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RESEARCH PAPER

Individual differences in verb aspect processing in monolinguals and bilingual heritage speakers of Turkish

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Abstract Language processing in monolingual and heritage speakers shows variation when the concept of aspect processing, an understudied phenomenon in the literature, is taken into consideration. In this regard, this study focuses on grammatical aspect (i.e., imperfective and perfective) in monolingual and heritage speakers of Turkish, and aims to uncover Turkish monolinguals' and heritage speakers' processing of perfective aspect for completed events and imperfective aspect for ongoing events. Furthermore, the study also aims to explore whether language proficiency and processing speed capacity have an effect on language processing in heritage speakers' eye-tracking data. The data have been collected by employing a comprehension experiment with 28 monolingual speakers and 25 heritage speakers. The heritage speakers participated in an additional sociolinguistic survey, a language proficiency tests (i.e., self-rating and C-Test), and a cognitive speed index test (i.e., WAIS-4). The results indicate that both groups demonstrate greater sensitivity to the imperfective aspect than to the perfective aspect. The accuracy rates were higher in the imperfective condition, and the effect emerged earlier in this condition compared to the perfective condition. Additionally, the findings suggest that language proficiency and processing speed significantly influence grammatical aspect processing and comprehension. Specifically, participants who achieved higher scores on the linguistic and cognitive tests exhibited correspondingly higher

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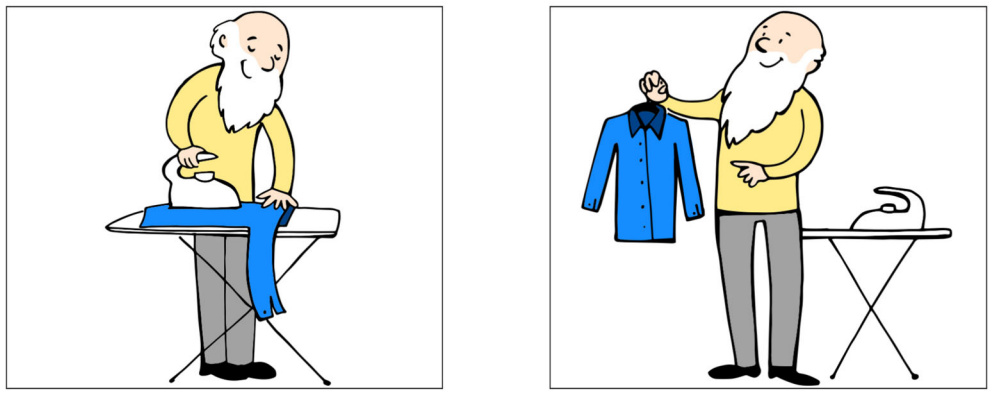

Fig. 1 The picture on the left illustrates an ongoing event, while the picture on the right represents a completed event. Corresponding example sentences are shown in (11) and (12)

accuracy rates. To conclude, the study highlights how linguistic structures differentially affect comprehension in monolinguals and heritage speakers, and how individual differences shape heritage speakers' language processing abilities.

Keywords Turkish · Heritage speakers · Heritage language · Grammatical aspect · Language processing · Individual differences

Introduction

Lohndal et al. (2019) describes a heritage language as one acquired at home in a non-majority language society, with heritage speakers acquiring the minority language naturally in their family environment. As they engage with society's institutions, the majority language typically becomes dominant, particularly in formal settings and education. Subsequently, heritage speakers face challenges in maintaining proficiency in their heritage language. Despite frequent exposure to the minority language in their early years, heritage speakers often use the majority language more frequently during late childhood and adolescence, resulting in structural differences in their heritage language compared to monolingual populations. These differences vary across linguistic domains and categories (Kupisch & Rothman, 2018; Montrul, 2022; Polinsky & Scontras, 2020). Language contact between the two languages is common in both individual repertoires and the speech community, emphasizing the dynamic nature of heritage language development (Montrul & Polinsky, 2011). As heritage speakers have shown vulnerability in comprehension and production of grammar across several linguistic domains (Polinsky & Scontras, 2020), grammatical aspect has been prominent in this line of research (Andreou & Tsimpli, 2017).

Comrie (1976) introduced a significant difference between the concepts of lexical aspect and grammatical aspect. Grammatical aspect, henceforth called 'aspect', is about understanding the time-related structure of a situation. It is different from the inherent temporal quality (lexical aspect) of the situation, which is also distinct from the external time indicated by tense. A crucial differentiation in grammatical aspect is established between the two classifications: imperfective and perfective (Comrie, 1976) and Turkish is one of the languages having this distinction.

Grammatical aspect has been investigated in various languages. In one of these studies, Rizou (2021) found that Greek heritage speakers in Germany and the US demonstrated greater accuracy in using the perfective aspect in an elicited production task without time constraints. In another study, Paspali et al. (2022) evaluated the accuracy of Greek heritage speakers in the US and Germany through a speeded grammaticality judgment task, where the German group performed well, while the US group, despite being the least accurate overall, showed better performance in the imperfective conditions, suggesting a preference for the morphologically default imperfective aspect, particularly the habitual form. Recent research on heritage Russian highlights systematic changes in the

use of perfective and imperfective aspects along with morphological differences during acquisition (Antonova-Ünlü & Wei, 2016; Gagarina, 2013; Gagarina et al., 2020; Kistanova & Sekerina, 2019; Laleko, 2008; Pereltsvaig, 2003; Mikhaylova, 2018; Pereltsvaig, 2008; Isurin & Ivanova-Sullivan, 2008). For Russian and Turkish heritage speakers, there is a tendency towards increased use of periphrasis and a decline in morphologically complex synthetic aspectual forms (Gagarina et al., 2020; Pfaff, 2000). While no study has explicitly investigated grammatical aspect in heritage Turkish speakers as an isolated phenomenon, some studies have focused on the comprehension and production of grammatical aspect. For instance, Arslan et al. (2015) demonstrated that Turkish heritage speakers are slower in responding to evidentiality violations and less accurate in processing evidentiality cues in eye-tracking tasks. Given that evidential morphology in Turkish partially overlaps with aspect-marking morphology, these results suggest potential difficulties in processing grammatical aspect.

Previous studies looked at many different linguistic domains and phenomena rather than grammatical aspect. To our knowledge, this is the first study that investigates the processing of grammatical aspect in heritage speakers.

Grammatical aspect in Turkish

In Turkish, aspect is morphologically marked. According to Göksel and Kerslake (2005), aspect in Turkish is conveyed through explicit verbal suffixes, which occasionally also carry tense aspects. In the realm of Tense/Aspect/Modality (TAM) markers, Turkish is quite complex, as pointed out by Ketrez (2012). Many suffixes in Turkish that fall under TAM can have two or three functions at the same time. In Turkish there are five aspect markers (i.e., -(I)yor, -A/Ir, -(y)AcAK, -DI and -mIş) in the verbal domain. In our study, we focused on perfective (-DI) and imperfective progressive (-(I)yor) aspects. As we are interested in studying the contrast between the two main aspectual categories, perfective and imperfective, we only illustrate the most frequent markers of these, -DI and -(I)yor. Perfective aspect is correlated with a completed action, while the imperfective aspect is associated with an ongoing event (Comrie, 1976; Kornfilt, 1997).

