. 2014). In a VFT, participants are given a prompt, for which they produce as many words as possible in a given amount of time, usually 60 seconds. Participants are required to engage in lexical retrieval within a search set restricted by certain categorical norms (Patterson2011). Given that VFTs are brief neuropsychological assessment tools, and they are considerably easy to administer, two specific types of VFTs have commonly been used in research and clinical settings: semantic and phonological verbal fluency tasks. In semantic VFTs, participants are given a semantic category (e.g., "animals"), for which they generate words or signs. In phonological VFTs, participants are given a phoneme, and they produce words or signs that begin with that phoneme: that is, an initial sound as in /k/ or /b/ for spoken languages or a handshape (e.g., "5-handshape") or a location (e.g., "arm") for sign languages. In a limited time, individuals produce nonrepetitive and meaningful words while activating certain components of the EF, such as monitoring performance and updating information ("updating"), switching within and among semantic or phonological clusters ("shifting"), and inhibiting intrusion/out-of-category (OOC) responses or sustaining attentional resources ("inhibitory control") (Marshall et al. 2013; Miyake et al. 2000). To illustrate, in a VFT, individuals would need to (i) update information in the working memory to keep track of other previously mentioned lexical items in the trial in order not to repeat them, (ii) switch among semantically or phonologically related smaller sets (e.g., starting with root vegetables and then moving to leafy vegetables for the category "Vegetable"), and (iii) inhibit competing responses (e.g., suppressing a semantic neighbor in a phonological fluency task). Among these three subcomponents of EF, the updating abilities are more robustly reflected in analyses of correct responses produced in VFTs (Shao et al. 2014). Inferences for the other two subcomponents, shifting and inhibition, require further examination of response clusters and errors respectively.

Retrieving meaning-based representations from the mental lexicon according to different categorical norms is a daily routine for most people, where their vocabulary size and strength of semantic links become prioritized. Furthermore, psycholinguistic models of speech production suggest that, in lexical access, semantic activation of a word precedes phonological activation (Levelt, Roelofs & Meyer 1999). Thus, it is suggested that a semantic VFT is an easier and more proceduralized task than a phonological VFT (Giezen & Emmorey 2017; Marsh et al. 2019; Patra, Bose & Marinis 2020). Since phonological retrieval entails the suppression of the semantic network via response inhibition, the overall difficulty of a phonological task is increased. Additionally, there is a strong dependence on an initially available search set that is governed by the strength of connections in the phonological network, and also on phonemic awareness. For this reason, phonological fluency tasks are demanding not only on the individual's ability to identify or manipulate individual phonemes but also on the maintenance of EF.

3. Analysis of word retrieval and response latency

Previous research concerned the exponential decline rate in the number of the responses over the course of VFTs (60 seconds) and closely associated it with the utilization of the working memory or the updating subcomponent of EF. It is assumed that the cognitive load on EF must increase as the trial proceeds since participants have more to remember and inhibit. They also need to control previous responses and shift among categories (Luo, Luk & Bialystok 2010). Thus, the number of items produced during the task decreases by time (Kail & Nippold 1984). Accordingly, the random-search model views lexical access as a serial process where the categories are first semantically constrained to a smaller set upon receiving a prompt, and then exemplars that comply with the given categorical criterion are randomly selected (Wixted & Rohrer 1994). Each item that has yet not been selected within a given subset has an equal chance of being retrieved. As time progresses, the number of possible responses accessible to the individual becomes limited and thus more challenging to produce.

An individual's verbal fluency is a function of both the size of their search set given unlimited time and the rate at which they sample responses from the working memory. Consequently, variation in fluency is dependent on either the size of the search set, which is proportional to category size, or the recall rate which is dependent on updating abilities. As time progresses, the number of recalled items decreases. After a certain time, almost each recall retrieves an item which has already been sampled earlier in the task.

Assuming the principles of random sampling in free recall, few studies investigated the effect of the updating ability on verbal fluency performances with a time course analysis. Rohrer et al. (1995) analyzed the production of the given responses during each task in 5-second time intervals and derived a measure of subsequent response time (henceforth SRT). This measure corresponds to the average of response latencies that denote the elapsed time since the onset of the initial response. The mean number of correct responses provided by the participant is explained by prior vocabulary knowledge; any change through time mostly indicates updating abilities (Friesen et al. 2015)—namely, the size of an initially available search set can be smaller because of fewer existing lexical items in the lexicon, yet how an individual performs over the course of the task is mostly dependent upon the efficient use of the updating abilities. If the SRT is longer— in other words, if the responses are in a relatively even distribution across the 60-second trial, accompanied by a lower number of correct responses—it is assumed to be due to retrieval slowing. Alternatively, individuals can have shorter SRTs, meaning that they have run out of items relatively early in the task, again reaching a lower number of correct responses in total compared to the other group(s). Similar analyses were carried out to explore the effects of bilingualism in VFTs in relation to SRT and associated longer latency among bilingual participants who outperformed monolingual participants, with an advantage in executive control (Friesen et al. 2015; Luo, Luk & Bialystok 2010). Longer latencies accompanied by a higher mean score mark better updating abilities. It should also be pointed out that the final possibility born out of these two factors (i.e., high number of responses along with a shorter SRT) has not been attested to our knowledge, and we do not discuss it in this article.

4. Age of acquisition effects on verbal fluency

There is little information on the effects of the age of acquisition of a sign language on verbal fluency. To examine semantic cluster productions, Marshall et al. (2013 used a semantic fluency task with a group of signing deaf children. They reported similar semantic organization and fluency performance among deaf children whose onset of exposure to British Sign Language (BSL) ranged from birth to 10 years of age, although they did not test for age of acquisition effects. Other research presented data from deaf adults and children using American Sign Language (ASL) who were given semantic and phonological VFTs (Beal-Alvarez & Figueroa 2017). The previous study looked at the age of acquisition effects on verbal fluency and reported weak correlations between the onset of exposure to a sign language and the mean scores achieved in semantic and phonological VFTs among children. They did not find any correlation among adolescents. This finding implies that verbal fluency is somewhat similar among deaf individuals despite the varying years of exposure. Beal-Alvarez & Figueroa (2017) concluded that early cognitive and lexical discrepancies observed in deaf children may disappear as they get older and that language deprivation only has permanent effects in syntax, leaving semantic knowledge and organization intact. However, a few studies provided support for the age of acquisition effects on verbal fluency among deaf adult signers. The findings of Sehyr, Giezen & Emmorey (2018) and Marshall et al. (2018) support the finding that natives, in verbal fluency tasks, perform better than late signers.

5. Effects of categorical size on verbal fluency

Another factor that affects the performance in VFTs is the selection of phonological categories, assuming that lexical frequency decreases as categorical difficulty increases (Morford & MacFarlane 2003). Different from phonemes in spoken languages, "handshape" (or the hand configuration) together with the parameters of "location" of the hands within the sign space, "movement" of the manual articulators (arms and hands), and "orientation" of the palm make up the phonological composition of a sign (Brentari, 1998).[2] Marshall et al. (2013) identified the frequency of occurrence of each phonemic handshape from an existing BSL dictionary and chose the handshapes "G," "claw 5," and "I," ranging from most frequent to least. They intuitively chose two location categories for different difficulty settings and concluded that increasing phonemic frequency led to increased number of retrievals. These findings support previous theories of free recall that suggest that individuals will recall more items for larger categories and fewer items for smaller categories (Wixted & Rohrer 1994).

