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

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 were found to be suitable measures 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.

Keywords: verbal fluency, word learning, memory, linguistic deprivation, Turkish Sign Language (TİD)

# 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 a deaf child is implanted with a cochlear implant, 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 et al. 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 (Trovato, 2013). In those families, an initial attempt at communication is made possible with the emergence of home sign[[1]](#footnote-1). This indicates that DCHP are mostly deprived of frequent conventional language exposure until they proceed to formal education in a deaf school starting from age four and onward (Mayberry, 2007). Although the most recent report issued by the Turkish Ministry of National Education (MoNE) (2020, pp. 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 (Akalın, 2013). 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 in Deaf[[2]](#footnote-2) culture. 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, quite similarly to that of hearing peers (Chamberlain, Morford, & Mayberry, 2000; Lyness, Woll, Campbell, & Cardin, 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, Waters, Brammer, Woll, & Goswami, 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 accompanying a slower rate of vocabulary acquisition 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, Rowley, Mason, Herman, & Morgan, 2013). This might be expected given that the only interaction many DCHP have is often based on home sign. Other studies also reported less developed vocabulary (Cuetos, Monsalve, Pinto, & Rodríguez-Ferreiro, 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, and 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) among DCHP (Richardson et al., 2020; Woolfe, Want, & Siegal, 2002), and executive functioning (EF) (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, Eigsti, Bortfeld, & Lillo-Martin, 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. However, there is considerable support that these differences, if there are any, resolve with maturation. 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, Schwanenflugel, Everhart, & Bartini, 1996; Mayberry, 1993; 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 more recent research (Lecciso, Levante, Baruffaldi, & Petrocchi, 2016; Marschark, Edwards, Peterson, Crowe, & Walton, 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 et al., 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. Still, this may imply that some but not all cognitive disadvantages observed for deaf children who have hearing parents might persist into adulthood.

## 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, Janse, Visser, & Meyer, 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 (Patterson, 2011). In a limited time, they need to produce nonrepetitive and meaningful words while monitoring their 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). It is possible to dichotomize inhibitory control into response inhibition, which comprises the suppression of a strong out-of-category alternant (e.g., inhibiting a semantic neighbor during a phonological fluency task) and interference control which is against competing stimulus or ambivalent data (Brydges et al., 2012). Among the 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. 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.

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, Hansson, Sörman, & Ljungberg, 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.

## 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 which 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. To illustrate, previous research on response latency describes the cumulative number of recall by the exponential equation in (1):

F(t) = N(1 – e -λt) (1)

In the equation above, F(*t*) is the number of recalled items by a given time *t*, and *N* represents asymptotic recall (i.e., the estimated number of recalled items if there were unlimited time). Finally, *λ* in the equation corresponds to the rate of approach to the asymptote. Note that in this representation 1/*λ* equals the response latency. As a result, a large *λ* indicate a short mean latency whereas a small *λ* indicate a long mean latency.This means that 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. This equation is in line with the random search model defined earlier: 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, Wixted, Salmon, and Butters (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 which 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 while any change through time mostly indicates updating abilities (Friesen, Luo, Luk, & Bialystok, 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 et al., 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 paper.

## 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 and 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, and Emmorey (2018) and Marshall et al. (2018) support the finding that native signers, in verbal fluency tasks, perform better than late signers.

## 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)[[3]](#footnote-3). 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 which 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).

## 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)[[4]](#footnote-4). 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.

### Native vs. Late Acquisition

Mayberry (1993) and Parasnis (1983) reports that EF delays observed in early childhood may not be as persistent and not continue into adulthood. This contrasts with some other studies that report a persisting negative effect of late sign language acquisition among deaf adult signers on certain socio-cognitive measures (Lecciso et al., 2016; Marschark et al., 2019). For late deaf adult signers in particular, it is not clear whether the reduced vocabulary size and poorer performance on tasks that measure cognitive abilities observed among DCHP persist or disappear with maturation. 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.