The perfective aspect in Turkish is denoted by the -DI marker, serving the dual purpose of indicating the past tense and perfective aspect. In its function as a marker for the perfective aspect, the event is viewed as completed (Kornfilt, 1997), establishing the perfective as the default and unmarked form. This morpheme has 8 phonological variations according to Turkish vowel harmony, consonant assimilation and final devoicing (i.e., -dı, -di, -du, -dü, -tı, -ti, -tu, -tü). Below the variation of the instances can be observed:

(1)	al-dı-m.
	take-PST.PF-1SG
	‘I took.’
(2)	git-ti-m.
	go-PST.PF-1SGs
	‘I left.’
(3)	gel-di-m.
	come-PST.PF-1SG
	‘I came.’
(4)	vur-du-m.
	hit-PST.PF-1SG
	‘I hit.’
(5)	gör-dü-m.
	see-PST.PF-1SG
	‘I saw.’
(6)	çık-tı.
	exit-PST.PF-3SG
	‘He/She/It exited.’
(7)	koş-tu-k.
	run-PST.PF-1PL
	‘We ran.’
(8)	ürk-tü.
	startle-PST.PF-3SG
	‘He/She/It startled.’

On the other hand, the imperfective aspect in Turkish is typically expressed through -(I)yor (a marker of Progressive Aspect and Present Tense),-(A/I)r (aorist, a marker of present tense), -mAktA (locative), and -DI (past copular marker) and what we used was signifying an ongoing event in the past tense (as in“-yordu”) (Göksel & Kerslake, 2005). Thus, the imperfective is considered a marked form.

(9)	gid-iyor-du-m.
	go-IMP-PST-1SG
	‘I was going.’

Monolingually raised Turkish speakers acquire the primary aspect/tense markers early in their language development. These markers include the perfective-past marker -DI and the progressive-imperfective marker -(I)yor (which has the same four vowel allomorphs as above) (Aksu-Koç, 1998). These distinct markers are crucial for understanding the contrast between perfective and imperfective aspects and are typically used productively by around the age of three (Acarlar et al., 2008).

Processing grammatical aspect

Languages differ in how they grammatically encode aspect, ranging from languages with obligatory aspectual marking to those without a grammatical aspect system. These differences are known to influence how speakers process aspectual information during real-time language comprehension.

Processing grammatical aspect studies have been conducted in various languages and eye-tracking experiments have been widely employed to explore the impact of visual context on language comprehension and processing because this method effectively captures rapid mental processes in spoken language comprehension and offers insights into various topics, from spoken word recognition to cooperative problem solving. In addition, eye-tracking experiments provide a close link between the visual system and language processing mechanisms, which highlight the role of implicit cognition in grammar comprehension.

In one of the earliest studies, Tanenhaus et al. (1995) tracked the eye movements of the English-speaking participants while they followed instructions to manipulate real objects. The results indicated that even in the earliest language processing moments, visual context influenced word recognition and shaped syntactic processing. The researchers concluded that people naturally align language with their behavioral goals early in processing and non-linguistic information promptly influences linguistic structuring.

In another study with English speakers, Huette et al. (2014) focused on grammatical aspect while participants listened to sentences without any accompanying visual stimuli or explicit task. The aim was to demonstrate how grammatical information is processed spontaneously, in the absence of overt instructions or task-related responses. The study found that eye movements were closely linked to the processing of grammatical aspect: participants' eyes moved in systematic patterns that reflected the grammatical structure of the sentences, despite only viewing a blank screen. This indicated that participants could implicitly parse grammatical information, with their spontaneous eye movements aligning with grammatical expectations. The timing of eye movements suggested that aspectual processing occurs rapidly and efficiently-often before participants become consciously aware of the manipulation or its relevance to the task.

Minor et al. (2022) investigated Russian aspectual prefixes and found that Russian speakers exhibited a preference for target pictures related to ongoing or completed events before the conclusion of the verb, indicating rapid and incremental processing of grammatical aspect information at a fine-grained word-internal level.

Bott (2013) explored the incremental interpretation by investigating aspectual mismatch and coercion in German sentences in terms of lexical aspect. Since German lacks grammatical aspect marking, the study focused on distinctions arising from the inherent (lexical) properties of verbs. He found that the detection of these aspectual distinctions depended on a complete verb argument structure, contradicting the idea of fully incremental interpretation. The delay in effects until all arguments were encountered suggests a more global processing level for certain semantic phenomena.

Eye-tracking experiments have also been used to investigate the cross-linguistic differences in processing grammatical aspect. Bott and Gattnar (2015) focused on achievement verbs modified by aspectually mismatching adverbials in Russian and German. They found that Russian readers quickly detected aspectual mismatches with achievement verbs, irrespective of verb position, whereas in German, mismatch effects only occurred after the complete predication. These findings highlight cross-linguistic differences in event interpretation increment sizes, which are likely driven by the availability of grammatical aspect: Russian obligatorily marks grammatical aspect (perfective vs. imperfective) and thus promotes early aspectual processing, while German does not have a grammatical aspect system, leading to delayed integration of aspectual information. Hence, aspectual processing varies across languages depending on whether and how grammatical aspect is encoded. In a recent study,

Minor et al. (2023) investigated how Russian, Spanish and English speakers process grammatical aspect. Their results showed a preference for ongoing events in imperfectively marked forms across the languages. In the perfective form, Russian emphasized event completion, Spanish to a lesser degree, and English did not show a preference. This suggests that the English Simple Past form does not encode a preferential cognitive salience for either the activity portion of an event or its result state, supporting the analysis of the English Simple Past as a non-aspectual tense form.

The cross-linguistic differences in processing grammatical aspect have also been investigated via self-paced reading experiments. For example, Bott and Hamm (2014) studied cross-linguistic processing of grammatical aspect in English and German. The findings suggested that coercing a past accomplishment into an activity reading caused processing difficulty in English but not in German. The authors attributed this difference to immediate aspectual specification in English and delayed aspectual specification in German. The study supports the Cross-Linguistic Aspectual Variation (CAV) hypothesis, emphasizing how a language's grammatical means influence immediate commitment to aspectual interpretation during language processing.