The semantic categories chosen for VFTs have been broad categories such as "Animals" and "Vegetables" (Patterson 2011). Studies in spoken languages indicated that normative category size is a function of continuous recall of exemplars from the semantic memory (Herrmann & Murray 1979; Wixted & Rohrer 1994). For both phonological and semantic frequency, the general understanding is that people produce fewer words as category size decreases (i.e., the search set gets smaller), and in contrast, they have less difficulty in accessing words as categorical size increases (i.e., the search set gets larger).

6. Present study

Here, we examine the effects of age of acquisition (native versus late) and the effects of category size with difficulty settings (easy, medium, hard) on VFT performance in Turkish Sign Language (Türk İşaret Dili [TİD]).[3] We examined the semantic and phonological fluency performances of deaf adult signers through an analysis of the number of correct responses and the time course in which these responses are produced.

[2]In studies adapting VFTs to sign languages, movement is traditionally less likely to be selected as a task category since it is the last parameter to be processed due to its changing nature (Thompson, Emmorey & Gollan 2005). Namely, movement of the hands is not present at the beginning of a sign but extends over a period of time; thus it is more challenging to perceive or retrieve it. The orientation of the palm has not been used in phonological fluency tasks as a contrasting phonemic quality either because it displays very few values: the dorsal, palmar, ulnar, and radial sides of the hand (Channon & Hulst2011). On the other hand, there are 23 phonemic handshapes and 12 locations identified for ASL (Stokoe 1960), 33 and 26 for Turkish Sign Language (TİD) (Makaroğlu & Dikyuva 2017).

[3]Distinct from any other smaller community sign languages, Turkish Sign Language (TİD) is the officially recognized national sign language that is used by the deaf community all across Turkey. TİD is estimated to be the native language of 84,000–180,000 people in the country, corresponding to 0.13%–0.27% of the total population (Kemaloğlu 2016). Some lexical dialectical variation has been reported for the language (Zeshan 2003). In this article, we mainly report data from TİD varieties used in the western and central parts of Turkey.

6.1. *Native vs. late acquisition*

Previous research reported a long-lasting effect of language deprivation on many components of language, including vocabulary skills (Cuetos et al. 2004; Jones et al. 2019). Our expectation is that the late acquisition group will produce a lower number of correct responses in the test compared to the matched native group, indicative of poorer linguistic resources. As for the time course analysis, considering the aforementioned masking effects of the linguistic demands in most cognitive tasks and the complex relationship between language and cognition, it is difficult to estimate whether our participants will have similar or different lexical access and updating abilities. As a result, we have the general prediction that if language deprivation leads to more impoverished updating skills, then we should expect a difference in the number of responses in the set time intervals as well as the mean SRT numbers for the two acquisition groups. This would imply a change in the lexical access rate between groups, meaning that participants access their mental lexicon differently. If, in contrast, both acquisition groups have similar updating abilities and lexical access rates, we will fail to find a difference between acquisition groups and signs produced in the set time intervals.

6.2. *Task parameters*

Previous research on verbal fluency shows that phonological fluency tasks are more challenging compared to semantic fluency tasks since they rely more on the efficient use of the updating abilities (Giezen & Emmorey 2017; Patra, Bose & Marinis 2020). We have the general expectation that participants will perform worse on phonological fluency than semantic fluency. However, the phonology of sign languages encompasses different parameters such as handshape, location, and movement, as we mentioned previously. Although theoretical and empirical studies suggest that signers process and retrieve movement the latest (Emmorey & Corina 1990; Thompson, Emmorey & Gollan 2005), there is not an agreement for the effect of handshape and location on processing and recall. As a result, we do not have any expectations as to whether participants will find one phonological parameter easier over another.

6.3. *Category size and difficulty settings*

Given the lack of resources required for objectively determining phonemic or normative frequency of task categories in the visual-gestural modality, most of the existing research either intuitively determined task categories or failed to incorporate different difficulty settings to test the effects of frequency-correlated or normative category size on performance (e.g., Marshall, Rowley & Atkinson 2014). In the present study, we test whether frequency-based semantic and phonological difficulty settings (easy, medium, and hard) for task categories affect the overall performance. Taking into account the random search model of lexical access, we expect that the rate of recall by the participants will decrease over time in a similar manner. Based on observed categorical size effects, we expect that sign recall will decrease gradually as difficulty increases (i.e., category size gets smaller) for the two phonological parameters, handshape and location, and semantics.

7. Method

7.1. *Participants*

Fifteen native and 16 late deaf adult signers of TİD participated in the study. All of the participants (between 18 and 50 years old, 15 females) reported using TİD as their primary language of communication. The criteria to be a native signer were to be born into a family with deaf parent(s) and to start to acquire TİD from birth onward. Late signers were all born into a family with hearing parents, and their age of exposure to TİD ranged between 3 and 17 years (M = 8.9 years, SD = 3.6). All participants completed at least eight years of compulsory education. Their level of education (M = 12.2 years, SD = 1.9) ranged between eight and 16 years. With the exception of one native signer who only attended mainstream schools together with hearing peers, all the other participants attended one deaf school at least. On a 1 (*poor*) to 5 (*proficient*) point scale, native participants' self-rated productive TİD skills (M = 5.0, SD = 0.0) and late participants' self-rated productive TİD skills (M = 4.9, SD = 0.6) did not statistically differ, $t(29) = -1.4$, p = .2. For receptive TİD skills, all participants indicated that they were proficient (M = 5.0, SD = 0.0). Native signers' Turkish speaking (M = 2.7, SD = 1.4), writing (M = 3.6, SD = 0.7), and reading (M = 3.7, SD = 0.7) skills also matched with late signers' speaking (M = 3.3, SD = 0.7), writing (M = 3.4, SD = 0.5), and reading skills (M = 3.5, SD = 0.6); p's > .1.

We present the participant demographic information based on self-reports in more detail in Appendix A. In their childhood, the primary mode of communication between late signers and their caregivers mainly consisted of home sign and Turkish; TİD was mainly used by the native signers and their caregivers. Late-signing participants reported to have a varying estimated range for age of TİD acquisition (3–, 8–12, and 13–17 years), which corresponded to the age at which they began formal education in a residential or nonresidential school for the deaf.

We estimated the years of TİD use following its acquisition for each participant. It is important to note here that, although the two groups of participants started learning TİD at different ages, native signers' exposure to TİD (M = 29.3 years, SD = 6.8 years) was similar to late signers' exposure to TİD (M = 28.8 years, SD = 7.2 years), $t(29) = -0.2$, p = .8. However, the participants in the late group had a higher average age (M = 37.7 years, SD = 7 years) than those in the native group (M = 29.7 years, SD = 6.8 years), t(27) = 3.4, p < .01. This is expected given that the average years of TİD use are similar in both groups.

