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PREDICTION OF ASPECT IN THE PROCESSING OF CROATIAN SIGN LANGUAGE

DOCTORAL DISSERTATION

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Supervisors:
Marina Milković, Ph.D., Associate Professor
Evie A. Malaia, Ph.D., Associate Professor

Zagreb, 2025

Sveučilište u Zagrebu

Centar za poslijediplomske studije

Interdisciplinarni znanstveni poslijediplomski studij
Jezik i kognitivna neuroznanost

Tomislav Radošević

PREDVIĐANJE GLAGOLSKOGA VIDA U OBRADI HRVATSKOGA ZNAKOVNOG JEZIKA

DOKTORSKI RAD

Mentorice:
izv. prof. dr. sc. Marina Milković
izv. prof. dr. sc. Evie A. Malaia

Zagreb, 2025.

The supervisors:

Marina Milković, Ph. D., is an Associate Professor at the University of Zagreb (Zagreb, Croatia), Faculty of Education and Rehabilitation Sciences, Department of Hearing Impairments. Currently, she is the Chair of the department. She earned her Master's degree in 2005 with a thesis on word order in Croatian Sign Language, and in 2011 completed her PhD with a dissertation titled *"Verb Classes in Croatian Sign Language – Syntactic and Semantic Properties",* both at the University of Zagreb.

Dr. Milković is the course holder and lecturer for numerous subjects related to Croatian Sign Language, deafness, and sign language research methodology. Since 2020, she has been head of the Laboratory for Research of Sign Language and Deaf Culture (HZJ Lab). She also serves as Head of the Department of Hearing Impairments since October 2020, in her second consecutive term.

Her research is focused on Croatian Sign Language research and its application to early intervention, Deaf education, and teaching Croatian Sign Language as a second language (L2). She has published 16 scientific and 7 professional papers, participated in 6 scientific and 18 professional projects, and presented over 80 papers at national and international conferences. She has served as editor and program committee member of scientific conferences and reviewed for several academic journals. Dr. Milković is an active collaborator with Deaf associations, contributed to legislative efforts for Croatian Sign Language, and has led numerous training programs for sign language interpreters.

Evie Malaia, Ph.D., is an Associate Professor at the University of Alabama, Department of Communicative Disorders, where she specializes in computational neurolinguistics and cognitive neuroscience. She holds a PhD in Linguistics from Purdue University (2005), an MS (2001), and a BS (2000) from Chuvash State Pedagogical University in Russia.

Dr. Malaia's research focuses on the neural and computational mechanisms of communication, particularly in autistic populations and sign language users. Her interests include the perception-action-cognition relationship in language development and evolution, as well as the application of fundamental research to educational practice. She uses machine learning approaches to model brain-language relationships, with clinical relevance for autism spectrum disorders and sign language cognition.

Dr. Malaia has authored over 65 peer-reviewed publications and numerous book chapters. She serves on editorial boards of *Frontiers in Human Neuroscience* and *Frontiers in Psychology*, and reviews for leading journals in neuroscience, linguistics, and education.

She has held fellowships at the Netherlands Institute for Advanced Studies and the Freiburg Institute for Advanced Studies, and remains active in international collaborations on sign language research and autism intervention science.

Acknowledgements

This research was made possible thanks to the help and support of many people.

First, I would like to thank my supervisors for their guidance and the many hours they invested in discussing each phase of this journey. I am very grateful for their encouragement and support.

Secondly, I would like to thank Professor Emerita Melita Kovačević, the director of my doctoral program, for her support along the way. My heartfelt thanks go to Marijan Palmović, Eva Pavlinušić Vilus and Ana Matić Škorić from the Laboratory for Psycholinguistic Research. Their expertise, EEG supervision and much needed moral support during the many hours I spent in the lab were invaluable.

I am especially grateful to Marina Olujić Tomazin for sacrificing many mornings, evenings and weekends to help with data collection for cognitive tasks and data analysis. I would also like to thank Dora Knežević for her camaraderie, for her willingness to talk about ideas and frustrations, and for making sure there was no shortage of baked goods. A big thank you also goes to the professors in my department, Sandra Bradarić Jončić, Iva Hrastinski and Luka Bonetti, for their encouragement and support.

I am very grateful to Irena Bogunović from the University of Rijeka for allowing me to record participants from the Rijeka region in their Laboratory for Language and Cognitive Neuroscience (LACON).

I am especially grateful to all the participants who made this research possible. I know you were all very happy when the experiment was over after being in the lab. Special thanks go to Nives Gotovac for her help in recruiting native signers.

To Jasminka Težak, PUNO-HVALA, for the countless hours we spent discussing quirky sentences and for filming all the stimuli. I have learned so much about HZJ and Deaf culture through our discussions.

I would also like to acknowledge the contributions of many others who have helped me along the way: Vanja Štefanec, Marlijn ter Bekke, Maarten van den Heuvel, and Julia Krebs.

I na kraju, hvala mojoj obitelji i mnogim divnim ljudima na podršci i guranju naprijed.

ABSTRACT

This thesis investigated how hearing signers and non-signers process visual events that are linguistically encoded by the verbal aspect in Croatian Sign Language (HZJ). Three groups of participants were recruited: hearing native bimodal bilinguals (Signers), action video games players without knowledge of any sign language (Gamers) and hearing non-signers who do not play action video games (Controls). Three experiments were conducted: (1) an EEG experiment examining the neural correlates of aspectual congruence in Signers, (2) an EEG experiment examining the neural correlates of aspectual processing in Gamers and Controls, and (3) an assessment of cognitive abilities (working memory and perceptual reasoning).

In the EEG experiments, participants watched videos of HZJ sentences. Each sentence contained a temporal adverb (already vs. still) followed by a verb or a handling classifier predicate in either perfective or imperfective aspect, resulting in congruent and incongruent conditions. For Signers, incongruent perfective verbs and classifiers elicited an early- onset negativity (100-300 ms), consistent with an anterior negativity associated with a prediction violation, followed by a sustained negativity peaking at 500-700 ms. Incongruent imperfective verbs and classifier predicates elicited a sustained positivity (P600) that began and peaked in the 500-700 ms time window after the onset of the critical sign. Non-signers also showed significant Aspect × Congruence interactions from the earliest time windows, with perfectives eliciting more negative amplitudes and imperfectives eliciting more positive amplitudes, suggesting sensitivity to motion-based cues rather than linguistic prediction. Gamers performed significantly better than Controls on the WAIS Perceptual Reasoning Index and verbal working memory, but this advantage did not translate into earlier or stronger ERP effects. Correlation analyses showed that the ERP responses of the Signers were associated with verbal short-term memory, those of the Gamers with verbal working memory and those of the control group with spatial short-term memory.

These results show that while all groups are sensitive to aspectual congruence in HZJ, the underlying mechanisms are different: signers rely on linguistic predictions, whereas non-signers rely on general visual perceptual resources shaped by previous experience.

Keywords: EEG; event-related potentials; Croatian Sign Language; verbal aspect; event processing; working memory

PROŠIRENI SAŽETAK

Znakovni jezici prirodni su jezici čija se proizvodnja i razumijevanje odvijaju u vizualnom modalitetu. Istraživanja su pokazala da se tijekom percipiranja i segmentiranja vizualnih događaja ljudi oslanjaju na obilježja pokreta kako bi događaj segmentirali u manje dijelove. S obzirom na to da se u jeziku događaji najčešće opisuju glagolima, nije iznenađujuće da su ta fizikalna obilježja pokreta iz percepcije vizualnih događaja gramatikalizirana u gramatici znakovnih jezika, poput hrvatskog znakovnog jezika (HZJ).

Teorijski okvir nazvan Višerazinski prijenos informacija (engl. *Multiscale information transfer*) objašnjava da se tijekom percepcije podražaja istovremeno aktivira više razina, kako onih odozdo prema gore utemeljenih na podražaju, tako i onih odozgo prema dolje utemeljenih na predviđajućoj obradi. Znakovni jezici predstavljaju izvrstan primjer hijerarhijske jezične strukture za osobe koje ih poznaju, dok za neznakovatelje, s druge strane, odražavaju hijerarhijske motoričke obrasce.

Cilj ovoga istraživanja bio je istražiti kako čujući znakovatelji i neznakovatelji obrađuju događaje (engl. *events*) u vizualnom modalitetu koji su jezično kodirani kroz glagolski vid u HZJ-u. Tri skupine sudionika sudjelovale su u istraživanju: 24 čujućih izvornih znakovno-govorno dvojezičnh sudionika (znakovatelji), 16 čujućih igrača akcijskih videoigara bez znanja bilo kojeg znakovnog jezika (igrači) te 18 čujućih neznakovatelja koji ne igraju akcijske videoigre (kontrolna skupina).

Provedena su tri eksperimenta: (1) EEG eksperiment kojim se ispituju neuralni korelati obrade kongruentnosti glagolskoga vida u HZJ-u, (2) EEG eksperiment kojim se ispituju neuralni korelati obrade kongruentnosti glagolskoga vida kod igrača i kontrolne skupine te (3) procjena kognitivnih sposobnosti (kratkoročno pamćenje, radno pamćenje i perceptivno rasuđivanje). Kao mjera perceptivnog rasuđivanja upotrijebljen je Indeks perceptivnog rasuđivanja iz Wechslerovog testa inteligencije za odrasle. Za procjenu verbalnog kratkoročnog pamćenja odabran je zadatak ponavljanja brojeva unaprijed, dok su za procjenu verbalnog radnog pamćenja odabrani zadaci raspona radnog pamćenja pri računanju te ponavljanje brojeva unazad. Za procjenu raspona prostornog kratkoročnog pamćenja upotrijebljen je Corsi zadatak, a za procjenu prostornog radnog pamćenja zadatak s rotacijama.

U EEG eksperimentima sudionici su gledali videozapise rečenica na HZJ-u dok je istovremeno sniman EEG pomoću 32 aktivne elektrode umetnute. Svaka rečenica sadržavala je vremenski prilog (*već* ili *još uvijek*) nakon čega je slijedio glagol ili klasifikatorski predikat kojim se izražava rukovanje u svršenom ili nesvršenom obliku. Time su dobiveni kongruentni i nekongruentni uvjeti s obzirom na ograničenje koje nameće prilog, odnosno ostvarenje predviđenog glagolskog vida: svršeni kongruentni (npr. *već pozvati*), nesvršeni kongruentni (npr. *još uvijek pozivati*), svršeni nekongruentni (npr. *već pozivati*) i nesvršeni nekongruentni (npr. *još uvijek pozvati*).

Rezultati pokazuju da su u skupini znakovatelja nekongruentni svršeni glagoli i klasifikatori izazvali ranu negativnost (100-300 ms), što je u skladu s anteriornom negativnošću koja se smatra korelatom neispunjenog predviđanja. Nakon toga slijedila je dugotrajna negativnost koja je dosegla vrhunac između 500 i 700 ms. Nekongruentni nesvršeni glagoli i klasifikatorski predikati izazvali su dugotrajnu pozitivnost (P600) koja je započela i dosegnula vrhunac u vremenskom prozoru od 500-700 ms nakon početka ciljanoga znaka.

Sudionici neznakovatelji također su pokazali značajne interakcije Glagolski vid × Kongruentnost od najranijih analiziranih vremenskih prozora, pri čemu su svršeni oblici izazvali negativne amplitude, a nesvršeni više otklon u pozitivnom smjeru. Navedeno upućuje na to da su čak i sudionici koji ne poznaju ni jedan znakovni jezik bili osjetljivi na razlike u pokretu znakova koje je moglo voditi predviđajuću obradu, oslanjajući se na znanja iz vizualne percepcije događaja.

Igrači videoigara postigli su značajno bolje rezultate od kontrolne skupine na indeksu perceptivnog rasuđivanja te u verbalnom radnom pamćenju, ali ta prednost nije se odrazila na morfologiju ili vremensku dinamiku evociranih potencijala. Korelacijske analize pokazale su da je u skupini znakovatelja amplituda evociranih potencijala pozitivno povezana s verbalnim kratkoročnim pamćenjem. U skupini igrača videoigara amplituda je bila negativno povezana s rasponom radnog pamćenja pri računanju, a pozitivno povezana također s verbalnim radnim pamćenjem, ali mjerenim ponavljanjem brojeva unatrag. U kontrolnoj skupini pronađena je pozitivna korelacija između amplitude i prostornog kratkoročnog pamćenja.

Zaključno, iako su sve skupine pokazale osjetljivost na aspektnu kongruentnost u HZJ-u, temeljni su mehanizmi različiti: znakovatelji se oslanjaju na jezična predviđanja, dok se neznakovatelji oslanjaju na opće vizualne perceptivne resurse oblikovane prethodnim iskustvom.

Ključne riječi: EEG; evocirani potencijali; hrvatski znakovni jezik; glagolski vid; obrada događaja; radno pamćenje

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1. INTRODUCTION

The concept that human brains are oriented towards future and anticipation of events in its environment has been present for a long time, although in various forms. However, only in the 21st century did the notion of predictive processing (PP) gain wider recognition in philosophy and cognitive (neuro)science (Clark, 2016; Hohwy, 2013). The PP is not a unitary framework, but it can be defined broadly as "any type of processing which incorporates or generates not just information about the past or the present, but also future states of the body or the environment (Bubić et al., 2010, p. 1). In the literature, there is strong experimental evidence that PP underlies many brain functions from the domains of motor function, perception and cognition, such as motor control and imagery, visual processing, attention, emotional processing, executive function, music processing, theory of mind, and language (Bubić et al., 2010; Radvansky & Zacks, 2014). Importantly, prediction error has been proposed as a mechanism that further refines predictions, both in linguistic and non-linguistic PP (Cohn & Paczynski, 2019; Hohwy, 2013).

One of the central topics in research of perception and perceptual predictions are events. Moreover, event perception stands out as being on the crossroad and acting as a link between action perception and language (Bott, 2010; Malaia, 2014, Radvansky & Zacks, 2014). In the following chapter, a more detailed view of event perception and segmentation will be presented, as well as its relationship to language.

1.1. PERCEPTION OF VISUAL EVENTS AND COGNITIVE INFLUENCES

1.1.1. Defining events

Events can be seen both from the standpoint of cognitive psychology and linguistics, therefore they act as a link between visual action perception and language. From a standpoint of cognitive psychology, an event is defined as "a segment of time at a given location that is conceived by an observer to have a beginning and an end" (Zacks & Tversky, 2001, p. 3). Therefore, when people perceive their environment, they do so through events. Where one ends and the other begins is determined through a process called event segmentation. Event segmentation, according to Radvansky and Zacks (2014, p. 54) "emerges as a side effect of ongoing perceptual prediction." A prominent theory in visual perception of events is Event

Segmentation Theory (EST) proposed by Zacks et al. (2007). It assumes that event segmentation originates from the brain's perceptual processing system, which converts sensory inputs into predictions about future states of the environment. Sensory inputs, such as visual or auditory information, are integrated into multimodal representations, encoding object identity, motion, and human actions. This perceptual processing is guided by event models or working models[1] - working memory (WM) representations that keep track of "what is happening" and provide stability even during transient disruptions in sensory input. Working models are shaped by both bottom-up sensory information and top-down influences from event schemata, that is, semantic memory structures that encode patterns and expectations from past experiences. Prediction errors occur when the current event model does not match the sensory input, which triggers an update of the model and thus marks the boundaries of the event. Observers perceive stable periods as distinct events, while moments of change are recognized as the boundaries separating these events, allowing the system to switch between stable events and boundary transitions.

Radvansky and Zacks (2014) state that the core visual cue for event segmentation is a change in movement. More specifically, changes in movement indicate event boundaries. Evidence for this comes from two lines of research. Behavioral studies, such as Newtson et al. (1977, cited in Zacks et al., 2009) analyzed the positions of actors' bodies at 1-second intervals and found that shifts in body configuration were linked to event segmentation. Furthermore, motion tracking study of naturalistic everyday activities by Zacks et al. (2009) found that viewers were more attuned to the movements of individual body parts and the distances between them, rather than to the relative speed and acceleration of the body parts in relation to each other. Finally, the authors found that movement-related variables more accurately predicted fine-grained segmentation (i.e. for shorter time intervals) than they did coarse-grained segmentation.

[1] In later publications, such as Radvansky and Zacks (2014), Zacks and colleagues introduced the term „working model" for what they previously called „event model", primarily to delineate more clearly that working models are dependent on working memory, while event schemata is based on semantic representation from long-term memory.

1.1.2. Processing of visual events

In a recent review, Cohn and Paczynski (2019) compared event processing for linguistic and visual events. Interestingly, similar event-related potentials (ERPs) and time-frequency components normally found for language processing (e.g., the N400 or theta-band oscillatory activity) were reported in studies of visual event processing. Some studies manipulated predictability, while others manipulated congruency of visual event processing.

For instance, Reid & Striano (2008) investigated the processing of action sequences by showing their participants still images depicting everyday actions, such as scooping corn and bringing a spoon to the mouth. However, half of the actions had an unpredicted ending, e.g. when the empty spoon was brought to the mouth. This condition resulted in increased N400 amplitude compared to a predictable ending, although the topography was slightly broader than the centro-parietal reported for the linguistically elicited N400 – the negativity was greater over frontal than central electrode sites, more negative over central than parietal sites, and more negative over the right than left hemisphere.

A similar task to the one from Reid & Strano (2008) was used by Reid et al. (2009). They found a larger N400 amplitude for unexpected action endings, but unlike Reid & Striano (2008), there was no location effect here, i.e. the effect occurred in frontal, central and parietal regions. In addition, they performed a time-frequency analysis and found a higher induced theta power for the unexpected versus the expected condition. Increased oscillations in the theta frequency band were also previously reported for semantic violations in language processing. Together with the findings on the N400, this study suggests that similar semantic processing systems are used for both language and action processing.

However, Giglio et al. (2013) reported slightly different ERP results. They presented participants with visual actions using three pictures. Importantly, the actions were feasible, such as peeling a banana, but the end, the third picture, could be expected or unexpected (throwing away the peel or banana, respectively). They found that the N400 had more negative amplitude in the first picture, compared to the second and third one. Since no incongruity could be detected at this time, the authors interpret this larger N400 amplitude as an effect related to primary contextual understanding and not to the detection of incongruity. Unexpected endings, on the other hand, had a larger amplitude of the late positive potential

(LPP) compared to expected endings, indicating a reprocessing of information from the context with increased complexity.

Although these studies focused primarily on the semantic level of event comprehension, it has been observed that motion characteristics influence event perception at the brain level. For example, Zacks et al. (2006) investigated this question by examining how are changes in speed of movement related to neural activity during the perception of event boundaries. In the study participants first viewed animated moving objects while functional magnetic resonance imaging was performed. Then they saw the same stimuli and segmented it into individual meaningful events. Of several studied movement features, only speed of movement was found to be related to the activity in motion complex area (MT+). Moreover, increased speed of movement was related to an increase in activity in MT+ area. In addition, during boundary perception both MT+ and the posterior superior temporal sulcus were activated, which suggests that these brain structures are involved in event segmentation. These findings indicate a relationship between the perception of visual event boundaries and the processing of motion, especially because the MT+ area was found to be sensitive to variations in speed of movement.

The idea that event segmentation is closely linked to motion processing aligns with research on prosodic and kinematic boundaries in speech and action. Hilton et al. (2019) explored this further. More specifically, they conducted two experiments to compare the processing of boundaries in speech prosody (prosodic boundary cues) and visual event perception, i.e. action (kinematic boundary cues). In the first experiment, participants listened to sentences in German in two conditions: those that contained prosodic boundary and those that did not. In the second one, another group of participants watched videos of an actor manipulating balloon sand weight. Again, one condition contained a kinematic boundary, while the other one did not. ERP analysis of the data recorded in the first experiment showed a broadly distributed closure positive shift (CPS) component that was greater for boundary-condition. Interestingly, ERP analysis of kinematic boundary processing also showed broadly distributed CPS in the boundary-condition only. These results suggest that similar processes are involved in auditory and kinematic boundary processing.

1.1.3. Cognitive factors in event perception

1.1.3.1. Working memory

As discussed in the previous section, working memory is included in the EST through event models. Therefore, the ability to hold and manipulate incoming information would be crucial for event perception and segmentation. Indeed, indirect evidence comes from populations that have reduced WM abilities, such as older adults, adults with Alzheimer's disease and adults with schizophrenia. These populations have been found to have difficulties with event segmentation (Henderson & Campbell, 2023; Radvansky, 2017).

Another piece of evidence for the role of WM in event perception comes from a reading study from Speer and Zacks (2005). Their results demonstrated that memory for items in the narrative was weaker when a temporal break occurred between the mention of the item and the subsequent test. Similar findings were obtained based on movie stimuli (Swallow et al., 2009). Together, these studies suggest that information related to the currently active event model, and therefore present in the WM, is more readily accessible than information linked to a previously active model.

1.1.3.2. Visual-spatial skills and expertise

Another factor that was found to influence the event perception is expertise. Research suggests that individuals with expertise in a particular skill process visual stimuli from that area more efficiently, therefore enabling them to segment events more efficiently. Cohn & Paczynski (2019) highlight this relationship by examining how expertise modulates prediction in event perception. An example of such study comes from Zhao et al. (2021). They examined video processing in halfpipe snowboard athletes in comparison to their non-snowboarding peers. They discovered that videos with congruent endings elicited more negative N400 amplitude, compared to incongruent ones, but only in the expert group. In the time-frequency domain, the expert group showed larger theta oscillations in the pre-stimulus period (a pause was shown before the last part of the video with congruent or incongruent ending) than the control group, indicating a prediction. In the control condition, which consisted of videos of walking, main effects of the group in N400 amplitude or theta band oscillations were not found. The authors suggest that the action of walking was too simple to trigger meaning processing. In summary, this study shows that expertise enables the prediction of upcoming visual actions and confirms previous studies that have shown that expert groups are more sensitive to the perception of corresponding actions (e.g. Amoruso et al., 2014 for dancers and Lu et al., 2019 for tennis players).

1.1.3.2.1. Gamers

Another group of experts that has received much attention are gamers, especially action video game players (AVGPs). According to Video Game Questionnaire from Bediou et al. (2023), AVGPs are those gamers that played first- or third-person shooter video games at least five hours per week during the last 12 months. In addition, people who played action-role play games/adventure, sports/driving, real-time strategy or multiplayer online battle arena games are also considered gamers based on number of hours played during the last 12 months and any time before the past year.

For instance, the gaming population was also tested for perceptual advantage in motion perception as well as in visual skills. Hutchinson & Stocks (2013) compared gamers and non-gamers using three groups of random-dot kinematograms that assess different types of motion: translational, radial and rotational. The groups performed similarly on translational and rotational tasks but differed in the radial task. More specifically, gamers performed better than non-gamers only in radial contraction task, possibly because radial contraction movements are more common in gaming than in the real world. However, despite the strict selection criteria for gamers – more than ten hours of first-person action video gaming per week to ensure group homogeneity, the interpretation of these findings warrants caution due to the small sample size in each group (n = 16). More direct investigation of the relationship, between visual abilities and the AVGPs' ranking comes from Cretenoud et al. (2021). They found a strong correlation between visual abilities such as peripheral visual acuity and susceptibility to the Honeycomb illusion on the one hand, and players' rankings on the other, although, the causal relationship remains unclear.

In addition to visual abilities, the relationship between gaming and cognitive functions has also been extensively researched. Bediou et al. (2018) conducted a meta-analysis on perceptual, attentional and cognitive skills in AVGPs. The authors found that the most robust effect sizes were for perception (g = 0.77; measured by tasks such as contrast sensitivity and lateral masking), spatial cognition (g = 0.75; e.g. mental rotation, and spatial WM tasks) and top-down attention (g = 0.62; e.g. complex search, flanker tasks, multiple object tracking).

There was even a weak effect for verbal cognition ($g = 0.30$), mostly measured by verbal STM and WM tasks, although action video games rely heavily on non-verbal visual processing. Newer studies have corroborated said findings about WM. Waris et al. (2019) tested 503 gaming and non-gaming participants on verbal, visuospatial and n-back tasks. They found that gamers outperformed the non-gamers on all three tasks. The hierarchical multiple regression analysis revealed a significant positive relationship between weekly hours of video gaming and visuospatial WM performance, specifically in Step 2 of the analysis, which accounted for video gaming hours after controlling for background factors like age, education, and childhood wealth (Step 1). This distinction between the effects in Step 1 and Step 2 suggests that the influence of playing video games on visuospatial WM performance is independent of these background factors.

Although no direct studies have examined event perception or segmentation in AVGPs, their enhanced visuospatial WM suggests they may have an advantage in these domains. Since event segmentation relies on the ability to perceive boundaries in continuous input, it is plausible that the cognitive and perceptual benefits observed in gamers could translate into superior event segmentation. However, empirical evidence for this connection is still lacking.

1.1.3.2.2. Signers

Beyond gamers, another population that has been studied for enhanced visuospatial and cognitive abilities are sign language users. Given the strong reliance on visual-spatial processing in SL, researchers have investigated whether these individuals show similar cognitive advantages in the visual domain.

Earlier literature provides evidence of enhanced visual and cognitive abilities in populations that use SL. However, Emmorey (2002, p. 268) points out that "sign language use does not create a general enhancement of visuospatial cognitive processes; rather, there appears to be a selective effect on certain processes argued to be involved in sign language production and comprehension." At the receptive level, these processes include motion discrimination, recognition of hand configuration, identification of facial expressions, and recognition of linguistically relevant spatial contrasts. At the expressive level, these processes relate to the production of distinct motion patterns, memory for spatial locations, and the integration of mental images with signing space (Emmorey, 2002, p. 243).

Many studies have found advantages in visual working memory (WM) as well as some visuospatial skills in the deaf population, thus making them another expert group. For example, a study by Heled & Ohayon (2021) found that congenitally deaf participants (n = 40, half of whom were signers) performed better on the Corsi block task, which measures non-verbal visuospatial short-term memory (STM), than their hearing peers. However, the source of this advantage could not be attributed to deafness and visual orientation alone, as the sample was quite diverse in terms of language modality. A more precise answer is provided by the study of Marschark et al. (2016), who measured performance on three complex WM tasks: two verbal (reading span and operation span) and one non-verbal (symmetry span) in deaf and hearing signers and non-signers, so that the effects of hearing status and SL use could be controlled for. The authors found that the hearing groups performed better than the deaf groups on both verbal WM tasks, while they did not differ significantly on the non-verbal visuospatial tasks. Furthermore, the signing groups performed as well as the non-signing groups regardless of hearing status. Given that the latter result contrasts with a body of literature showing that signers have an advantage over non-signers on tasks involving visuospatial processing (Emmorey, 2002), the authors speculate that differences in experience and cognitive ability may be the cause of the observed equal performance.

Emmorey et al. (2017) analyzed STM and WM in three groups: Deaf ASL signers (23 native and 12 before the age of eight), hearing bimodal ASL-English bilinguals (15 native and 5 after the age of 12), and monolingual hearing non-signers. They measured verbal STM with the ASL letter span and the English letter span, verbal WM with sign span and the listening span, non-verbal i.e. spatial STM with the Corsi block tapping test, and spatial WM with a spatial span task. They found that deaf native and early signers performed similarly on all tasks and were therefore analyzed as a single group. In terms of verbal memory, the English letter span of the hearing monolinguals was longer than the ASL letter span of Deaf signers. However, the two groups did not differ in verbal WM, as Deaf signers and hearing monolinguals performed similarly on sign vs. listening span, respectively. The data for the hearing bimodal bilinguals' results were not reported in relation to the Deaf group, only that the bimodal bilinguals as a group showed the same pattern of results – longer span for letters than ASL letters; similar sign and listening span. Interestingly, there were no group differences in the spatial STM and WM measures.

Nevertheless, it seems that exposure to SL alone does not lead to general improvement in visuospatial skills. The study from Lammert et al. (2023) compared how successful hearing signers and non-signers are in identifying faces and discriminating direction of biological motion and found no significant differences. This could be due to the fact that although the hearing signing group consisted of bimodal bilingual signers, the average age of ASL acquisition was 21.43 years because participants were predominantly interpreters who had ASL as L2. Although the group had used ASL for an average of 15.59 years, this does not appear to provide the perceptual advantage that native signers acquire. The question remains whether there would be perceptual differences if the sample consisted of native bimodal bilingual signers.

Findings from early studies show that people who use SL have better visuospatial abilities (Emmorey, 2002, p. 267). However, later studies point otherwise, mainly for visuospatial STM and WM (Emmorey et al., 2017; Lammert et al., 2023; Marschark et al., 2016). Recent evidence for lack of superior performance in signing groups comes from a meta-analysis from McFayden et al. (2023). They compared performance on verbal and non-verbal STM tasks in deaf signers and hearing non-signers. Their findings confirm previously reported results that hearing non-signers outperformed deaf signers on verbal STM tasks. However, they did not find significant effects of deafness on visuospatial STM. These differences could be explained by future studies by considering several potential factors that differ in previous studies, such as task complexity, participant characteristics or the effect of hearing status versus sign language use.

1.1.4. From event perception to language

As noted in chapter 1.1.1. (Defining events), events are also a research topic in linguistics. Event models play a role in language comprehension and Radvansky and Zacks (2014, p. 69) identify two advantages of such models: 1) to understand the circumstances being described, and 2) to function as mental simulations that predict upcoming information. They further explain several concepts that are important for understanding how people construct event models based on language: integration, perspective, and entity properties. Integration emphasizes the need for language to be well composed. Continuous description of an event enables incremental build-up of understanding, thus making it easier to build upon the previous event model. Perspective, on the other hand, relates to the perspective that an event conveys. Evidence for this comes from a study in which participants had faster reaction times in a reading task to objects that are place along the above/below dimension, compared to ahead/behind and left/right dimensions. Finally, important information when constructing an event model come from entity properties, with overtly described information making event construction easier. Apart from constructing a single event model, Radvansky & Zacks (2014, p. 73) point time, space, and goals as important concepts that govern relations within and among event models.

Another piece of evidence that language and motion event cognition are connected comes from Athanasopoulos & Bylund (2013). They investigated whether grammatical aspect influences motion event cognition by comparing native speakers of English (which marks grammatical aspect) and Swedish (which does not) in four tasks: verbal descriptions, memory-based and online triads matching with and without a verbal interference task. The results showed that Swedish speakers were more likely to mention and remember motion event endpoints, while English speakers were more sensitive to ongoing motion. However, both groups performed similarly in real-time comparisons. When verbal interference was introduced, the memory-based difference disappeared, suggesting that language serves as a cognitive tool rather than fundamentally influencing perception. These results suggest that language fine-tunes attention but does not override universal perceptual tendencies. Ultimately, the study shows that language-related cognitive differences emerge when verbal encoding is relevant but disappear when language processing is disrupted.