To sum up, the above-mentioned studies demonstrate some general patterns in the processing of grammatical aspects. There is a general tendency that native speakers can implicitly parse grammatical information and grammatical aspect processing occurs rapidly and efficiently (except for Bott (2013)). In addition, both eye-tracking and self-paced reading methods indicate cross-linguistic differences in processing grammatical aspect based on the specification of aspect in the language. However, despite this growing body of evidence on cross-linguistic variation, important gaps still remain. In particular, little is known about how aspect is processed in Turkish, a language that grammatically encodes aspect differently from languages like English or Russian. Moreover, even less is known about how Turkish heritage speakers - whose dominant societal language often lacks grammatical aspect - process aspectual information.

Inflectional processing in Turkish heritage speakers

Previous processing studies with Turkish heritage speakers have focused on the verbal as well as the nominal domain. We outline both here as they inform about different strategies and patterns applied by heritage speakers when processing inflectional marking.

In a recent study conducted by Karaca et al. (2024), the complex relationship between heritage speakers and language processing has been explored. They investigated the role of case-marking cues in predictive processing by Turkish heritage speakers in the Netherlands. This group is highly comparable to the group of Turkish heritage speakers in Germany given similar conditions for the development of Turkish in Germany and the Netherlands (YaÄŸmur & Van De Vijver, 2012). The study aimed to investigate how heritage speakers process morphological cues and the role of verb semantics in this process. The methods involved a combination of eye-tracking experiments and comprehension tasks designed to assess their reliance on grammatical versus semantic cues. The findings indicate that heritage speakers face challenges in relying solely on grammatical cues, highlighting the essential role of verb-semantic information in predictive language processing.

Moreover, the study underscores the significant impact of both spoken and written language experiences on the predictive processing of spoken language, aligning with previous research by Özsoy et al. (2023), which found that Turkish heritage speakers in Germany demonstrated some ability to predict the thematic role of NP2 using morphosyntactic cues on NP1. This study involved Turkish heritage speakers in Germany, using eye-tracking to measure anticipatory looks to the target object based on morphosyntactic cues. The aim was to compare the predictive abilities of heritage speakers and monolinguals in real-time language processing. The study also successfully replicated the predictive case use effect in monolinguals by Özge et al. (2019) through webcam-based eye-tracking. Individual analysis revealed diverse patterns among heritage speakers, suggesting that the predictive use of case is influenced by different factors across individuals (Özsoy et al., 2023), emphasizing the need to place heritage speakers on a native-speaker continuum to explain language outcome variability (Wiese et al., 2022). This indicates that the variability in heritage speakers' data might be due to differences in language exposure, proficiency levels, and individual language experiences (Arslan et al., 2017).

Within the verbal domain, previous studies with Turkish heritage speakers have focused on evidentiality as part of the broader TAM-marking. Evidentiality refers to the grammatical marking of the source of information, and in Turkish, this is typically indicated through specific suffixes that denote whether the information was directly witnessed, inferred, or heard from another source (Tokaç-Scheffer et al., 2023). According to the research by Tokaç-Scheffer et al. (2023), Turkish heritage speakers, who are typically raised in a dominant language environment different from Turkish, still maintain the evidential distinctions in their speech. This preservation highlights the robustness of their mental representation of Turkish grammatical rules, demonstrating that foundational aspects of the language remain intact despite limited exposure.

However, the study also indicates that these heritage speakers exhibit slower processing and production of evidential markers compared to monolingual speakers in Türkiye. This latency can be attributed to several factors, including reduced language exposure, less frequent use, and the cognitive demands of managing multiple languages. The slower processing might reflect the additional cognitive load required to retrieve and apply these grammatical rules in real-time communication. Moreover, the context in which heritage speakers use Turkish-often limited to family and community settings rather than broader societal use-might contribute to less automaticity and increased retrieval time for evidential markers.

Arslan et al. (2015) also provides evidence for divergence in processing grammatical evidentiality among Turkish heritage speakers compared to monolinguals. In an eye-tracking experiment, monolinguals processed direct and indirect evidential markers equally well, while bilinguals were less accurate and slower for direct evidentials, showing fewer target fixations in these conditions. Similarly, Arslan et al. (2017) found that heritage speakers were slower and less accurate than monolinguals when responding to evidentiality violations, suggesting a reduced sensitivity to evidential markers. Together, these studies highlight dynamicity in heritage speakers' evidentiality systems, shaped by differential exposure and cognitive constraints in heritage language settings.

Overall, the findings underscore the complexity of heritage language maintenance, where core grammatical distinctions can be preserved even as processing efficiency is affected by the linguistic environment. This research provides valuable insights into the cognitive and linguistic adaptations of heritage speakers, highlighting both the resilience and challenges of maintaining a minority language in a dominant language setting.

Further insights into the detailed dynamics of heritage language use come from the work of Coşkun Kunduz and Montrul (2023). Their investigation into heritage speakers of Turkish reveals a distinct pattern in the reduced sensitivity of these individuals to evidential marking. Notably, the research delineates a contrast between first-generation immigrants, who exhibit a preservation of evidential distinctions, and heritage speakers, whose proficiency declines and may be influenced by factors beyond parental language skills. They assume that language exposure emerges as a crucial factor, surpassing parental language skills in shaping the linguistic competence of heritage speakers. Two decades of heritage language research show that there are several key factors influencing proficiency and linguistic competence (Montrul & Polinsky, 2021). The quantity and quality of exposure to the heritage language are fundamental, with more extensive and rich language input aiding retention (Gagarina et al., 2014). The contexts in which the language is used, such as home, community, school, or media, significantly affect proficiency. Peer interactions in the heritage language provide practical and social contexts for use, further enhancing language skills. Educational support through language classes or bilingual programs supports linguistic competence (Leeman & King, 2014). Additionally, personal motivation and positive attitudes towards the heritage language and culture are critical. Support from the broader heritage community, including cultural organizations and events, encourages language use and provides additional practice contexts. Finally, the ability and willingness of parents and grandparents to use the heritage language consistently with children play a vital role in effective intergenerational transmission (Rodina et al., 2020).

As the sections above show, previous studies have mostly focused on offline data of heritage speakers' aspect production and comprehension. Additionally, sources of individual differences such as processing speed or language proficiency were often not accounted for. Our study adds to the literature by providing the first experimental online study on aspect

processing as well as accounting for individual differences in aspect comprehension.

Individual differences in bilingual processing

While studying individual differences in psycholinguistic studies has generally gained momentum in recent decades, individual processing and comprehension abilities in bilinguals are still largely underexplored (Karaca et al., 2021; Rothman et al., 2023). We illustrate some important studies in this area and show how our study adds to the growing pool of interest into individual differences in bilingual processing and prediction.