Furthermore, all the participants preferred TİD as their first language of communication and reported that they were proficient users of TİD. We excluded two participants' (1 and 2) responses only for the "Hard-1" category for Semantics (i.e., "diseases") because they did not understand the instructions clearly and failed to produce correct responses.

7.2. *Task categories and difficulty settings*

The test design included six handshape (HS) and six location (LOC) categories for the phonological parameter and six semantic (SEM) categories, with "easy (x2)," "medium (x2)," and "hard (x2)" difficulty settings (see Figure 1). For phonology, we estimated the difficulty of the phonemes (both handshape and location) from an online TİD dictionary (Makaroğlu & Dikyuva 2017) using frequency of occurrence as a measure. Using the phonological search engine function of the dictionary, we searched for the combination of handshape and location categories and then counted the tokens. We assumed decreasing frequency of occurrence (i.e., smaller category size) for increasing difficulty. We adapted semantic difficulty from revised categorical norms provided by Van Overschelde, Rawson & Dunlosky (2004). The "category

Table 1. Phonological and semantic categories.

Parameter	Easy		Medium		Hard	
	1	2	1	2	1	2
Phonology						
Handshape	Flat B  *(506)*	Index  *(338)*	V/2  *(152)*	T  *(150)*	L  *(36)*	8  *(6)*
Location	Above-shoulder *(567)*	Hands *(503)*	Chest *(162)*	Arms *(92)*	Belly *(37)*	Shoulders *(30)*
Semantic	Relatives	Veg & fruits	Professions	Made of wood	Diseases	Sciences

potency" in their norming study was defined as the mean number of responses participants provided for each category in 30 seconds. Our easy categories resulted in seven or more responses (M = 8.4 responses); medium categories resulted in five or more responses (M = 6.0 responses); and hard categories resulted in four or more responses (M = 4.7 responses). All items and the frequencies of occurrence for phonological categories are given in Table 1.

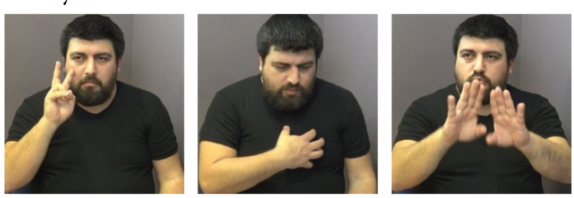
7.3. *Task procedure*

Participants were asked to produce as many signs as possible within 60 seconds for each of the 18 categories. All instructions for the task were given in TİD in a video by a deaf native signer. First, participants watched a general video explaining what the test was about prior to the onset of the trials. Then they were given specific instructions before each parameter (handshape, location, and semantics). An additional deaf research assistant was present in all sessions to answer questions and explain the task again if requested. The experimenter used a stopwatch to mark the start and the end of each trial. The participants were shown the categories (i.e., the pictures of handshapes and locations) on a computer screen during the experiment. We did not use pictures for the names of semantic categories; however, they were presented both in written Turkish and in TİD in video. The three blocks (Handshape, Location, and Semantics) were completed in the same order, but the six categories within each parameter were randomized for each participant. All trials were video-recorded, and then annotated with ELAN Linguistic Annotation Software (Crasborn & Sloetjes 2008).

7.4. *Coding*

Each response that was unique, nonrepetitive, meaningful, and complied with the given semantic or phonological constraint was coded correct as in (1).

(1) Correct responses for the categories Handshape ("V/2"), Location ("Torso"), and Semantics ("Made of wood") respectively.



$_{1}$SEE$_{2}$ MOTHER CLOSET

Other responses were coded incorrect. The types of incorrect responses we observed were as follows: intrusion or out of category (OOC) as in (2), repetition, inflection on a previously recalled item as in (3), and nonintelligible signs. For the location category of "hands," we only included two-handed signs that were asymmetrical[4] and therefore excluded signs that were symmetrical or were placed in the neutral signing space as in (4). For semantic categories only, responses from both subordinate and superordinate categories (as in FEN "physical sciences" and KİMYA "chemistry" for the "Science" category) were coded correct. Since mouthing is lexically contrastive in TİD (Taşçı 2020:86),[5] we allowed for signs that have the same handshape and location but with different mouthings, as exemplified in (5).

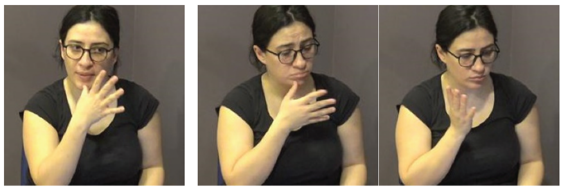
[4]In two-handed asymmetrical signs, the dominant hand is active. It moves to the nondominant hand, which is passive and functions as a place of articulation, i.e., location.

[5]Mouthing is the partial or full and usually voiceless articulation of a word at the same time with a corresponding sign.

(2) Out-of-category (OOC) errors for the Handshape ("Index"), Location ("Stomach"), and Semantics ("Science").

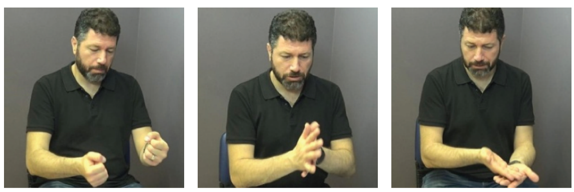
SWEET HEART PROFESSOR

(3) Inflection error for the Handshape ("Flat B"). The second instance was coded incorrect.



KNOW KNOW NOT

(4) Incorrect and correct responses in the "Hand" location category. The first two instances depict errors due to the use of two-handed signs that are symmetrical. The last instance depicts a correct response where the nondominant hand functions as a place of articulation.



DRIVE SIGN GRILL

Following Sehyr, Giezen & Emmorey (2018) and Marshall, Rowley & Atkinson (2014), we coded the color varieties of items correct (as in ELMA YEŞİL 'green apple' and ELMA KIRMIZI 'red apple'). If there is not a standardized equivalent sign in TİD, fingerspelled borrowings from Turkish were regarded correct (as in K-İ-V-İ 'kiwi').

(5) Signs that have the same phonological parameters but have different mouthings. Both instances are coded correct.

CHERRY SOUR CHERRY

In cases where fingerspelled items were followed by a lexical sign, we excluded the former, as in example (6). Indexed or pointed signs where the signer points to an object in the testing room were coded incorrect. Similarly, we excluded any responses that embodied the exact replication of the illustrations and text available to participants on the screen. All the annotations were done by the first author, who is a hearing late signer of TİD. A hearing research assistant with good TİD knowledge was trained to code all of the data again only for whether the responses were correct or incorrect. The initial agreement between the two raters was 90.7% for handshape, 83.5% for location, and 87.3% for semantics. Some of the disagreements between the two raters arose due to problems such as decontextualization of the signs, acceptability of certain semantic derivations (e.g., kinship terms as in "great-great-grandmother"), and the use of home sign alternants in lieu of established signs. Some were resolved by consulting an additional proficient deaf signer of TİD. After the consensus, the percent agreement was 92.8% for handshape, 90.4% for location, and 89.3% for semantics. To measure the interrater reliability, we employed Cohen's Kappa test (κ = 0.71, 0.78, 0.64 for each parameter respectively). These coefficients correlate with substantial/good levels of reliability according to Altman's (1990:406–407) guidelines. For the statistical analysis, we used the updated data set that was agreed upon by the two raters.