### 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 et al., 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 above. Although theoretical and empirical studies suggest that signers process and retrieve movement the latest (Emmorey & Corina, 1990; Thompson et al., 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.

### 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 et al., 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.

# Method

## Participants

15 native and 16 late deaf adult signers of TİD participated in the study. All of the participants (aged between 18 and 50, 15 females) reported using TİD as their primary language of communication. The criteria to be a native signer was to be born into a family with deaf parent(s) and 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*age of acquisition = 8.9 years, *SD* = 3.6). All participants completed at least 8 years of compulsory education. Their level of education (*M* = 12.2 years, *SD =* 1.9) ranged between 8 and 16 years. With the exception of one native signer who only attended mainstream schools together with hearing peers, all the other participants at least attended one Deaf school. 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* = 0.2. 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 > 0.1.

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 whereas 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 (4-7, 8, and 13-17 years) which corresponded to the age at which they began formal education in a residential or non-residential 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* = 0.8. Furthermore, all the participants preferred TİD as their first language of communication and reported that they were proficient users of TİD. Their self-rated proficiency on average was 4.94 for TİD on a 1 (poor) to 5 (proficient) point scale. Using the same scale, participants also assessed their reading (3.7 for native, 3.5 for late signers), writing (3.6 for native, 3.4 for late signers), and speaking proficiency (2.7 for native, 3.3 for late signers) levels in Turkish. 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.

## Task Categories and Difficulty Settings

The test design included six handshape (HS) and six location (LOC) categories for the phonological (PH) parameter, and six semantic (SEM) categories, with “easy (x2),” “medium (x2),” and “hard (x2)” difficulty settings (see Table 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, and Dunlosky (2004). The “category 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 7 or more responses (*M* = 8.4 responses); medium categories resulted in 5 or more responses (*M* = 6.0 responses); and hard categories resulted in 4 or more responses (*M =* 4.7 responses). All items and the frequencies of occurrence for phonological categories are given in Table 1.

<Table 1 around here>

## 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 is 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).

## 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.

  

1SEE2  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 non-intelligible signs. For the location category of “hands,” we only included two-handed signs which were asymmetrical[[5]](#footnote-5), and therefore excluded signs which 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)[[6]](#footnote-6), we allowed for signs that have the same handshape and location but with different mouthings as exemplified in (5).

(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 are symmetrical. The last instance depicts a correct response where the nondominant hand functions as a place of articulation.

  

DRIVE SIGN GRILL

Following Sehyr et al. (2018) and Marshall et al. (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 have arisen 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 (1990, pp. 406–407)’s guidelines. For the statistical analysis, we used the updated dataset 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

## 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[[7]](#footnote-7).

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 order 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 towards 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 they vary in the distribution of their posterior probability distributions. We interpret this as greater 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.

# 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. 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.

<Figure 1 around here>

<Figure 2 around here>

## 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.

<Figure 3 around here>

Notice that we did not use age of acquisition groups (0-3, 4-7, 8-12, 13-17) as a predictor but chose to collapse it into two groups: native and late. It is because the last three groups of participants were exposed to TİD in similar settings, and the years of exposure among the participants were similar. These years of age of acquisition intervals are self-reported, and more likely to vary within. Our focus was on the exposure to TİD from birth onwards versus the later stages.[[8]](#footnote-8)

### Discussion

Native signers maintained a higher mean number of correct responses 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 et al., 2018). To illustrate, the mean scores of native signers in the “Easy-2” semantic category “Vegetables & Fruits” (20.1 signs on average by native 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 et al., 2020) for the same category, and to adult native BSL signers with 23-24 signs on average (Marshall et al., 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 et al. (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) whereas 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 and Figueroa (2017)’s 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 whereas 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 et al. (2014)’s sample generated 11 signs on average for the handshape “G” which is reported to have 167 entries in the BSL dictionary as opposed to 7 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 et al., 2004) are suitable measures to test the effect of the categorical difficulty of signs on signers’ performance.

## Time Course Analysis

The analysis above 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 et al., 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 4-B. 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 4-A. This configuration would mean similar vocabulary sizes but different updating abilities.