In one of the earliest studies, Becker (2011) examined cognitive and German language skills in Turkish children of different generational groups in Germany. Children from inter-marriages exhibit higher performance in both areas compared to other Turkish children. Conversely, children with a first generation mother and a second generation father fare the worst. Disparities in processing speed among children could be attributed to socio-economic status and educational resources within families. However, for language skills, factors like parental proficiency in the receiving country's language (German) also played a significant role alongside socio-economic factors. In another study, Karaca et al. (2021) examined the prediction abilities of bilingual children, contrasting them with those of monolingual children and adult second language (L2) speakers. They illustrate how exploring the prediction skills of bilinguals can enhance the comprehension of the mechanisms underlying predictive processing. They argued that individual factors such as language proficiency, the quantity and quality of language exposure and input in a bilingual's two languages, cumulative length of language exposure, vocabulary size, and richness of the language environment might modulate prediction skills in bilinguals. Prystauka et al. (2024) explored prediction and lexical interference in Russian heritage speakers, examining individual factors like vocabulary, cognitive control, and language background. In an eye-tracking experiment, they found that heritage speakers could predict based on semantic constraints. However, they experienced interference from locally coherent but contextually irrelevant lexical cues. Individual differences, especially cognitive control and vocabulary, influenced the degree of prediction and interference, with higher vocabulary correlating with better management of interference, and greater cognitive control enhancing predictive accuracy.

Bice and Kroll (2021) compared how bilingual heritage speakers process sentences in their native and dominant languages and found that heritage bilinguals exhibited smaller N400 and P600 effects in their non-dominant native language compared to monolinguals. Processing speed was crucial for monolinguals, while language proficiency mattered more for bilinguals. Bilinguals also showed differences in N400 effects depending on the language they used. Overall, what they concluded is that bilingualism enables the flexibility to adapt more quickly in language processing, while monolingual processing is influenced by stable factors like processing speed.

These studies illustrate that there is a need to account for individual differences in bilingual processing and prediction research. Individual's abilities and skills significantly influence linguistic effects which calls for more research that investigates the broad portfolio of individual background factors. Additionally, this opens a path in the field to move away from monolingual comparisons to a more nuanced understanding of bilingualism (Rothman et al., 2023).

The present study

In the present study, we aimed to investigate the extent to which Turkish heritage speakers display a preference for the perfective aspect in the processing of completed events and the imperfective aspect for ongoing events, in comparison to monolingual speakers. Additionally, we explore whether the absence of grammatical aspect in German influences Turkish heritage speakers, potentially leading to a reduced effect in processing patterns in Turkish. The intricate relationship between language proficiency and processing speed capacity is also a focal point of our investigation, as we seek to understand how these factors may impact the participants' processing of aspectual information at the sub-word level. By addressing the following research questions, we hope to contribute valuable insights into the interplay of linguistic and cognitive factors in the processing of aspectual distinctions among Turkish heritage speakers and shed light on potential cross-linguistic influences arising from bilingual experiences. Our research questions are as follows:

Table 1 Metadata comparison between heritage speakers and monolingual speakers

	Heritage speakers	Monolingual speakers
Age	32 (10.89, 20–54)	23 (1.30, 21–26)
Accuracy PF	0.79 (0.10, 0.41–1.00)	0.76 (0.42, 0.58–1.00)
Accuracy IMP	0.94 (0.22, 0.58–1.00)	0.96 (0.19, 0.83–1.00)
C–Test Score	21.55 (5.25, 9–35)	–
WAIS–Symbol Search Score	27.94 (7.24, 15–40)	–
WAIS–Symbol Coding Score	57.56 (9.41, 32–74)	–
Self-Rating ScoreTR	4.41 (0.22, 1–5)	–
Self-Rating ScoreDE	4.98 (0.02, 4–5)	–

1. Do Turkish heritage speakers and monolinguals prefer perfective aspect for completed events and imperfective aspect for ongoing events?
2. How do processing speed and language proficiency affect participants' processing of aspectual information at the sub-word level?

Methods

Participants

28 monolingual Turkish-speaking participants (75% females, age mean = 23, range 21–27) were recruited from Necmettin Erbakan University in Konya and participated in the webcam-based eye-tracking experiment and picture-selection task. The participants were all bachelor's students. They all were raised monolingually, and their first encounter with another language was in elementary school. The data from 21 participants were included in the analysis after excluding the data 6 participants due to technical errors while data elicitation.

25 Turkish-speaking heritage speakers, with German as their majority language, (60% males, age mean = 29, range 20–54) living in Berlin participated in the experiment in our psycholinguistics lab. We examined the educational background of our participants in the sociolinguistic survey and a substantial portion (18) were university graduates or still studying at the university, while the rest were either graduated from high school (4) or have an apprenticeship (3). In addition, the participants were asked whether they had received Turkish language education and more than half of them received it (mean = 0.69).

Table 1 gives an overview of the measures that characterize the groups and participants in this study. The first column labels the variables and the second and third columns label the groups. Comparison of demographic and cognitive performance metrics between heritage speakers and monolingual speakers, showcasing differences in age distribution, accuracy scores, and self-assessment measures are presented. The reported values represent the mean as well as the standard deviation and range in brackets.

In Table 1 we observe the age, Accuracy PF and IMP,[1] C-Test score, WAIS-Symbol Search and Coding score as well as self-rating scores for Turkish and German.

It can be seen that both heritage and monolingual speakers had higher accuracy rates for IMP in the picture-selection task. For the self-rating scores, it can be said that heritage speakers gave a high score for both German and Turkish languages, with Turkish having a slightly low score.

The participants gave written consent to participate in the study. Participants in both countries were compensated for their participation. The study was approved by the ethics committee of the German Linguistics Society (Deutsche Gesellschaft für Linguistik, DGfS) (approval number #2022-02-220202) before data collection started. The procedures used in

[1] Ranges for accuracies are reported for all but one participant in each group. In both groups, there was one participant who chose the strategy of only selecting the ongoing event picture as a response. This strategy would misrepresent the lowest range value for the PF condition in both groups which is why this single participant was disregarded here. The strategy indicates that the participant was not sensitive to the experimental condition. However, the fact that there is one such participant in both groups potentially indicates that this is not induced by heritage or monolingual status and rather is an indication of a rare individual behavior.

this study adhere to the tenets of the Declaration of Helsinki.

Materials

Eye-tracking experiment

For collecting the data, a lab- and Webcam-based Visual Word Paradigm incorporating eye-tracking technology was utilized. The experiment followed the paradigm of Minor et al. (2022), which involved experimental stimuli comprising 24 test items. Each item consisted of a visual display paired with a spoken preamble sentence and a spoken target sentence. In this context, our study represents a conceptual replication of Minor et al. (2022) and Minor et al. (2023), with adaptations that include a new language, a bilingual participant group, and an emphasis on individual differences.

All target sentences featured verbs in the past tense and focused on the grammatical aspect, distinguishing between perfective and imperfective forms. Participants heard either the perfective or imperfective version of each sentence. Each visual display showed two pictures side by side: one depicting an ongoing event (action in progress) and the other a completed event (action outcome). The same visual stimuli were used, and the sentences were translated into Turkish using the domestication method to ensure the stimuli sounded natural to participants (Venuti, 1995). Additionally, the word order in Turkish was modified from the typical *SOV* to *OVS* to allow participants to hear the verb-aspect earlier, potentially influencing gaze patterns. Since Turkish has a flexible word order due to its rich case-marking system, this change was not expected to meaningfully impact the results (Ergin & Stromswold, 2023).