While Radvansky & Zacks (2014) describe event models in language comprehension, recent research has explored broader frameworks that integrate event processing across modalities. Blumenthal-Dramé and Malaia (2018) propose the *Multiscale Information Transfer* (MSIT) framework, which unifies event segmentation in action observation with language processing. This model highlights how cognitive mechanisms underlying event perception may be shared across linguistic and non-linguistic domains. Sign languages are especially relevant in this framework because a single visual stimulus, such as a sign in a SL, can trigger either action observation or language processing, depending on viewer's familiarity with the language. In addition, the authors propose that both types of input have analogous and hierarchical structure because both refer to a layered system where each higher level includes multiple elements from the level directly below it.

The MSIT model consists of four axes, as illustrated in Figure 1: abstractness, source of information, time window, and representational granularity. Abstractness refers to the level of conceptual abstraction present in the information being processed. Concrete elements (e.g. certain motor acts and phonemes) are typical of the lower levels, while the higher, more abstract levels are concerned with the goals or intentions of communication (e.g. why something is done, the meaning of utterances).

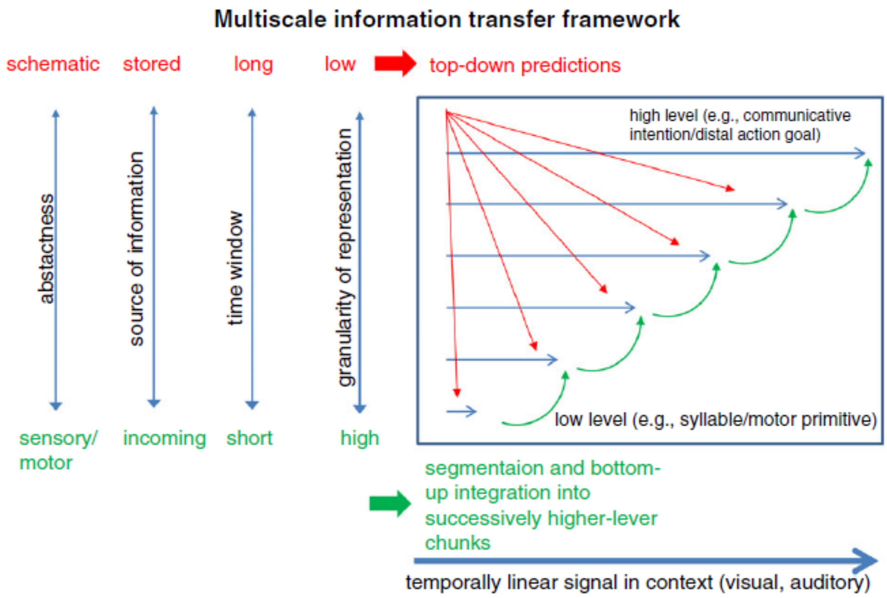

Figure 1. Multiscale information transfer framework (Blumenthal-Dramé & Malaia, 2018, p. 2)

As for the source of information, the MSIT framework embraces not only peripheral bottom-up sources of information (or sensory sensations, such as vision or hearing) but also central top-down information (like memory, context, and expectations). The source of information impacts event perception and the construction of meaning, whether that information is based on memory or on an anticipation.

The processing of information takes place at different temporal scales. Lower-level processes function within a narrower time frame and concern shorter periods of time, whereas higher level processes last longer within the temporal aspect as these combine information of different time points in order to understand how sequence of events works, such as predicting the outcome of an ongoing conversation or action. Finally, the granularity of representation concerns the levels of processing information. Smaller units get to be processed at a finer granularity (i.e. syllables or motor primitives) and larger units at a coarser granularity (i.e., sentences or relatively big actions).

As mentioned previously, the MSIT framework is applicable to both language processing and action processing as it highlights that they both have a hierarchical structure. In both instances, lower levels take charge of complex sensory-motor details while higher levels focus on abstractions such as intention and meaning. The framework further suggests that cognitive mechanisms, such as PP and event segmentation, have parallels in the domain of language and action, thus making the framework suitable for understanding human cognition across these domains. By modelling information transfer and processing across different scales, the MSIT framework bridges the gap between language and action research, demonstrating that they rely on similar cognitive and neural resources for comprehension and production.

Together, these studies highlight the interplay between language, event perception, and cognition. While linguistic structures fine-tune attention to event features, fundamental cognitive mechanisms remain stable across modalities and languages. The MSIT framework bridges language and action research by demonstrating that both domains rely on hierarchical, predictive structures. Meanwhile, studies on grammatical aspect suggest that language refines perception when verbal encoding is active but does not fundamentally alter perceptual mechanisms. These findings reinforce the idea that event cognition is shaped by both linguistic and non-linguistic influences, contributing to a broader understanding of human cognitive architecture.

1.2. STUDYING LANGUAGE PROCESSING WITH EEG

Electroencephalography (EEG) is an electrophysiological method for recording postsynaptic potentials on the surface of the head (Luck, 2014). It is used in cognitive neuroscience to investigate various cognitive processes. More specifically, it is used in language processing research to investigate specific brain activities that are thought to reflect differences in processing. However, since language-related effects are of lower amplitude compared to general EEG activity, a continuous raw EEG is of little use for the study of language processing. To overcome this problem, two main approaches to EEG analysis are used.

1.2.1. Event-related potentials

As early as the 1960s, event-related potentials (ERPs) were used to distinguish stimulus-related activity from general brain activity (Luck, 2014). Since general brain activity has a much higher voltage compared to stimulus-related activity, repetition of the stimuli is required to increase the signal-to-noise ratio. During EEG recording, triggers (also called *markers* or *event codes*) must be sent from the presentation computer to the recording computer to time lock specific events of interest. The EEG signal is then epoched around these triggers and averaged across trials and participants. Statistically significant differences between conditions are referred to as effects. If such an effect is described in the literature and is associated with a specific cognitive and/or linguistic function, it is referred to as a component (Luck, 2014). ERPs are plotted on graphs that show time on x-axis and amplitude voltage on y-axis.

As mentioned above, to obtain ERPs, triggers must be paired with specific events of interest. For reading studies where one word after another appears on the screen, determining when to send the triggers is fairly straightforward. However, for continuous stimuli such as spoken or signed sentences, the task becomes more complex, especially for signed stimuli that have big and visible transitional movements. A common way to avoid this problem is to extract time frames manually for every sign in which the handshape of the critical sign is formed, or the frame in which the fully formed handshape reaches the target location of the critical sign (Hänel-Faulhaber et al., 2014; Hosemann et al., 2013; Krebs et al., 2018; Wienholz et al., 2018).

However, even with such workarounds, averaging preserves only phase-locked neuronal activity, discarding non-phase-locked responses. In other words, since brain activity itself is oscillatory, some of the brain activity that is not phase-locked is lost during averaging as it cancels out (Bastiaansen et al., 2012; Hari & Puce, 2017; Luck, 2014).

A further limitation of the ERP technique is the low spatial resolution. Neurons behave like dipoles. Therefore, the electrical activity recorded by the electrodes, i.e. the voltage distribution, cannot be assigned with certainty to a specific brain region. In the literature, this phenomenon is referred to as the "inverse problem" (Hari & Puce, 2017; Luck, 2014), which arises from mathematical and physical principles. It states that for a given voltage on the scalp, an infinite number of dipole configurations could have generated it.

On the other hand, ERPs are very accurate in the time domain. This makes it possible to study cognitive processes with millisecond precision. For example, if a visible difference in ERP between two conditions begins 400 ms after stimulus onset, then this represents an actual difference in processing that occurred 400 ms after stimulus onset (Luck, 2014). Such millisecond accuracy is also characteristic of magnetoencephalography or MEG (Hari & Puce, 2017). In contrast, another method commonly used in cognitive neuroscience, functional magnetic resonance imaging (fMRI), has very low temporal precision because the recorded signal comes from differences in blood oxygenation, which is inherently slower than the postsynaptic potentials that make up the EEG.

ERPs are defined by four parameters: their latency, amplitude, polarity, and topography (Hari & Puce, 2017; Kemmerer, 2015). Latency refers to the time in milliseconds after the onset of the critical stimuli. Amplitude represents the size of the effect in microvolts, with greater amplitudes usually associated with greater processing costs. Polarity indicates whether a deflection is positive- or negative-going (n.b. older studies have plotted negativity upwards, while more recent studies have plotted negativity downwards). Finally, the effects are distributed differently on the scalp, which means that the electrodes show different activity. To illustrate, the N400 component refers to the negative-going waveform that peaks approximately 400 ms after the onset of the critical stimuli and has a characteristic centro-parietal distribution.

As for the components that are typically observed in response to linguistic stimuli, several of them have been traditionally described in the literature on spoken, written and SL processing: N400 for semantic processing, P600, LAN and ELAN for different aspects of syntactic processing, among others (Gutiérrez-Sigut & Baus, 2020; Kaan, 2007; Hernández et al, 2022; Swaab et al, 2012).

N400 is a component traditionally associated with meaning processing. In their seminal study, Kutas & Hillyard (1980) found that sentences containing semantically incongruent endings, such as *He spread the warm bread with socks* have been found to elicit more negative amplitude in the centro-parietal areas approximately 400 ms after the critical word onset compared to congruent endings. More specifically, the N400 amplitude was graded based on semantic congruency, i.e. sentences with strong incongruity had more negative amplitude than those with moderate incongruity. Since then, numerous studies have replicated and extended the results. For example, linguistic material in any modality, whether spoken, signed or written, was found to trigger N400, suggesting that N400 reflects amodal processing of meaning (Kutas & Federmeier, 2011).

Another set of commonly reported components in studies investigating syntactic processing includes ELAN, LAN and P600. LAN or left anterior negativity occurs approximately 300-500 ms after stimulus onset, while ELAN or early left anterior negativity occurs 100-300 ms poststimulus onset. They have typically been observed in response to word category violations as well as to grammatical sentences that have long-distance dependency constructions (Swaab et al., 2012).

P600, on the other hand, is a positive-going deflection that peaks approximately 600 ms poststimulus onset. It has been found in studies of syntactically anomalous sentences and syntactically correct but ambiguous sentences (Swaab et al., 2012). Although it was previously thought to reflect syntactic processing only, this view was challenged when the P600 was observed in association with violations of thematic role assignment.

1.2.2. Time-frequency analyses

While ERPs offer insight into phase-locked activity, they do not capture the full spectrum of brain dynamics. Time-frequency analysis complements ERP methods by focusing on oscillatory activity. The EEG contains rhythmic activity known as oscillations, which allows for a different set of analyses beyond traditional time-domain ERPs. Oscillations refer to "fluctuations in the excitability of populations of neurons" (Cohen, 2014, p. 31). According to Cohen (2014) oscillations can be characterized by three key parameters: frequency, power and phase. Frequency indicates how fast oscillation occurs and is measured in Hertz (Hz), which indicates the number of cycles per second. Power represents the energy contained in a specific frequency range and is calculated as the square of the amplitude of oscillation. Phase describes the specific point on the waveform at a given time and is expressed in either radians or degrees.

Oscillatory activity is commonly categorized into canonical frequency bands: delta (2-4 Hz), theta (4-8 Hz), alpha (8-12 Hz), beta (12-30 Hz) and gamma (> 30 Hz), with slight variations (Cohen, 2014; Hari & Puce, 2017). Occasionally, these bands are subdivided, e.g. into lower (8-10 Hz) and higher (9-13 Hz) alpha bands (Benwell et al., 2019). However, apart from frequency, power and phase, the location, i.e. the EEG electrode site(s) where an oscillation is observed, is also important. For example, alpha and mu rhythms share the frequency band but differ in topography. While alpha rhythms are usually found at parietal sites, mu rhythms are commonly found over the motor cortex. It is therefore recommended to specify both the frequency band and the respective location in EEG studies (Hari & Puce, 2017).

Time-frequency analyses generate a large amount of data. The most common variables in language processing studies are oscillatory power, phase of the ongoing oscillation, cross-frequency coupling and coherence (Hauk et al., 2017). While time-frequency analysis shows oscillations across multiple frequency bands, oscillatory activity can also be analyzed in a single frequency-band. In such instances synchronization is assumed to reflect coupling, and desynchronization uncoupling of functional brain networks (Bastiaansen et al., 2012). Regardless of the number of analyzed frequency bands, changes in power are thought to reflect local synchrony, while changes in synchrony are thought to reflect synchronization of activity in distant brain regions, i.e. entrainment (Bastiaansen & Hagoort, 2006; Prystauka & Lewis, 2019).

A widely used approach for analyzing oscillatory EEG activity is time-frequency analysis. It allows researchers to visualize how the spectral or amplitude content of the EEG signal evolves over time across all frequencies of interest (Hari & Puce, 2017). It is particularly useful for the study of non-phase-locked brain activity (i.e. not consistently time-aligned across trials), which is usually filtered out in the averaging process of ERP analysis (Bastiaansen et al., 2012). Such oscillatory activity that is both time- and phase-locked to the target stimuli is referred to as evoked power and is roughly equivalent to ERPs, but in the frequency domain. Oscillatory activity can also be time- but not phase-locked to a target stimuli and is referred to as induced power (Prystauka & Lewis, 2019). Since both evoked and induced power can be included in the observed "total activity", a common method for extracting e.g. induced power is to subtract the evoked power from the total activity (Hari & Puce, 2017).

Though fewer in number, studies examining oscillatory responses to language stimuli have begun to map specific frequency bands to linguistic processes. As for the relationship between language comprehension and respective brain oscillatory activity, there is less data compared to the numerous studies investigating ERPs and language, which is understandable because ERP studies of language were started some 20 years earlier than time-frequency ones. Nevertheless, since the early 2000s, a growing body of literature has been published on the topic and several review articles provide some converging evidence on the neural oscillatory substrate underlying language comprehension (Bastiaansen & Hagoort, 2006; Meyer, 2017; Prystauka & Lewis, 2019).

For example, power increase in theta-band oscillations that is time-locked to target word onset is associated with the retrieval of lexical-semantic information, although some studies reported alpha, beta and gamma power decrease (Prystauka & Lewis, 2019). More specifically, in studies investigating semantic violations, incongruent words elicited increased theta power (Davidson & Indefrey, 2007; Hald et al., 2006; Kielar et al., 2014; Schneider et al., 2023), along with decreases in alpha and beta power (Gastaldon et al., 2020; Kielar et al., 2014; Kielar et al., 2018; Luo et al., 2010). Additionally, some studies report increased gamma power in response to highly predictable target words, but not to less predictable or semantically anomalous ones (Bastiaansen & Hagoort, 2015 for oscillations above 40 Hz; Hald et al., 2006 for oscillation around 40 Hz; Rommers et al., 2013 for oscillations in 50 to 70 Hz range). However, although Bastiaansen and Hagoort (2015) argue for gamma oscillations as underlying semantic unification (i.e. integration), it is a methodological issue to extract gamma activity related to processing from high-frequency noise that always occurs during EEG recording due to muscle artifacts, line noise etc. (Prystauka & Lewis, 2019).

Furthermore, studies on syntactic violations, such as subject-verb or gender and number violations, as well as verb tense errors, typically report decrease in alpha and beta power (Bastiaansen et al., 2010; Bastiaansen & Hagoort, 2015; Davidson & Indefrey, 2007; Kielar et al., 2014; Kielar et al., 2018; Lewis et al., 2016). Some studies also report an increase in theta power (Bastiaansen et al., 2002; Pérez et al., 2012; Regel et al., 2014) time-locked to the critical word onset (thus suggesting a role in integration processes). Interestingly, the study from Bastiaansen et al. (2010) found a gradual increase in beta power as the sentence unfolded, which was abruptly interrupted when a word category violation occurred.
Given that increase in theta power is observed in response to both semantic and syntactic violations, it is possible that it might reflect a general violation detection mechanism (Prystauka & Lewis, 2019).

Finally, from a methodological standpoint, analyzing EEG signals related to SL stimuli may be more accurate using time-frequency analysis. As mentioned previously, time-frequency analysis offers the possibility to investigate non-phase locked brain activity (Bastiaansen et al., 2012). This is especially important as researchers have become more aware of the importance of naturalistic stimuli (i.e. unaltered, fluent sentence presentations that preserve transitional movements in SL) when studying sentence processing in a SL (Hernández et al., 2022; Krebs et al., 2022). This means that sentences should not be cross-spliced, so that, for example, only the final, critical sign is "joined" with a sentence frame, because this removes important transitional movements. However, including naturalistic, non-cross-spliced stimuli, introduces variability both within and between conditions, potentially leading to processing differences that are unrelated to the linguistic factors of interest and not accounted for in the experimental design. However, given that there are practically no published studies on SL processing using EEG that is analyzed in the time-frequency domain, the interpretation of such results would be rather difficult.

1.3. LINGUISTIC PREDICTION IN LANGUAGE COMPREHENSION

Ample evidence suggests that people engage in prediction during language processing, utilizing various grammatical and contextual cues regardless of language modality (Gastaldon et al., 2024; Radošević et al., 2022). In addition, it has been found in typical infants (Mornati et al., 2022), children (Bosch & Foppolo, 2024), and native (Kaan, 2014), L2 (Schlenter, 2023) and heritage adult speakers (Parshina et al., 2022), even with deaf and hard of hearing children (Holt et al., 2021), who despite degraded auditory input predicted auditorily presented sentence completions, thus suggesting that linguistic prediction is a robust processing mechanism.

When discussing linguistic prediction, it is important to clarify what is considered to be evidence of prediction. Ryskin et al. (2020) state that empirical evidence for prediction can come from two sources. One is pre-stimulus or anticipatory activity, and the other is activity during or after the (not) predictable stimulus. The first one relates to the pre-activation, i.e. activation that precedes target word. An example of such study would be Van Berkum et al. (2005), where an article determines the subsequent noun. An example of the latter approach would be a study from Freunberger & Roehm (2017) where processing to predictable vs. unpredictable condition is compared.

In the following sections main findings from studies on prediction in SL comprehension will be presented, as well as the role of other variables that influence prediction, such as working memory, age, and literacy.

1.3.1. Prediction in sign languages

The vast majority of current knowledge on linguistic prediction comes from studies on spoken languages (Gastaldon et al., 2024). However, there is a growing body of research on PP in SLs, as evidenced by Radošević et al. (2022) in a systematic review.

Their review summarizes the findings of seven key studies and provides evidence that signers indeed do predict upcoming signed input, especially Deaf native or native-like signers. This suggests that PP, a well-documented phenomenon in spoken language, may be an amodal feature of language processing that functions similarly in both the auditory-verbal and visual-manual modalities, with some modality-specific differences.

To date, the most evidence for PP in SLs is based on semantic prediction. Hosemann et al. (2013) investigated prediction in German Sign Language (DGS) using the semantic violation paradigm. They recorded the EEG while adult Deaf native participants watched natural sentences in DGS that were not cross-spliced or manipulated in another way (which was usual practice in SL processing research up to that point). The ERP analysis showed that unexpected signs elicited a biphasic N400 effect accompanied by a late positivity. Moreover, the N400 effect started during the transition between two signs and thus occurred before the onset of the target lexical sign. This study provides the only evidence so far for semantic prediction in a sign language other than ASL (6 of the 7 studies reported by Radošević et al. (2022) were related to ASL).

Lieberman et al. (2018) also investigated semantic prediction, but using the visual world paradigm with eye tracking, in both children and adult ASL L1 signers. They presented short sentences such as POUR WHAT? MILK in the center of the screen, with four pictures in the corners, one target and three distractors. They found that for constraining sentences, both groups made anticipatory looks towards the target picture before the noun appeared, providing evidence for semantic prediction in ASL.

Wienholz and Lieberman (2019) also used eye tracking with adult and child ASL L1 adult and children signers, but the sentence structure was different from Lieberman et al. (2018). Wienholz and Lieberman (2019) presented participants with linguistic and non-linguistic information in ambiguous scenarios within the visual world paradigm. They found that both groups were able to anticipate the target image as soon as disambiguation was possible. In addition, participants in both groups fixated the target more frequently for adjective-noun sentences than for noun-adjective sentences, with adults doing so earlier in the sentence and children later. This suggests that PP is already developed in children aged 4 years and 1 month to 8 years and 1 month. However, the timing of their eye movements suggests that children are more affected by competing linguistic distractions during processing than adults.

Possible phonological cues in predicting SLs were investigated in two studies by Brozdowski & Emmorey. Brozdowski and Emmorey (2020) have investigated shadowing in the manual modality. In spoken language research, the task is for participants to repeat speech immediately after hearing it, often within milliseconds (Marslen-Wilson, 1973). In the manual modality, i.e. with SLs, participants watch signing and repeat it immediately as they observe it. By including Deaf signers and hearing non-signers, Brozdowki (2018) and Brozdowski and Emmorey (2020) investigated whether motor simulation underlies action and language processing in these groups. Participants were asked to shadow pre-recorded videos of themselves, a friend or a stranger. The stimuli they were asked to shadow included pseudo-signs, which are phonologically plausible in ASL but have no meaning, and grooming gestures, which are non-linguistic. These stimuli were also categorized into one-handed or two-handed gestures. This design made it possible to control for egocentric bias and visual familiarity effects that could influence PP. Handedness was also controlled for, as suppression of the non-dominant hand could lead to longer reaction times for one-handed signs. Interestingly, only the non-signers showed an egocentric bias, and only in the grooming gesture condition, which makes sense given their inability to predict ASL phonology from the pseudosigns. In addition, signers showed slower shadowing production for one-handed signs compared to two-handed signs. Based on these findings, the authors argue that the results do not strongly support the motor simulation account of PP.

In addition, Brozdowski and Emmorey (2023) investigated whether signers and non-signers rely on transitional information to predict upcoming input. They used videos of pseudo-signs and grooming gestures under three conditions: normal videos, videos with blurred hands, and videos with a frozen frame just before the onset of transitional movement. Both signers and non-signers recognized blurred videos faster than static videos, suggesting that both groups use transitional movements to make predictions. However, for pseudo-signs, which are linguistic stimuli, only signers responded faster to normal videos than to blurred videos, suggesting that they rely on phonological information contained in the transitional movements.

Finally, Brookshire et al. (2017) investigated the phenomenon of entrainment, in which low-frequency brain oscillations synchronize with the volume envelope of incoming speech stimuli. Similarly, they expected the visual cortex to entrain to a visual language, i.e. sign language. The EEG of early signers (under the age of five) and non-signers was recorded in response to watching ASL narratives. To quantify the visual change, the authors developed the Instantaneous Visual Change (IVC), a metric based on the change in pixels from frame to frame. The IVC showed higher power at 2-8 Hz. Subsequently, the cortical coherence between the quasi-rhythmic fluctuations of the visual signal in SL (measured by IVC) and the EEG channels was calculated. The authors found significant coherence at lower frequencies (0.4 to 5 Hz, peaking at 1 Hz) for the EEG averaged across all channels, as well as significant coherence at occipital channels only (0.8 to 5 Hz), indicating entrainment of the visual cortex. In addition, the coherence was stronger at the frontal electrodes for signers than in non-signers, indicating top-down control based on language knowledge, in other words, language prediction. However, Radošević et al. (2022) point out that IVC is a rather crude metric that omits important information contained in the SL signal, and direct instead to optical flow (Borneman et al., 2018; Malaia et al., 2019). Malaia et al. (2019) recorded the EEG of Deaf signers while they were watching sentences in Austrian Sign Language (ÖGS) played normally or backwards. Frequency domain analysis revealed cued entrainment at 1.2 Hz, 2.4 Hz and 4.2 Hz in response to language stimuli. For unintelligible video stimuli played backwards, entrainment peaks occurred at 1 Hz, 1.6 Hz, 2.6 Hz, 3.2 Hz and 4.2 Hz. This indicates a broad search for cues at lower frequencies and a consistent response around the syllable frequency (~4 Hz), regardless of the type of stimulus.

Radošević et al. (2022) also discuss the influence of language proficiency – whether SL was acquired as a first language (L1), second language (L2) or as part of a bimodal bilingualism – on PP. However, the relationship between language proficiency and the effectiveness of prediction mechanisms remains unclear due to the limited number of studies and small samples. In addition, some of the studies analyzed investigate the neural basis of predictive processing in signers and often establish a link to theories of motor simulation.

To summarize, while this review confirms the presence of PP in SL users, particularly at the semantic level, it also highlights the need for extended research into other aspects of PP, such as phonetic and syntactic prediction, and deeper exploration of how different levels of fluency influence these processes. These findings emphasize the complexity and uniqueness of predictive processing in the visual-manual modality and call for more comprehensive studies to fully elucidate this phenomenon in SLs.

1.3.2. Moderating variables in linguistic prediction

Huettig (2015) notes that studies investigating the prediction of language have largely overlooked the potential influence of factors such as working memory and general cognitive ability. Nevertheless, he identifies three groups of mediating factors: 1) working memory and processing speed; 2) age; 3) literacy.

It is generally recognized that working memory (WM) is a variable related to language processing (Rončević Zubković, 2010). Moreover, it has been shown that people with average WM scores use different sentence processing strategies depending on their WM span (Malaia et al., 2009). Therefore, it is reasonable to expect a positive relationship between WM and language prediction. Indeed, Huettig & Janse (2016) conducted a study on syntactic predictive processing and found that the working memory construct (consisting of spatial short-term memory (STM), auditory STM, and backward digit span) positively correlated with anticipatory looks ($r = .39$) and explained 7% of the unique variance portion. However, based on a large sample study ($n = 487$), Hintz et al. (2024) reported weaker evidence for the role of WM in linguistic prediction. They speculate that the use of two pictures in the visual world paradigm in their experiment compared to four pictures used by Huettig & Janse (2016) may be the reason for the lower demands on WM.

Li & Qu (2024) went one step further, investigating semantic and phonological prediction in relation to the verbal WM score. Based on the score in the reading span task, they divided participants into high and low span groups. They found that in a visual world paradigm participants with a higher verbal WM score showed earlier semantic prediction than the low span group, while in phonological prediction both groups had anticipatory fixations at the same time, although they lasted longer in the high span group. The authors argue that these results suggest that a higher span WM enables the retention of more information from the previous sentence context as well as the retention of previously generated predictions.

In addition to measuring working memory, Hintz et al. (2024) also measured processing speed. They measure it with visual and auditory reaction time tasks. In visual task a red dot appeared on the screen, while in the auditory task a 440 Hz pure tone was played. In each case, participants had to press the spacebar as soon as they noticed a stimulus. As would be expected, they found that processing speed co-varied with age. Also, participants who responded faster also demonstrated quicker responses in sentence comprehension tasks. Moreover, the study emphasized that processing speed particularly improved PP in predictable scenarios compared to unpredictable ones. This finding implies that quicker processing speed enhances the ability to anticipate forthcoming linguistic information using contextual cues. The interaction between processing speed and the condition suggests that individuals with faster processing speeds are better at making language predictions, leading to more efficient language comprehension. This study confirmed findings from Huettig & Janse (2016). They measured processing speed with digit-symbol substitution (DSS) task from WAIS and with Letter Comparison task and found that processing speed (DSS+letter matching) uniquely contributed 3% of the total variance. In addition, they found negative correlation (r = -0.33) between processing speed and log-transformed ratios of anticipatory fixations, meaning that participants with lower scores (indicating faster processing) looked at predictive targets more than to the distractors.

Regarding the effects of age on language prediction, studies report contradictory results (Huettig, 2015). While some studies have found that reliance on prediction decreases with increasing age (e.g., Wlotko & Federmeier, 2012), other studies have found that prediction increases with age (e.g., Huettig & Janse, 2012, as cited in Huettig, 2015; Milburn et al., 2021). Factors that could influence this relationship may lie in the type of task used in an experiment. For example, if participants in a study are required to read words or sentences, one might expect prediction abilities to be weaker because reading itself declines with age (Hannon & Daneman, 2009). On the other hand, if the visual world paradigm is used in studies with older participants, prediction effects could be found. Huettig concludes that it is more likely that "different studies have measured different influences of the interaction of an increasing life-long experience and cognitive decline in older adults" and "if age-related differences in processing speed and working memory are accounted for, age may in fact support predictive processing because of older adults' increased life-long experience" (2015, p. 12). However, a recent study by Hintz et al. (2024) found that prediction does not change as a function of age. Although younger participants responded faster, the study suggests that the underlying mechanisms of linguistic prediction do not differ significantly in their effectiveness across the lifespan. Although effectiveness might not change, some authors have found distinct neurophysiological correlates of prediction in older adults compared to younger ones. For example, Hubbard & Federmeier (2024) report that older adults had reduced and delayed frontal theta oscillations compared to younger group in response to unexpected words.

The third mediating factor in language prediction studies is literacy. Huettig (2015, p. 12) considers literacy as a "proxy for experience”, suggesting cross-modal effects. In other words, experience in one modality (reading) is related to anticipatory, i.e. predictive (spoken) language processing. Evidence for such a relationship comes from studies that included participants with high and low literacy levels (e.g. Mishra et al., 2012) and participants with dyslexia (Engelhardt et al., 2021).

Some authors have also investigated the role of general cognitive abilities, i.e. non-verbal intelligence, in linguistic prediction. However, Huettig & Janse (2016) reported that the Raven’s Progressive Matrices score does not contribute unique variance to anticipatory gaze, beyond what was already explained by WM and processing speed. In addition, Li & Qu (2024) compared prediction in high and low WM groups matched by Raven's Matrices score. Although these groups performed differently, this difference could not be attributed to non-verbal intelligence score.