(6) Fingerspelling preceding a lexical sign. We considered this as a single correct response.

K-A-V-U-N 'MELLON' MELLON

7.5. *Statistical analysis*

We use Bayesian regression models and report the credible intervals of the coefficients in our statistical analyses. We do not form the models from scratch but use the brms package in R (Bürkner 2018) to define our models. We set contrast codings, model formula, and data family for the regression model.[6]

For the regression models, we report the median estimate, 50% and 95% credible intervals of the coefficients. The basic workings of Bayesian inference follow from the prior and the likelihood (the data) to get the posterior. We did not define our own priors, and the models we have use the default prior settings provided by the brms package (Bürkner 2018).

We used sum contrasts and sliding differences for our predictors. Sum contrasts are used to compare two or more levels with one another. Sliding differences are used for a predictor like "difficulty," which is expected to yield a gradual effect with each increase in the predictor setting. We used the "contr.sum" and "contr.sdiff" (Ripley et al. 2020) functions in R to set contrasts after we ordered the levels of a predictor. The magnitudes for sum contrasts are +/−.5 so that the level comparison is made with regards to the "0" in the plots. In the plots, the coefficients that have a "*" (star) are the interaction terms. The coefficients that have a "–" (dash) show the gradual level comparisons in sliding differences.

We interpret the coefficients according to the median estimate, distribution of the posterior probability, and how "wide" the distribution is. If most of the posterior probability (>95% CI) is toward a sign (–/+), this is interpreted as a categorical effect of decrease/increase for that level with regards to what it is compared against. Assume that two coefficients have similar median estimates but vary in their posterior probability distributions. We interpret this as greater

[6]We use 1,000 as our sample rate.

variation for the "wider" distribution and smaller one for the other. If the posterior probability distributions overlap to an extent (>50%), we conclude that those predictors yielded similar effects. We are not interested in the values of decrease/increase in terms of time (ms) or word count, but we are interested in the relative effects of the predictors.

8. Results

The annotation results were organized into a data frame and analyzed using the R programming language. Figure 1 shows the distribution of the responses by task category, acquisition group, and response coding. We are only interested in the "correct" responses for the rest of the study. Furthermore, for our final statistical analyses, we did not use all four age of acquisition groups (0–3, 4–7, 8–12, 13–17) but chose to collapse participants into two groups (Native [0–3] and Late [4–17]). This is because having more than two age of acquisition groups would not be informative due to the small sample size in each interval.[7]

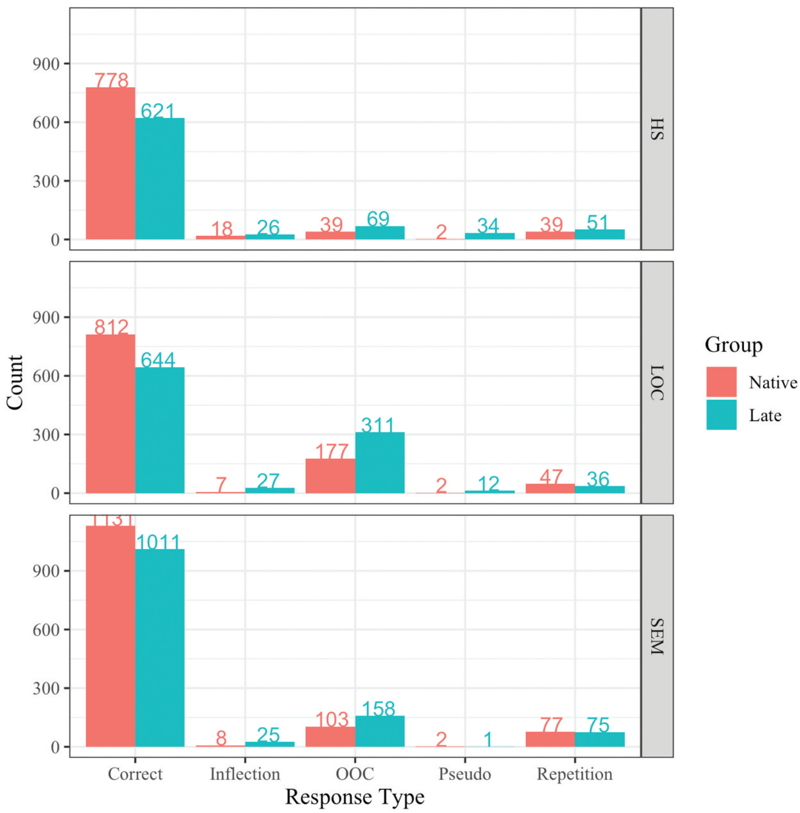


Figure 1. Total number of responses by task category, acquisition group, and response type.
Note: HS: Handshape, LOC: Location, SEM: Semantics, OOC: inhibiting intrusion/out-of-category, Pseudo: pseudo or non-intelligible signs.

[7]We recognize that keeping such information present in data analysis can prove useful in a meta-analysis for a collection of verbal fluency tasks. Having subdivided the late group into two, we present our exploratory analysis using three different age of acquisition groups (Native [0–3], Early [4–7], and Late [8–17]) as a supplementary material. In the model, "Group 1" refers to Late signers, "Group 2" refers to Early signers, and "Group 3" to Native signers. Given the wide posterior distributions, the results indicate that differences between early and late signers did not reach statistical significance.

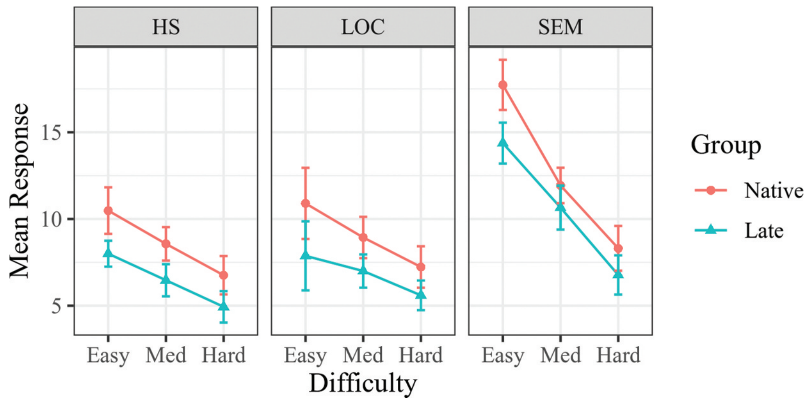


Figure 2. Mean correct responses by task category, acquisition group, and difficulty.
Note: Vertical bars indicate 95% confidence intervals. HS: Handshape, LOC: Location, SEM: Semantics, Med: Medium.

Figure 2 shows the mean correct responses by task category (handshape, location, semantics), acquisition group (native, late), and difficulty (easy, medium, hard). Overall, native signers had a higher number of correct responses than late signers, and increasing difficulty reduced mean responses. For more inference, we made two different analyses. In the first analysis, we used the number of correct responses, and in the second analysis we used time intervals. The first analysis gives insight into the participants' vocabulary inventory and whether it is affected by task category, difficulty, and acquisition group. The second analysis gives insight into how the participants retrieve signs over time.