The experimental stimuli included a total of 48 critical items, evenly split between 24 perfective and 24 imperfective instances, along with 20 filler items. The spoken sentences were recorded by a monolingual Turkish speaker, ensuring a focus accent on the verb-aspect. The visual displays featured color drawings from Minor et al. (2022), while fillers, taken from Özsoy et al. (2023), depicted two event-related pictures. Unlike the critical items, these fillers did not test grammatical aspect but rather agent-patient role differences, making them suitable for maintaining task engagement.

The items were introduced with a context sentence as shown in example (10). Each critical sentence then included verbs with different suffixes to convey aspect: the perfective marker -DI for completed events (see example (11)), and the imperfective suffix -(I)yor and the past tense suffix -DI for ongoing actions (see example (12)).

(10) Akşama bir davet vardı.
evening an invitation was
'There was going to be a dinner this evening.'

(11) Temiz gömleğini ütüle-di yaşlı amca özene bezene.
clean shirt iron-PST.PF old uncle properly
'The elderly uncle carefully ironed his clean shirt.'

(12) Temiz gömleğini ütülü-yor-du yaşlı amca özene bezene.
clean shirt iron-IMP-PST old uncle properly
'The elderly uncle was carefully ironing his clean shirt.'

Language proficiency task

For the language proficiency task, we first used a self-rating scaled survey including questions to evaluate participants' self-assessment regarding both their Turkish and German skills (i.e., speaking, listening, reading, and writing). Participants gave a rating from 1 to 5 for each of the skills, summing up to a maximum score of 20.

To assess the Turkish proficiency of participants in detail, we employed two C-Tests as outlined by Karayayla (2018). C-Test, widely recognized as an indicator of overall language proficiency

(Schmid, 2004), involves a fill-in-the-blanks format. In this particular task, the second half of every second word within a paragraph was omitted, while the first and last sentences were retained. Participants were then tasked with completing the words, resulting in a total of 40 items.

Responses were considered accurate if they contained a correct and complete word. The proficiency score was determined based on the total number of accurate responses provided by participants.

Processing speed index

To measure the processing speed of the participants, we used a processing speed index test. The processing speed index of the Wechsler Adult Intelligence Scale (WAIS-IV; Wais-iv. (2011)) test includes the symbol coding and symbol search tests and these are administered with pencil and paper. In the symbol coding test, participants received a key that paired numbers from 1 to 9 with nine distinct geometrical symbols. They were given a table where each digit appeared multiple times in a random sequence with a blank box beneath each digit. They were instructed to code as many symbols as they could in 90 s in the symbol coding task. In the symbol search test, participants were shown two target symbols on the left side of each row and an array of five symbols on the right side. They were instructed to search for as many target symbols as possible within 90 s in the symbol search task.

Procedure

The in-lab Tobii eye-tracking experiment took place at the psycholinguistics laboratory of Leibniz-ZAS in Berlin with 25 heritage speakers of Turkish. Each participant sat in front of a high-end stationary Tobii Pro Fusion 120 Hz eye-tracker connected to a stimulus computer. Calibration was managed using Tobii Pro Lab software and validated by the experimenter. Participants had 30–45-minute appointments during which they completed the eye-tracking task, followed by a sociolinguistic questionnaire, a C-Test, and the WAIS-IV Processing Speed Index subtest. The sociolinguistic questionnaire was administered at the end of the session to gather information about participants' language background and daily language use.

Data analysis

To answer the first research question, we ran a statistical analysis on the eye-tracking experiment results, looking into both picture-selection accuracy for both groups and eye movements for heritage speakers only. To give an answer to the second research question, we included language proficiency and cognitive processing speed variables in our model.

For the data analysis, we used Generalized Linear Mixed Models (GLMMs) with aspect preference as the dependent variable. This included analyses of both picture-selection accuracy and eye movement patterns. The fixed effects included aspect condition (imperfective vs. perfective), participant group (monolingual vs. heritage), language proficiency, and cognitive processing speed. Random intercepts for participants and items were included where appropriate.

Language proficiency was conducted through a combination of C-Test scores and self-rated proficiency. Cognitive processing speed was assessed using the processing speed index from the WAIS-IV. These variables were included to account for individual differences that may influence aspect processing.

While the study originally aimed to include eye-tracking data from both heritage and monolingual participants, a technical issue during online data collection using PCIbex in Türkiye prevented access to monolingual eye-tracking recordings. As a result, eye movement analyses are reported only for the heritage group.

All data and analysis code are openly available at this OSF repository: https://osf.io/uhbya/?view_only43a00dfb68304e869b360b93fee6865f.

Picture-selection accuracy

To analyze the picture-selection task, we coded the participants' responses as follows: a correct selection (imperfective aspect item for ongoing action and perfective aspect item for completed action) was coded as 1, and an incorrect selection was coded as 0. Participants pressed either F or J to select the pictures representing completed or ongoing events based on the stimuli items presented in either imperfective or perfective aspect.

After coding the accuracy scores as (1) and (0) for each item selected by our participants, we employed the lme4 package (Bates et al., 2015) within the R statistical software version 4.2.1 to conduct a mixed-effects logistic regression analysis. This analysis aimed to estimate the log-odds of accurately responding, considering the aspectual condition (perfective vs. imperfective) as a fixed effect. Along with this, we also conducted an analysis to see whether language proficiency has an effect on the participants' accuracy on the picture-selection task.

Gaze patterns

Our analysis of the data was based on the scripts that (Minor et al., 2023) provided which makes it highly comparable when considered as a conceptual replication. However, we emphasize that we only analyzed eye-tracking data for the heritage speaker group. Key-press data were available and analyzed for both groups. As (Minor et al., 2022, 2023) show, the overlap between the gaze patterns and the key-press accuracies is very high which indicates that both tasks are informative to learn about monolingual and heritage speaker's aspect comprehension.

During preprocessing, all trials with over 50% track loss were excluded from the analysis. Any looks directed outside the pictures (i.e., looks to white space) were excluded from the analysis. We examined the gaze patterns directed towards the target picture, distinguishing between two aspectual conditions: Imperfective and Perfective. In the Imperfective trials, looks at the ongoing event picture were coded as Target (1), whereas looks at the completed event picture were coded as Competitor (0). For the Perfective trials, the Coding was reversed. We calculated the proportion of looks to the target picture in 50 consecutive 50 ms intervals starting from the verb onset. In the vast majority of the time bins (>95%), the proportion of looks to a picture was either 1 or 0. Thus, we modeled our dependent variable as binary: any time bin where the proportion of looks was equal to or greater than 0.5 was labeled as 1, and 0 otherwise (Huang & Snedeker, 2020). We centered the numeric variables to improve numerical stability and model convergence. Dummy contrasts were used on the categorical variables as there were no independent variables with more than two levels.