1.4. PROCESSING OF ASPECT

1.4.1. Theoretical background

1.4.1.1. Defining aspect

Aspect and tense are two fundamental grammatical categories that encode temporal information in verb phrases, but they do so in distinct ways. According to Comrie (1976), tense is deictic, placing situations in time relative to the present or other events. Therefore, grammaticalized time reference is possible through tense. If a language does not have a tense system, time reference can be conveyed with temporal adverbials. Aspect, in contrast, focuses on the internal structure of a situation's time, thus distinguishing between internal (aspect) and external (tense) temporal perspectives. Radvansky and Zacks point out that “verb aspect specifies a temporal perspective on events – in particular whether an event is ongoing or completed” (2014, p. 176). Comrie (1976, p. 3) further defines aspect as “different ways of viewing the internal temporal constituency of a situation.” In other words, aspect offers means to express that an action is ongoing or completed. Therefore, linguistically, although both situations can be in past (tense), one can be complete and the other incomplete (aspect): *John read the book* versus *John was reading the book.*

Comrie further (1976) states that there is much confusion with respect to terminology in linguistic study of aspect, which still seems to be the case, according to later articles (Bertinetto, 2001; Novak Milić, 2010). To avoid this confusion, it is vital to be clear about what aspectual phenomenon one is writing about. Crucially, grammatical aspect and lexical aspect should be differentiated. On the one hand, grammatical aspect, also named as viewpoint or outer aspect, stands for aspectual meanings that are grammaticalized, i.e. that are expressed by means of inflectional morphology or periphrasis. Examples of such grammaticalized aspect are perfective and imperfective aspects in Slavic languages or progressive and non-progressive meanings in English.

Lexical aspect, on the other hand, which is also called aktionsart, situation or inner aspect, refers to aspectual meanings that are not grammaticalized and are lexically specified. On the difference between grammatical and lexical aspect, Comrie (1976, p. 7) points two distinctions: "The first distinction is between aspect as grammaticalisation of the relevant semantic distinctions, while aktionsart represents lexicalisation of the distinctions, irrespective of how these distinctions are lexicalised. (…) The second distinction, which is that used by most Slavists, and often by scholars in Slavic countries writing on other languages, is between aspect as grammaticalization of the semantic distinction, and aktionsart as lexicalisation of the distinction provided that the lexicalisation is by means of derivational morphology."

1.4.1.2. Grammatical aspect

Typical examples of languages with systematic difference in perfective and imperfective aspect are Slavic and Romance languages (Comrie, 1976; de Swart, 2012). For perfectivity Comrie (1976, p. 16) notes that it "indicates the view of a situation as a single whole, without distinction of the various separate phases that make up that situation". Conversely, for imperfectivity he states that "the imperfective pays essential attention to the internal structure of the situation".

Every Slavic verb in its lexical entry has specified perfective or imperfective meaning, with a notable exception of a small subset of biaspectual verbs in which a single form can have both perfective and imperfective reading, e.g. in Croatian (Barić et al., 2005) and Polish (Klimek-Jankowska & Błaszczak, 2020). Perfective verbs are derived from imperfective roots through affixation or stem alternations, and the reverse process also occurs, producing imperfective verbs from perfective roots. When different prefixes attach to the same verb, they generate a variety of meanings (de Swart, 2012). For example, Croatian verbs *pisati* ‘to write$_{\text{ipfv}}$’ and *napisati* ‘to write$_{\text{pfv}}$’ form an aspectual pair because the only difference between them is aspectual; the former marks that the action is imperfective, i.e. still in progress, while the latter means that the action of writing is finished, i.e. it is not ongoing at the present time. However, not all verbs of opposite aspectual meaning in terms of perfective-imperfective dichotomy form an aspectual pair. This is evident in Croatian verbs *pisati* ‘to write$_{\text{ipfv}}$’ and *dopisati* ‘to add in writing$_{\text{pfv}}$’. Although the latter is derived from the former and it has perfective meaning, they do not form an aspectual pair because *dopisati* diverges from *pisati* in both aspect and new meaning. Examples above demonstrate that aspectual meanings are systematically differentiated on the level of morphology.

This distinction becomes even more nuanced when we consider common misconceptions in studies of (im)perfectivity (Comrie, 1976). One of them is understanding that the perfective aspect indicates a short action, while the imperfective aspect signifies a long one. That this is incorrect he argues with an example from Russian (Comrie, 1976, p. 17): the English sentence *I stood there for an hour* can be translated as being either imperfective *ja stojal tam čas,* or as being perfective *ja postojal tam čas* or *ja prostojal tam čas*. This example illustrates that although both sentences refer to the same amount of time, they differ in grammatical aspect. The second misconception is related to common understanding of perfectivity as indicating a completed action. However, Comrie (1976) points that it is important to distinguish between "completed" and "complete" event. The perfective aspect reflects an entire event from start to finish without focusing on its end. Rather than emphasizing the end, it treats the whole event as a single, unified occurrence. Moreover, he points that languages like Ancient Greek can even use perfective meaning to indicate the very beginning of an action, especially with stative verbs. Therefore, it is more precise to think of perfectivity as indicating a complete action, rather than a completed one.

Despite the frequent usage of Slavic languages and their binary system in the perfective and imperfective aspect as typical examples of grammatical aspect, other languages, for example English, encode aspect in typologically different ways. English primarily distinguishes between progressive and non-progressive forms. The progressive aspect (e.g., *John is reading*) presents an event as ongoing or unfolding at a particular time, whereas the non-progressive (e.g., *John reads; John wrote*) conveys a broader, often more neutral temporal perspective without highlighting the internal phase of the action. These aspectual distinctions are marked morphologically in English, typically through auxiliary constructions involving *be* and the present participle (-ing form).
It is important, however, not to conflate progressiveness with imperfectivity. Although the progressive is a subtype of imperfective aspect, the two are not synonymous. According to Comrie (1976), imperfectivity houses a number of temporal perspectives, one of them being habituality. For example, the sentence John used to write poems reflects a habitual reading in a non-progressive form, whereas John used to be writing poems combines both habitual and progressive readings. This illustrates that a situation can simultaneously be viewed as habitual and progressive. In this sense, the progressive overlaps with what Comrie refers to as "continuousness", a kind of imperfectivity that is not defined by habitual repetition. This means that the English progressive aspect captures a narrower meaning than imperfective aspect as envisaged in Slavic languages, but it remains a key grammatical device for encoding the internal temporal contour of events.

Another example of grammaticalized aspect but from a typologically different system is Mandarin Chinese, which lacks morphological changes (Hao et al., 2021). Instead, Chinese uses aspect markers, such as *le* for completed actions and *zhe* for progressive actions. These markers combine with verbs of different lexical aspect types (such as states, activities, accomplishments, and achievements), and their compatibility reflects both syntactic structure and the temporal semantics of the event being described.

1.4.1.3. Lexical aspect

Lexical aspect is a category of verbal aspect that is often used in contrast to grammatical aspect (Filip, 2012). For lexical aspect, Filip (2012, p. 721) states that it is “a semantic category that concerns properties of eventualities” and that “the properties in question have to do with the presence of some end, limit or boundary in the lexical structure of certain classes of verbs and it lack in others.” A central theme in the literature on lexical aspect is the notion of telicity, a semantic property of verbs that have (or do not have) an endpoint encoded. Verbs such as *sing* or *swim* are considered atelic because there is no inherent endpoint and the action can potentially continue indefinitely. On the other hand, verbs such as *send* or *hit* have an inherent endpoint and are therefore considered telic.

The concept of aktionsart, a German term meaning "manner of action," is discussed under lexical aspect. Originally, it referred to aspectual classes of German verbs, which often use affixes to derive new meanings. For example, from the verb *schreiben* (‘to write’), new forms such as *unterschreiben* (‘to sign’), *abschreiben* (‘to copy’), and *ausschreiben* (‘to announce’ or ‘to advertise’) are derived. However, Filip (2012) notes that since the 1970s, the term aktionsart has been extended beyond derivational morphology to describe aspectual classes in a broader sense, encompassing properties such as telicity and the internal temporal structure of events. In addition, aktionsart is not restricted to verbs, but rather involves verb and its arguments, i.e. verb phrases (Bott, 2010).

Based on the homogeneity of an event (Vendler, 1957, cited in Filip, 2012), i.e. durativity and identifiable temporal reference of an event (Vendler, 1969, cited in Malaia & Milković, 2021), Vendler distinguishes four aspectual classes: achievements, accomplishments, activities and states. Of these, *achievements* and *accomplishments* are considered telic because they have a change of state. While accomplishments contain a durative component, achievements involve an immediate change. In contrast, *activities* and *states* are atelic, as they have no inherent temporal reference. More specifically, actions that have a duration are called activities, while actions that do not require a duration are states. In addition to these four Vendler’s categories, Smith (1991, cited in Bott, 2010) added a fifth aspectual class named semelfactives. Those are very short events such as "flash," which represent an event without indicating any change of state. They often happen repeatedly or in succession (Malaia & Milković, 2021).

A frequent topic in the literature on the lexical aspect literature is coercion. It is defined as “the process by means of which an argument adapts to the requirement of the functor with which it combines” (de Swart, 2012, p. 769). Thus, one can encounter coercion in sentences in which a typical or default interpretation is not possible. Bott (2010) distinguishes between two types of coercion: complement coercion, where a noun must be re-interpreted, and aspectual coercion, where an alternative aspectual interpretation must be reached. An example sentence for complement coercion is *The author began the book* (Bott, 2010, p. 36). The problem with this sentence is that "begin selects an event, but the book doesn't have an event denotation", therefore, the event of reading must be reconstructed. Since writing is a typical activity associated with authors, the book is coerced into representing a writing event and not a reading event.

Aspectual coercion on the other hand, occurs when the aspectual class of a verb does not match the typical interpretation of a sentence (de Swart, 2012). For example, the English temporal adverbials *for* and *in* are typically used with atelic and telic verbs respectively. However, alternative interpretations are also grammatical after re-analysis, as the following sentence shows: *John hit a golf ball into the lake for an hour* (de Swart, 2012, p. 771). Although the verb hit is normally regarded as telic, the event and thus the aspectual interpretation are coerced into an atelic, iterative reading in the context of the adverbial phrase *for an hour*.

1.4.2. Processing of aspect in spoken languages

Studies of processing of aspect provide a unique insight into how are linguistically coded events processed. In this section, experimental findings from various methodologies (behavioral, eye-tracking and EEG) will be overviewed to examine how listeners and readers process both grammatical and lexical aspectual information.

1.4.2.1. Behavioral studies

Madden-Lombardi et al. (2017) used a rebus sentence paradigm to investigate in two experiments how grammatical aspect constrains event simulation at specific event roles. Native speakers read sentences in French word by word replacing the target nouns (instrument and object) with pictures that were either congruent or incongruent with the aspect of the verb, while the reaction time was measured. The results of both experiments showed that participants processed pictures faster when they were congruent with the aspect of the verb, especially for resulting objects in perfective sentences, suggesting that the aspect of the verb influences the representation of events and role focus. This effect occurred regardless of the sequence of the resulting object in relation to the instrument (Experiment 1:

instrument-object; Experiment 2: object-instrument). The findings support the idea that the grammatical aspect not only determines the temporal structure of events, but also influences the way comprehenders mentally simulate and prioritize the different elements of an action.

1.4.2.2. Eye-tracking studies

Foppolo et al. (2021) used the visual world paradigm to investigate how listeners process telicity and grammatical aspect in real time, in particular whether perfective aspect leads to immediate inferences about the completion of an event. Participants were asked to listen to sentences containing telic and punctual verbs while viewing pictures of completed or ongoing events. The study found that participants quickly integrated aspectual cues with visual context. They also showed an early preference for pictures of completed events when verbs were in the perfective form, especially for durative telic predicates where visual information helped to confirm completion.

Minor et al. (2022a) used the same method as Foppolo et al. (2021) to investigate how quickly and incrementally Russian listeners process grammatical aspect. More specifically, they investigated how early aspectual cues (such as aspectual morphemes within a verb) influence interpretation during spoken sentence comprehension. Their results showed that participants began interpreting aspectual information even before the verb was fully pronounced, suggesting rapid sub-word integration of grammatical aspect. Zhou et al. (2014) reported similar findings across language development. They found that Mandarin-speaking children and adults use grammatical aspect to guide real-time event recognition. More specifically, using a visual world eye-tracking paradigm, they tracked eye movements as participants listened to sentences with either the perfective morpheme (*-le*) or the durative morpheme (*-zhe*) while viewing scenes showing completed and ongoing events. Both adults and children as young as three years old used cues from aspectual markers to direct their gaze to the appropriate event type, indicating early and efficient integration of grammatical aspect during sentence processing.

Building on these language-specific findings, Minor et al. (2022b) and Minor et al. (2023) extended their research to a cross-linguistic comparison of languages with different aspectual systems: Russian, Spanish and English. They investigated how grammatical aspect, in particular the perfective versus the imperfective, influences the interpretation of telic events in these languages. Minor et al. (2022b) found that the perfective forms elicited strong completion inferences in Russian, moderate ones in Spanish and no significant bias in English, while the imperfective forms consistently led to ongoing- event interpretations in all three languages. Their results were further corroborated by Minor et al. (2023), who used both eye-tracking and picture selection tasks. They found that Russian speakers focused strongly on the result state in perfective contexts, Spanish speakers did so to a lesser extent and English speakers showed no clear preference. Taken together, these studies show that the imperfective aspect consistently directs attention to event progression, while the cognitive salience of the perfective aspect varies greatly across languages.

1.4.2.3. EEG studies

EEG studies of aspectual processing mostly used violation paradigms to investigate ERP correlates. For example, Zhang and Zhang (2008) used ERPs to examine how Mandarin speakers process agreement violations involving grammatical aspect, particularly combinations of progressive and perfective markers. Participants read sentences containing either correct aspectual combinations, semantic violations, or aspectual mismatches, and the EEG was recorded. Aspectual mismatches elicited a posterior negativity followed by a P600, which differs from the N400 observed with semantic violations, suggesting that aspectual violations are processed syntactically. The results suggest that grammatical aspect in Mandarin is processed via structured morphosyntactic mechanisms and not just semantics. Their findings were also confirmed by Qi and Zhou (2012). They investigated how native Mandarin speakers process disagreements between temporal adverb and aspectual marker *guo*. The authors found that sentences with such mismatches showed a P600 with centro-parietal distribution, time-locked to the critical word onset.

Insight into how English speakers process aspectual violations comes from Ferretti et al. (2009). More specifically, the authors examined how grammatical aspect influences the mental representation of events and referential processing in discourse. In their ERP experiment, they tested whether perfective (e.g., “shifted”) versus imperfective (e.g., “was shifting”) aspect affects expectations about which event participant (Source or Goal) will be mentioned next. They found that pronouns referring to the Source were processed differently depending on the verb's aspectual marking. More precisely, Source-referring pronouns elicited anterior negativities for both aspectual conditions, but the topography and latency varied: perfective sentences triggered an earlier negativity (100-300 ms) over the left anterior scalp, whereas imperfective sentences elicited a later (300-500 ms), more broadly distributed

frontal negativity. Additionally, only perfective sentences produced a biphasic LAN-P600 pattern. These results suggest that grammatical aspect shapes discourse-level expectations by influencing how comprehenders construct situation models during real-time language processing.
Flecken et al. (2015) extended this by examining ERPs for various linguistic violations in English. In line with previous literature, they found that semantic violations elicit N400 and morphosyntactic violations elicit P600. However, aspectual violations led to an early, centrally located negativity (250-350 ms) with additional P600, but with lower amplitude compared to morphosyntactic violations. These results suggest that different systems are involved in aspectual processing than in semantic and morphosyntactic processing.

Zeller & Clasmeier (2020) studied how native Russian speakers process aspectual violations in iterative sentence contexts. They found that sentences with incorrect aspectual marking (e.g. perfective verbs in habitual contexts) elicited a robust P600 effect, typically associated with morphosyntactic processing, but no N400 effect. This suggests that aspectual mismatches are processed grammatically rather than semantically in Russian.

Similarly, Klimek-Jankowska and Błaszczak (2020) conducted two experiments on aspectual processing in Polish. Native speakers of Polish read sentences word by word while EEG was recorded. The manipulated parts of the sentence were temporal adverbials and aspect. Also, in Experiment 1 the temporal adverbial appeared in pre-verbal position (temporal adverb – verb – object), and in the Experiment 2 it appeared in post-verbal position (verb – object – temporal adverb). Temporal modifiers were "for X time" and "in X time". The former implies durative meaning and is associated with imperfective verbs. The latter is used for expressing time span and is usually used with perfective verb. In that way, 4 possible combinations of temporal modifiers and predicates were possible: 1) perfective mismatch, 2) perfective match, 3) imperfective mismatch, 4) imperfective match. In Experiment 1 ERPs were measured at the verb onset and the following object onset, while in the Experiment 2 the temporal adverb onset, as well as the following word "in order to" were used as markers.

Interestingly, in the Experiment 1 (pre-verbal temporal adverb) there were no significant effects measured at the verb. Only on the following word, the object, there was a significant effect between perfective mismatch and perfective match conditions (N400 with atypical, wider distribution). No effects were found for processing imperfective match vs. imperfective mismatch sentences. The latter is explained in aspectual theory that claims that imperfective verbs are semantically underspecified and therefore no processing costs were recorded (although acceptability ratings were lower for mismatch, compared to imperfective match condition). The effect recorded for perfective match vs. mismatch sentences, the N400, is thought to reflect the integration problem at the semantic level (durative temporal adverb + perfective verb).

In Experiment 2 (post-verbal temporal adverb) the authors found biphasic ERP effects, only at the position of temporal adverb. Firstly, they observed early positivity in 200-400 ms time window. The amplitude for perfective mismatch condition was more positive going compared to perfective match condition. The authors interpreted this effect as early P600.
Also, they found LAN (200-400 ms) for imperfective mismatch vs. imperfective match conditions. They explain it as an index of violation based on detection of a prediction error. The authors conclude that imperfective and perfective verbs are processed differently in mismatching contexts.

In addition to classic aspectual violation paradigms where temporal adverbials or context don't match the aspect form of a verb, several studies also investigated processing costs of aspectual coercion, mostly for Germanic languages. For example, Bott (2010) investigated how German speakers processed aspectual coercion using EEG, focusing on cases where the aspectual class of a verb did not match its temporal context and required reinterpretation (e.g., interpreting a punctual verb as durative). Participants read sentences from three conditions: aspectual mismatch (incompatible and unresolvable), coercion (incompatible but reinterpretable), and control (fully compatible), while EEG was recorded. The author observed a sustained anterior negativity, interpreted as a working memory LAN, emerging between 500 and 900 ms in response to additive coercion. This effect was triggered by sentences containing an *in X time* prepositional phrase combined with a punctual achievement verb, in contrast to control sentences. Additionally, Bott reported a P600 in response to unresolvable aspectual mismatches involving *for X time* adverbials paired with achievement verbs. He interpreted the P600 as reflecting difficulties in semantic interpretation at the phrasal level, while the sustained anterior negativity was taken to indicate the inferential enrichment of the achievement predicate with a preparatory process, increasing demands on working memory through the integration of world knowledge. Bott's (2010) findings were corroborated in a study on processing of punctual and durative verbs in English, conducted by

Paczynsky et al. (2014), who also report sustained negativity (500-1200 ms) for mismatch (punctual verbs in durative context), compared to match condition (punctual verbs in punctual context).

1.4.2.4. Prediction of aspect

Compared to studies on general processing of aspect, prediction of aspectual information has on the other hand, received much less attention. Although PP was not the primary focus, some aforementioned studies did interpret (a part of) their findings as reflecting prediction. For example, Flecken et al. (2015) and Klimek-Jankowska and Błaszczak (2020) interpret the observed anterior negativity as an index of prediction error or increased demands of WM processing to construct appropriate event representation.

Yano (2018) conducted a study specifically designed to investigate whether native Japanese speakers process aspectual information even before the verb appears in a sentence. Participants read sentences on the screen, presented word by word, for 500 ms or 800 ms respectively, while the EEG was recorded. Aspectually coerced sentences with longer presentation duration (800 ms) showed both early anterior negativity (300-500 ms) and late anterior negativity (500-700 ms). However, sentences with shorter presentation durations (500 ms) showed only late anterior negativity (500-700 ms). The author argues that participants were only able to make predictions based on temporal adverbials when they had sufficient time, i.e. only at a presentation duration of 800 ms as indicated by the early anterior negativity.

Anterior negativity was also reported in a study on the processing of aspectual agreement in Mandarin Chinese (Hao et al., 2021). The authors presented native Mandarin speakers with sentences containing the progressive aspectual marker *zhe* in combination with aspectually agreeing or disagreeing verbs. The ERP results showed three key effects: an N400-like negativity time-locked to aspect marker, indicating a semantic mismatch between the predicted and actual aspect marker based on the lexical features of the verb; this was followed by a P600, reflecting syntactic reanalysis and repair; and finally, a late anterior negativity was observed time-locked to the word that followed aspect marker, which the authors interpreted as a sign of secondary reinterpretation or sentence-level wrap-up processing. These results show that even without verb inflections, Mandarin speakers rapidly integrate lexical aspect information to predict upcoming grammatical markers, and when expectations are violated, both semantic and syntactic systems are engaged to resolve the conflict.

1.4.3. Processing of aspect in sign languages

There is paucity of research on the topic of aspectual processing in SLs. Moreover, no direct studies on grammatical aspect processing in SLs have been published to date. However, there are several studies on the processing of lexical aspect.

Emmorey (1991) conducted a study with repetition priming paradigm. Participants were presented with prime-target ASL signs in a way that prime was inflected for habitual or continual aspect on the one hand, or agreement morphology for dual, reciprocal or multiple meaning on the other hand. Target signs were in their non-inflected i.e. citation form for both type of pairs.

The study found that aspectual morphology produced stronger priming effects than agreement morphology, suggesting that aspect marking may play a more robust role in lexical access for ASL signers compared to agreement marking. No priming was observed for unrelated or non-sign stimuli, indicating that the effects were linguistically specific rather than purely visual or motoric. Overall, the results suggest that aspectual morphology can be primed, and is therefore a modality-independent phenomenon.

Another aspectual topic that has been explored is telicity. As will be introduced in more detail in Chapter 1.5.2., telicity is an ubiquitous feature of SLs. Under the Event Visibility Hypothesis, Wilbur (2008) proposed that the semantics of the event structure of a sign is visible in its phonological form. This has since been shown to be true for several unrelated SLs, as has the fact that even non-signers can correctly distinguish telic and atelic signs without knowing what they mean (Strickland et al., 2015). The neural substrate of lexical aspect processing, i.e., telicity in ASL, was investigated by Malaia et al. (2012). They conducted an fMRI study in which two groups of participants, Deaf native signers and hearing non-signers, observed telic and atelic signs while a simple gesture in which the arm was moved upward from a resting position on the body to a T-position served as the baseline condition. In the non-signers, activity in response to ASL signs showed extensive bilateral activation in multiple brain regions, including the bilateral temporal and occipital lobes, inferior parietal lobes and cerebellum, and left frontal gyri, compared to the baseline condition. Deaf signers only showed activation of the left inferior and middle frontal gyri. When comparing activation for telic and atelic signs in non-signers, bilateral activation was higher in the fusiform gyrus, the left lingual gyrus and the right superior temporal and superior parietal gyri. Deaf signers, on the other hand, showed activity in the right superior temporal gyrus in response to telic signs. Malaia et al. (2012) interpret this focal activity in Deaf native signers as an index of the phonological complexity of the telic signs.

As far as EEG studies on aspect processing in SLs are concerned, only Krebs et al. (2023) have so far conducted a study on the processing of telicity. More specifically, they investigated the neural correlates of telicity in hearing, non-signing participants, native German speakers. Telic and atelic signs were selected from HZJ, Italian SL (LIS), Dutch SL (NGT) and Turkish SL (TID) to prevent participants from lip-reading and thus accessing the meaning of the signs being signed. Participants watched videos while the EEG was recorded and were asked to guess the meaning of the sign and to click on the word they thought represented the meaning of the sign presented among the two words offered. The behavioral data showed that participants made above change correct judgments about the telicity for all four SLs. In addition, participants had shorter reaction times (RTs) for telic signs compared to atelic signs. The ERP analysis showed that telic signs had a more negative amplitude over anterior areas in the early time window (100-150 ms) compared to atelic signs. Several later time windows showed a more positive amplitude for telic compared to atelic signs over posterior sites and a more negative amplitude over anterior sites. The authors interpret the early anterior effects as reflecting differences in perceptual processing, as telic signs exhibit greater velocity and acceleration of movement. Later posterior effects, on the other hand, reflect the integration of perceptual and language processing required by the task, according to the authors. In addition, the different spatio-temporal distribution of the effects indicates that the observed early and late processes are based on different processes.

1.5. ASPECT IN HZJ

In language, speakers usually use verbs when describing an event, which means that sentences are centered around verbs or verb-like units (Malaia, 2014). Event boundaries, or information about whether an event is over or ongoing, are encoded in the verbal aspect. More specifically, since both verbs (lexical predicates) and classifiers (classifier predicates) can function as predicates in sign languages (Özyürek & Perniss, 2011), these terms are further used in the dissertation. This is also in line with a trend in aspectology to shift the focus from (Slavic) verbs to the predicate and its arguments (Novak Milić, 2010).

1.5.1. Predicate types in HZJ

1.5.1.1. Verbs/lexical predicates

In SL linguistics, verbs are traditionally categorized into plain, agreeing, and spatial verbs (Emmorey, 2002; Mathur & Rathman, 2012; Milković, 2011). Milković (2011) summarizes that plain verbs are those that give no information about the person or number, they do not move in the signing space, but can express aspect. Agreeing or directional verbs, on the other hand, give information about the person and/or number and can move in the signing space. The position at which the movement of the verb begins indicates the subject, while the final position indicates the object. The notable exception is so-called backward verbs, which start with the object and end with the subject. In addition, agreeing verbs can express aspect. Finally, spatial verbs are those that agree with locative arguments and provide information about the path, trajectory, speed and location.

However, in their analysis of verb agreement in Brazilian Sign Language (LIBRAS), Lourenço & Wilbur (2018) questioned the traditional tripartite division of verbs. After analyzing plain verbs in LIBRAS, they found that non-body-anchored plain verbs also show agreement. They emphasize that it is the joint localization of verb and object that matters (i.e. co-localization), not the sole direction of the movement. This new approach to plain vs. agreeing verbs was recently applied to HZJ data, a language unrelated to LIBRAS. Milković & Wilbur (2022) found that the same analysis holds for HZJ.

1.5.1.2. Classifier predicates

Classifiers are “morphemes with a non-specific meaning” (Zwitserlood 2012, p. 158). They are assumed to represent certain prominent semantic features of the associated noun referents

(Frishberg, 1975, as cited in Tang et al., 2021). This means that such a morpheme can represent an entire semantic class (e.g. flat objects). In order for a comprehender to understand what the classifier refers to, a referent should therefore be introduced first, and only then is a classifier used in further discourse. There are various categorizations of classifiers in the literature, but currently two main categories are distinguished based on their grammatical function: whole entity classifiers, and handling classifiers (Zwitserlood, 2012). Whole entity classifiers symbolize referents by highlighting specific semantic characteristics or shape features (Zwitserlood, 2012). For example, various classifiers for animate entities, vehicles, trees, etc. have been described in numerous SLs. In the group of animate entities, different classifiers have been described for human vs. non-human referents, four-legged vs. two-legged referents, etc.

Handling classifiers, on the other hand, do not represent the object itself, but rather how the object is held or moved. For example, different handshapes are used for handling round, thin, thick or square objects.

In HZJ, similar to other studied SLs, several types of classifiers have been described. The first and so far only overview of classifiers in HZJ was conducted by Ujević (2011)[2]. Analyzing data from five native signers, she found that HZJ classifiers can be divided into four categories that have already been established for other SLs: whole entity classifiers, handling classifiers, size and shape specifiers, and body part classifiers. In this dissertation, only the handling classifiers are considered in more detail because they were used in sentence stimuli.

In the HZJ data, Ujević (2011) found 11 different handling classifiers, which are listed in Table 1 based on handshape. She notes that the S-handshape was the most common handshape observed in the data. However, it is not clear whether this handshape is the most common for handling classifiers in absolute terms, or whether objects held with the S-handshape were over-represented in the elicitation materials.

[2] Belaj & Majdenić (2018) discuss classifiers in SLs from the standpoint of cognitive linguistics. Although they do mention HZJ, it is not central focus of the paper and thus it is not included in this overview of (handling) classifiers in HZJ.

Table 1. Handshapes in HZJ handling classifiers (adopted from Ujević, 2011).

Handshape	Meaning
S	long and thin objects; pipes
C	cylindrical and round objects; a carpet
bent-5	round objects; an apple
X-th-adj	long and thin objects with a handle, small objects; hammer, marble
flat-O	flat objects; a paper, a watch, a letter
C-th-adj	bigger, flat objects; a pillow
B-th	flat objects; a plate
flat-B-th	big and heavy objects with sharp edges; a wardrobe
baby-O-flat-ext	little thin objects with a handle; a paintbrush
baby-O-flat	little thin objects with a handle; a paintbrush
baby-O-ext	little thin objects; a mouse

1.5.2. The Event Visibility Hypothesis

Visual reality and SLs share a common modality that has enabled SLs to exploit and grammaticalize this connection. One example is event visibility in SLs with an interface between semantics and phonology (Wilbur, 2003, 2005, 2008, 2010). Following Pustejovsky's classification of events into States, Processes, and Transitions, Wilbur (2003) analyzed ASL verbs. She found that ASL telic verbs have an end-State (semantic level) and end marking (phonological level). End marking shows up as a different phonological specification of the initial and final x-slot describing the movement, according to Brentari's (1998) sign language phonology model. Conversely, atelic verbs do not have an end-State, and therefore cannot show completion with the path movement of the sign, which telic verbs can. This was later summarized in the Event Visibility Hypothesis (EVH): "In the predicate system, the semantics of the event structure is visible in the phonological form of the predicate sign" (Wilbur, 2008, p. 229).

The EVH was formulated on the basis of observations in ASL. However, it was later tested in two other languages unrelated to ASL. The same pattern of event visibility was found in

Austrian Sign Language (ÖGS) by Schalber (2006) and in HZJ by Milković (2011). Additional major cross-linguistic study on SLs that are not historically related to each other and to ASL, including Italian Sign Language (LIS), Sign Language of the Netherlands (NGT) and Turkish Sign Language (TID), confirmed the EVH (Strickland et al., 2015).

Further experimental studies provided additional evidence in favor of the EVH. Motion capture study on ASL (Malaia & Wilbur, 2012) investigated the kinematic properties of telic and atelic predicates. End marking of telic predicates, initially observed at the phonological level (Wilbur, 2003), was now measured instrumentally and they showed greater deceleration compared to atelic predicates, regardless of medial or final sentence position. This motion capture approach was then extended to HZJ (Malia et al., 2013). It was found that telic predicates last longer, had greater peak speed and deceleration, compared to atelic predicates. Recently, Krebs et al. (2023) tested event visibility in ÖGS using motion capture and electromyography (EMG). Using motion capture data, they found similar results to ASL and HZJ for telic vs. atelic verbs: shorter duration, higher acceleration, higher deceleration at the end. The EMG also showed that the upper arm muscles were more active with telic verbs than with atelic verbs.