<Figure 4 around here>

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

<Figure 5 around here>

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). Figure 6 shows the results of the regression model only for the relevant coefficients of the acquisition group, time intervals, and their interaction .

<Figure 6 around here>

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 towards 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.

### 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) remains unaffected by age of acquisition.

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, Gollan, Ferreira, & Salmon, 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 et al., 2010). Unlike the work cited above, the present study did not find a difference for neither the signs produced in time intervals (i.e., the rate of recall) nor the SRT values.

# 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 poorer linguistic resources initially available to the late signers. The mean number of correct responses in these tasks have 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 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 a smaller number of lexical items initially available to the late signers, possibly highlighting a less developed vocabulary.

Previous research that reported a disadvantage in different components of EF skills among deaf children with late exposure to sign language (Figueras et al., 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 results have 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 called “home sign” 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 and engagement in EF (Marshall et al., 2013). As discussed before, certain cognitive differences previously observed among children with limited access to language, seem not to continue into adulthood and late adult signers perform on a par with age-matched native signers in tests that measure short term memory span and abstract reasoning (Mayberry, 1993; Parasnis, 1983). Yet, for other cognitive skills such as the ToM, recent experimental studies imply the persistence of these negative effects (Lecciso et al., 2016; Marschark et al., 2019). In this study, we observed no such effects on the updating subcomponent of EF for our late acquisition group. 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 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, which 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 paper, 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. Previous findings suggest that lexical frequency facilitates early vocabulary use for both spoken language acquisition (Naigles & Hoff-Ginsberg, 1998), and sign language acquisition (Caselli & Pyers, 2017). As a result, we propose that our findings could be partially explained with a usage-based account of language learning (Tomasello, 2000, 2009). This approach proposes that the frequency of language use later determines its strength of representation in memory. If we assume that the relationship between category size and free recall also parallels the degree of frequency of the constructions the child receives in the input and their later use, this will imply that frequently used patterns will be more strongly represented in memory. Instead, less frequently used patterns will have a smaller chance of being retrieved during lexical access. 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 pre-school 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.

# Declaration of interest

No conflicts of interest were reported.

# Data availability statement

For this double-blind review, we have anonymized the data and code which are openly available in Anonymous Github at <https://anonymous.4open.science/r/anonrepo-vf-34EF>

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# Appendix A

Table A-1. 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 |
| 6a | 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 |
| 15b | 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 0-3 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 4-7. Given that he has a deaf father who signs TİD, we also considered this participant a native signer.

# Appendix B

Table B-1. Means and standard deviations for the number of correct responses by Task, Difficulty, and Group.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Task | Native | | Late | |
|  | *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 B-2. Means and standard deviations for the subsequent time responses (in seconds) by Task, Difficulty, and Group.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Task | Native | | Late | |
|  | *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 C1

Table C-1. 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 |

# Appendix C2

Table C-2. 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 |

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). [↑](#footnote-ref-1)
2. . Here, we use “Deaf” with an uppercase ‘d’ to indicate the Deaf culture and community. To refer to the audiological status of the individual, we use “deaf” with a lowercase ‘d’. [↑](#footnote-ref-2)
3. . 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 & Hulst, 2011). 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). [↑](#footnote-ref-3)
4. . 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 paper, we mainly report data from TİD varieties used in western and central parts of Turkey. [↑](#footnote-ref-4)
5. . 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. [↑](#footnote-ref-5)
6. . Mouthing is the partial or full and usually voiceless articulation of a word at the same time with a corresponding sign. [↑](#footnote-ref-6)
7. . We use 1000 as our sample rate. [↑](#footnote-ref-7)
8. . We recognize that keeping such information present in data analysis can prove useful in a meta-analysis for a collection of verbal fluency tasks. Nevertheless, we present our exploratory analysis using three 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, while ‘Group 2’ refers to Early signers, and ‘Group 3’ to Native signers. The results confirm that the early and late signers display no statistical difference among one another. [↑](#footnote-ref-8)