We then conducted a cluster-based permutation analysis to determine if the likelihood of looks to the Target picture was significantly above chance (Maris & Oostenveld, 2007). The analysis for each aspectual condition (Perfective and Imperfective) was performed in five steps. First, for each time bin, we fit a mixed-effects logistic model to evaluate the log-odds of looks to the Target picture. The model included an intercept term, with Item and Participant as random intercepts. The intercept represented the difference between the log-odds of looks to the Target picture and 0, which corresponds to a 0.5 probability (chance level). Second, we identified clusters of consecutive time bins where the intercept p-value was below 0.1. The z-values for all time bins in each cluster were summed to generate a cluster sum statistic. A higher threshold for including time bins in a cluster was chosen to capture potential weak but long-lasting effects and avoid artificial fragmentation of clusters. This choice does not compromise the validity of the cluster-based permutation test (Maris & Oostenveld, 2007; Hahn et al., 2015). Third, the null hypothesis posited that the probability of looks to the Target picture was at chance level, meaning looks to the Target and Competitor pictures were equally probable. To derive the distribution of the sum statistic under the null hypothesis, we randomly permuted the picture labels (Target vs. Competitor) for each participant, permuting the labels in either all or none of the trials with a 0.5 probability. We then repeated steps 1 and 2 on the permuted dataset and stored the largest sum statistic obtained. Fourth, this process (Step 3) was repeated 1,000 times to generate a distribution of the sum statistic under the null hypothesis. Finally, we compared the sum statistics of the clusters identified in the original dataset to the null hypothesis distribution to produce a p-value for these clusters. Clusters with $p < 0.05$ were considered significant.

Additionally, we fitted a binomial GLMM to account for individual variation in gaze patterns. We modeled the dependent variable of target looks as predicted by a complex interaction of time, aspect condition WAIS-search scores as a measure of processing speed and C-Test scores as a measure of language proficiency. We chose WAIS-symbol search scores instead of WAIS-symbol coding scores as it was the chronologically first processing speed test that we conducted and both test measure the sameprocessing speed. The range of results for both tests is comparable as seen in Table 1.

Table 2 Heritage speakers

	Dependent variable: accuracy
Aspect Category (Pf)	−2.182***
	(0.696)
CtestTotal	0.093**
	(0.044)
Observations	606

Note: *p < 0.05 **p < 0.01; ***p < 0.001

Table 3 Monolingual speakers

	Dependent variable: accuracy
Aspect Category (Pf)	−1.857***
	(0.410)
Observations	528

Note: *p < 0.05 **p < 0.01; ***p < 0.001

Results

Picture-selection accuracy

In their offline responses, both monolingual and heritage speakers showed a higher preference for the ongoing event picture in the Imperfective condition compared to the completed event picture in the Perfective condition. As shown in Table 1, which represents the mean accuracy rates of monolingual speakers for imperfective (Imp) and perfective (Pf) items, monolinguals' selections were more accurate for Imp, with a mean accuracy of 0.96, compared to 0.76 for Pf.

This indicates that they processed items marked with Imp more accurately. On the other hand, if we take heritage speakers into consideration, we can see that they also were more correct when it comes to the items with Imp aspect, with the mean of 0.94 and 0.79 for Pf aspect items. Thus, all in all, both groups processed the items with imperfective aspect marking more accurately compared to the ones with perfective aspect. This is also confirmed as a significant difference in a generalized linear mixed effects model for

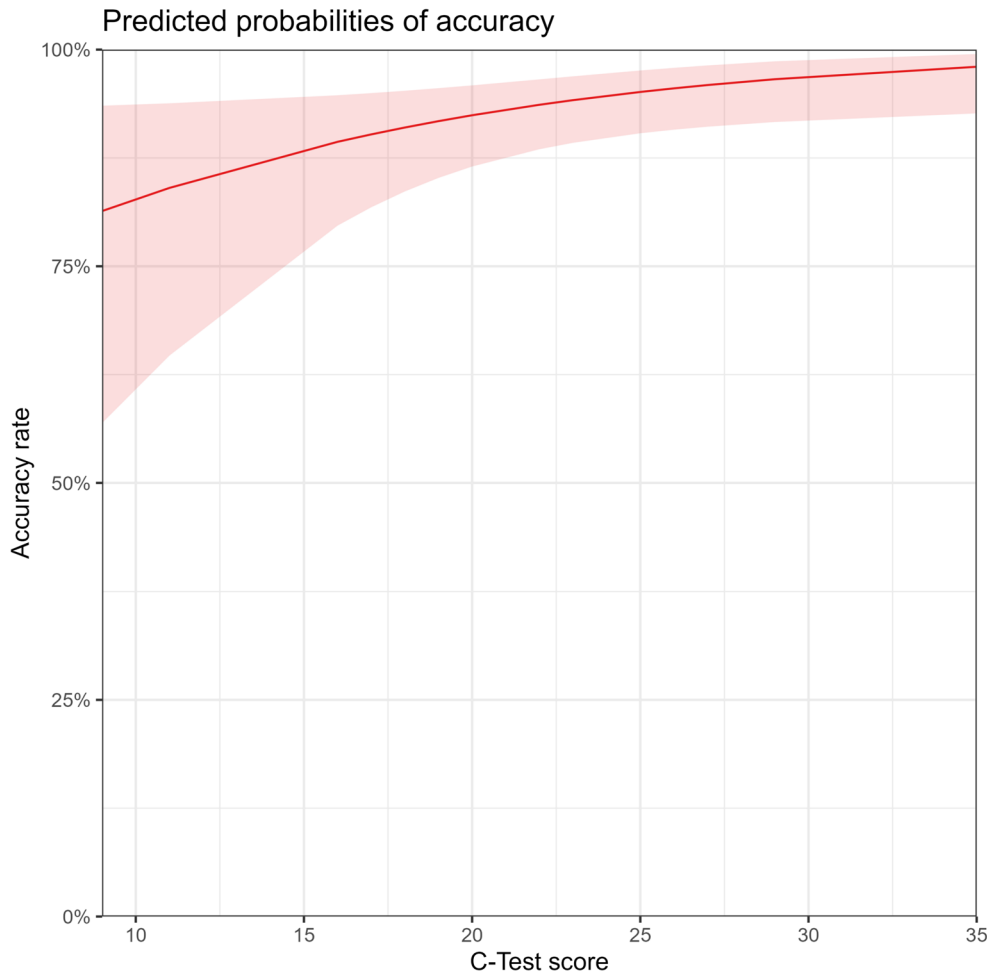

Fig. 2 Predicted probabilities for participants' accuracy rates depending on C-Test scores