It is noteworthy that all the above studies have investigated EVH in verbs, i.e. lexical predicates. Since both verbs and classifiers function as predicates in SLs, one would expect classifiers to distinguish telic from atelic signs as well. However, studies on classifiers and EVH are scarce. A notable example of a departure from lexical predicates is a study by Grose et al. (2007). Based on observations in ASL body part classifiers, they conclude that "telicity is overtly marked in classifier predicates as it is in the non-classifier predicates" (Grose et al. (2007, p. 1270).

1.5.3. Expression of aspect in HZJ

The verbal aspect in HZJ was analyzed by Milković (2011). Aspectually modulated verbs were elicited in isolation as well as in context from nine native Deaf signers. Aspect was found to be a grammatical category in HZJ, and three groups of verbs were described in terms of the way they express perfective and imperfective meaning: verbs with different stems, verbs of composition, and verbs of modification.

Verbs of different stems is a category of verbs that use two different signs to express the difference between the perfective and imperfective aspect. An example of such a pair is the verbs TRAVEL (imperfective) and ARRIVE (perfective).

Secondly, the verbs of composition form their aspectual counterpart by adding another sign. More precisely, verbs that have multiple movements in their unmodulated basic form express an activity or a process. To express the perfective meaning, i.e. an outcome or a final state, another sign must be added. Such a sign can be another verb (e.g. FINISH, GET), an adverb (e.g. STILL), a quantifying argument (e.g. ALL) or a prepositional phrase (e.g. TO + object). An example of this category of verbs is the pair BUILD (imperfective) and BUILD+FINISH (perfective).

Milković (2011) called the third group "verbs of modification". This group is important for further context and is described in more detail below. Depending on the root movement, some verbs in the HZJ are perfective (BUY) and others are imperfective (TRAVEL). This distinction is important because it has been found that these two types of verbs express aspect differently, as the change in the phonological feature [movement][3] causes a change in aspect.
On the one hand, verbs that are perfective by their root have a single [sharp movement] at the end, i.e. they have a visible end-marking. Their basic characteristic is that they occur with a change in phonological features, such as handshape change, change of settings, change in path or orientation. The imperfective meaning is formed with a root repetition. Importantly, repetitions do not have [sharp movement]. In the following, each of these categories is briefly discussed and both perfective and imperfective examples are described phonologically.
Signs that have handshape change display [change of aperture]. An example of such sign is EXTINGUISH_{pfv}, where there is change from [open] to [closed] handshape. Imperfective sign EXTINGUISH_{ipfv} is signed with repeated [open] to [closed] handshape change.
Change of settings refers to movement between two points within a plane. Therefore, movement that has [ipsilateral] to [contralateral] change in signing space is considered to have change of settings. The perfective sign DELIVER_{pfv} has [ipsilateral] to [contralateral] single movement. By repeating the [ipsilateral] to [contralateral] movement, we get imperfective meaning.

[3] All verbs in Milković (2011) were analysed within the phonological framework of Brentari's (1998) *Prosodic Model of Sign Language Phonology*.

Signs with change in path may show [pivot] movement around a joint, such as elbow or wrist (Milković, 2011). For example, verb SELL$_{pfv}$ is signed with [pivot] from the wrist. Imperfective meaning is made with repeated [pivot] movement. Another possibility for a sign is to have [direction] towards a location in signing space, as in sign GIVE$_{pfv}$. Imperfective sign GIVE$_{ipfv}$ is made by repeating feature [direction].

Finally, signs can exhibit change in orientation. In these signs we observe that initial and final hand(s) position is different. Milković (2011) found two types of these differences: those that involve [pronation] and those that involve [extension]. An example of a perfective sign with [pronation] is DIE$_{pfv}$ because palm of the initial handshape is facing upwards, while the final handshape is facing downwards. Imperfective verb DIE$_{ipfv}$ is signed with repeated [pronation]. On the other hand, some verbs are imperfective by their root and have multiple trilled movements. Importantly, they do not display [sharp movement]. Milković (2011) observed that from such signs perfective meaning is made in one of two ways. DRAW$_{ipfv}$ is an example of such verb. Perfective meaning is expressed by adding extra [path] in the movement and finishing with [sharp movement]. For other imperfective verbs, such as TRAVEL$_{ipfv}$, perfective meaning is created with single [arc] movement.

Although the signs in which the movement is reduplicated[4] are summarized as "imperfective", they can have different meanings depending on the type of reduplication. For HZJ, Milković (2011) describes four variants: habitual, iterative, durative and incessant.
For signs with habitual meaning, it was found that the [return] movement is the same size as the root movement. In contrast, for signs with iterative meaning, the [return] movement is longer than the root movement. Durative meaning has two subtypes: continuous and progressive. If a sign receives [repeat] movement plus [smooth circling], it has a continuous meaning, i.e. it is read as one long event. On the other hand, if a sign has [trilled movement] plus [tracing: straight], then it has a progressive meaning, indicating that a process is ongoing. Finally, a sign can have an incessant meaning for events that have no clear beginning or end

[4] Following Wilbur's (2005, 2009) work on reduplication in ASL, Milković (2011) distinguishes repetition from reduplication. The former is used for lexically or prosodically motivated instances, while the latter is used for derivational or inflectional purposes, thus reflecting predicate aspect and argument structure (Wilbur, 2005). In addition, since movement is inherent to every SL syllable, Wilbur defines reduplication as the repetition of a change in movement (2009, p. 326).

time. Such signs have [repeat] plus [return: TM<root], meaning that return movement is trilled and longer in duration compared to the root movement.

2. AIM AND HYPOTHESES

The aim was to investigate predictive processing in Croatian Sign Language. More specifically, this study addressed whether signers and non-signers can predict linguistically coded event structure in the visual modality via aspect. Also, the relationship between working memory (retention and manipulation of linguistic and spatial features) and linguistic prediction will be addressed.

H1: Native signers will engage in predictive processing based on aspectual constraints.

H1.1: Signers will exhibit linguistic prediction, as reflected in anterior negativity in response to conditions with prediction violation for lexical predicates. Additionally, P600 effects will index syntactic reanalysis.

H1.2. Signers will exhibit linguistic prediction, as reflected in anterior negativity in response to conditions with prediction violation for classifier predicates. Additionally, P600 effects will index syntactic reanalysis.

H2: Gaming non-signers will show predictive processing based on motion-based visual features of signs encoding verbal aspect.

H2.1: Electrophysiological differences in processing are expected to be in later time window for lexical predicates.

H2.2: : Electrophysiological differences in processing are expected to be in earlier time window for classifier predicates.

H3: Working memory abilities will be positively correlated with predictive processing abilities.

H3.1: Verbal short-term memory and working memory will be positively correlated with ERP amplitudes in signers.

H3.2: Spatial short-term memory and working memory will be positively correlated with ERP amplitudes in non-signers.

3. METHODS

3.1. Participants

Three groups of participants were recruited. Firstly, 24 hearing native bimodal bilingual HZJ signers (CODAs – children of deaf adults) were recruited for participating in Experiment 1 and 3. Secondly, 16 hearing gamers were recruited who had no knowledge of any sign language. Lastly, 18 hearing non-signers and non-gamers were recruited as a control group. The two-non-signing groups participated in Experiment 2 and 3. All participants received a gift voucher worth 200 HRK (26,54 EUR). None of the participants reported having neurological or language disorders. All participants demonstrated typical cognitive abilities, as measured by the Nonverbal Reasoning task of the *Wechsler Adult Intelligence Scale – Fourth Edition* (WAIS-IV).

Twenty-four hearing native HZJ signers were recruited through non-probabilistic convenient and snowball sampling. Nineteen participants identified as women, and 5 as men. The mean age was 42.96 years (*SD* 10.73 years, range 20 to 58), and mean years of education was 14.46 years (*SD* 2.4). Nineteen participants were recruited from the Zagreb region, and 5 from the Rijeka region. All participants reported understanding all sentences from the experiments, despite reporting that they would not use a particular sign for a concept but rather another, even within the Zagreb region. Twenty-one participants were right-handed, one was left-handed, and one was ambidextrous. Of these 24, two were excluded from further EEG analyses due to the equipment failure.

Sixteen hearing gamers were recruited through non-probabilistic convenient and snowball sampling. The group consisted of 16 participants, of whom three were women, and 13 were men. The mean age was 27.94 years (*SD* 8.04, range 19 to 45), while mean years of education was 14.50 (*SD* 2.16). Fourteen people were right-handed, one was left-handed, and one was ambidextrous. Before participating in the study, all participants filled the Video Game Questionnaire (Bediou et al., 2023) to check if they fit the criteria for being categorized as action videogame players (playing 1st or 3rd person shooters or action-RPG for at least 5 hours per week during the last 12 months).

The group of non-gamers non-signers (further Control group) had 18 participants, of whom 13 women and 5 men. The mean age was 38.06 years (*SD* 13.22, range 21 to 64), and mean years of education 15.22 (*SD* 2.39). Thirteen people were right-handed, 2 were left-handed and 3 were ambidextrous.

A one-way ANOVA revealed significant differences between the groups with regard to age ($F(2, 55) = 9.63$, $p < .001$, $\eta^2_p = .26$). The Gamers were significantly younger ($M = 27.94$, *SD* 8.04) than the Controls ($M = 38.06$, *SD* 13.22, $p = .021$) and the Signers ($M = 42.96$, *SD* 10.73, $p < .001$), while the age difference between the Controls and the Signers was not statistically significant ($p = .309$). Given the significant age differences between the groups and the large effect size ($\eta^2_p = .26$), age was included as a covariate in the subsequent analyses of working memory skills to control for its potentially confounding influence. No significant differences were found in years of education between the three groups, $F(2, 55) = 0.64$, $p = .532$, $\eta^2_p = .02$.

A Chi-square test revealed a significant difference in sex distribution between the groups ($\chi^2(2, N = 58) = 16.18$, $p < .001$). More precisely, the Gamers had significantly more men and significantly fewer women than expected by chance, while the Signers and Control groups showed no significant differences. Furthermore, there were no significant differences in handedness distribution between the groups ($\chi^2(4, N = 58) = 2.13$, $p = .712$).

All participants signed the informed consent in Croatian and filled in the demographic questionnaire. If a person had stated in the questionnaire that they know HZJ or they play video games regularly, they were given additional questionnaires, language questionnaire constructed for the purpose of this research, or Video Game Questionnaire – Version of November 2022 (Bediou et al., 2023), both in Croatian. Handedness was assessed by an adapted Croatian version of Edinburgh Handedness Inventory (Oldfield, 1971). All participants reported having no history of neurological or language disorders, as well as normal or corrected vision.

3.2. Materials

3.2.1. Experiment 1

To investigate the processing of verbal aspect in HZJ, an aspect violation paradigm was employed with two predicate types: lexical predicates i.e. verbs and with classifier predicates. The design followed a 2 × 2 structure, combining two temporal adverbs (lexicalized for either perfective or imperfective aspect) with two predicate forms (perfective vs. imperfective). Using the aspect violation paradigm, this design produced sentences that were either aspectually congruent or incongruent. This resulted in four experimental conditions:

1. perfective congruent (already + perfective predicate)
2. imperfective congruent (still + imperfective predicate)
3. perfective incongruent (already + imperfective predicate)
4. imperfective incongruent (still + perfective predicate)

This design allowed to compare sentences that were aspectually congruent versus incongruent, depending on whether the predicate matched the aspectual constraint of the adverb.

Previous work on grammatical aspect in HZJ (Milković, 2011) showed that verbs, or in broader sense predicates, express aspect through various strategies, including movement modification. Within this class, some predicates have a perfective root form, while others have an imperfective root form. Perfective-root predicates express imperfective meaning through movement reduplication. Conversely, imperfective-root predicates typically feature a trilled movement in their basic form and express perfective meaning through movement modification (speed + path).

For the present study, only predicates with a perfective root were selected, due to much smaller number of imperfective root-predicates. Verbs were primarily sourced from the Croatian Plurilingual Morphology Dictionary (Jelaska & Cvikić, 2005), and supplemented by the Croatian Frequency Dictionary (Moguš et al., 1999), and the Frequency Dictionary of Croatian Children's Language (Kuvač Kraljević et al., 2022). Translations to HZJ were verified by a native signer.

A total of 132 perfective-root verbs were initially selected. Of these, 38 were one-handed, 88 were two-handed, and 6 had different handedness combination (e. g. a one-handed perfective form and two-handed imperfective form, or both one- and two-handed sign variants existed).

Some verbs were excluded due to semantic constraints, such as verbs that denote action of an object, that is verbs that cannot have an animate agent (e. g. PLATE-FALL-OVER). The final set included 17 one-handed and 17 two-handed verbs. Due to an insufficient number of suitable verbs, two verbs were used twice. This yielded 36 sentence contexts, each with 4 possible continuations representing 4 conditions, resulting in 144 sentences. However, only 143 sentences were presented in the experiment due to a recording issue with one sentence.

In addition to verbs, handling classifier predicates were included in this experiment to test whether aspectual processing generalizes across predicate types. The initial list of handling classifiers was compiled based on Ujević's (2011) description of HZJ classifiers. Additional handling classifiers were also included based on previously collected data on HZJ classifier usage. The final set consisted of six one-handed handshapes and six two-handed handshapes. For each handshape, three distinct actions were created, resulting in 18 one-handed and 18 two-handed handling classifier predicates. As with verbs, 36 sentence contexts were created, each presented in 4 conditions, resulting in 144 sentences. All stimuli were reviewed and verified by two native signers, one Deaf and one hearing.

A hearing native signer first interpreted sentences from Croatian into HZJ from a randomized list. Recordings were then re-signed from memory by a native Deaf signer in front of a blue screen, following a different randomized list. Each sentence began and ended with the signer's hands in a neutral position in front of the torso. Sentences were recorded in an artificially lit room with no natural light, using a Sony FDR-AX33 camera at 25 frames per second with the image size of 1920 x 1080.

Each item consisted of a sentence context followed by a target sentence. The sentence frame was consistent across the four conditions. Target sentences were appended to the context-sentence using iMovie, separated by a 1000 ms black screen. This approach was used as a trade-off between ecological validity of the stimuli and maintaining variation across conditions at the minimum, based on guidelines by Hernandez et al. (2023) and Krebs et al. (2022).

Although the length of sentences varied, all target sentences ended with a fixed three-sign structure: pronoun + adverb + predicate (verb or classifier). Pronouns included first-person singular, third person singular, first person plural or third person plural. Temporal adverbs were used to anchor the event time and ensure only one aspectual form of the predicate would be congruent. More precisely, certain adverbs in HZJ require particular aspectual forms of a predicate. For example, the temporal adverb ALREADY should be followed by a verb with perfective form and meaning. Likewise, temporal adverb STILL must be followed by a verb with imperfective form and meaning. In all the sentences, either of these two adverbs appeared.

The dynamics or duration of signs and intervals between them in the recorded sentences were checked according to the guidelines of Krebs et al. (2022). Time points were extracted in the ELAN software, which were later used to calculate the intervals.

A one-way ANOVA was performed to test for differences in the duration of the predicates across conditions. Levene's test revealed that the variances were not equal across conditions ($F(7, 279) = 22.92$, $p < .001$). Therefore, Welch's ANOVA was further used and showed a significant difference in the duration of predicates across conditions ($F(7, 118.04) = 129.67$, $p < .001$).

Games-Howell post-hoc tests for unequal variances showed significant differences in duration between perfective and imperfective predicates. Mean durations per conditions were as follows: Condition 1[5], $M = 616.09$ ms ($SE = 56.03$); Condition 2, $M = 1639.47$ ms ($SE = 55.24$); Condition 3, $M = 1720.53$ ms ($SE = 55.24$); Condition 4, $M = 639.70$ ms ($SE = 55.24$); Condition 5, $M = 693.70$ ms ($SE = 55.24$); Condition 6, $M = 1950.89$ ms ($SE = 55.24$); Condition 7, $M = 1855.47$ ms ($SE = 55.24$); and in Condition 8 $M = 632.83$ ms ($SE = 55.24$). No significant differences were found among conditions that use perfective forms (Conditions 1, 4, 5, 8) or among those that use imperfective forms (Conditions 2, 3, 6, 7), i.e. differences within-predicate and aspect type were not significant, suggesting that both perfective forms from congruent and incongruent conditions lasted statistically similar, as well as imperfective ($ps > .05$). These findings are expected because predicates in imperfective forms involve movement repetition. Since all verbs and classifiers selected for the stimuli were perfective by

[5] Conditions 1 to 4 relate to lexical predicates i.e. verbs, while conditions 5 to 8 relate to classifier predicates. Conditions 1 and 5 involve adverb *already* with perfective form (perfective congruent), conditions 2 and 6 involve adverb *still* with imperfective form (imperfective congruent), conditions 3 and 7 involve adverb *already* with imperfective form (perfective incongruent), and condition 4 and 8 involve adverb *still* with perfective form (imperfective incongruent).

root movement, forming imperfective aspect required movement repetition, resulting in increased duration.

3.2.2. Experiment 2

The materials used in Experiment two were the same as in Experiment 1. In addition, a psychologist conducted the Block Design, Visual Puzzles, and Matrix Reasoning tasks from the Wechsler Adult Intelligence Scale (WAIS-IV-HR, Wechsler, 2020) to obtain the Perceptual Reasoning Index.

3.2.3. Experiment 3

Four tasks were used to measure verbal and non-verbal short- term (STM) and working memory (WM) abilities. Verbal STM was assessed with the Digit Span Forward task implemented in E-Prime 3.0 (Psychology Software Tools, 2016). The task was retrieved from the publicly available E-Prime experiment library from Psychology Software Tools (number 34456[6]). Nonverbal, i.e. spatial, STM was assessed with the Corsi Block-Tapping task also from the E-Prime experiment library (number 34537[7]). Verbal WM was assessed with the Digit Span Backward (E-Prime experiment library, number 34457[8]) and Shortened Operation Span task (Foster et al., 2015), while non-linguistic spatial WM was assessed with the Rotation Span task (Foster et al., 2015). The latter two tasks were accessed from Attention and Working Memory Lab's public repository[9]. Instructions for all tasks were translated into Croatian, except for the Shortened Operation Span task which was already pre-translated.
In the Digit Span Forward task, the participants saw sequences of black-colored digits on a white background. Each digit was displayed individually in the center of the computer screen, and it followed the fixation cross. The first block started with three digits and the length was gradually increased in the following blocks. After the presentation of the sequence of digits was completed, the next screen asked participants to enter the digits on the keyboard in the

[6] https://support.pstnet.com/hc/en-us/articles/360044725853-Digit-Span-Forward-Task-34456 (accessed on 4th July 2024)
[7] https://support.pstnet.com/hc/en-us/articles/360045547754-Corsi-Block-Tapping-Task-34537 (accessed on 4th July 2024)
[8] https://support.pstnet.com/hc/en-us/articles/360044778053-Digit-Span-Backward-Task-34457 (accessed on 4th July 2024)
[9] https://englelab.gatech.edu/shortenedtasks.html (accessed on 4th July 2024)

order in which they were presented. The participant's score was defined as the length of the longest sequence of digits that they were able to recall correctly in the exact order (span score).

In the Corsi Block-Tapping test, computerized version, participants saw a series of blue squares on a black background. The target squares lit up in yellow one at a time, forming a sequence. Participants were instructed to watch the sequence and memorize the order in which the squares lit up. After each sequence, they used the mouse to click on the squares in the same order. The practice block with three trials was followed by the experimental blocks. The participant's score was determined by the number of correct items in the longest block (span score) as well as the total number of correct trials (trials score).

In the Digit Span Backward task, similarly to Digit Span Forward task, participants saw sequences of black-coloured digits on a white background that were individually displayed. The first block contained two digits. However, in this task, participants were asked to type the digits in backward order, i.e. from the one that was presented last towards the beginning of the sequence. The participant's score was defined as the length of the longest sequence of digits that they were able to recall correctly in the backward order (span score).

In the Shortened Operation Span Task (Foster et al., 2015), three blocks were presented. Participants were asked to memorize the letters displayed on the screen while solving simple equations, such as (3 x 3) +1. An illustration of the task is provided in Figure 2.

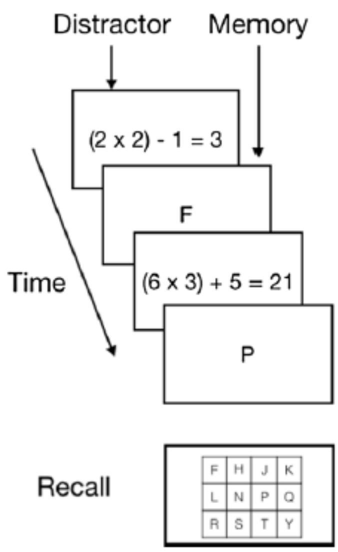

Figure 2. Operation span task procedure (retrieved from Foster et al., 2015, p. 228)

The task began with a three-part practice block. In the first part, participants were asked to memorize a series of letters shown on the screen and then select, from 12 options, the letters they had previously seen by clicking on the boxes, following the order in which they were shown. In the second part of the practice, the participants solved simple equations. After each equation, a number was displayed, and participants answered whether it was the correct solution or not. In addition, the computer calculated the average time needed to solve the equation. It was therefore important to give quick answers during the experimental trials. If a participant took longer than average to answer, the program marked this attempt as incorrect. Finally, in the third part of the practice block, both equations and letters were combined. More specifically, an equation was presented first, followed by a number. After the participants had given their answer (correct/incorrect), a letter was displayed. This sequence continued until the end of the trial, when a screen displaying multiple letters appeared. The participants had to choose the letters they had seen in the order of the presentation. The score was calculated by adding the number of letters that were recalled in the correct order, a measure referred to as the partial score.

Finally, in the Rotation span task, participants were asked to decide whether the letter was mirrored or not, and to memorize the size and direction of the arrows. A three-part practice block was provided. An illustration of the task is shown in Figure 3.

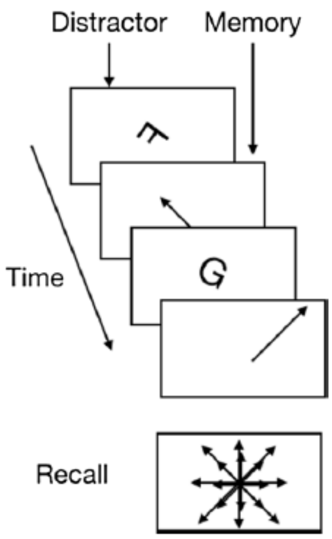

Figure 3. Rotation span task procedure (retrieved from Foster et al., 2015, p. 228)

In the first part, short and long arrows appeared sequentially, pointing outward from the center of the screen. Three to ten arrows were presented, and participants were then asked to choose from 16 possible options displayed on the screen by clicking on the arrowhead, in the order they were presented. In the second part, participants viewed letters that were either normal (i.e. unmirrored) or mirrored. Both normal and mirrored letters could have been rotated within a plane. Importantly, the computer measured the time needed for the answer. In the third part of the practice, both components were combined: a letter was presented, participants judged whether it was normal or mirrored, and after giving an answer, an arrow appeared, which repeated through the trial. In the experimental block, participants completed the same combined task. Similar to the Operation span, the final score was calculated by adding the number of arrows that were recalled in the correct order (the partial score).

3.3. Procedure

The majority of the data collection was conducted individually at the Faculty of Education and Rehabilitation Sciences, University of Zagreb, in the Laboratory for Psycholinguistic Research. Five native signers were recruited and their data were collected at the Laboratory for Language and Cognitive Neuroscience at the University of Rijeka using the same equipment as described in section 3.4.

Participants were seated comfortably at a desk and given instructions on how to complete the tasks. In all three groups of participants (signers, non-signing gamers, and non-signing non-gamers), the order of task administration was counterbalanced: half of the participants completed the short-term memory (STM) and working memory (WM) tasks first, while the other half completed the EEG experiment first. The STM and WM tasks took about 45 minutes in total. The preparation of the EEG cap took about 30 minutes per participant. The EEG experiment itself lasted about 2 hours. During the EEG experiment, the participants were seated in front of a screen. To familiarize them with the procedure, they were first presented with 8 practice sentences. During this practice phase, the participants could ask questions to clarify the task.

The experimental session consisted of 16 blocks, each lasting around 8 minutes. Participants were allowed to take self-paced breaks between blocks to minimize fatigue. Each trial began with a fixation cross displayed for 1000 ms, followed by a blank black screen for 200 ms. Then the video stimulus was presented. At the end of the video, a black screen appeared for 500 ms, followed by a comprehension question that was displayed until the participant answered it. The trial ended when the participant pressed the space bar to continue to the next trial.

Participants were instructed to avoid any body, head or eye movements during the presentation of the sentence stimuli in order to maintain data quality and minimize artifacts in the EEG recordings. The entire presentation of the stimuli and the experimental control were managed with the software Presentation (Neurobehavioral Systems).

3.4. Electrophysiological recording, pre-processing, and analysis

Continuous EEG was recorded with 32 active electrodes inserted in elastic cap (ActiCap Slim Snap). Electrodes 1 to 32 used for recording were the following: FP1, Fz, F3, F7, FT9, FC5, FC1, C3, T7, TP9, CP5, CP1, Pz, P3, P7, O1, Oz, O2, P4, P8, TP10, CP6, CP2, Cz, C4, T8,FT10, FC6, FC2, F4, F8, and FP2, respectively. The EEG signal was amplified with ActiChamp amplifier (Brain Products GmbH) and recorded with BrainVision Recorder software at a sampling rate of 1000 Hz, without applying any hardware filters during recording. Electrode impedances were kept bellow 15 kΩ. The signal was online referenced to Fz electrode. Bipolar electrooculography (EOG) was recorded using two pairs of passive electrodes to capture vertical (VEOG) and horizontal (HEOG) eye movements.
All data pre-processing and analyses was performed in BrainVision Analyzer 2.3. The continuous signal was downsampled to 500 Hz and filtered with a zero-phase shift Butterworth high pass filter of 0.1 Hz and low pass filter of 30 Hz high cut-off with a slope of 48 dB/octave. Ocular independent component analysis (ICA) was used to remove ocular artifacts. Follwing ICA, the EEG was re-referenced to the average of mastoid electrodes (FT9 and FT10), after which FT9, FT10, VEOG and HEOG channels were excluded from further analysis.

Artifact rejection was carried out using the following four criteria: maximal allowed voltage step of 50 μV/ms, maximal allowed absolute difference of values in 200 ms intervals of 90 μV, maximal and minimal amplitude difference of -100 to 100 μV, and lowest allowed activity was set to 0.5 μV within a 100 ms interval length. Epochs containing artifacts were marked, and 200 ms before and after each artifact intervals were excluded from averaging. Epochs were created time-locked to verb onset (marked as a frame in which the dominant hand reaches sign location, just prior to start of the path movement), starting at 500 ms before the onset, and ending at 2500 ms after the onset. Baseline correction was applied to -500 to 0 ms pre-stimulus period. Grand averages were additionally filtered with a low-pass filter of 15 Hz for visualization purposes.

The mean amplitude per participant per condition per time window was exported to an Excel file then imported into the SPSS statistical software. Five time windows were selected in line with the literature: 100-300 ms post-stimulus onset, 300-500 ms, 500-700 ms, 700-1000 and 1000-1300 ms. Individual electrodes were grouped into six lateral regions of interest (ROIs) and three midline ROIs. The lateral ROIs were anterior left (F3, F7, FC5), anterior right (F4, F8, FC6), central left (FC1, CP1, CP5), central right (FC2, CP2, CP6), posterior left (P3, P7, O1) and posterior right (P4, P8, O2). The midline ROIs were Fz, Cz, and Pz, and each made their own ROI.

3.5. Statistical analysis

For short-term and working memory tasks, group differences were assessed with one-way analyses of variance, with age included as a covariate (ANCOVA), because groups significantly differentiated in age, as presented in Section 3.1., p-values for pairwise comparisons were corrected for multiple comparison with Bonferroni correction.

As for the EEG data, to test for significant differences at lateral ROIs, repeated measure ANOVA (rmANOVA) was conducted with four factors: ANTERIORITY (frontal, central, posterior), LATERALITY (left, right), ASPECT (perfective, imperfective), and CONGRUENCE (congruent, incongruent). The same were used for central ROIs, except for the factor LATERALITY, which was not used. The Greeenhouse-Geisser correction was applied when there was a statistically significant violation of sphericity. P-values for pairwise comparisons were corrected for multiple comparison with Bonferroni correction.

For the third experiment, Spearman's ρ rank correlation coefficients were used to assess associations between STM/WM and ERP amplitudes. An alpha level of .05 was chosen as acceptable for type I errors. Only significant correlations, with 95 % confidence intervals (CIs) are reported. To account for multiple comparisons and control for false discovery rate, the Benjamini-Hochberg correction was applied to the *p*-values.

4. RESULTS

4.1. Experiment 1

4.1.1. Behavioral results

The analysis of behavioral data included mean percentages and standard deviations of Yes responses to question "Do you think the action is completed" per sentence type, and mean response times in milliseconds, with respective standard deviations.

Table 2. Descriptive statistics for sentence types in the Signers group. Standard deviations are in parentheses.

	Mean % of "yes" responses (SD)	Mean response times in ms (SD)
Perfective congruent verbs	99.22 (1.57)	1122.29 (732.61)
Imperfective congruent verbs	0.51 (1.39)	1103.15 (664.01)
Perfective incongruent verbs	67.68 (34.42)	1697.21 (1517.85)
Imperfective incongruent verbs	21.59 (30.80)	1944.45 (1784.22)
Perfective congruent classifiers	99.62 (0.98)	1060.34 (495.30)
Imperfective congruent classifiers	0.13 (0.59)	1124.58 (784.50)
Perfective incongruent classifiers	64.39 (35.94)	1738.78 (1394.99)
Imperfective incongruent classifiers	26.89 (33.38)	1850.59 (1517.42)

The results from Table 2 indicate that native bimodal bilingual signers had near-ceiling percentage of judging sentences with perfective congruent predicates as expressing a completed action, whether the predicate was a verb (99.22%) or a classifier (99.62%). In contrast, sentences with imperfective congruent predicates were almost never judged as expressing a completed action, both for verbs (0.51%) and classifiers (0.13%). Incongruent conditions, on the other hand, show a different pattern. For both perfective incongruent verbs and classifiers, participants were more likely to rate them as a completed action, (67.68% and

64.39% respectively). For the imperfective predicates, the trend reversed: 21.59% of sentences with incongruent verbs and 26.89% with incongruent classifiers were rated as completed. Notably, for all incongruent conditions, longer response time is observed for both the verbs and the classifiers, compared to congruent conditions.