8.1. *Analysis of the number of correct responses*

We fit a regression model to the total number of correct responses using task category (handshape [HS], location [LOC], semantics [SEM]), acquisition group (native, late), and difficulty (easy, medium, hard) as predictors (model definition = total_trial_response ~ [category+difficulty+acquisition] ^ 2). We used sum contrasts for task category and acquisition group and sliding differences for difficulty.

Figure 3 shows the regression model results. The estimates indicate that there was a decrease in responses when the task category was handshape or location. Both of these categories are phonological. Participants produced more signs when the task category was semantics, followed by location and handshape. There was an increase in the sign production when the participant was a native signer. Increase in difficulty translated into decrease in overall responses. Each increase in difficulty had similar decreases in sign production. There is a likely interaction with location and the difficulty shift. Over 90% (95% LOC*M-E, 92% HS*H-M) of the posterior probability distribution is on the increasing side. This means that increasing difficulty in the location categories did not decrease the number of responses as much as increasing difficulty in the semantic category did. This interaction effect is not observed for the handshape category. We do not have a clear explanation for this interaction. This interaction is not kept for the difficulty change from Medium to Hard. We interpret this as a spurious and uncontrolled variation tied to the items making up the handshape category. The items for each category combination are distinct, and correlation of an item and a category cannot be separated. This means that random effects of an item cannot be separated from the predictors of difficulty and task category. Remaining coefficients for interactions indicate no interaction taking place.

8.1.1. *Discussion*

Native signers maintained a higher mean number of correct responses than late signers in each parameter (see Figure 1 for a summary). This replicates some of the reported effects in the literature (e.g., Marshall et al. 2018; Sehyr, Giezen & Emmorey 2018). To illustrate, the mean scores of native signers in the "Easy-2" semantic category "Vegetables & Fruits" (20.1 signs on average by native

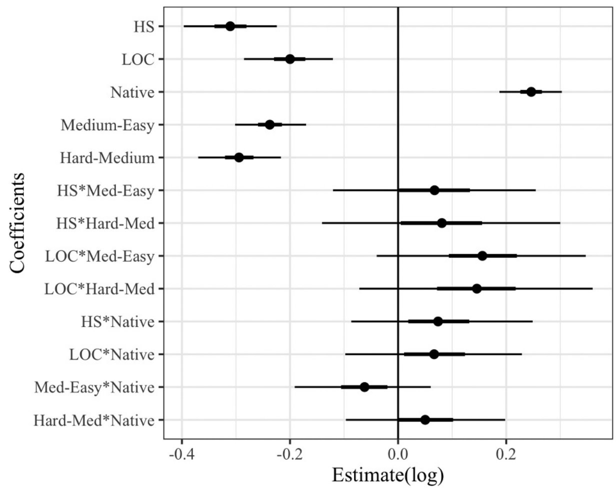


Figure 3. Regression model results for the total number of responses.
Note: The point represents the median estimate, the thick line represents 50% credible intervals, and the thin line represents 95% credible intervals. Sem = semantic; Med, M = medium.

signers opposed to 15.8 signs on average by late signers) compared similarly to previously reported adult monolingual speakers of English with 21.5 words (Patra, Bose & Marinis 2020) for the same category, and to adult native BSL signers with 23–24 signs on average (Marshall, Rowley & Atkinson 2014), and adult ASL signers with 21 signs on average (Morere, Witkin & Murphy 2012) for other broad semantic categories as “Animals” and “Food.” These results support those of Sehyr, Giezen & Emmorey (2018), who reported that native adult signers compared to late signers fared better in semantic fluency when fingerspelled responses were included, contra Beal-Alvarez and Figueroa (2017), who did not observe an age of acquisition effect in the mean scores of verbal fluency among the deaf adult participants in their study. However, the authors note that none of their participants had deaf parents and consequently learned ASL from another source (school or other members in the family); the present study along with others reporting an age of acquisition effect grouped signers for whether they had deaf parents or not. It is likely that Beal-Alvarez & Figueroa’s (2017) sample did not distinguish native acquisition from late acquisition and thus yielded insignificant results.

The difficulty settings—easy, medium, and high—were equidistant from one another: As categorical difficulty increased, the number of signs produced decreased in both groups (see Appendix B). This finding is consistent with that of Rohrer et al. (1995), whose small-category condition generated a lower number of responses. The more items there are in a search set, the more likely it is to sample a not-yet-selected item upon a semantic prompt.

A direct comparison of the mean number of correct responses in the phonological easy categories (10.8 by native and 7.9 by late signers on average) in our study to that of F-A-S or C-F-L phonological fluency tasks, which are the letter categories conventionally given for assessing verbal fluency in spoken languages, is infeasible given that the selection of the letters does not truly correlate with the frequency of occurrence. A meta-analysis of oral phonological tasks revealed that older adult English speakers produce 13 correct words on average (Harrison et al. 2000). The mean scores of native signers in the “Medium-1” handshape “V/2” correlating to the medium frequency with 152 observed instances in the TİD dictionary was 9.1; they produced 6.3 signs on average for low frequency “Hard-1” handshape “L” with only 36 observed instances, as opposed to late learners of TİD who scored 6.8 and 5.3 respectively. To compare, the participants with early acquisition in Marshall, Rowley & Atkinson’s (2014) sample generated 11 signs on average for the handshape “G,” which is reported to have 167 entries in the BSL dictionary as opposed to seven signs on average produced for the handshape “I” with 29 entries. This is also reflected in the location and semantic task results.

The effect of age of acquisition in general can be attributed to how the vocabulary inventory is formed. With early exposure to TİD, rate of sign acquisition increases. In light of the aforementioned findings, we suggest that delayed exposure to first language leads to more reduced verbal fluency in adulthood in TİD. Furthermore, both the difficulty level of a phonological category as determined by our frequency count in the TİD dictionary (Makaroğlu & Dikyuva, 2017) and the adapted semantic categorical norms (Van Overschelde, Rawson & Dunlosky 2004) are suitable measures to test the effect of the categorical difficulty of signs on signers' performance.

8.2. *Time course analysis*

The aforementioned analysis of the total number of responses treats each task completed by a participant as one unit. This does not give insight into the nature of word retrieval over time. In the literature, some derivative measures like SRT or first word response time (e.g., Friesen et al. 2015; Luo, Luk & Bialystok 2010) have been used to represent the access to the vocabulary inventory in different settings (see Introduction). Here, instead of averaging the time over responses or using one point of response time, we analyzed responses for the whole duration of the task.

Figure 4 is an illustrative way of the possible inferences that can be drawn before we take a look at the data where the dashed and solid lines correspond to different groups. If the two groups only differ in the number of responses but their retrieval rate is the same, then we would expect the data to look like the cumulative recall in Figure 4B. This configuration would mean different vocabulary sizes but similar updating (part of EF) abilities. By now, we know that native signers recalled more signs than late signers. However, if the number of responses were identical but the retrieval rate was different, then we would expect the data to look like the cumulative recall presented in Figure 4A. This configuration would mean similar vocabulary sizes but different updating abilities.