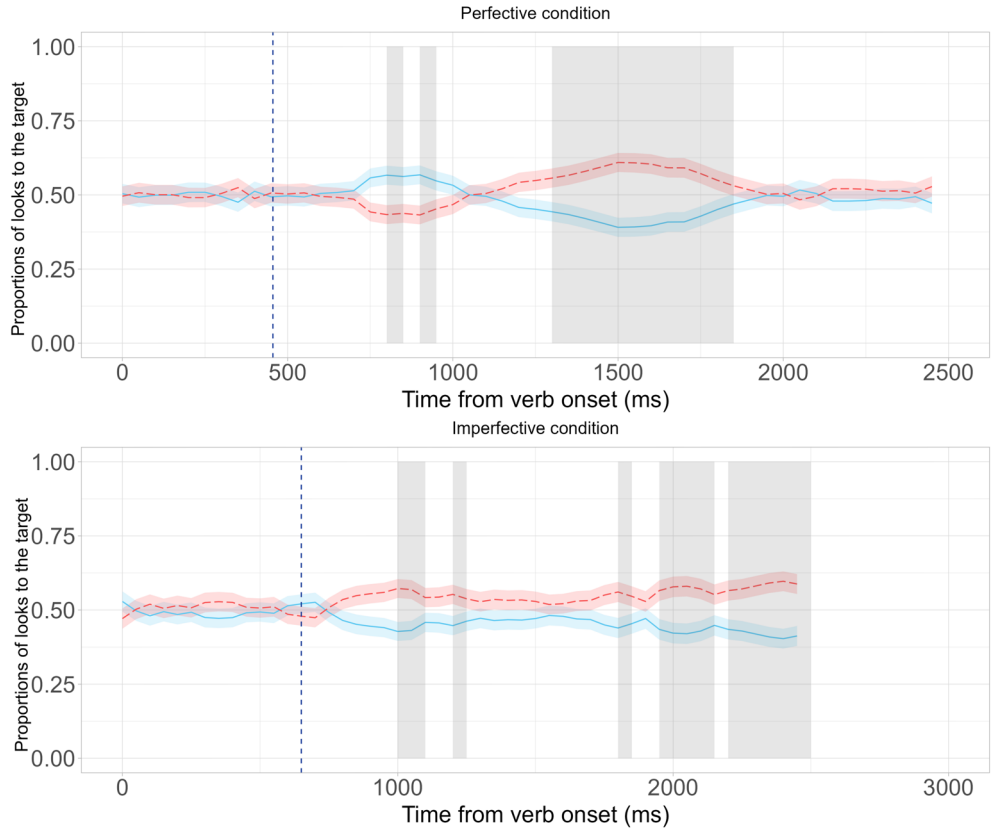

Fig. 3 Eye-tracking results for heritage speakers: looks to Target (red) and Competitor (blue) under Perfective and Imperfective conditions. Grey shading marks significant time clusters, and the dashed line shows mean verb offsets

both groups. The outcome of these models can be seen in Tables 2 and 3. Another generalized linear mixed effects model with both groups did not show any significant difference between the accuracy rate of both groups ($p > 0.8$). We also applied a proficiency test (i.e., C-Test) to heritage speakers to see whether this test has an effect on aspect processing comprehension. To see the relationship between C-Test scores and accuracy of the picture-selection task, we ran a mixed-effects regression model in R (R Core Team, 2022) and we used *tidyverse* for data preprocessing and visualization, and *lme4* for fitting a model.

As can be seen from the following model results in Table 2, we observed an effect of C-Test scores on accuracies in the picture-selection task. As shown in Fig. 2, participants who scored higher on the C-Test also had a higher accuracy rate for the picture-selection.

Besides, we have considered whether receiving a Turkish language education has an effect on the results of the picture-selection task. However, as there was a correlation between the scores on C-Test and receiving a Turkish language education, this factor was not included to avoid collinearity issues. As one expects, participants who scored relatively higher on the C-Test are those who received more Turkish language education.

Gaze patterns

The gaze patterns observed in each aspectual condition are depicted in Fig. 3. In the Perfective condition, our analysis revealed three significant clusters of increased gaze probability towards the Target (the Completed Event picture). The first and second clusters extended from 750 to 900 ms following the verb onset (sum $z = 3.628$, $p < 0.001$). However, the effect goes in the reverse direction of what was expected. The third cluster is meaningful and was noted from 1300 to 1800 ms (sum $z = 3.194$, $p <$

Table 4 Logistic regression results for target picture looks in the heritage speaker group with Time, C-Test scores, Aspect condition, and WAIS scores as independent variables

	Estimate	Std. Error	*p-value*
TimeBin	0.1115	0.0086	$<2 \times 10^{-16}$ ***
CtestTotal	− 0.1350	0.0469	0.00395 **
AspectPf	−0.1283	0.0120	$<2 \times 10^{-16}$ ***
WAISsearch	−0.0862	0.0370	0.01997 *
TimeBin:CtestTotal	−0.0894	0.0108	$<2 \times 10^{-16}$ ***
TimeBin:AspectPf	−0.0519	0.0120	1.62×10^{-5} ***
CtestTotal:AspectPf	0.1543	0.0152	$<2 \times 10^{-16}$ ***
TimeBin:WAISsearch	0.0036	0.0091	0.69493
CtestTotal:WAISsearch	−0.0468	0.0408	0.25030
AspectPf:WAISsearch	0.0997	0.0126	2.30×10^{-15} ***
TimeBin:CtestTotal:AspectPf	−0.0290	0.0152	0.05589.
TimeBin:CtestTotal:WAISsearch	−0.0231	0.0097	0.01759 *
TimeBin:AspectPf:WAISsearch	−0.0718	0.0126	1.23×10^{-8} ***
CtestTotal:AspectPf:WAISsearch	0.0630	0.0136	3.43×10^{-6} ***
TimeBin:CtestTotal:AspectPf:WAISsearch	0.0419	0.0136	0.00204 **

Note: $^{*}p < 0.05$ $^{**}p < 0.01$; $^{***}p < 0.001$

0.001). These findings indicate a significantly above-chance probability of looks directed at the Target during these intervals. Conversely, in the Imperfective condition, the analysis identified several significant clusters. The first group of clusters ranges from 1000 to 1300 ms post-verb onset (sum $z = 2.777$, $p < 0.001$). The second group of clusters is found between 1800 ms and 2500 ms (sum $z = 2.533$, $p < 0.001$). This suggests that the probability of gazes towards the Target (the ongoing event picture) was notably higher than chance within this timeframe. These results highlight distinct temporal dynamics in visual attention depending on the aspectual marking of the verb, aligning with the hypothesis that aspect influences event perception and Turkish heritage speakers are able to incrementally process and recognize this distinction.