Paired samples t-tests for mean response times showed that signers responded significantly more slowly in the incongruent than in the congruent condition for both perfective verbs ($t(20) = -2.90$, $p = .009$) and classifiers ($t(20) = -2.96$, $p = .007$) as well as for imperfective verbs ($t(20) = -2.51$, $p = .021$) and classifiers ($t(20) = -2.51$, $p = .02$) Although mean RTs for incongruent predicates were longer for imperfectives than perfectives by approximately 247 ms for verbs and 111 ms for classifiers, these differences were not significant ($p > .05$).

4.1.2. EEG

4.1.2.1. Verbs

Grand average plots for perfective verbs are shown in Figure 4, for imperfective verbs in Figure 5, while respective topographical maps are shown in Figure 6 and 7.

4.1.2.1.1. Lateral sites

100-300 ms time window

In the earliest time window, there was a main effect of Anteriority ($F(1.23, 25.74) = 5.25$, $p = .024$, $\eta^2_p = .20$) and main effect of Congruence ($F(1, 21) = 7.59$, $p = .012$, $\eta^2_p = .27$). A significant three-way interaction was observed between Anteriority × Laterality × Aspect, $F(2, 42) = 3.90$, $p = .028$, $\eta^2_p = .16$. Additionally, the interaction between Anteriority × Congruence was significant, $F(1.10, 23.19) = 5.36$, $p = .027$, $\eta^2_p = .28$, as well as the interaction between Aspect × Congruence, $F(1, 21) = 8.26$, $p = .009$, $\eta^2_p = .28$. Finally, there was a significant three-way interaction between factors Anteriority × Aspect × Congruence, $F(2, 42) = 5.35$, $p = .008$, $\eta^2_p = .20$. The post-hoc analysis of the latter interaction showed that significant congruency effects were present only in the perfective aspect condition. More specifically, for perfective verbs only, significant differences between congruent and incongruent forms emerged at both central ($M = -1.21$, $SE = 0.34$, $p = .002$) and posterior sites ($M = -1.04$, $SE = 0.22$, $p < .001$), with incongruent forms having more negative amplitude. Imperfective verbs showed no significant differences at any anteriority level.

300-500 ms time window

In the second analyzed time window, there was a main effect of Anteriority ($F(1.34, 28.09) = 12.02$, $p = .001$, $\eta^2_p = .36$) and main effect of Congruence ($F(1, 21) = 11.81$, $p = .002$, $\eta^2_p = .36$). A two-way interaction Aspect × Congruence was observed, $F(1, 21) = 9.79$, $p = .005$, $\eta^2_p = .32$, as well as a three-way interaction Anteriority × Aspect × Congruence, $F(2, 42) = 9.35$, $p = .001$, $\eta^2_p = .31$. The perfective incongruent forms had more negative amplitude compared to the perfective congruent forms at all three sites, frontal ($M = - 0.51$, $SE = 0.21$, $p = .024$), central ($M = - 1.61$, $SE = 0.34$, $p < .001$) and parietal ($M = - 0.81$, $SE = 0.27$, $p = .007$), with the most negative amplitude at central ROIs. No pairwise comparisons for imperfective verbs reached significance.

500-700 ms time window

A significant main effect of Anteriority was observed ($F(2, 42) = 15.34$, $p < .001$, $\eta^2_p = .42$), as well as of Aspect ($F(1, 21) = 9.71$, $p = .005$, $\eta^2_p = .32$). A significant two-way interaction was observed between factors Laterality × Aspect, $F(1, 21) = 4.62$, $p = .043$, $\eta^2_p = .18$, and factors Aspect × Congruence, $F(1, 21) = 37.15$, $p < .001$, $\eta^2_p = .64$. Finally, a three-way interaction Anteriority × Aspect × Congruence was observed, $F(2, 42) = 13.22$, $p < .001$, $\eta^2_p = .39$. Pairwise comparisons revealed that incongruent perfectives had more negative amplitude over anterior ($M = -0.87$, $SE = 0.17$, $p < .001$), central ($M = -1.97$, $SE = 0.36$, $p < .001$), and posterior sites ($M = -1.12$, $SE = 0.51$, $p = .04$) than congruent perfectives. Imperfective incongruent verbs, on the other hand, had more positive amplitude compared to imperfective congruent verbs on frontal ($M = 0.69$, $SE = 0.18$, $p = .001$) and central ROIs ($M = 1.55$, $SE = 0.30$, $p < .001$).

700-1000 ms time window

The analysis revealed the main effect of Anteriority ($F(2, 42) = 6.16$, $p = .005$, $\eta^2_p = .23$) and the main effect of Aspect ($F(1, 21) = 6.94$, $p = .016$, $\eta^2_p = .25$). In addition, the Aspect × Congruence interaction was observed, $F(1, 21) = 30.94$, $p < .001$, $\eta^2_p = .60$. Pairwise comparison confirmed that perfective incongruent verbs had more negative amplitude compared to congruent ones ($M = -0.92$, $SE = 0.26$, $p = .002$), while imperfective incongruent verbs showed more positive amplitude than imperfective congruent verbs ($M = 1.25$, $SE = 0.24$, $p < .001$).

1000-1300 ms time window

The final analyzed time window revealed the main effect of Anteriority, $F(2, 42) = 6.71$, $p = .003$, $\eta^2_p = .24$. In addition, two interactions were significant: Anteriority × Congruence ($F(1.44, 30.18) = 5.74$, $p = .014$, $\eta^2_p = .22$), and Aspect × Congruence ($F(1, 21) = 10.64$, $p = .004$, $\eta^2_p = .34$). Incongruent imperfectives had more positive amplitude compared to their congruent form ($M = 0.90$, $SE = 0.26$, $p = .003$). Perfective verbs had no significant differences in amplitude in this time window.

4.1.2.1.2. Midline sites

100-300 ms time window

At the midline electrodes there was a main effect of Congruence, $F(1, 21) = 34.02$, $p < .001$, $\eta^2_p = .62$. There was also a significant interaction Aspect × Congruence, $F(1, 21) = 13.19$, $p = .001$, $\eta^2_p = .40$. Post-hoc comparison revealed that perfective incongruent verbs had more negative amplitude than perfective congruent verbs ($M = -1.59$, $SE = 0.28$, $p < .001$). Imperfective verbs showed no significant differences in this time window.

300-500 ms time window

The second time window revealed the main effect of Congruence, $F(1, 21) = 6.84$, $p = .016$, $\eta^2_p = .25$. The interaction Aspect × Congruence was also significant, $F(1, 21) = 74.74$, $p < .001$, $\eta^2_p = 0.78$. The post-hoc analysis of this interaction showed significant difference in amplitude only within perfective verbs. Perfective incongruent forms had more negative amplitude that their congruent counterparts ($M = -2.67$, $SE = 0.49$, $p < .001$).

500-700 ms time window

There was a significant main effect of Aspect, $F(1, 21) = 4.65$, $p = .043$, $\eta^2_p = .18$. A significant interaction Aspect × Congruence was found, $F(1, 21) = 32.19$, $p < .001$, $\eta^2_p = .61$. Post-hoc comparison revealed significant differences in amplitude for both perfective and imperfective verbs. Perfective incongruent forms had more negative amplitude compared to congruent forms ($M = -3.07$, $SE = 0.78$, $p < .001$), while imperfective incongruent forms had more positive amplitude compared to their congruent forms ($M = 1.98$, $SE = 0.38$, $p < .001$).

700-1000 ms time window

No main effects were found in this time window. However, the interaction Aspect × Congruence was significant, $F(1, 21) = 25.39$, $p < .001$, $\eta^2_p = .55$. More specifically, imperfective incongruent verbs had more positive amplitude than imperfective congruent verbs ($M = 2.88$, $SR = 0.45$, $p < .001$). Perfective verbs showed no significant comparisons in this interaction.

1000-1300 ms time window

In the final time window, only the main effect of Congruence was significant, $F(1, 21) = 5.95$, $p = .024$, $\eta^2_p = .22$. While the overall interaction was not significant, pairwise comparisons suggest that imperfective incongruent verbs have more positive amplitude than their congruent counterparts ($M = 2.12$, $SE = 0.52$, $p < .001$).

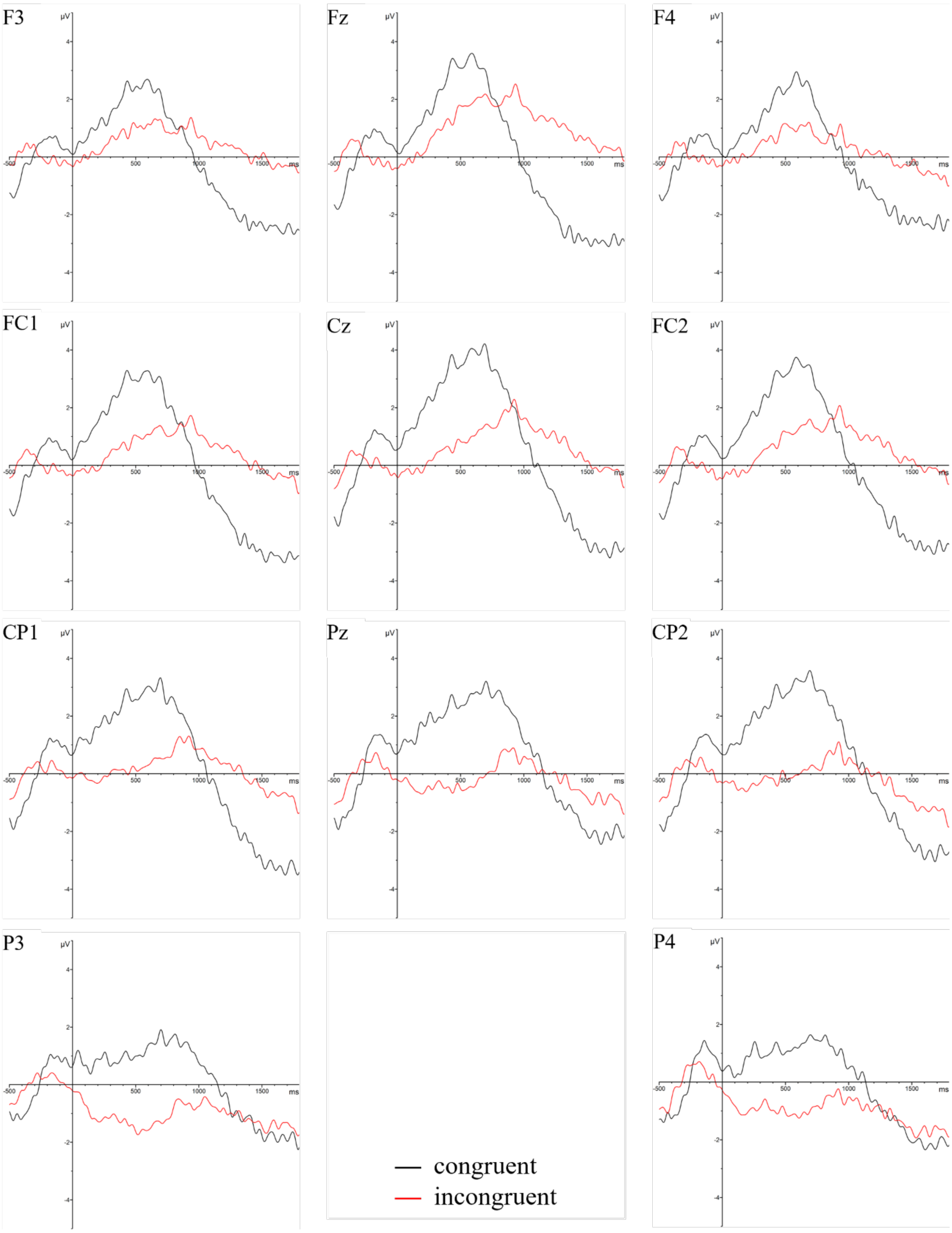

Figure 4. Grand average waveforms plotted for representative electrodes for perfective verbs in the Signers group. Negativity is plotted downward.

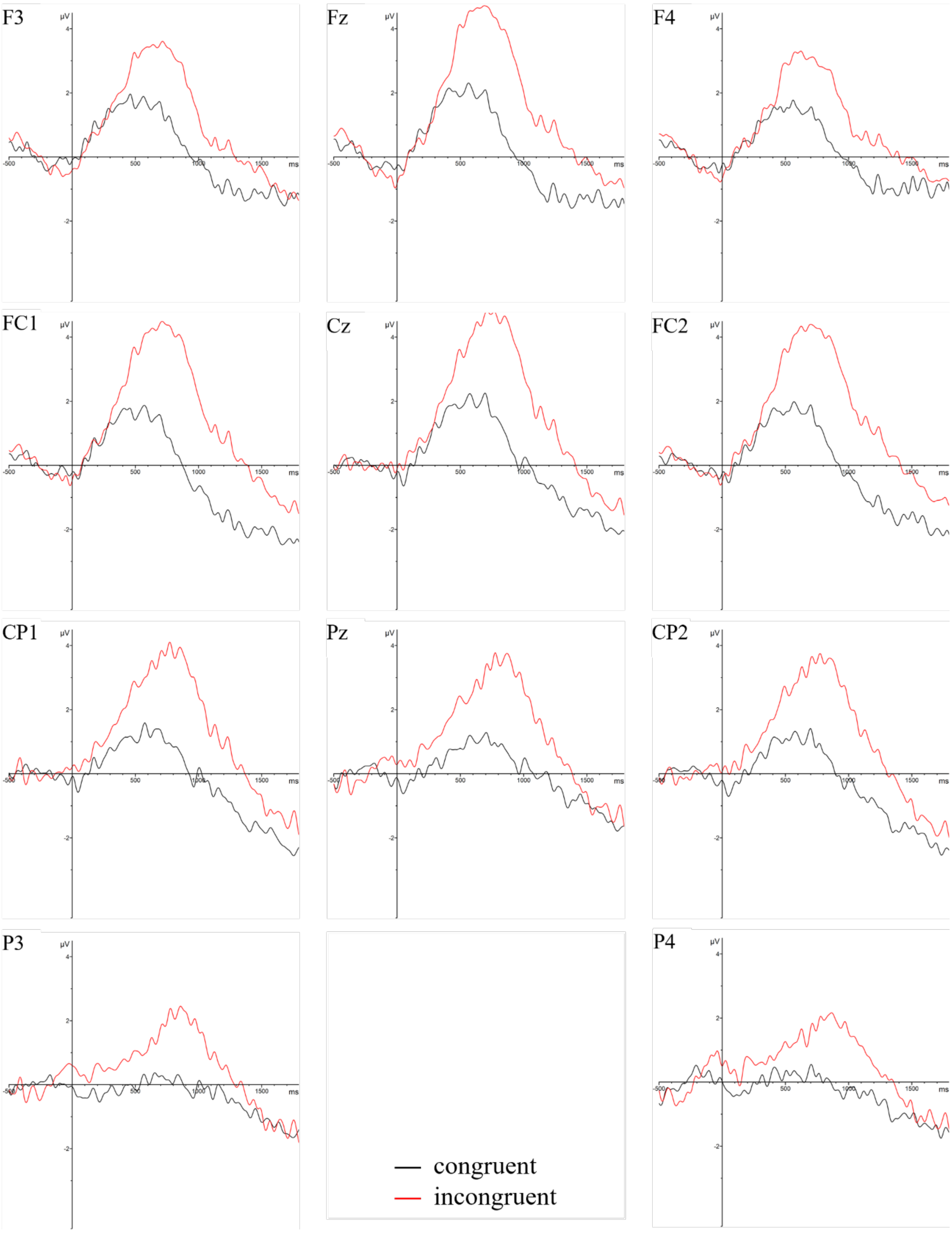

Figure 5. Grand average waveforms plotted for representative electrodes for imperfective verbs in the Signers group. Negativity is plotted downward.

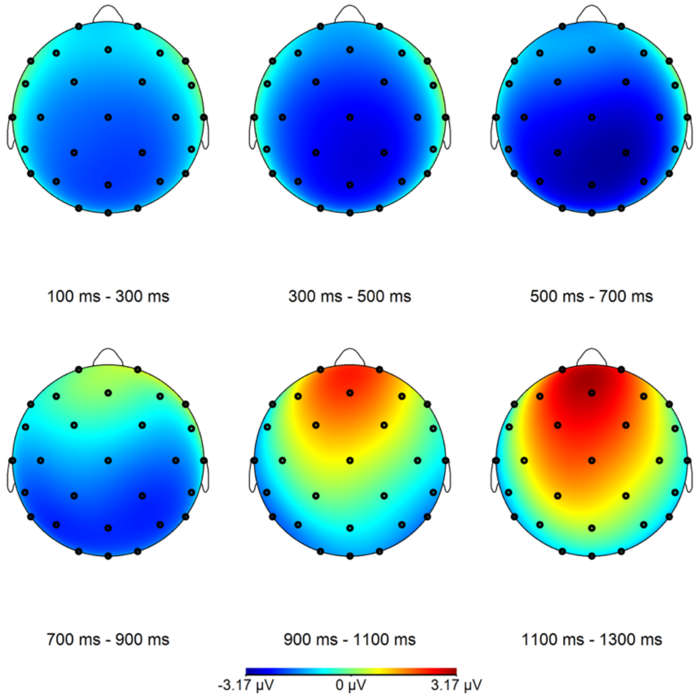

Figure 6. Topographic maps for perfective verbs, computed by subtracting Incongruent – Congruent activity.

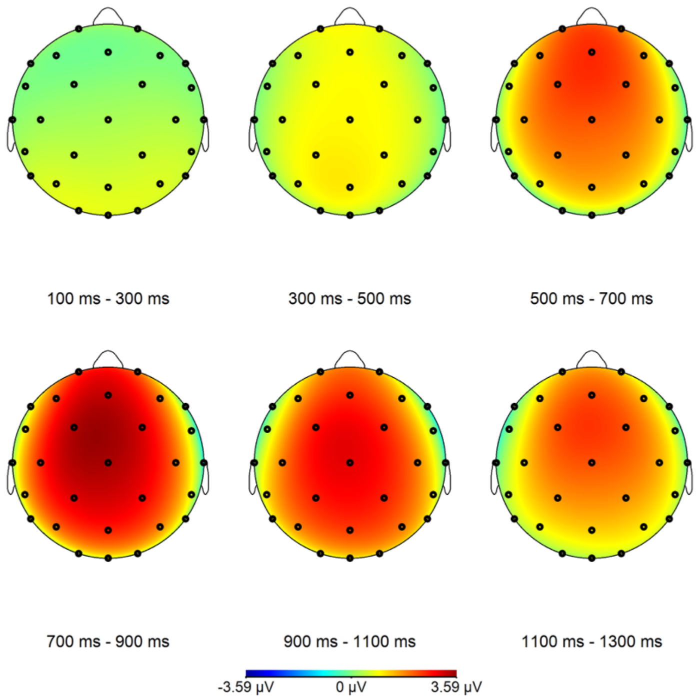

Figure 7. Topographic maps for imperfective verbs, computed by subtracting Incongruent – Congruent activity.

4.1.2.2. Classifiers

Grand average plots for perfective classifiers are shown in Figure 8, for imperfective classifiers in Figure 9, while respective topographical maps are shown in Figure 10 and 11.

4.1.2.2.1. Lateral sites

100-300 ms time window

There was a significant main effect of Anteriority ($F(1.24, 26.01) = 9.74$, $p = .003$, $\eta^2_p = .32$), as well as of Congruence ($F(1, 21) = 11.62$, $p = .003$, $\eta^2_p = .36$). In addition, two two-way interaction Anteriority × Aspect ($F(1.30, 27.33) = 5.64$, $p = .018$, $\eta^2_p = .21$) and Aspect × Congruence ($F(1, 21) = 31.28$, $p < .001$, $\eta^2_p = .60$) were observed. Finally, the interaction Anteriority × Aspect × Congruence was significant ($F(2, 42) = 8.76$, $p < .001$, $\eta^2_p = .29$). Post-hoc comparisons revealed that incongruent perfective classifiers had overall more negative amplitude compared to congruent perfective classifiers ($M = -1.08$, $SE = 0.16$, $p < .001$). Moreover, incongruent perfective classifiers had more negative amplitude over anterior ($M = -0.49$, $SE = 0.22$, $p = .039$), central ($M = -1.74$, $SE = 0.29$, $p < .001$), and posterior ROIs ($M = -1.01$, $SE = 0.19$, $p < .001$), compared to their congruent forms.

300-500 ms time window

A significant main effect of Anteriority ($F(1.33, 27.92) = 9.39$, $p < .001$, $\eta^2_p = .31$) and of Congruence ($F(1,21) = 7.65$, $p = .012$, $\eta^2_p = .27$) was observed. Also, an interaction Anteriority × Congruence was observed ($F(2, 42) = 3.38$, $p = .045$, $\eta^2_p = .14$), as well as Aspect × Congruence ($F(1, 21) = 54.58$, $p < .001$, $\eta^2_p = .72$). Finally, a three-way interaction Anteriority × Aspect × Congruence was significant, $F(2, 42) = 13.46$, $p < .001$, $\eta^2_p = .39$). Pairwise comparison showed that perfective incongruent classifiers had overall significantly more negative amplitude compared to perfective congruent ones ($M = -1.58$, $SE = 0.29$, $p < .001$). More specifically, both anterior ($M = -0.74$, $SE = 0.25$, $p = .009$), central ($M = -2.51$, $SE = 0.52$, $p < .001$), and posterior ROIs ($M = -1.51$, $SE = 0.31$, $p < .001$) had more negative amplitude for perfective incongruent forms, compared to congruent forms.

500-700 ms time window

In the third time window there was a main effect of Anteriority, $F(2, 42) = 12.58$, $p < .001$, $\eta^2_p = .38$. Furthermore, the interaction Aspect × Congruence was significant, $F(1, 21) = 41.95$, $p < .001$, $\eta^2_p = .67$. Finally, the interaction between Anteriority × Aspect × Congruence was significant, $F(2, 42) = 23.45$, $p < .001$, $\eta^2_p = .53$. Pairwise comparison revealed that incongruent perfective classifiers had overall more negative amplitude than their congruent forms (*M* = -1.95, *SE* = 0.44, $p < .001$). This difference was significant across all three regions: anterior (*M* = -1.34, *SE* = 0.40, $p = .003$), central (*M* = -2.93, *SE* = 0.75, $p < .001$), and posterior (*M* = -1.59, *SE* = 0.37, $p < .001$).

700-1000 ms time window

The significant main effect of Anteriority was found in this time window, $F(1.92, 40.28) = 6.64$, $p = .003$, $\eta^2_p = .24$. Furthermore, the interaction Aspect × Congruence was observed, $F(1, 21) = 24.85$, $p < .001$, $\eta^2_p = .54$. Finally, the three-way interaction Anteriority × Aspect × Congruence was significant, $F(2, 42) = 15.17$, $p < .001$, $\eta^2_p = .42$. The post-hoc comparisons revealed that perfective incongruent forms elicited more negative amplitude than congruent forms (*M* = -1.99, *SE* = 0.73, $p = .013$). Conversely, imperfective incongruent forms elicited more positive amplitude than congruent forms (*M* = 0.77, *SE* = 0.34, $p = .037$). The post-hoc analysis of the Anteriority × Aspect × Congruence interaction showed that over anterior sites, neither perfective nor imperfective incongruent versus congruent forms elicited significant differences in amplitude. However, over central sites perfective incongruent forms had more negative amplitude than congruent ones (*M* = -2.95, *SE* = 1.05, $p = .026$), while imperfective incongruent forms had more positive amplitude compared to their congruent forms (*M* = 1.93, *SE* = 0.50, $p < .001$). Over posterior sites only perfective classifiers showed significant difference, with incongruent forms having more negative amplitude compared to congruent forms (*M* = -2.26, *SE* = 0.65, $p = .002$).

1000-1300 ms time window

In the final time window there was a main effect of Anteriority, $F(2, 42) = 10.48$, $p < .001$, $\eta^2_p = .33$. When the Anteriority × Congruence interaction was corrected for violated sphericity with the Greenhouse-Geisser method, the p value turned out to be marginally significant ($F(1.42, 29.81) = 3.72$, $p = .05$, $\eta^2_p = .15$). Furthermore, a significant Aspect × Congruence interaction was found, $F(1, 21) = 7.35$, $p = .013$, $\eta^2_p = .26$, indicating that congruency effects differed between perfective and imperfective aspect. Finally, Anteriority × Aspect × Congruence interaction was found, $F(1.40, 29.40) = 11.76$, $p < .001$, $\eta^2_p = .36$. The post-hoc comparison revealed that incongruent imperfective classifiers had more positive amplitude over central (*M* = 1.45, *SE* = 0.35, $p < .001$) and posterior sites (*M* = 0.87, *SE* = 0.36, $p = .025$). On the other hand, incongruent perfective classifiers had more negative amplitude only at the posterior sites (*M* = -2.73, *SE* = 1.07, $p = .019$).

4.1.2.2.2. Midline sites

100-300 ms time window

In the first time window for midline sites, there was a main effect of Anteriority (F(1.21, 25.43) = 9.68, $p < .001$, $\eta^2_p = .32$) and a main effect of Congruence (F(1, 21) = 9.00, $p = .007$, $\eta^2_p = .30$). There was also a significant interaction Aspect × Congruence, F(1, 21) = 35.75, $p < .001$, $\eta^2_p = .63$. Pairwise comparison revealed that for perfective classifiers incongruent forms had more negative amplitude than congruent forms (M = -2.04, SE = 0.30, $p < .001$).

300-500 ms time window

In the second time window there was also the main effect of Anteriority, F(1.27, 26.73) = 11.33, $p = .001$, $\eta^2_p = .35$. Furthermore, an interaction Anteriority × Congruence was observed, F(2, 42) = 8.37, $p < .001$, $\eta^2_p = .29$, suggesting that congruency effects varied depending on anterior-posterior scalp distribution. Finally, the Aspect × Congruence interaction was robust (F(1, 21) = 61.38, $p < .001$, $\eta^2_p = .75$), indicating that the effects of congruency varied between perfective and imperfective classifiers. More precisely, perfective incongruent classifiers had more negative amplitude than their congruent forms (M = -2.85, SE = 0.59, $p < .001$).

500-700 ms time window

There was a main effect of Anteriority, F(1.41, 29.57) = 12.57, $p < .001$, $\eta^2_p = .38$. Furthermore, the interaction Anteriority × Congruence was significant, F(1.50, 31.43) = 7.43, $p = .002$, $\eta^2_p = .26$, as well as the robust interaction Aspect × Congruence (F(1, 21) = 43.70, $p < .001$, $\eta^2_p = .68$. Finally, a three-way interaction Anteriority × Aspect × Congruence was observed, F(2, 42) = 3.42, $p = .042$, $\eta^2_p = .14$. Pairwise comparison revealed that perfective incongruent classifiers elicited more negative amplitude on anterior (M = -2.62, SE = 0.92, $p = .01$), central (M = -3.76, SE = 1.18, $p = .005$), and posterior sites (M = -3.45, SE = 0.88, $p < .001$). Imperfective incongruent forms, on the other hand, showed significantly more positive amplitude at the anterior region only (M = 2.52, SE = 1.16, $p = .041$).

700-1000 ms time window

In this time window there were no main effects. However, a significant interaction Anteriority × Congruence was found (F(1.55, 32.62) = 5.70, $p = .012$, $\eta^2_p = .21$), as well as robust interaction Aspect × Congruence (F(1, 21) = 34.25, $p < .001$, $\eta^2_p = .62$). Pairwise comparisons showed that imperfective incongruent classifiers elicited more positive amplitude than their congruent forms (*M* = 2.44, *SE* = 0.90, *p* = .013).

1000-1300 ms time window

In the final analyzed time window there were no significant main effects. The interaction Anteriority × Congruence was however found ($F(1.37, 28.67) = 5.32$, $p = .020$, $\eta^2_p = .20$), as well as the interaction Aspect × Congruence ($F(1, 21) = 4.58$, $p = .044$, $\eta^2_p = .18$). Finally, a three-way interaction Anteriority × Aspect × Congruence was significant ($F(2, 42) = 5.66$, $p = .007$, $\eta^2_p = .21$), suggesting that the effect of congruency on ERP amplitudes was modulated by both verbal aspect and scalp distribution. More specifically, only for imperfective classifiers, incongruent forms showed more positive amplitude than congruent forms on all three sites: anterior (*M* = 1.62, *SE* = 0.57, *p* = .010), central (*M* = 1.77, *SE* = 0.81, *p* = .041), and posterior (*M* = 1.48, *SE* = 0.63, *p* = .030).