Figure 5 shows the cumulative distribution of correct responses over time by task category, acquisition group, and difficulty. The figure shows the cumulative mean response over time, together with SRT values for each combination. Native signers of TİD maintained higher mean responses, but the retrieval rate slowed down similarly in both groups. We divided response times into 10-second intervals, and then made comparisons between each interval. This means

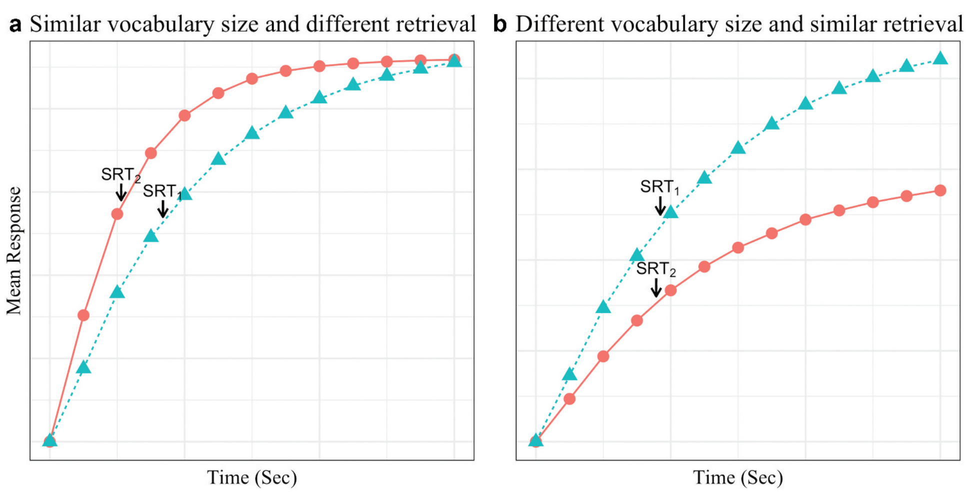


Figure 4. Hypothetical effects of vocabulary size and retrieval rate on cumulative recall.
Note: In this hypothetical recall, the outcome (A) illustrates different retrieval rate (as indicated by mean subsequent response time) but similar vocabulary size (as indicated by mean number of responses). The outcome (B) denotes similar retrieval rate but different vocabulary size. SRT: Subsequent response time.

that time was treated consisting of steps as opposed to being a truly continuous predictor. The interval setting of 10 seconds was arbitrary. Different analyses with changing bin size can be made depending on the available data.

Our objective in the response time analysis was to see if there was an interaction between acquisition group and word retrieval over time. This would show differences in accessing the vocabulary inventory between native and late signers. We fit a regression model to the cumulative number of responses, adding the predictor "time intervals" (20–10, 30–20, 40–30, 50–40, 60–50) with sliding differences to the other predictors: task category (handshape, location, semantic), acquisition group (native, late), and difficulty (easy, medium, hard) (model definition = cumulative_trial_response ~ (category+acquisition+time_-interval+difficulty) ^ 2). Figure 6 shows the results of the regression model only for the relevant coefficients of the acquisition group, time intervals, and their interaction.

The increase in time resulted in an increased number of responses as expected because we fit the model to the cumulative responses over time. The magnitude of the increase got smaller from one time interval to the other. The important finding here is that there was no interaction of time intervals and native acquisition. The median estimates are close to zero with posterior probability distributions relatively even toward each sign (−/+). We interpret this as no difference between native and late signers in terms of access to the vocabulary inventory—namely, the updating ability of the participants. EF and their possible interactions with the age of acquisition requires the testing of other subcomponents, inhibition and shifting.

8.2.1. *Discussion*

The time course indicated that both groups had similar decay in their responses over time (Figure 5). This finding complies with the principle that participants sample from an initial search set and gradually recall fewer items (Wixted & Rohrer 1994). In this regard, we postulate that although late first-language acquisition results in a smaller search set, the updating abilities in the working memory (as indicated by recall rate) remain unaffected by age of acquisition.

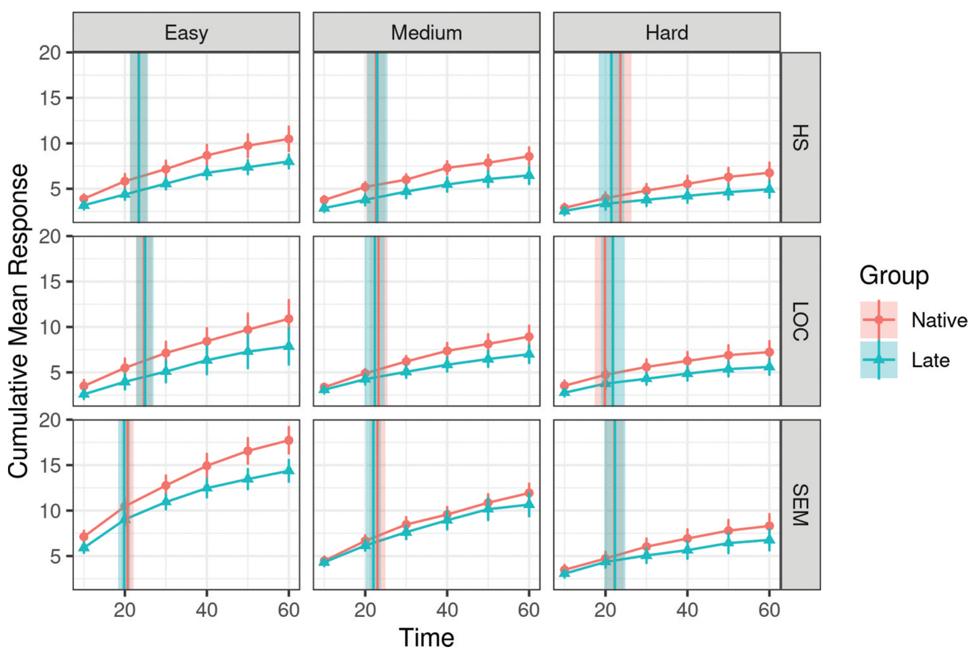


Figure 5. Cumulative distribution of correct responses over time by task category, acquisition group, and difficulty.
Note: The continuous vertical line indicates the mean SRT, and the shaded area is the 95% confidence interval for the SRT. The mean SRT values are too close, and the confidence intervals overlap highly. Points indicate cumulative mean responses and the non-continuous vertical lines on those points are the 95% confidence intervals for the responses.