As shown in Table 4, we observed significant effects of both language proficiency (C-Test scores) and processing speed (WAIS task) on participants' gaze patterns, including higher-order interactions with time and aspect condition. These findings indicate that individual differences in language proficiency and processing speed modulate how participants process grammatical aspect over time. Specifically, participants with higher C-Test and WAIS scores exhibited increased target preference as the sentence unfolded-that is, in the later time bins. This suggests that greater proficiency and faster processing speed support more robust integration of aspectual cues during incremental comprehension.

Discussion

While different factors may impact language use and comprehension, the extent to which grammatical aspect is sensitive to processing and prediction offers valuable insights into individual differences. The present study aimed to examine how the incremental processing of aspectual information, previously observed in English, Russian, and Spanish (Minor et al., 2023), manifests in Turkish, particularly among heritage speakers in Germany. The choice of Turkish-German bilinguals is motivated by German's lack of grammatical aspect and the variability often seen in this group (Karaca et al., 2024; Coşkun Kunduz & Montrul, 2023). Thus, the study also sought to explore whether heritage speakers display a reduced sensitivity to grammatical aspect and how individual differences such as processing speed and proficiency influence aspect processing at the subword level. The offline picture-selection task revealed that both monolingual and heritage speakers preferred ongoing event representations when hearing verbs in the imperfective aspect. Monolinguals achieved a mean

accuracy of 96% in the imperfective condition and 76% in the perfective condition. Heritage speakers showed a similar pattern, with means of 94% and 79%, respectively. These results confirm that imperfective morphology effectively directs attention to in-progress events in both groups.

However, these results are context-specific. The narrative framing in the stimuli may have constrained some interpretations and discouraged habitual or generic readings. Within this setting, the imperfective consistently cued ongoing actions across both groups. Eye-tracking data corroborated the offline results. In the imperfective condition, significant gaze clusters were found between 1,000–1,300 ms and 1,800–2,500 ms post-verb onset, indicating sustained attention to the ongoing event picture. In contrast, the perfective condition showed earlier but less stable clusters (750–900 ms and 1,300–1,800 ms), with an initial reversal effect toward the competitor picture.

One explanation is the morphological structure of Turkish, where aspectual information appears mid-word. Imperfective markers such as the progressive-*Iyor* appear closer to the verb stem and provide early aspectual cues, whereas perfective interpretations typically rely on the past tense marker-*DI*, which occurs later in the verb complex and is less aspect-specific on its own. This difference in marker position and salience may influence the timing of aspect integration, consistent with findings by Grüter et al. (2017) showing that earlier availability of morphosyntactic cues facilitates processing. Yet, the prolonged focus on the ongoing picture in the perfective condition suggests that morphology alone does not explain the gaze patterns. Factors like aspectual frequency or different levels of predictability of aspectual markers may also be involved.

The overlap between evidential and aspectual morphology in Turkish adds complexity. The perfective marker-*DI* also encodes evidentiality, possibly leading participants to interpret the ongoing event as more plausible due to its association with direct experience. This could explain lower accuracy for perfective forms and early gaze reversals. Additionally, adverbial modifiers in the post-critical region (e.g., *düzgünce*, *özene bezene*, properly) may have guided participants toward a more accurate interpretation by the sentence's end. The regression analysis revealed that higher language proficiency and faster processing speed significantly predicted better comprehension of aspect. Participants with higher C-Test scores demonstrated greater accuracy and earlier gaze shifts in the perfective condition. Faster processing speed also facilitated aspect integration. These findings align with (Bice & Kroll, 2021), who argue that bilingual grammatical processing is shaped by both domain-specific (e.g., proficiency) and domain-general (e.g., processing speed) cognitive skills. Our results highlight the variability among heritage speakers and suggest that individual differences must be considered when examining grammatical processing.

Cross-linguistic influence may also play a role. The absence of grammatical aspect in German could lead to weakened sensitivity in Turkish heritage speakers. Karaca et al. (2024) observed a similar reduction in predictive processing of morphosyntactic cues among heritage speakers. Moreover, the dual-language experience may limit the predictive value of aspectual cues in the heritage language. However, these patterns cannot be attributed solely to cross-linguistic influence. General bilingualism related factors such as input quantity, quality, and cognitive demands may also affect processing. To disentangle these influences, future research should include heritage speakers whose dominant languages share aspectual structures with Turkish (e.g., Turkish-Russian bilinguals). The comparison with (Minor et al., 2023) supports the generalizability of incremental aspect processing across languages. Like speakers of English, Russian, and Spanish, Turkish speakers, both monolingual and heritage, showed robust effects for imperfective forms. However, gaze data from heritage speakers featured shorter and less consistent clusters, indicating reduced incremental integration. This may stem from limited input, lower proficiency, or higher cognitive demands when processing the heritage language. Long-term exposure to a dominant language without grammatical aspect may lead to attrition of grammatical knowledge in the heritage language (Polinsky, 2018). This highlights the importance of examining how bilingual environments shape grammatical processing.

Considering the limitations of our study will help to inform us about future lines of research. Having eye-tracking data for monolinguals would have provided a deeper insight into how they process aspect beyond the offline comprehension that we could measure. In this study, due to a technical problem during online eye-

tracking data collection with PCIbex in Türkiye, we were unable to access monolingual eye-tracking data, so these results could not be obtained.

Understanding the phenomenon of incremental aspect processing provides valuable insights into how heritage speakers navigate multiple languages and how their language environment and individual experiences and skills shape their linguistic abilities. This also emphasizes the importance of considering language proficiency and processing speed because they play crucial roles in the processing of grammatical aspects as we have demonstrated here.

Conclusion

In conclusion, this study investigated the processing of imperfective and perfective aspect among Turkish monolinguals and heritage speakers living in Germany. The findings revealed that both groups showed a strong preference for ongoing events when presented with imperfective aspect verbs, demonstrating higher accuracy rates compared to perfective aspect verbs. Heritage speakers' eye-tracking data partially supported these results, showing significant gaze clusters towards the ongoing event picture during early time windows in both imperfective and perfective trials. However, in later time windows, participants in the perfective condition shifted their gaze preference toward the completed event picture, suggesting delayed integration of aspectual information. However, without eye-tracking data from monolingual speakers, we cannot definitively conclude whether these timing patterns are specific to the heritage group or reflect general properties of aspect processing in Turkish. Factors such as reduced input, lower language proficiency, increased cognitive load, or transfer from German (which lacks grammatical aspect) may all play a role in shaping heritage speakers' processing strategies. We were able to explore some of these effects, but future research will show that there are many more facets of a bilingual experience and individual variation at play when it comes to language prediction and processing. Our findings underscore the importance of language proficiency and processing speed in aspect processing and suggest further research with larger participant groups and additional eye-tracking data to deepen our understanding of these phenomena.

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Data availability The datasets presented in this study can be found at: https://osf.io/uhbya/.

Declarations

Conflict of interest The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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