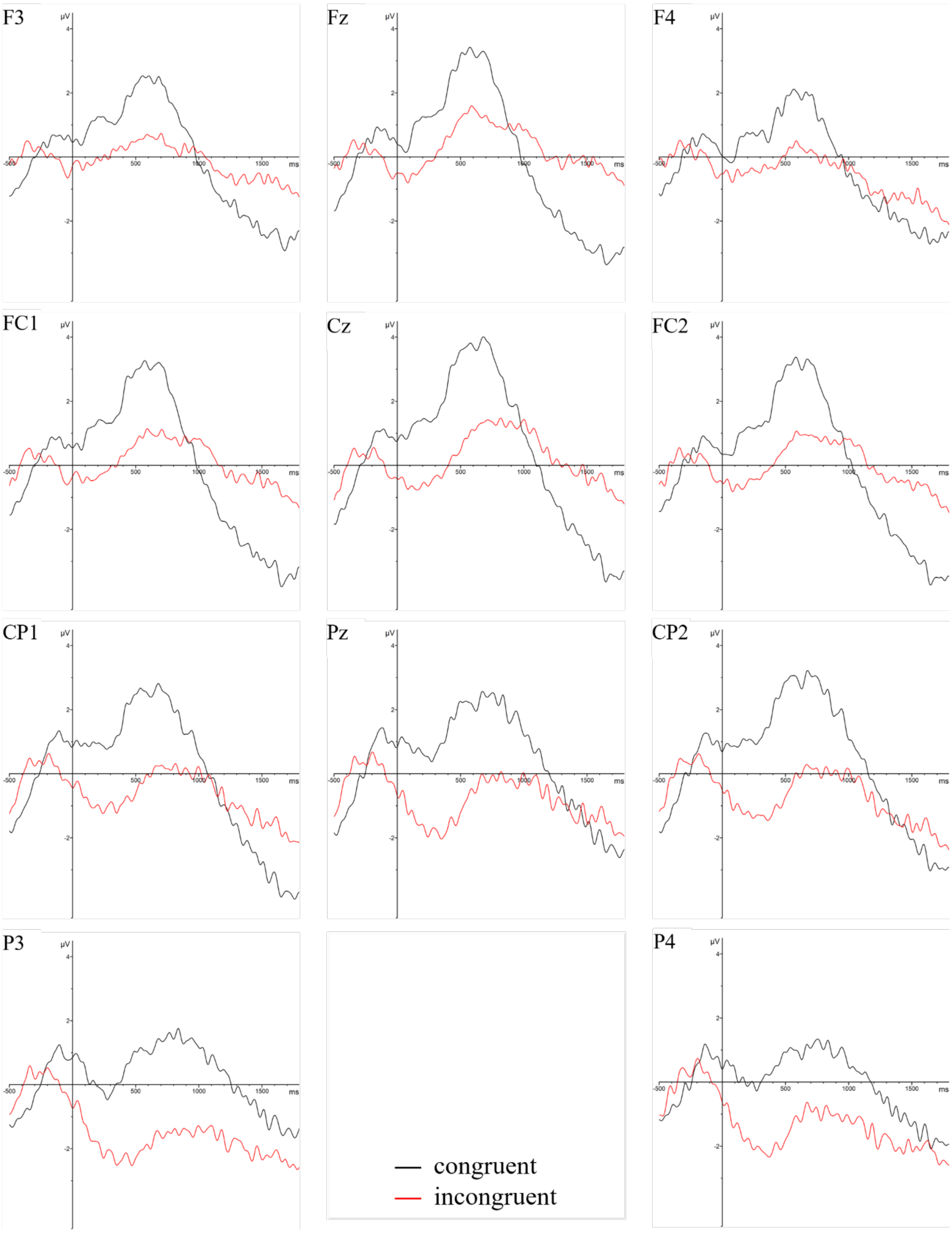

Figure 8. Grand average waveforms plotted for representative electrodes for perfective classifiers in the Signers group. Negativity is plotted downward.

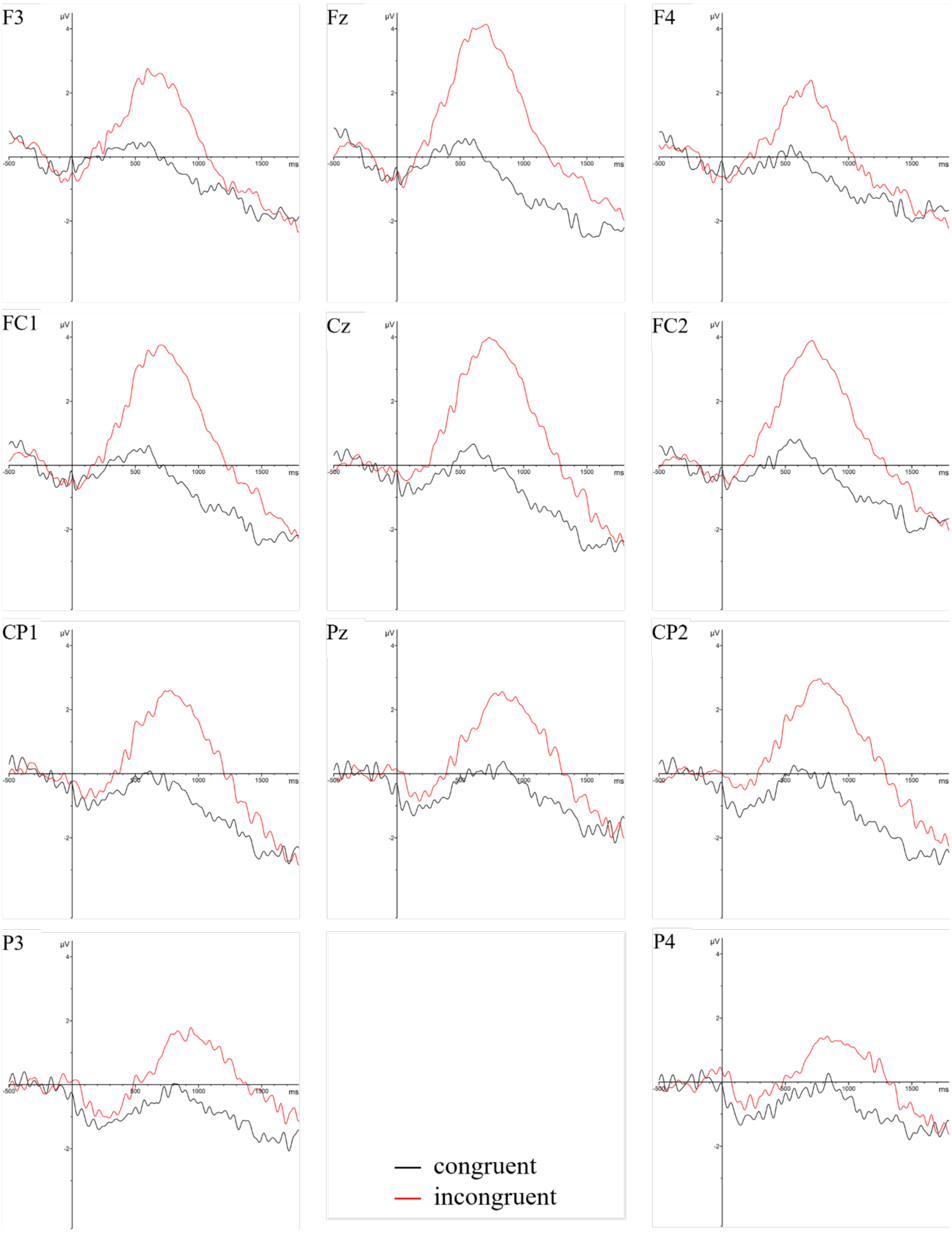

Figure 9. Grand average waveforms plotted for representative electrodes for imperfective classifiers in the Signers group. Negativity is plotted downward.

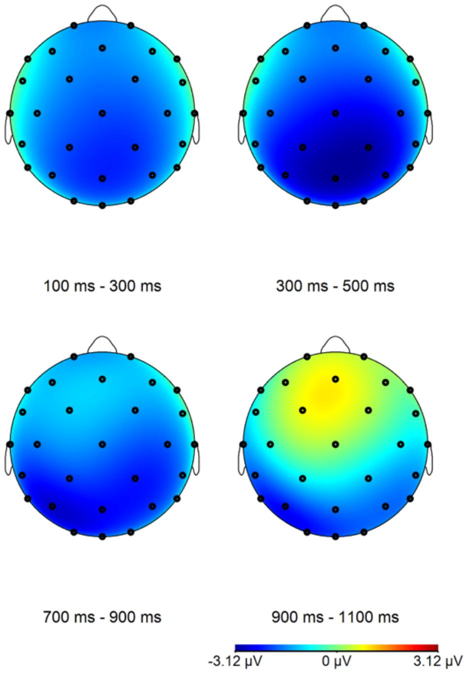

Figure 10. Topographic maps for signers group for perfective classifiers, computed by subtracting Incongruent – Congruent activity.

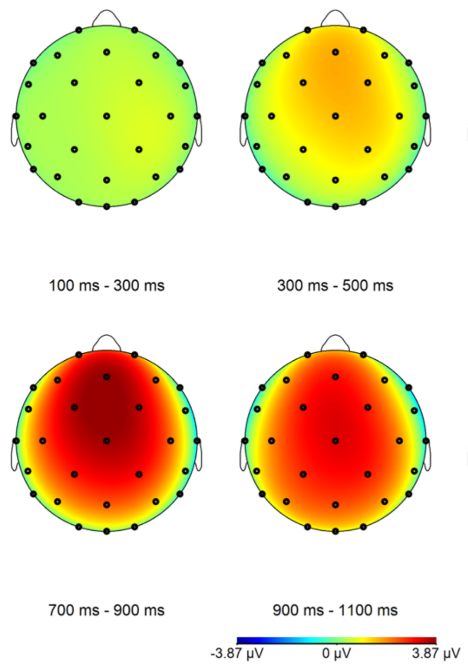

Figure 11. Topographic maps for signers group for imperfective classifiers, computed by subtracting Incongruent – Congruent activity.

4.2. Experiment 2

4.2.1. Behavioral results

Visuospatial skills were operationalized through an index from Wechsler Adult Intelligence Scales, namely the Perceptual Reasoning Index (PRI). Descriptive statistics for the PRI standard scores are presented in Table 3 for overall data and in Table 4 organized by groups.

Table 3. Overall Descriptive Statistics for the Perceptual Reasoning Index Standard Score

N	M	SD	Median	Min	Max	IQR	Skewness	Kurtosis
57	109.32	14.49	110.00	80	137	23.00	–0.24	-0.84

Table 4. Descriptive Statistics for WAIS Perceptual Reasoning Standard Score by Group

Group	N	M	SD	Median	Min	Max	IQR	Skewness	Kurtosis
Signers	23	108.26	12.36	108.00	82	129	14.00	-0.162	-0.260
Control	18	102.17	14.88	102.00	80	123	29.50	0.045	-1.450
Gamers	16	118.88	12.15	121.50	96	137	16.00	-0.667	-0.470

The data from Table 4 show that the participants in the Gamers group had the highest standard score as a group (M = 118.88, SD = 12.15), followed by the Signers (M = 108.26, SD = 12.36) and the Control group (M = 102.17, SD = 14.88). The interquartile ranges (IQR) reflected comparable variability for the Signers (IQR = 14.00) and Gamers (IQR = 16.00), with the Control group showing a wider range (IQR = 29.50). Normality was tested using the Shapiro-Wilk test, which revealed a normal distribution of WAIS standard scores in all groups: Signers ($W = 0.98$, $p = .864$), Controls ($W = 0.92$, $p = .141$), and Gamers ($W = 0.93$, $p = .202$). The assumption of homogeneity of variances, a prerequisite for the analysis of covariance (ANCOVA), was then tested with the Levene test, which was not significant ($p = .815$), meaning that the variances were equal between the groups.

ANCOVA was conducted to examine the effect of group on perceptual reasoning ability while controlling age. There was a significant main effect of Group, $F(2, 53) = 4.57$, $p = .015$, $\eta^2_p = .147$, suggesting that perceptual reasoning performance differed by group. The effect of age was not statistically significant, $F(1, 53) = 2.55$, $p = .116$, $\eta^2_p = .046$. Pairwise comparisons with Bonferroni correction revealed that the Gamers group scored significantly higher than the Control group, *M* difference = 14.05, *SE* = 4.76, $p = .014$, 95% CI [2.29, 25.81]. No other group comparisons reached statistical significance. The Signers group did not differ significantly from the Control group ($p = .245$), nor from the Gamers group ($p = .535$). Taken together, these findings indicate that Gamers demonstrated superior performance in perceptual reasoning compared to Controls, while Signers performed similarly to both groups.

The analysis of behavioral data from the EEG experiment included mean percentages and standard deviations of Yes responses to question “Do you think the action is completed” per sentence type, and mean response times in milliseconds, with respective standard deviations. The results from Table 5 show that both groups preferred to answer that the action they saw was completed when either the verb or the classifier had perfective form. This was the case for congruent perfectives, e.g. “already met”, and for incongruent imperfectives, e.g. “still met”. In contrast, conditions in which imperfective forms occur, i.e. imperfective congruent, e.g. “still meet”, and perfective incongruent, e.g. “already meet”, have the lowest proportion of “yes" answers. T-tests with independent samples revealed no significant differences between the groups, neither in the percentage of “yes" answers nor in the response times (*p*s > .05).

Table 5. Descriptive statistics for sentence types in the Gamer and the Control group. Standard deviations are presented in parentheses.

	Gamers		Controls	
	% yes	RT	% yes	RT
Perfective congruent verbs	76.43 (25.07)	1397.30 (800.08)	72.86 (21.43)	1330.17 (454.37)
Imperfective congruent verbs	31.77 (23.79)	1557.64 (922.28)	33.33 (27.97)	1363.41 (465.61)
Perfective incongruent verbs	31.94 (26.74)	1379.07 (772.31)	30.56 (26.71)	1318.63 (447.22)
Imperfective incongruent verbs	78.99 (19.82)	1381.64 (848.07)	71.30 (23.88)	1304.96 (409.22)
Perfective congruent classifiers	74.13 (23.10)	1484.19 (894.28)	69.29 (28.67)	1315.45 (517.55)
Imperfective congruent classifiers	28.65 (24.02)	1403.56 (848.94)	23.92 (20.19)	1312.21 (454.45)
Perfective incongruent classifiers	26.39 (22.15)	1430.28 (791.05)	27.16 (21.74)	1262.61 (476.21)
Imperfective incongruent classifiers	71.18 (23.83)	1323.14 (805.93)	66.51 (28.86)	1302.67 (488.83)

4.2.2. EEG

4.2.2.1. Gamer group

4.2.2.1.1. Verbs

Grand average plots for perfective verbs are shown in Figure 12, for imperfective verbs in Figure 13, while respective topographical maps are shown in Figure 14 and 15.

4.2.2.1.1.1. Lateral sites

100-300 ms time window

The analysis revealed a significant main effect of Congruence, $F(1, 15) = 4.84$, $p = .044$, $\eta^2_p = .24$. Also, two interactions were observed: Laterality × Congruence ($F(1, 15) = 5.70$, $p = .031$, $\eta^2_p = .28$), as well as Aspect × Congruence ($F(1, 15) = 5.84$, $p = .029$, $\eta^2_p = .28$). Pairwise comparison revealed that incongruent perfective verbs had more negative amplitude than respective congruent verbs, $M = -0.65$, $SE = 0.23$, $p = .014$.

300-500 ms time window

This time window showed the main effect of Congruence, $F(1, 15) = 5.98$, p = .027, $\eta^2_p = .29$. Furthermore, the interaction Aspect × Congruence was significant ($F(1, 15) = 7.46$, $p = .015$, $\eta^2_p = .33$), as well as a three-way interaction Anteriority × Aspect × Congruence ($F(2, 30) = 3.74$, $p = .035$, $\eta^2_p = .20$). Pairwise comparisons revealed that incongruent perfective verbs had more negative amplitude over anterior ($M = -1.11$, $SE = 0.23$, $p < .001$) and central sites ($M = -1.14$, $SE = 0.34$, $p = .004$). Pairwise comparisons with imperfective verbs were not significant.

500-700 ms time window

Three significant main effects were found in this time window: Anteriority ($F(2, 30) = 6.80$, $p = .004$, $\eta^2_p = .31$), Laterality ($F(1, 15) = 5.55$, $p = .033$, $\eta^2_p = .27$), and Aspect ($F(1, 15) = 5.79$, $p = .029$, $\eta^2_p = .28$). Furthermore, two two-way interactions were significant: Laterality × Congruence ($F(1, 15) = 4.97$, $p = .041$, $\eta^2_p = 25$), and Aspect × Congruence ($F(1, 15) = 9.96$, $p = .007$, $\eta^2_p = .40$). Finally, a significant three-way Anteriority × Aspect × Congruence interaction was found, $F(2, 30) = 6.52$, $p = .004$, $\eta^2_p = .30$). Pairwise comparison revealed that incongruent perfective verbs elicited more negative amplitude over frontal ($M = -1.26$, $SE = 0.29$, $p < .001$) and central ($M = -1.17$, $SE = 0.44$, $p = .018$) sites. Imperfective incongruent verbs showed more positive amplitude that was significant only at the central site ($M = 1.17$, $SE = 0.44$, $p = .018$).

700-1000 ms time window

The analysis revealed two main effects: Anteriority (F(2, 30) = 6.22, p = .005, η^2_p = .29), and Laterality (F(1, 15) = 9.47, p = .008, η^2_p = .39). The Aspect × Congruence was the only significant interaction, F(1, 15) = 16.10, p = .001, η^2_p = .52. Pairwise comparisons revealed that both perfective and imperfective verbs showed differences in amplitude depending on congruency. More specifically, incongruent perfective verbs elicited more negative amplitude than their congruent pairs (M = -1.65, SE = 0.38, p < .001), while incongruent imperfective verbs showed more positive amplitude than respective congruent forms (M = 1.34, SE = 0.43, p = .007).

1000-1300 ms time window

In the final time window the analysis revealed two main effects: Anteriority (F(1.44, 21.58) = 4.97, p = .014, η^2_p = .25), and Laterality (F(1, 15) = 11.59, p = .004, η^2_p = .44). Finally, the Aspect × Congruence interaction was also significant, F(1, 15) = 8.60, p = .010, η^2_p = .36. Incongruent perfective verbs elicited more negative amplitude than their congruent counterparts only at the central site (M = -0.88, SE = 0.34, p = .021).

4.2.2.1.1.2. Midline sites

100-300 ms time window

In the first time window there was only a significant interaction Aspect × Congruence, F(1, 15) = 5.18, p = .038, η^2_p = .26. Pairwise comparison showed that incongruent perfective verbs had more negative amplitude than their congruent forms (M = -0.85, SE = 0.32, p = .020).

300-500 ms time window

In this time window Aspect × Congruence interaction was significant, F(1, 15) = 8.34, p = .011, η^2_p = .36. Pairwise comparison revealed that incongruent perfective verbs had more negative amplitude compared to their congruent forms (M = -1.26, SE = 0.39, p = .005).

500-700 ms time window

Only the interaction Aspect × Congruence was significant, F(1, 15) = 11.61, p = .004, η^2_p = .44. Pairwise comparisons showed that incongruent perfective verbs had more negative amplitude than congruent verbs (M = -1.44, SE = 0.43, p =.004). On the other hand, incongruent imperfective verbs elicited more positive amplitude compared to congruent imperfective forms (*M* = 1.13, *SE* = 0.44, *p* = .021).

700-1000 ms time window

In this time window, a main effect of Anteriority was found, $F(2, 30) = 7.21$, $p = .003$, $\eta^2_p = .33$. Furthermore, the interaction Aspect × Congruence was significant ($F(1, 15) = 13.67$, $p = .002$, $\eta^2_p = .48$). Pairwise comparison revealed that perfective incongruent pairs showed more negative amplitude (*M* = -1.85, *SE* = 0.56, *p* = .005), while imperfective incongruent pairs showed more positive amplitude (*M* = 1.44, *SE* = 0.48, *p* = .009), compare to their respective congruent forms.

1000-1300 ms time window

In the final time window there was again a main effect of Anteriority, $F(2, 30) = 3.94$, $p = .03$, $\eta^2_p = .21$. There was also a significant Anteriority × Congruence interaction, $F(1.35, 20.3) = 4.26$, $p = .042$, $\eta^2_p = .22$.

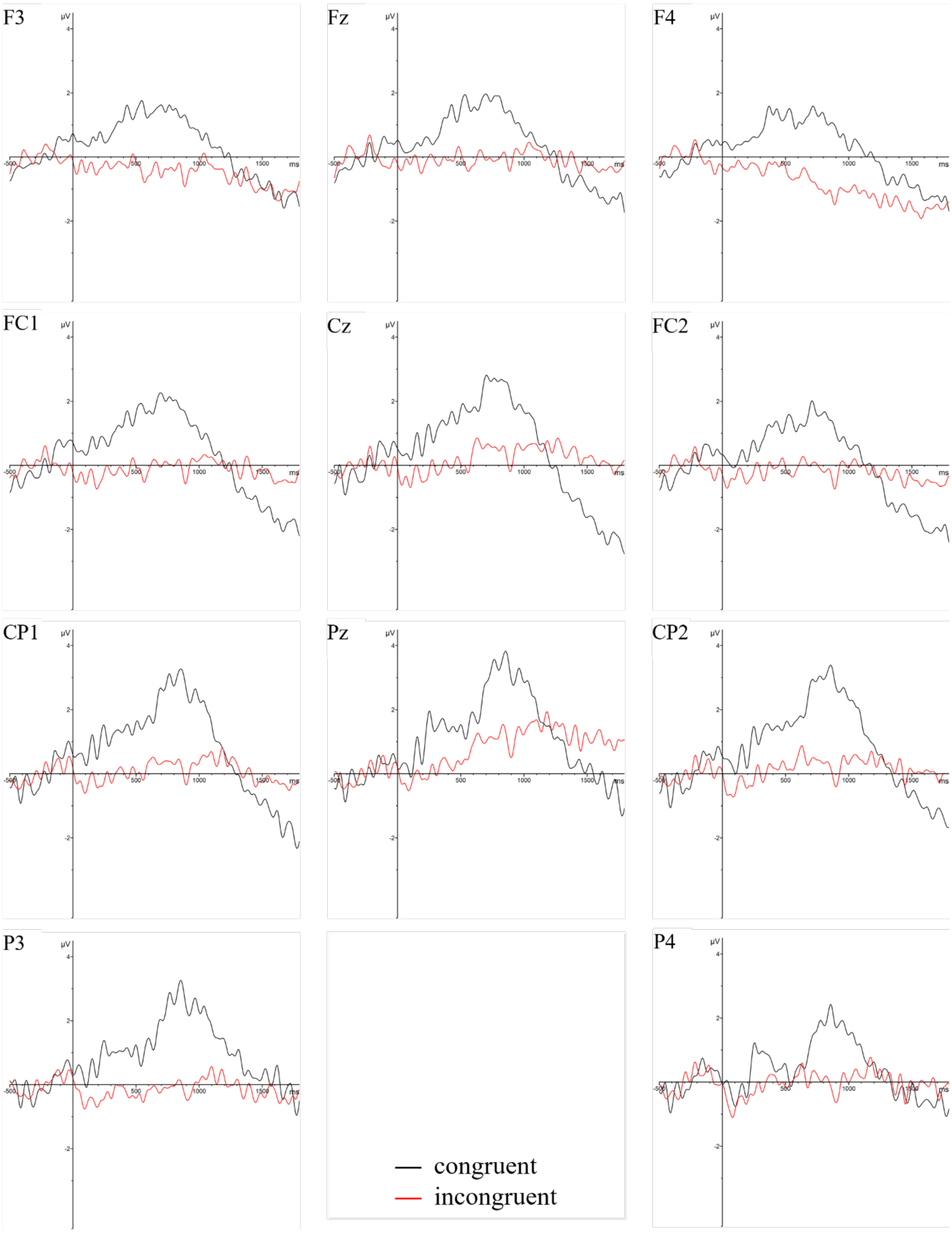

Figure 12. Grand average waveforms plotted for representative electrodes for perfective verbs in the Gamers group. Negativity is plotted downward.

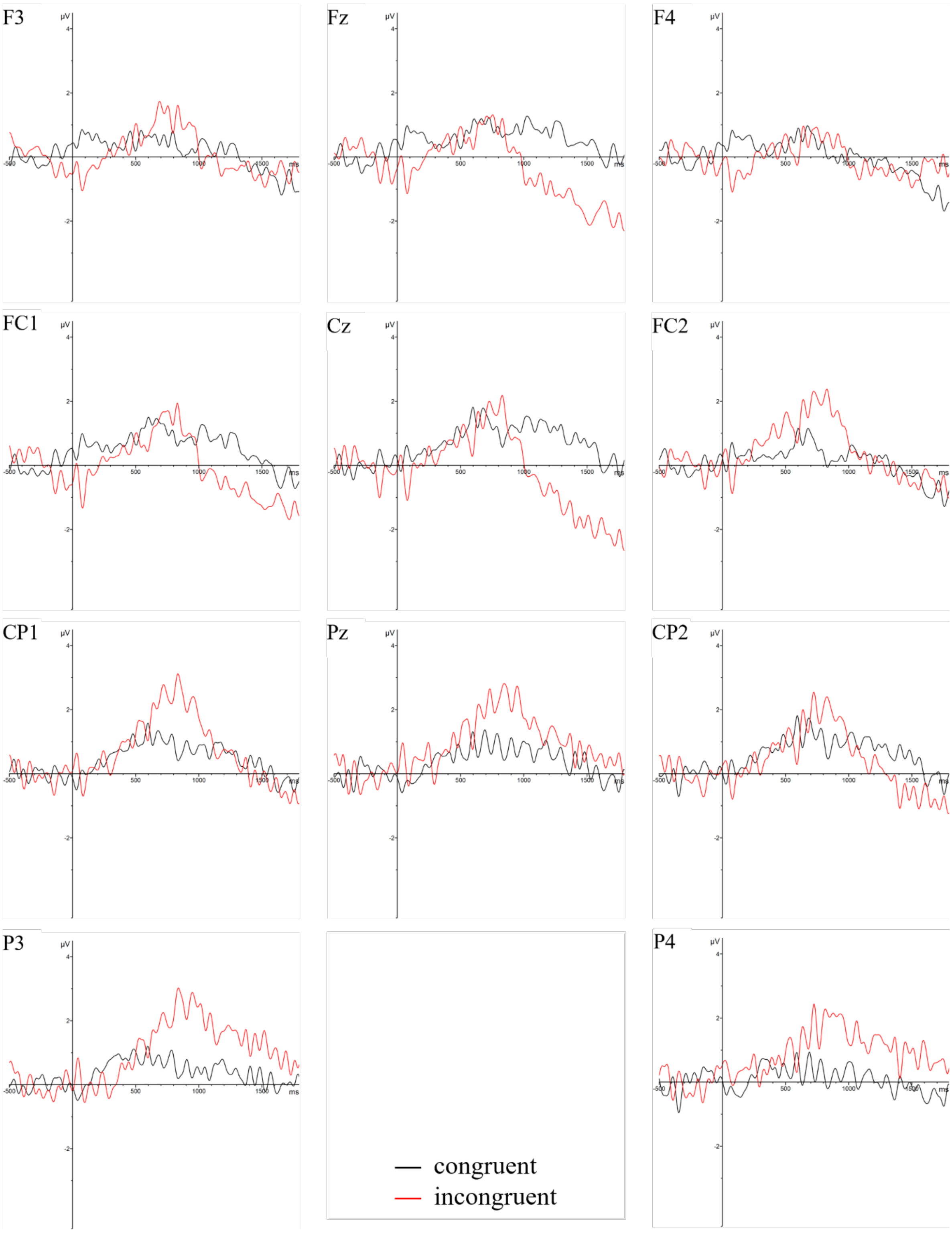

Figure 13. Grand average waveforms plotted for representative electrodes for imperfective verbs in the Gamers group. Negativity is plotted downward.

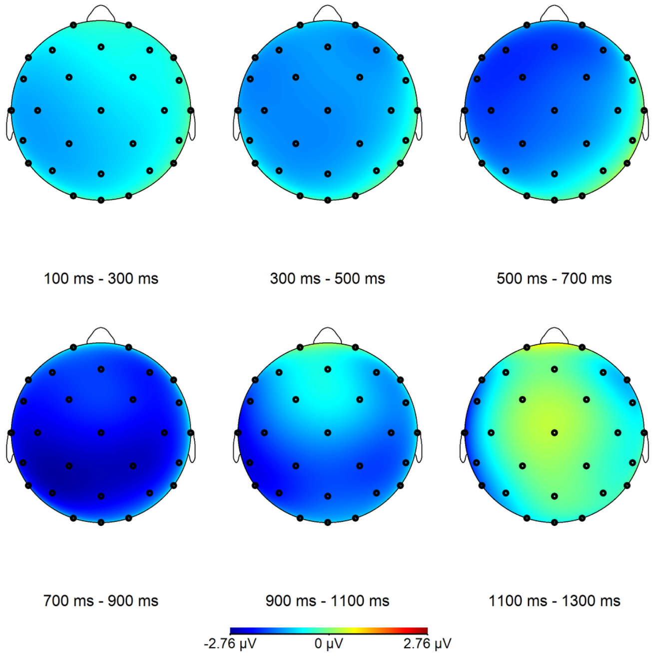

Figure 14. Topographic maps for the Gamers group for perfective verbs, computed by subtracting Incongruent – Congruent activity.

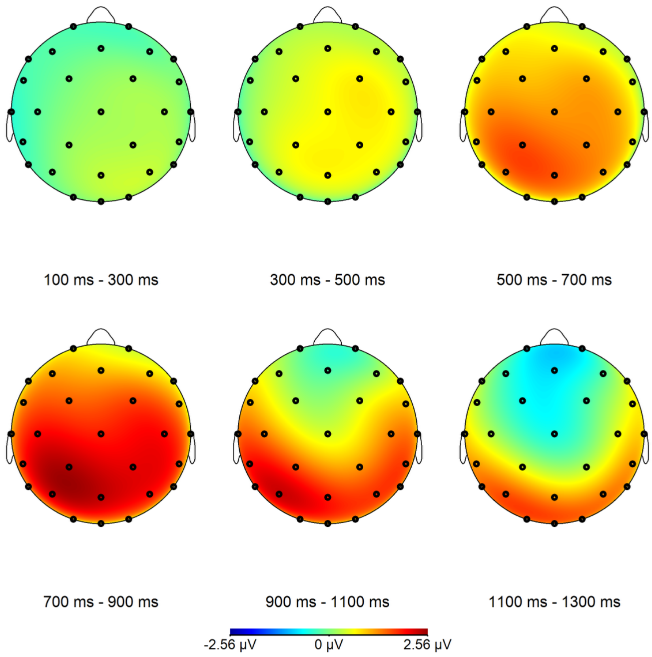

Figure 15. Topographic maps for the Gamers group for imperfective verbs, computed by subtracting Incongruent – Congruent activity.

4.2.2.1.2. Classifiers

Grand average plots for perfective classifiers are shown in Figure 16, for imperfective classifiers in Figure 17, while respective topographical maps are shown in Figure 18 and 19.

4.2.2.1.2.1. Lateral sites

100-300 ms time window

The analysis revealed a main effect of Anteriority, $F(2, 30) = 5.13$, $p = .012$, $\eta^2_p = .26$. In addition, two interactions were significant: Laterality × Aspect ($F(1, 15) = 4.93$, $p = .042$, $\eta^2_p = .25$), and Laterality × Congruence ($F(1, 15) = 5.80$, $p = .029$, $\eta^2_p = .28$).

300-500 ms time window

In the second time window there was a main effect of Anteriority ($F(2, 30) = 4.21$, $p = .025$, $\eta^2_p = .22$). Additionally, the interaction Anteriority × Laterality was also significant ($F(2, 30) = 5.18$, $p = .012$, $\eta^2_p = .26$) .