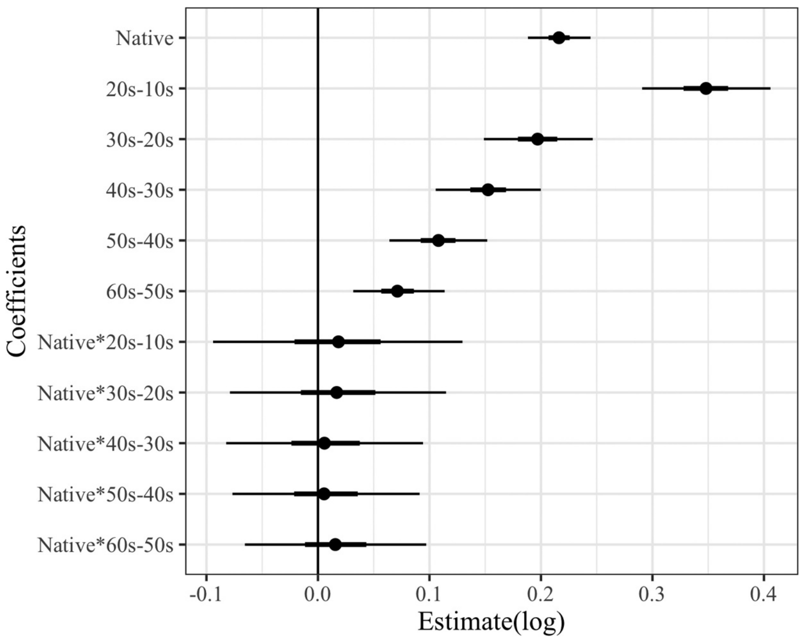


Figure 6. Regression model results for the time course analysis.
Note: The point represents the median estimate, the thick line represents 50% credible intervals, and the thin line represents 95% credible intervals.

The SRT values in our study were almost identical for both groups and verified the results of the time course analysis, which revealed a similar slope across both groups (see Figure 6). The random-search model suggests that SRT is dependent on the size of the search set and the time required to recall an individual item; that is, shorter latencies with a low mean number of responses indicate a reduced vocabulary. On the other hand, long latencies illustrate retrieval slowing in that search may not be congruent with production and delays latency (Sandoval et al. 2010; Wixted & Rohrer 1994). To this end, previous studies conducted with unimodal bilingual speakers hypothesized that participants with a higher mean number of responses and a longer SRT had superior executive control (Friesen et al. 2015; Luo, Luk & Bialystok 2010). Unlike the work cited previously, the present study did not find a difference for either the signs produced in time intervals (i.e., the rate of recall) or the SRT values.

9. General discussion

In this study, we examined the effects of the age of first-language acquisition among deaf adults on verbal fluency performance with difficulty settings through an analysis of the number of correct responses and the responses over the time course. The results revealed that (i) native acquisition of TİD increased the mean number of correct signs, but it did not affect access to the lexicon; (ii) participants were the most successful in semantic categories; and (iii) frequency- and norm-correlated category size had a gradual effect on performance. We suggest that access to the lexicon was presumably similar for both acquisition groups, but the mean difference in the number of correct responses resulted from smaller vocabulary resources initially available to the late signers. The mean number of correct responses in these tasks has been typically associated with prior vocabulary knowledge (Friesen et al. 2015). In this regard, the present study supports the conclusion that late sign language acquisition may indeed result in a smaller search set and mark slower sign vocabulary development, replicating some of the findings in the literature (Lu, Jones & Morgan 2016; Woll 2012). Given that we were unable to administer a language proficiency test for our participants, we would like to also explore the possibility of participants' overall TİD proficiency as an extraneous variable. Each participant in our two acquisition groups indicated that they considered

TİD as their preferred native language, which they used for most contexts. Despite the varying age of acquisition years, native and late signers had been using TİD for a similar mean number of years as well. For these reasons, we believe that both groups of signers are competent users of TİD, but the main difference in the number of responses must be due to the smaller number of lexical items initially available to the late signers, possibly highlighting a less developed vocabulary.

Previous research reported a disadvantage in different components of EF skills among deaf children with late exposure to sign language (Figueras, Edwards & Langdon 2008). Since we cannot exclude the possibility that the linguistic demands may have masked performance in certain cognitive tasks administered to late-signing deaf children, we can only suggest that, in contrast to studies that report deficits in working memory, deaf adult late and native signers in this study performed on a par in terms of accessing the lexicon and using updating abilities. To account for the lower mean number of responses in the verbal fluency tasks by late signers, we claim that language deprivation has long-lasting and detrimental effects on vocabulary. For many late-signing children, social communication is often restricted to the home environment, and it is constrained with a co-constructed gestural communication system in early childhood. This naturally limits the richness of the initial input and reduces opportunities for joint attention. Little joint attention along with fewer opportunities to observe peripheral communication may considerably reduce the sources of vocabulary learning (Marshall et al. 2013). Our findings then provide support to the notion that lexical access and updating abilities are similar across deaf native and late signers in adulthood but that certain linguistic effects of language deprivation do remain and persist into adulthood.

The findings of the present study also show that signers perform best in semantics, followed by location and handshape respectively. In the phonological fluency task, participants performed better in location over handshape, which contrasts with some of the previous findings that report that the processing, free recall, and clustering of handshape and location often align. We speculate that retrieval of location might be easier for the signers given the higher number of contrastive handshapes (33) compared to contrastive locations (26) in TİD (Makaroğlu & Dikyuva 2017). This implies that the number of phonemic neighbors that appear during the handshape trials may also be higher. Since there would be more competing responses from other categories for Handshape, signers could recall fewer items due to response inhibition. The scope of this study does not include a qualitative analysis of recall errors nor give insight into how participants inhibit competing responses and switch between clusters. For this, we urge more studies to investigate response inhibition during lexical access to further study the activation of the phonological network among signers with different linguistic backgrounds.

As discussed earlier, the inquiry into response latency indicated that cumulative recall is a function of the size of the search set and the efficient use of the working memory. The size of the search set is often attributed to category size. In this article, we found that there was a negative correlation between recall and categorical difficulty for phonology and semantics. This finding also has the implication that category size is a good estimate for the difficulty settings of the task items in verbal fluency. Taken altogether, these findings have direct implications for DCHP, highlighting the importance of early and systematic exposure to a sign language. The earlier opportunities for preschool instruction and interaction in a sign language available to linguistically deprived deaf children become prevalent, the more likely it is for them to retain future language skills and have good vocabulary knowledge when they reach adulthood.

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Declaration of interest

No conflicts of interest were reported.

Data availability statement

The data and code are openly available at https://osf.io/k3x7a/

Disclosure Statement

No potential conflict of interest was reported by the authors.

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Appendix A

Table A1. Participant demographic information based on self-report.

No	Status	Sex	AOA (yrs)	Age (yrs)	LOE	Deaf schools attended	Home language in childhood	Parental hearing status
1	Native	M	0–3	33	HS	PS, MS, HS	TİD, home sign	Both deaf
2	Native	F	0–3	27	HS	PS, MS, HS	TİD, home sign	Both deaf
3	Native	F	0–3	43	HS	None	TİD	Both deaf
4	Native	F	0–3	43	HS	PS	TİD	Both deaf
5	Native	M	0–3	26	HS	PS, MS, HS	TİD, home sign	Both deaf
6[a]	Native	F	0–3	27	HS	PS, MS, HS	Home sign	Both deaf
7	Native	M	0–3	29	HS	PS, MS, HS	TİD, home sign	Both deaf
8	Native	M	0–3	28	HS	PS, MS	TİD	Both deaf
9	Native	M	0–3	35	HS	PS, MS, HS	TİD	Both deaf
10	Native	F	0–3	23	HS	PS, MS, HS	TİD	Both deaf
11	Native	F	0–3	30	HS	PS, MS, HS	TİD	Both deaf
12	Native	F	0–3	25	HS	PS, MS, HS	TİD	Both deaf
13	Native	M	0–3	26	AD	PS, MS	TİD	Both deaf
14	Native	M	0–3	18	HS	PS, MS, HS	TİD	Both deaf
15[b]	Native	M	4–7	32	HS	PS, MS, HS	TİD	Father deaf, mother hearing
16	Late	F	4–7	35	AD	PS, MS	Home sign, TR	Both hearing
17	Late	F	4–7	46	MS	PS, MS	TR	Both hearing
18	Late	M	4–7	36	HS	MS	TR, home sign	Both hearing
19	Late	M	4–7	33	HS	PS, MS, HS	TR	Both hearing
20	Late	F	4–7	33	HS	PS, MS	TR, home sign	Both hearing
21	Late	F	4–7	31	AD	PS	Home sign	Both hearing
22	Late	M	4–7	35	HS	PS, MS, HS	Home sign	Both hearing
23	Late	F	8–12	46	HS	PS, MS	Home sign, TR	Both hearing
24	Late	F	8–12	41	HS	MS	Home sign	Both hearing
25	Late	F	8–12	49	MS	PS, MS	Home sign, TR	Both hearing
26	Late	M	8–12	43	BA/BS	PS, MS	TR	Both hearing
27	Late	M	8–12	28	BA/BS	MS	TR	Both hearing
28	Late	M	8–12	33	HS	PS, MS	Home sign	Both hearing
29	Late	M	13–17	50	MS	MS	TR, home sign	Both hearing
30	Late	F	13–17	34	HS	PS, MS	TR, TİD	Both hearing
31	Late	M	13–17	31	BA/BS	PS, MS, HS	TR	Both hearing

Note. AOA = age of acquisition, LOE = level of education, HS = high school, AD = associate degree, MS = middle school, PS = primary school, BA/BS = Bachelor of Arts/Science, TR = (Spoken) Turkish.

[a]Participant 6 reported to have deaf parents who do not use TİD. She also informed us that she learned TİD between ages 0 and 3 and that she has deaf aunts, uncles, and cousins in the family. Supposing she must have learned TİD from other family members, we considered this participant a native signer.

[b]Participant 15 reported to have acquired TİD between ages 4 and 7. Given that he has a deaf father who signs TİD, we also considered this participant a native signer.

Appendix B

Table B1. Means and standard deviations for the number of correct responses by Task, Difficulty, and Group.

	Native		Late	
Task	*M*	*SD*	*M*	*SD*
HS				
Easy	10.5	3.8	8.0	2.2
Medium	8.6	2.7	6.5	2.7
Hard	6.8	3.0	4.9	2.6
LOC				
Easy	10.9	5.7	7.9	5.7
Medium	8.9	3.3	7.0	2.8
Hard	7.2	3.3	5.6	2.4
SEM				
Easy	17.8	4.0	14.4	3.4
Medium	11.9	2.9	10.7	3.7
Hard	8.3	3.5	6.8	3.2

Table B2. Means and standard deviations for the subsequent time responses (in seconds) by Task, Difficulty, and Group.

	Native		Late	
Task	*M*	*SD*	*M*	*SD*
HS	S			
Easy	23.4	7.0	23.4	7.8
Medium	22.6	6.9	22.9	7.1
Hard	23.6	8.1	21.4	7.7
LOC				
Easy	24.7	6.4	24.9	6.6
Medium	23.2	7.0	22.3	9.1
Hard	19.8	9.6	21.8	9.6
SEM				
Easy	20.7	4.8	19.8	5.3
Medium	23.0	4.3	22.0	4.5
Hard	22.2	8.7	22.3	10.1

Appendix C

Table C1. Regression model results for the number of correct responses.

Parameter	Outer width	Inner width	Point estimate	ll	l	m	h	hh
HS	0.95	0.5	median	−0.400155	−0.341689	−0.310498	−0.281170	−0.225855
LOC	0.95	0.5	median	−0.281382	−0.227817	−0.199257	−0.170752	−0.115678
Medium-Easy	0.95	0.5	median	−0.304670	−0.261142	−0.238649	−0.216276	−0.171707
Hard-Medium	0.95	0.5	median	−0.370144	−0.318932	−0.291821	−0.266444	−0.218811
Native	0.95	0.5	median	0.188788	0.225642	0.246768	0.268210	0.305909
HS*Med-Easy	0.95	0.5	median	−0.135729	−0.007917	0.060532	0.126859	0.252082
LOC*Med-Easy	0.95	0.5	median	−0.033270	0.094248	0.164131	0.225642	0.357502
HS*Hard-Med	0.95	0.5	median	−0.133144	0.004400	0.078351	0.156372	0.298099
LOC*Hard-Med	0.95	0.5	median	−0.072897	0.074194	0.150593	0.223288	0.367555
HS*Native	0.95	0.5	median	−0.079327	0.026789	0.083653	0.141074	0.253314
LOC*Native	0.95	0.5	median	−0.105307	0.003594	0.059617	0.117808	0.223864
Med-Easy*Native	0.95	0.5	median	−0.185854	−0.102469	−0.057486	−0.011006	0.076356
Hard-Med*Native	0.95	0.5	median	−0.108778	−0.006408	0.044850	0.098149	0.193177
HS*M-E*Native	0.95	0.5	median	−0.261216	−0.000420	0.128173	0.261744	0.512388
LOC*M-E*Native	0.95	0.5	median	−0.430715	−0.179022	−0.051013	0.089146	0.328069
HS*H-M*Native	0.95	0.5	median	−0.454496	−0.171524	−0.026123	0.125026	0.438356
LOC*H-M*Native	0.95	0.5	median	−0.511401	−0.221333	−0.071880	0.086340	0.360593

Table C2. Regression model results for the time course analysis.

Parameter	Outer width	Inner width	Point estimate	ll	l	m	h	hh
Native	0.95	0.5	median	0.188098	0.206902	0.216643	0.226736	0.244917
20s–10s	0.95	0.5	median	0.288653	0.330724	0.350273	0.371008	0.410562
30s–20s	0.95	0.5	median	0.146664	0.181443	0.198956	0.217523	0.249989
40s–30s	0.95	0.5	median	0.104669	0.135812	0.152049	0.168879	0.201393
50s–40s	0.95	0.5	median	0.065876	0.094431	0.109943	0.124575	0.153783
60s–50s	0.95	0.5	median	0.028092	0.056756	0.072136	0.086649	0.113684
Native*20s–10s	0.95	0.5	median	−0.092071	−0.017633	0.021200	0.061268	0.137476
Native*30s–20s	0.95	0.5	median	−0.080465	−0.013455	0.020117	0.054895	0.120474
Native*40s–30s	0.95	0.5	median	−0.087342	−0.024771	0.007614	0.038617	0.101105
Native*50s–40s	0.95	0.5	median	−0.080355	−0.025752	0.004570	0.033976	0.092670
Native*60s–50s	0.95	0.5	median	−0.069139	−0.013440	0.016452	0.045015	0.100608