500-700 ms time window

In this time window there was a main effect of Anteriority ($F(2, 30) = 7.46$, $p = .002$, $\eta^2_p = .33$), as well as a main effect of Aspect. Furthermore, there was a significant interaction Anteriority × Laterality, $F(2, 30) = 6.53$, $p = .004$, $\eta^2_p = .30$.

700-1000 ms time window

The analysis revealed a significant main effect of Anteriority ($F(2, 30) = 4.67$, $p = .017$, $\eta^2_p = .24$), as well as of Aspect ($F(1, 15) = 8.09$, $p = .012$, $\eta^2_p = .35$). There was also a significant interaction Anteriority × Laterality, $F(2, 30) = 7.20$, $p = .003$, $\eta^2_p = .32$.

1000-1300 ms time window

In the final time window, a main effect of Laterality ($F(1, 15) = 7.21$, $p = .017$, $\eta^2_p = .33$) and main effect of Aspect were observed ($F(1, 15) = 7.47$, $p = .015$, $\eta^2_p = .33$). Furthermore, there was a significant interaction Anteriority × Laterality, $F(2, 30) = 7.51$, $p = .002$, $\eta^2_p = .33$.

4.2.2.1.2.2. Midline sites

100-300 ms time window

In the first analyzed time window, a significant main effect of Aspect was found, $F(1, 15) = 7.78$, $p = .014$, $\eta^2_p = .14$, indicating that ERP amplitudes differed between perfective and imperfective classifiers. No other main effects or interactions were significant.

300-500 ms, 500-700 ms, 700-1000 ms and 1000-1300 ms time windows
There were no significant main effects or interactions in these time windows.

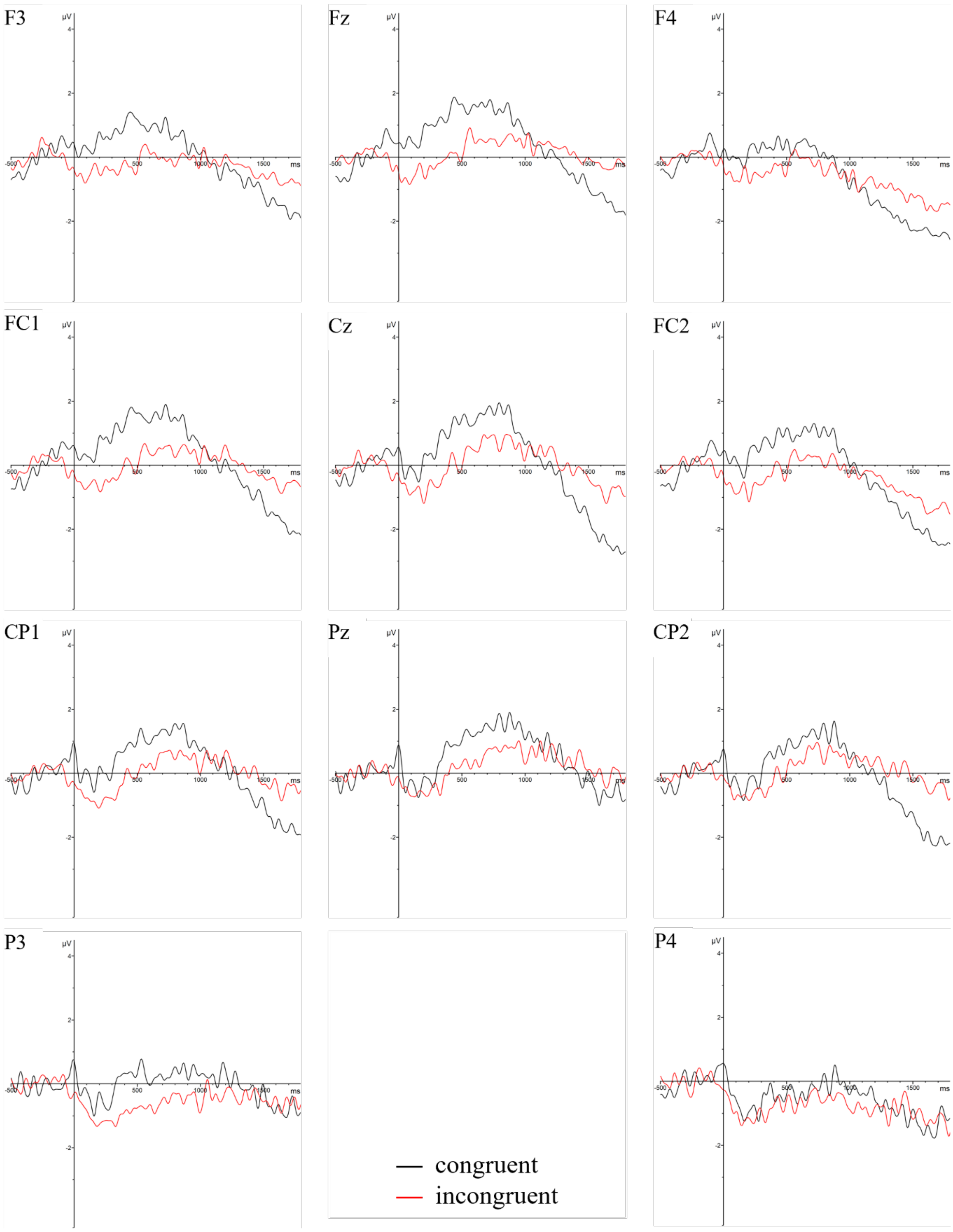

Figure 16. Grand average waveforms plotted for representative electrodes for perfective classifiers in the Gamers group. Negativity is plotted downward.

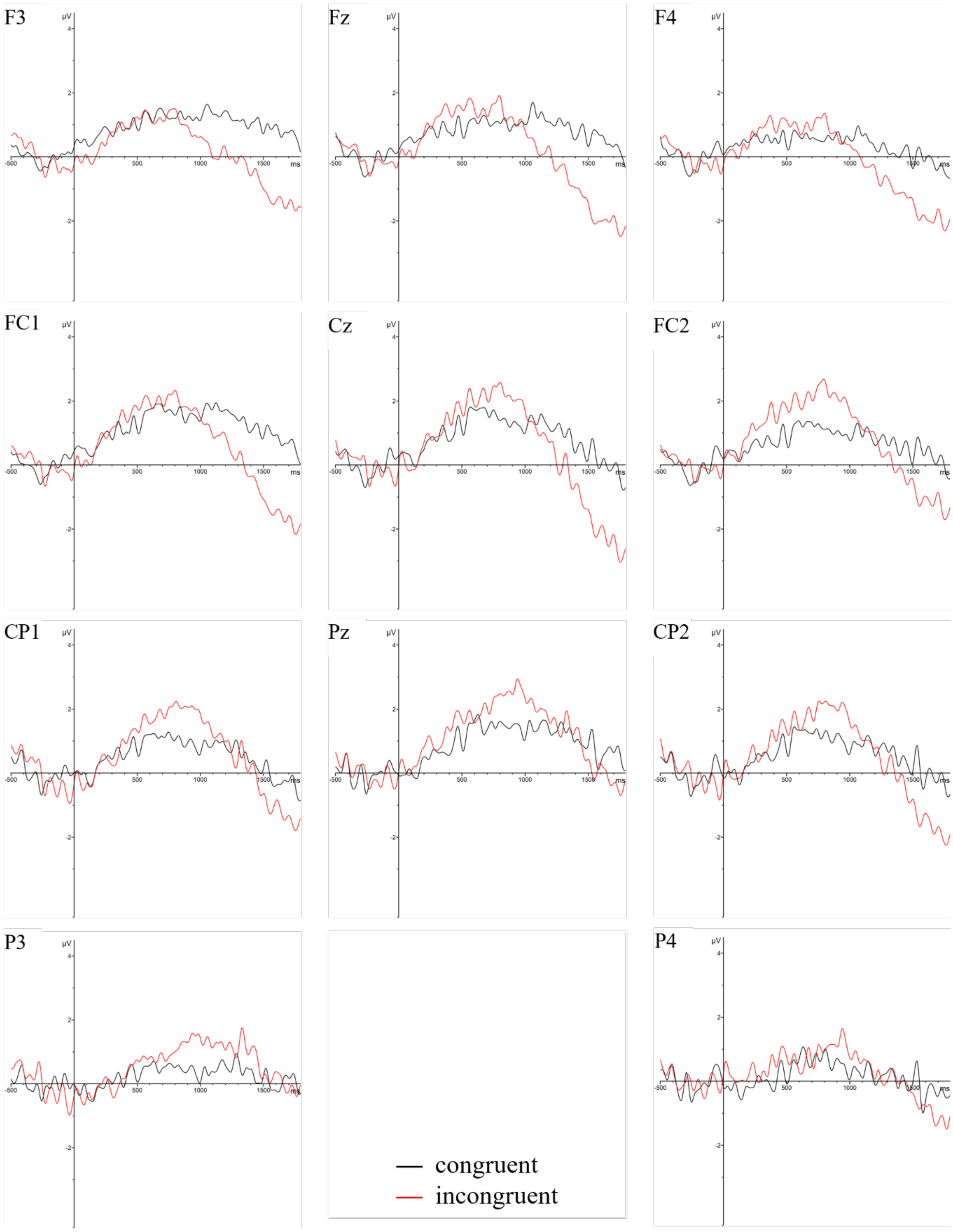

Figure 17. Grand average waveforms plotted for representative electrodes for imperfective classifiers in the Gamers group. Negativity is plotted downward.

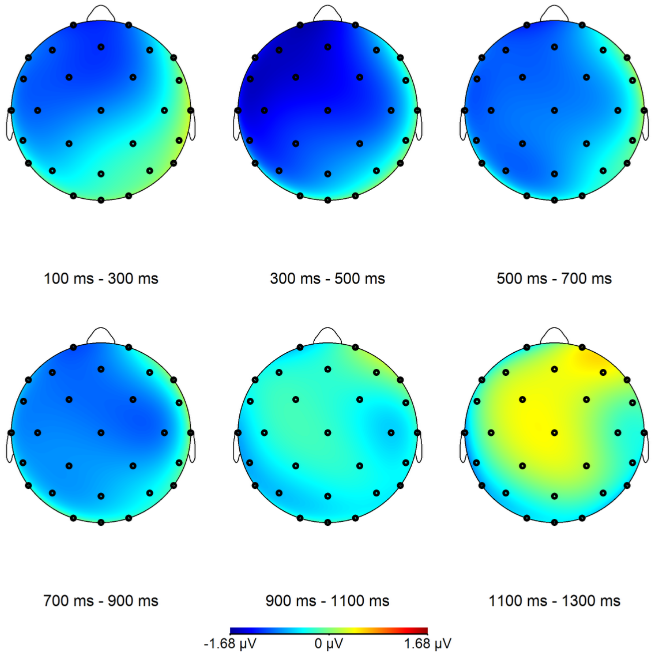

Figure 18. Topographic maps for the Gamers group for perfective classifiers, computed by subtracting Incongruent – Congruent activity.

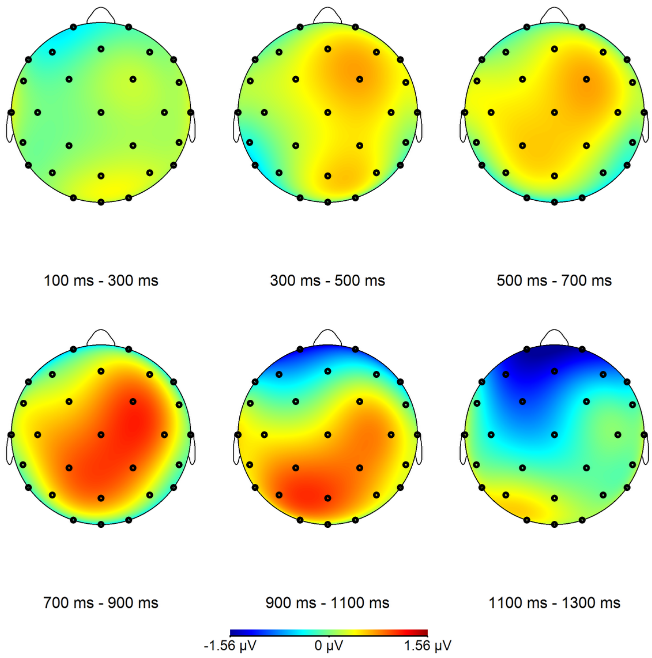

Figure 19. Topographic maps for the Gamers group for imperfective classifiers, computed by subtracting Incongruent – Congruent activity.

4.2.2.2. Control group

4.2.2.2.1. Verbs

Grand average plots for perfective verbs are shown in Figure 20, for imperfective verbs in Figure 21, while respective topographical maps are shown in Figure 22 and 23.

4.2.2.2.1.1. Lateral sites

100-300 ms time window

Significant main effects of Laterality ($F(1, 17) = 6.66$, $p = .019$, $\eta^2_p = .28$) and Aspect were found ($F(1, 17) = 11.63$, $p = .003$, $\eta^2_p = .41$). There was also a significant interaction Aspect × Congruence ($F(1, 17) = 12.50$, $p = .003$, $\eta^2_p = .42$). Pairwise comparisons revealed that imperfective incongruent verbs showed more positive amplitude than respective congruent forms ($M = 0.35$, $SE = .07$, $p < .001$).

300-500 ms time window

This time window revealed the main effect of Laterality ($F(1, 17) = 6.81$, $p = .018$, $\eta^2_p = .29$) and of Aspect ($F(1, 17) = 21.94$, $p < .001$, $\eta^2_p = .56$). Furthermore, two-way interactions Laterality × Aspect ($F(1, 17) = 6.86$, $p = .018$, $\eta^2_p = .29$) and Aspect × Congruence ($F(1, 17) = 29.12$, $p < .001$, $\eta^2_p = .63$) were significant. Finally, a significant three-way interaction Laterality × Aspect × Congruence was found ($F(1, 17) = 4.64$, $p = .046$, $\eta^2_p = .21$). Pairwise comparisons showed that incongruent perfective verbs had more positive amplitude in both left ($M = -0.65$, $SE = 0.18$, $p = .002$) and right hemisphere ($M = -0.41$, $SE = 0.19$, $p = .047$). Imperfective verbs showed similar topographic pattern but of opposite polarity. Incongruent imperfective verbs had more positive amplitude over both left ($M = 0.95$, $SE = 0.21$, $p < .001$) and right hemisphere ($M = 0.72$, $SE = 0.18$, $p = .001$).

500-700 ms time window

All four main effects were found in this time window: Anteriority ($F(1.43, 24.27) = 6.28$, $p = .012$, $\eta^2_p = .27$), Laterality ($F(1, 17) = 12.22$, $p = .003$, $\eta^2_p = .42$), Aspect ($F(1, 17) = 25.09$, $p < .001$, $\eta^2_p = .60$), and Congruence ($F(1, 17) = 5.51$, $p = .031$, $\eta^2_p = .25$). Furthermore, three two-way interactions were significant: Anteriority × Laterality ($F(1.42, 24.17) = 4.18$, $p = .039$, $\eta^2_p = .20$), Laterality × Aspect ($F(1, 17) = 8.16$, $p = .011$, $\eta^2_p = .32$), and Aspect × Congruence ($F(1, 17) = 15.86$, $p < .001$, $\eta^2_p = .48$). Finally, a significant three-way interaction Laterality × Aspect × Congruence was found ($F(1, 17) = 4.74$, $p = .044$, $\eta^2_p = .22$). Pairwise comparisons revealed that incongruent perfective verbs had more negative amplitude than their respective congruent forms only at left hemisphere electrodes (*M* = -0.46, *SE* = 0.20, *p* = .038). Conversely, incongruent imperfective verbs showed more positive amplitude than their congruent forms over both left (*M* = 1.17, *SE* = 0.26, *p* < .001) and right hemisphere (*M* = 0.73, *SE* = 0.23, *p* = .005).

700-1000 ms time window

This time window revealed three main effects: Anteriority ($F(2, 34) = 6.33$, $p = .005$, $\eta^2_p = .27$), Laterality ($F(1, 17) = 10.10$, $p = .006$, $\eta^2_p = .37$), and Aspect ($F(1, 17) = 19.62$, $p < .001$, $\eta^2_p = .54$). Furthermore, three two-way interactions were found: Anteriority × Laterality ($F(2, 34) = 5.85$, $p = .007$, $\eta^2_p = .26$), Laterality × Aspect ($F(1, 17) = 8.62$, $p = .009$, $\eta^2_p = .34$), and Aspect × Congruence ($F(1, 17) = 13.32$, $p = .002$, $\eta^2_p = .44$). Finally, a significant three-way interaction Anteriority × Aspect × Congruence was found, $F(2, 34) = 6.02$, $p = .006$, $\eta^2_p = .26$). Pairwise comparison showed that incongruent perfective verbs had more negative amplitude over central (*M* = -0.88, *SE* = 0.36, *p* = .026) and posterior sites (*M* = -1.04, *SE* = 0.34, *p* = .006). On the other hand, incongruent imperfective verbs showed more positive amplitude compared to their congruent forms also over central (*M* = 1.60, *SE* = 0.35, *p* < .001) and posterior sites (*M* = 0.95, *SE* = 0.36, *p* = .016).

1000-1300 ms time window

In the final time window three main effects were observed: Anteriority ($F(1.38, 23.43) = 4.55$, $p = .033$, $\eta^2_p = .21$), Laterality ($F(1, 17) = 8.19$, $p = .011$, $\eta^2_p = .33$), and Aspect ($F(1, 17) = 10.75$, $p = .004$, $\eta^2_p = .39$). Furthermore, the interaction Laterality × Aspect was significant again ($F(1, 17) = 4.95$, $p = .04$, $\eta^2_p = .23$). Finally, Anteriority × Aspect × Congruence interaction was also significant, $F(2, 34) = 4.26$, $p = .022$, $\eta^2_p = .20$). Pairwise comparison showed one significant difference in amplitude: at central site imperfective incongruent verbs had more positive amplitude than respective congruent forms (*M* = 0.97, *SE* = 0.41, *p* = .03).

4.2.2.2.1.2. Midline sites

100-300 ms time window

This time window showed a significant interaction Aspect × Congruence, $F(1, 17) = 5.56$, $p = .031$, $\eta^2_p = .25$. However, pairwise comparisons for incongruent vs. congruent perfective verbs (*M* = -0.43, *SE* = 0.23, *p* = .081) and incongruent vs. congruent imperfective verbs (*M* = 0.37, *SE* = 0.18, *p* = .057) did not reach significance.

300-500 ms time window

The analysis revealed a significant main effect of Aspect, $F(1, 17) = 13.41$, $p = .002$, $\eta^2_p = .44$, as well as the interaction Aspect × Congruence, $F(1, 17) = 20.11$, $p < .001$, $\eta^2_p = .54$. Pairwise comparisons showed that incongruent perfective verbs elicited more negative amplitude than their congruent forms ($M = -1.02$, $SE = 0.31$, $p = .004$). Conversely, incongruent imperfective verbs elicited more positive amplitude compared to their congruent forms ($M = 1.21$, $SE = 0.30$, $p < .001$).

500-700 ms time window

There was a significant main effect of Aspect, $F(1, 17) = 21.59$, $p < .001$, $\eta^2_p = .56$. Furthermore, the interaction Aspect × Congruence was significant again, $F(1, 17) = 10.68$, $p = .005$, $\eta^2_p = .39$. The amplitude for incongruent imperfective verbs was more positive than for their congruent forms ($M = 1.33$, $SE = 0.37$, $p = .002$). The comparison for perfective verbs did not reach significance ($p = .057$).

700-1000 ms time window

As in the previous time window, there was a significant main effect of Aspect ($F(1, 17) = 10.55$, $p = .005$, $\eta^2_p = .38$), as well as the interaction Aspect × Congruence ($F(1, 17) = 7.20$, $p = .016$, $\eta^2_p = .30$). Incongruent imperfective verbs showed more positive amplitude compared to their congruent forms ($M = 1.44$, $SE = 0.41$, $p = .002$). The comparison for perfective verbs was not significant ($p = .179$).

1000-1300 ms time window

In the final time window, only the main effect of Aspect was significant, $F(1, 17) = 4.96$, $p = .040$, $\eta^2_p = .23$, indicating that ERP amplitudes differed between perfective and imperfective classifiers. No other main effects or interactions were significant.

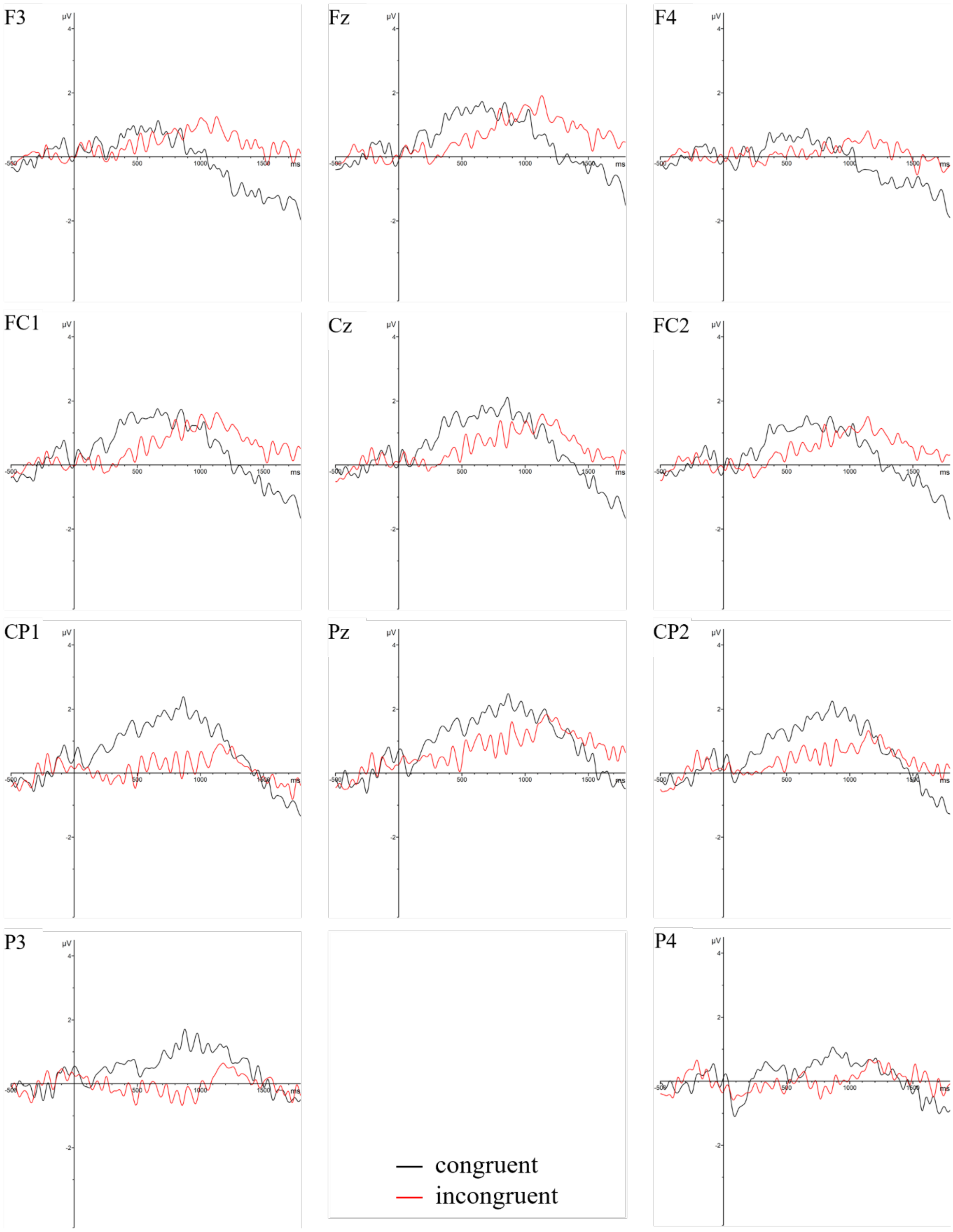

Figure 20. Grand average waveforms plotted for representative electrodes for perfective verbs in the Controls group. Negativity is plotted downward.

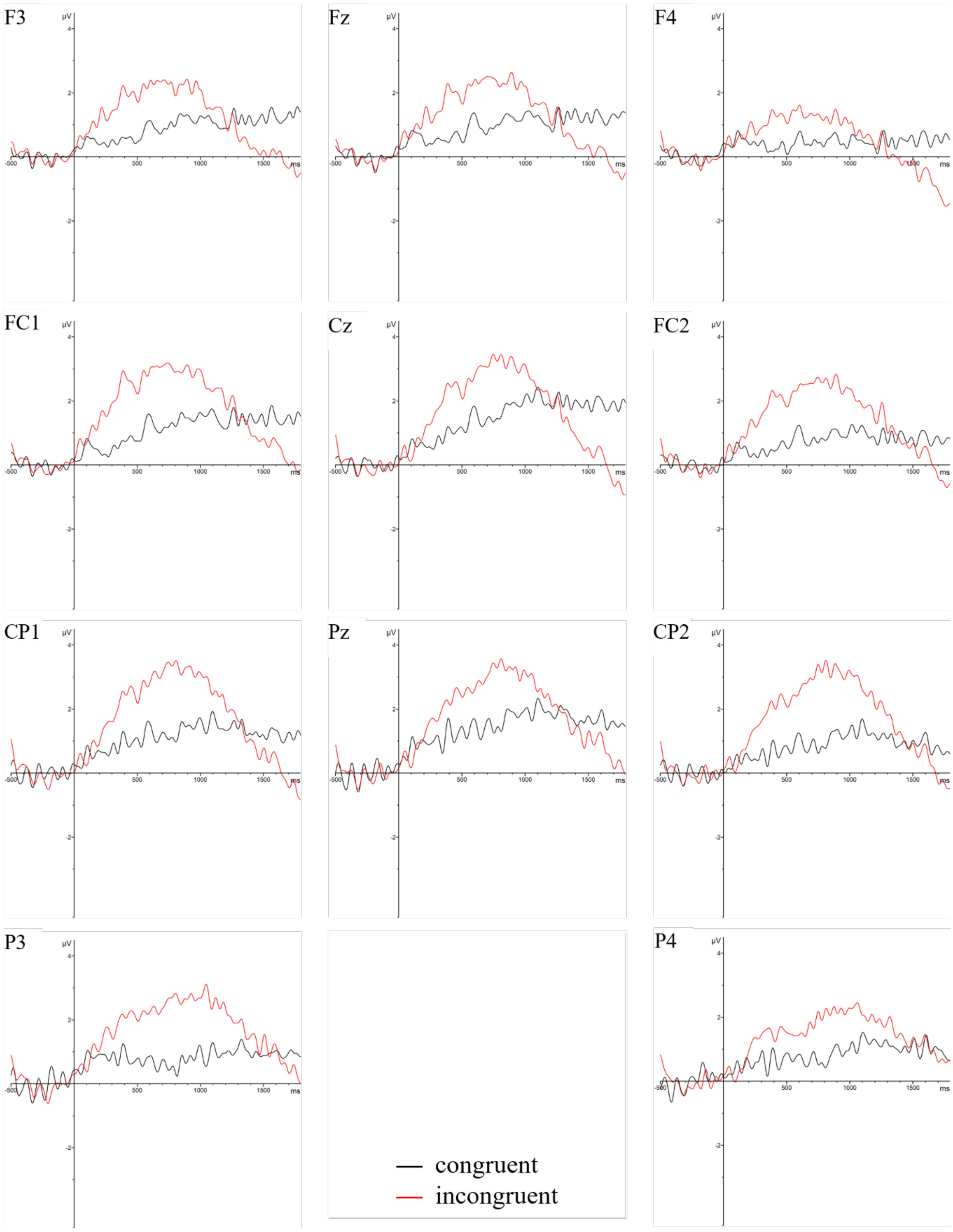

Figure 21. Grand average waveforms plotted for representative electrodes for imperfective verbs in the Controls group. Negativity is plotted downward.

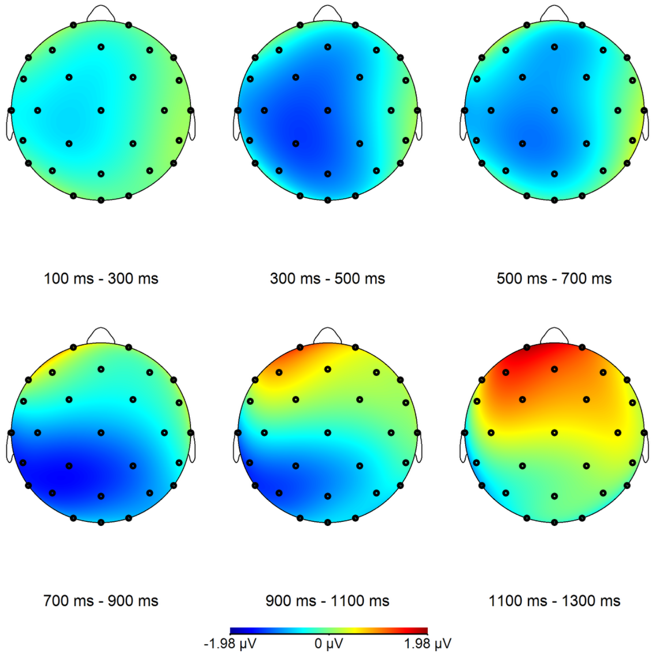

Figure 22. Topographic maps for the Control group for perfective verbs, computed by subtracting Incongruent – Congruent activity.

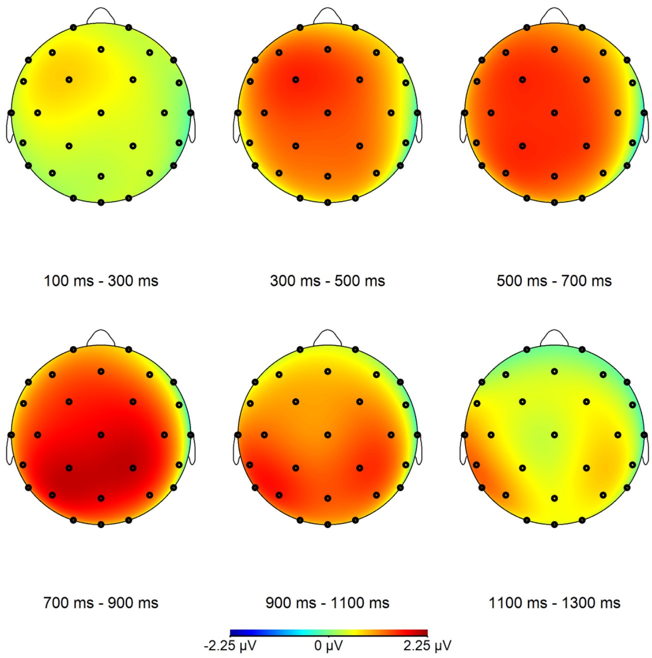

Figure 23. Topographic maps for the Control group for imperfective verbs, computed by subtracting Incongruent – Congruent activity.

4.2.2.2.2. Classifiers

Grand average plots for perfective classifiers are shown in Figure 24, for imperfective classifiers in Figure 25, while respective topographical maps are shown in Figure 26 and 27

4.2.2.2.2.1. Lateral sites

100-300 ms time window

The analysis showed main effects of Anteriority (F(1.25, 2.25) = 5.27, p = .025, η^2_p = .24), and Aspect (F(1, 17) = 19.06, p < .001, η^2_p = .53). In addition, three interactions were significant: Anteriority × Aspect (F(1.24, 21.12) = 8.84, p = .005, η^2_p = .34), Anteriority × Laterality × Aspect (F(2, 34) = 8.68, p = .001, η^2_p = .34), and Aspect × Congruence (F(1, 17) = 4.92, p = .04, η^2_p = .23). Pairwise comparisons showed that perfective incongruent classifiers had overall more negative amplitude compared to perfective congruent classifiers (M = -0.39, SE = 0.17, p = .035).

300-500 ms time window

In the second time window three main effects were found: Anteriority (F(1.30, 22.13) = 7.38, p = .008, η^2_p = .30), Aspect (F(1, 17) = 18.25, p < .001, η^2_p = .52), and Congruence (F(1, 17) = 6.22, p = .023, η^2_p = .27). Furthermore, three interactions were significant: Anteriority × Aspect (F(1.52, 25.86) = 3.95, p = .042, η^2_p = .19), Laterality × Congruence (F(1, 17) = 10.83, p = .004, η^2_p = .39), and Aspect × Congruence (F(1, 17) = 6.52, p = .021, η^2_p = .28). Overall, perfective incongruent classifiers had more negative amplitude compared to respective congruent forms (M = -0.71, SE = 0.22, p = .006).

500-700 ms time window

All four main effects were found in this time window: Anteriority (F(1.34, 22.81) = 8.63, p = .004, η^2_p = .34), Laterality (F(1, 17) = 5.89, p = .027, η^2_p = .26), Aspect (F(1, 17) = 11.14, p = .004, η^2_p = .40), and Congruence (F(1, 17) = 4.77, p = .043, η^2_p = .22). In addition, three interactions were observed: Anteriority × Laterality (F(1.39, 23.62) = 5.37, p = .020, η^2_p = .24), Aspect × Congruence (F(1, 17) = 6.47, p = .021, η^2_p = .28), and Anteriority × Laterality × Aspect (F(2, 34) = 4.80, p = .024, η^2_p = .22). Overall, perfective incongruent classifiers had more negative amplitude compared to respective congruent forms (M = -0.93, SE = 0.34, p = .013).

700-1000 ms time window

The analysis showed main effects of Anteriority (F(1.33, 22.63) = 6.82, p = .010, , η^2_p = .29), Laterality (F(1, 17) = 5.27, p = .035, , η^2_p = .24), and Aspect (F(1, 17) = 14.76, p = .001, η^2_p = .47). In addition, four interactions were found: Anteriority × Laterality (F(1.34, 22.77) = 4.35, p = .038, , η^2_p = .20), Anteriority × Aspect (F(1.45, 24.57) = 4.17, p = .039, , η^2_p = .20), Aspect × Congruence (F(1, 17) = 9.21, p = .007, η^2_p = .35), as well as Anteriority × Aspect × Congruence (F(2, 34) = 4.16, p = .034, , η^2_p = .20). Pairwise comparisons revealed that incongruent perfective classifiers had more negative amplitude than congruent perfective classifiers at central ROIs (M = -1.46, SE = 0.48, p = .008). In contrast, incongruent imperfective classifiers had more positive amplitude at central (M = 1.07, SE = 0.37, p = .01) and posterior ROIs (M = 0.88, SE = 0.34, p = .02), compared to their congruent form.

1000-1300 ms time window

The analysis in the final time window found three main effects: Anteriority (F(1.33, 22.60) = 4.64, p = .033, η^2_p = .21), Laterality (F(1, 17) = 9.66, p = .006, η^2_p = .36), and Aspect (F(1, 17) = 23.15, p < .001, η^2_p = .58). In addition, the interaction Aspect × Congruence was significant (F(1, 17) = 6.51, p = .021, η^2_p = .28), with incongruent perfective classifiers having overall more negative amplitude than their congruent forms (M = -0.92, SE = .38, p = .026).

4.2.2.2.2.2. Midline sites

100-300 ms time window

The analysis revealed a significant main effect of Aspect, F(1, 17) = 11.68, p = .003, η^2_p = .41. Furthermore, the interaction Anteriority × Aspect was found (F(2, 34) = 6.92, p = .003, η^2_p = .29), as well as the interaction Aspect × Congruence (F(1, 17) = 7.34, p = .015, η^2_p = .30). Pairwise comparisons revealed that perfective incongruent classifiers had more negative amplitude than perfective congruent ones (M = -0.67, SE = 0.22, p = .007).

300-500 ms time window

In the second time window the main effects of Anteriority (F(2, 34) = 4.17, p = .024, η^2_p = .20) and Aspect were found (F(1, 17) = 8.92, p = .008, η^2_p = .34). Furthermore, the interactions Anteriority × Congruence (F(1.37, 23.37) = 4.45, p = .035, η^2_p = .21) and Aspect × Congruence were observed (F(1, 17) = 15.32, p = .001, η^2_p = .47). Incongruent perfective classifiers showed more negative amplitude compared to congruent forms (M = -1.05, SE =

0.25, $p < .001$), while incongruent imperfective classifiers had more positive amplitude than congruent forms ($M = 0.58$, $SE = $ o.25, $p = .033$).

500-700 ms time window

Two main effects were found, Aspect ($F(1, 17) = 5.49$, $p = .032$, $\eta^2_p = .24$), and Congruence ($F(1, 17) = 5.01$, $p = .039$, $\eta^2_p = .23$). There was also a significant interaction Aspect × Congruence ($F(1, 17) = 7.87$, $p = .012$, $\eta^2_p = .32$). Pairwise comparisons revealed that incongruent perfective classifiers elicited more negative amplitude than their congruent forms ($M = -1.34$, $SE = 0.40$, $p = .004$).

700-1000 ms time window

The main effect of Aspect was found, $F(1, 17) = 5.92$, $p = .026$, $\eta^2_p = .26$. Additionally, the interaction Aspect × Congruence was significant, $F(1, 17) = 9.52$, $p = .007$, $\eta^2_p = .36$. Pairwise comparisons showed significant effects for both perfective and imperfective classifiers. Incongruent perfective classifiers had more negative amplitude compared to their congruent forms ($M = -1.34$, $SE = 0.49$, $p = 0.14$), while incongruent imperfective classifiers showed more positive amplitude than respective congruent classifiers ($M = 1.12$, $SE = 0.37$, $p = .007$)

1000-1300 ms time window

In the final time window only the main effect of Aspect was found, F(1, 17) = 10.94, p = .004, $\eta^2_p = .39$, indicating that participants from the Control group processed perfective and imperfective classifiers differently even 1300 ms after the sign onset.

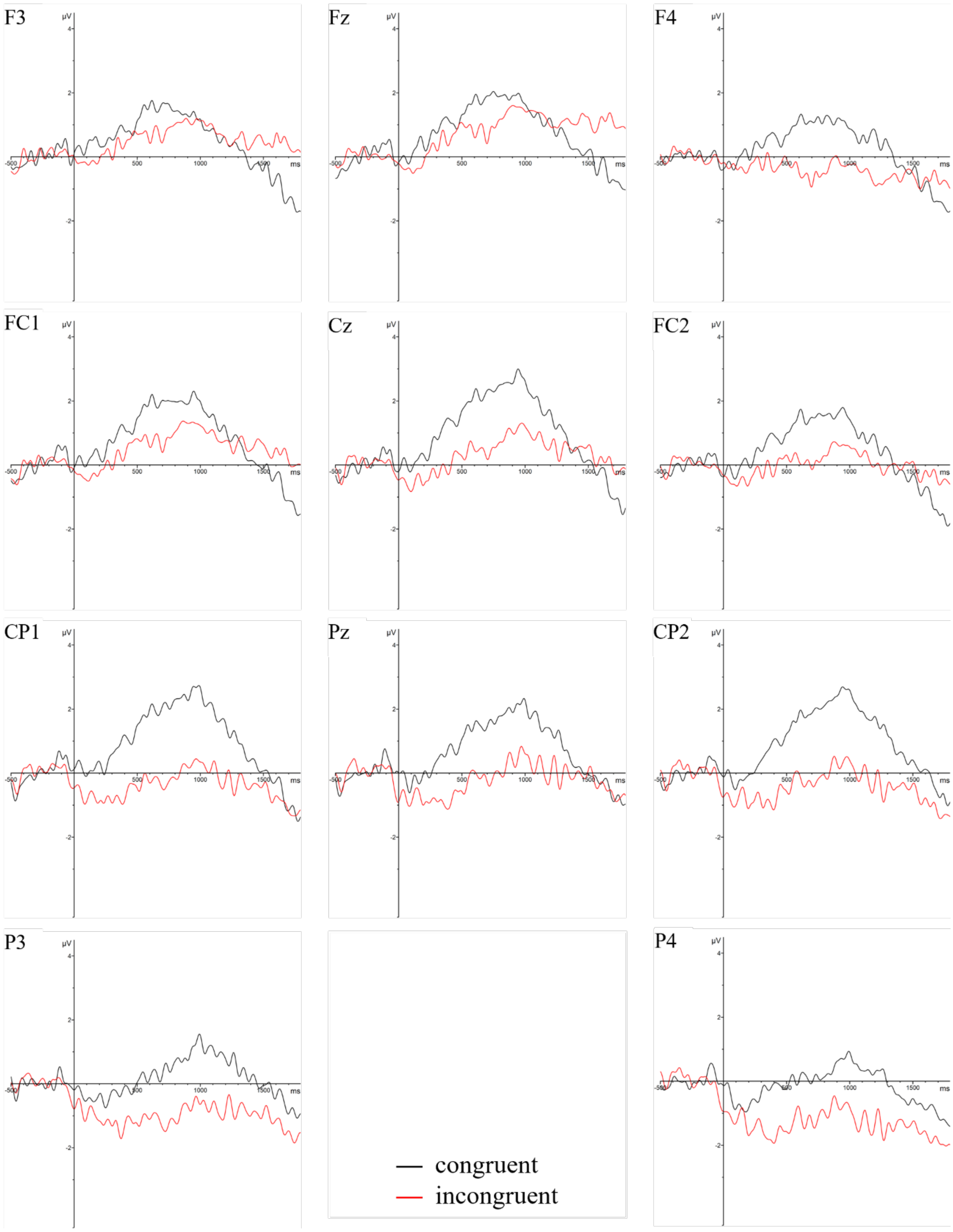

Figure 24. Grand average waveforms plotted for representative electrodes for perfective classifiers in the Controls group. Negativity is plotted downward.

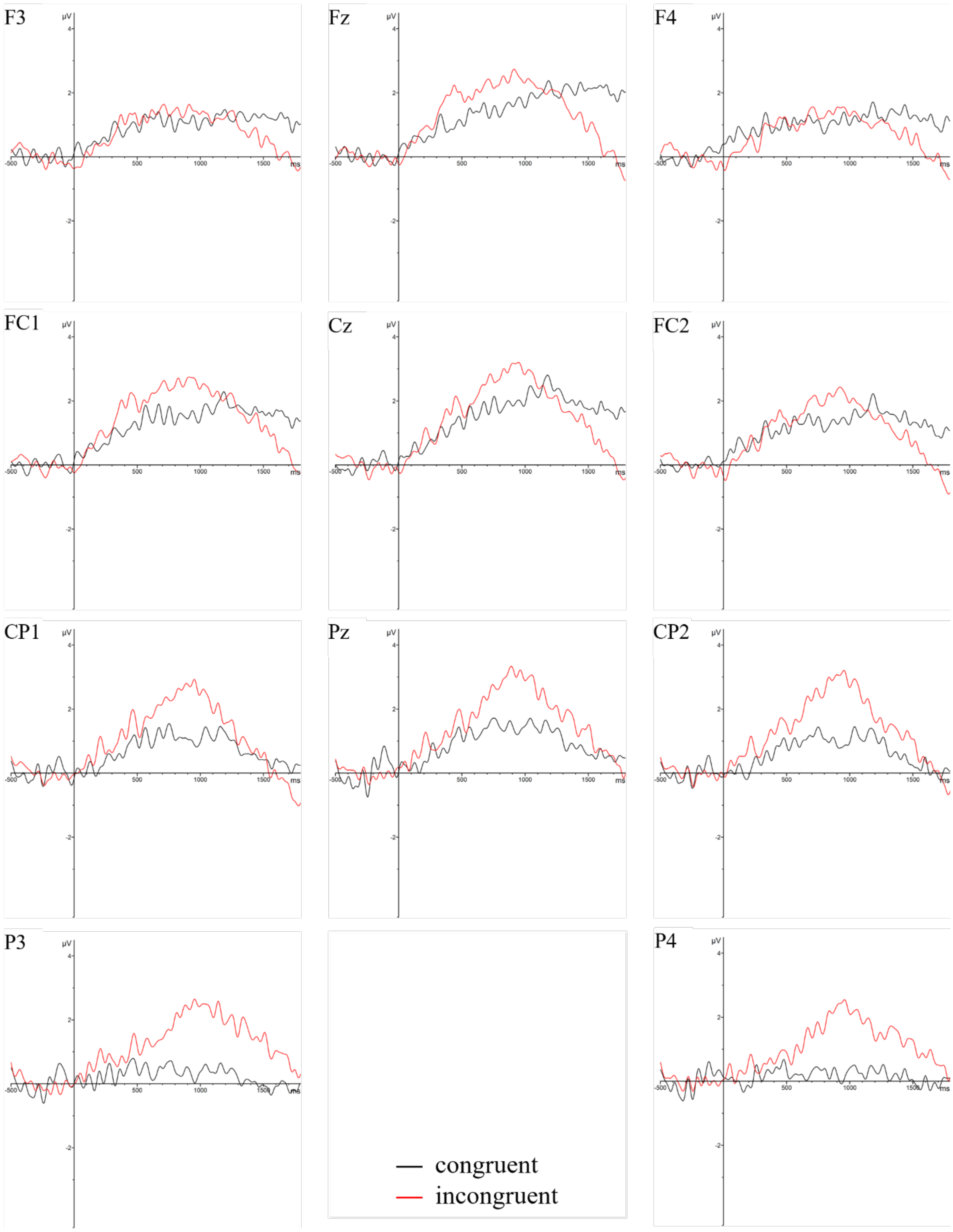

Figure 25. Grand average waveforms plotted for representative electrodes for imperfective classifiers in the Gamers group. Negativity is plotted downward.

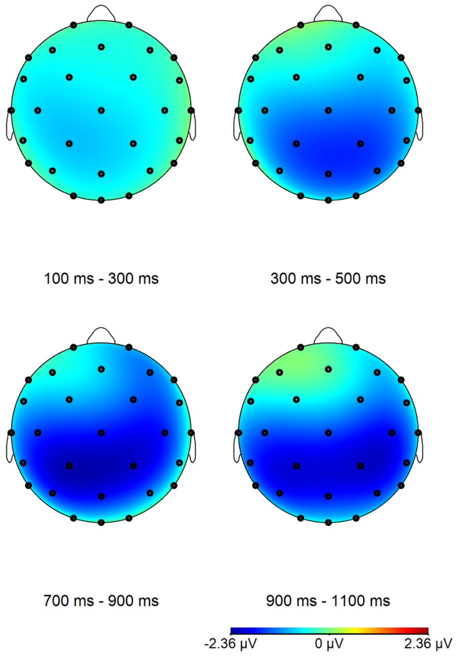

Figure 26. Topographic maps for the Control group for perfective classifiers, computed by subtracting Incongruent – Congruent activity.

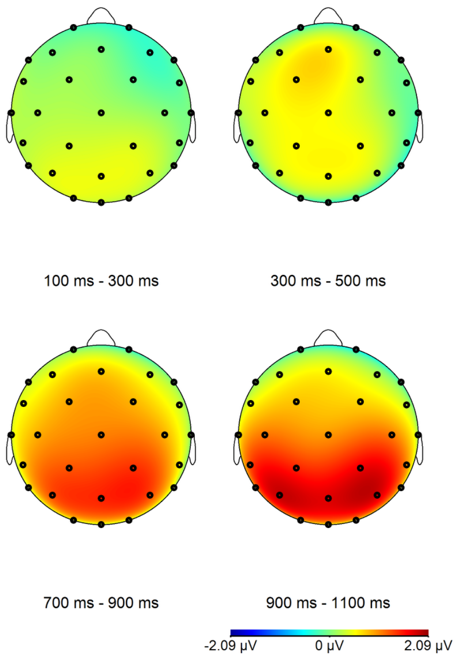

Figure 27. Topographic maps for the Control group for imperfective classifiers, computed by subtracting Incongruent – Congruent activity.

4.2.2.3. Comparison of Gamers and Controls

4.2.2.3.1. Verbs

4.2.2.3.1.1. Lateral sites

100-300 ms time window

The between-subject effect, i.e. the main effect of Group was not significant. However, a significant interaction Congruence × Group was observed ($F(1, 32) = 6.87$, $p = .013$, $\eta^2_p = .18$), indicating that congruence effects differed between the two groups. The mean difference from pairwise comparisons revealed that for the incongruent condition Gamers had more negative amplitude than Controls ($M = -0.33$, $SE = 0.16$, $p = .046$).

300-500 ms time window

The main effect of Group was not significant. Furthermore, a significant interaction Congruence × Group was observed ($F(1, 32) = 7.09$, $p = .012$, $\eta^2_p = .18$), however pairwise comparisons were not significant.

500-700 ms time window

The main effect of Group was not significant. There was a significant three-way interaction Laterality × Congruence × Group, $F(1, 32) = 5.18$, $p = .03$, $\eta^2_p = .14$, but pairwise comparisons between groups were not significant.

700-1000 ms & 1000-1300 ms time window

No significant main effect of Group or interactions involving Group were observed.

4.2.2.3.1.2. Midline sites

Neither the main effect of Group nor its interactions were significant in any of the five analyzed time windows.

4.2.2.3.2. Classifiers

4.2.2.3.2.1. Lateral sites

100-300 ms time window

The main effect of Group was not significant. However, there was a significant three-way interaction Laterality × Congruence × Group, $F(1, 32) = 4.95$, $p = .033$, $\eta^2_p = .13$, although pairwise comparisons between groups were not significant.

300-500 ms time window

The main effect of Group was not significant. However, there was a significant three-way interaction Laterality × Congruence × Group, $F(1, 32) = 10.69$, $p = .003$, $\eta^2_p = .25$, although pairwise comparisons between groups were not significant.

500-700 ms time window

While the main effect of Group was not significant, a significant four-way interaction Anteriority × Laterality × Aspect × Group was found, $F(2, 64) = 3.61$, $p = .033$, $\eta^2_p = .10$. Nonetheless, pairwise group comparisons were not significant.

700-1000 ms time window

The main effect of Group was not significant. A three-way interaction Anteriority × Aspect × Group was observed, $F(2, 64) = 5.17$, $p = .008$, $\eta^2_p = .14$, although pairwise comparisons between groups were not significant.

1000-1300 ms time window

No significant main effect of Group or interactions involving Group were observed.

4.2.2.3.2.2. Midline sites

No significant main effect of Group or interactions involving Group were observed in any of the five analyzed time windows.

4.3. Experiment 3

4.3.1. Behavioral results

The descriptive statistics for the short-term memory (STM) and working memory (WM) tasks are shown in Table 6. They show consistent trends in working memory and short-term memory performance between the groups. In almost all tasks, the Gamers group showed higher mean scores and less variability than the Singers and Control groups. In the Operation Span task (verbal WM), for example, the Gamers had the highest average score compared to Signers and the Controls. In the Digit Span Backward task (verbal WM), the Gamers showed the largest span compared to the other groups. A similar pattern emerged for the Rotation Span task (spatial WM), where Gamers again showed the highest mean and lowest standard deviation, indicating a more consistent performance of the group. In the STM measures, Gamers outperformed the other groups on Digit Span Forward, and the Corsi Block-Tapping task. Of note, the Gamers group had higher median scores and narrower interquartile ranges on most measures. Although the Signers and Control groups often had comparable means, their wider ranges and standard deviations indicate a more heterogeneous performance.

In order to assess normality of distribution across dependent variables, Shapiro-Wilk tests were conducted (see Table 7). The results showed that some variables deviated significantly from a normal distribution ($ps < .05$). Overall, these results suggest that some variables (particularly for the STM tasks) may not conform to parametric assumptions, while others (particularly for the WM) show normal distribution.

Table 6. Descriptive statistics for performance on working memory and short-term memory tasks across groups

Variable	Group	N	M	SD	Median	Min	Max	IQR	Skewness	Kurtosis
Operation span partial score	Signers	23	54.74	11.27	57.00	34	72	18.00	-0.20	-1.15
	Control	18	55.56	12.95	58.00	27	74	18.00	-0.67	0.00
	Gamers	16	68.31	5.85	70.50	54	75	7.50	-1.12	1.04
Rotation span partial score	Signers	23	25.87	7.37	25.00	15	41	11.00	0.31	-0.71
	Control	18	22.61	8.83	24.00	4	36	10.50	-0.98	0.60
	Gamers	16	31.06	4.45	31.50	22	39	4.75	-0.34	0.12
Corsi span_max	Signers	22	6.77	0.87	7.00	5	8	1.00	-0.47	-0.08
	Control	18	6.61	0.61	7.00	5	7	1.00	-1.36	1.13
	Gamers	16	7.31	0.87	7.00	6	9	1.00	-0.02	-0.55
Digit span forward_max span	Signers	23	6.57	0.99	7.00	4	8	1.00	-0.50	0.70
	Control	18	6.39	1.09	7.00	4	8	1.25	-0.60	-0.17
	Gamers	16	7.25	0.78	7.00	6	8	1.00	-0.49	-1.06
Digit span backward_max span	Signers	23	5.74	0.96	6.00	4	7	2.00	-0.09	-0.97
	Control	18	5.61	1.09	6.00	3	7	1.25	-0.62	0.46
	Gamers	16	6.44	1.15	6.50	4	8	1.00	-0.42	-0.19

Table 7. Shapiro-Wilk Tests of normality for all dependent variables by group

Variable	Group	Statistic	df	Sig.
Operation span partial score	Signers	0.939	22	.187
	Control	0.953	18	.478
	Gamers	0.897	16	.073
Rotation span partial score	Signers	0.962	22	.522
	Control	0.902	18	.063
	Gamers	0.972	16	.876
Corsi span_max	Signers	0.863	22	.006
	Control	0.662	18	<.001
	Gamers	0.883	16	.043
Digit span forward_max span	Signers	0.885	22	.015
	Control	0.894	18	.045
	Gamers	0.793	16	.002
Digit span backward_max span	Signers	0.875	22	.010
	Control	0.894	18	.045
	Gamers	0.920	16	.171

For the Operation span that measures verbal WM, Levene's test of homogeneity of variances was not significant (p = .091), indicating that variances were equal across groups.
The mean partial score on the Operation Span task adjusted for the covariate (age), was highest in the Gamers group (M = 65.74, SE = 2.86), and lower in the Signers (M = 56.34, SE = 2.29) and Control groups (M = 55.80, SE = 2.44). ANCOVA revealed a significant main effect of group, $F(2, 53) = 3.92$, $p = .026$, $\eta^2_p = .129$. and significant main effect of age, $F(1, 53) = 4.49$, $p = .039$, $\eta^2_p = .078$. Pairwise comparisons revealed that the Gamers scored significantly higher compared to the Control group ($M_{difference}$ = 9.95, SE = 3.80, p = .034, 95% CI [0.56, 19.33]). No other pairwise comparisons reached statistical significance after adjustment, however the difference between the Signers and Gamers approached significance ($M_{difference}$ = -9.40, SE = 3.90, p = .058).

For the Rotation Span task, which measures spatial WM, Levene's test was not significant (p = .140), indicating that the variances were equal between groups. The mean age-adjusted scores showed that the Gamers scored the highest (*M* = 28.82, *SE* = 1.88), followed by the Signers (*M* = 27.27, *SE* = 1.50), while the Control group scored the lowest (*M* = 22.82, *SE* = 1.61). ANCOVA revealed a significant main effect of group, $F(2, 53) = 3.57$, $p = .035$, $\eta^2_p = .119$, and a significant main effect of age, $F(1, 53) = 7.90$, $p = .007$, $\eta^2_p = .130$. No pairwise comparisons reached statistical significance, although one comparison approached significance. Namely, the Gamers scored marginally higher than the Controls ($M_{difference}$ = 6.00, *SE* = 2.50, $p = .059$, 95% CI [-0.17, 12.17], indicating a possible trend towards better spatial WM abilities in the Gamers group.

In the Corsi Block-Tapping task, variances were equal between groups as Levene's test was not significant ($p = .140$). Descriptive age-adjusted means showed that the Gamers had the highest span (*M* = 7.18, *SE* = 0.22, 95% CI [6.74, 7.61]), followed by the Signers (*M* = 6.86, *SE* = 0.18, 95% CI [6.50, 7.22]), and the Controls (*M* = 6.62, *SE* = 0.19, 95% CI [6.25, 7.00]), although ANCOVA revealed that these differences were not statistically significant. No main effect of group was found, $F(2, 52) = 1.84$, $p = .168$, $\eta^2_p = .066$, nor was the effect of age significant, $F(1, 52) = 2.18$, $p = .146$, $\eta^2_p = .040$.

On the Digit Span Forward task, Levene's test for homogeneity of variances was not significant ($p = .399$), indicating equal variances. Descriptive statistics showed that the Gamers had the highest digit span (*M* = 7.25, *SE* = 0.27, 95% CI [6.71, 7.80]), followed by the Signers (*M* = 6.56, *SE* = 0.22, 95% CI [6.13, 7.00]) and the Controls (*M* = 6.39, *SE* = 0.23, 95% CI [5.93, 6.85]). However, ANCOVA revealed that these differences were not statistically significant, although the main effect of group approached significance ($F(2, 53) = 2.99$, $p = .059$, $\eta^2_p = .101$). The effect of age was also not significant, $F(1, 53) < 0.001$, $p = .985$, $\eta^2_p < .001$.

Finally, for the Digit Span Backward task Levene's test of homogeneity of variances was not significant ($p = .805$), indicating that variances were equal across groups. Based on mean age-adjusted scores, the Gamers group had the highest backward span (*M* = 6.41, *SE* = 0.30, 95% CI [5.82, 7.00]), compared to the Signers (*M* = 5.76, *SE* = 0.24, 95% CI [5.28, 6.23]), and the Control group (*M* = 5.61, *SE* = 0.25, 95% CI [5.11, 6.12]). However, these differences were not statistically significant, as there was no main effect of group, $F(2, 53) = 2.17$, $p = .124$, $\eta^2_p = .076$. The effect of age was also not significant, $F(1, 53) = 0.04$, $p = .837$, $\eta^2_p = .001$.

4.3.2. Correlations

To reduce the number of comparisons, a difference amplitude was calculated for each individual ROI from Experiment 2 by subtracting the activity of a congruent condition from that of an incongruent condition. This resulted in one value per predicate type per time window per ROI for each participant. These amplitudes, reflecting differential activity, were further summarized so that two lateral and one midline ROI formed a new composite ROI. For example, the ROIs ant_left_perf_diff_V_100_300, ant_right_perf _diff_V_100_300, and Fz_perf _diff_V_100_300 were averaged to form a new ROI anterior_perf_diff_V_100_300.

Due to the relatively small samples of each group included in the correlation analysis and the fact that some WM and STM variables were not normally distributed, non-parametric Spearman's ρ rank correlation coefficients were used. An alpha level of .05 was chosen as acceptable for type I errors. Only significant correlations, with 95 % confidence intervals (CIs) are reported. To account for multiple comparisons and control for false discovery rate, the Benjamini-Hochberg correction was applied to the *p*-values.

4.3.2.1. Signers

There were no significant correlations between STM/WM and ROIs for verbs.
As for the classifier predicates, higher Digit Span Forward (largest span) scores were associated with more positive amplitude over central site for imperfective classifiers in 100-300 ms time window ($\rho = .62$, $p < .05$, 95 % CI [0.26, 0.83]).

4.3.2.2. Gamers

There were no significant correlations between STM/WM and ROIs for verbs.
For the classifier predicates, there was a significant negative correlation between Operation Span and amplitude at the posterior ROI for perfective classifiers in 100-300 ms time window ($\rho = -.71$, $p < .05$, 95 % CI [-0.90, -0.31]). In addition, the analysis revealed a positive relationship between Digit Span Backward (largest span) and amplitude at central ROIs for imperfective classifiers in 1000-1300 ms time windows ($\rho = .68$, $p < .05$, 95 % CI [0.26, 0.89]).

4.3.2.3. Controls

There were no significant correlations between STM/WM and ROIs for verbs.

However, for classifiers there was a significant positive correlation between Corsi Block-Tapping task (largest span) and amplitude for imperfective classifiers in 300-500 ms time window at the posterior site (ρ = .77, $p < .05$, 95 % CI [0.45, 0.91]), and in 700-1000 ms time window at the central ROI (ρ = .69, $p < .05$, 95 % CI [0.31, 0.88]).

5. DISCUSSION

5.1. Linguistic prediction in HZJ

The first experiment investigated how native bimodal bilingual signers process linguistically encoded events in HZJ and how they process incongruences resulting from different combinations between temporal adverbs and predicates. Temporal adverbs were used to anchor the time of the event, providing a linguistic constraint or cue to the verbal aspect form of the upcoming predicate. The adverb already requires perfective predicates, while the adverb still requires imperfective predicates. These incongruences were investigated in constructions with lexical predicates, i.e. verbs, as well as with handling classifier predicates.

Visual inspection of grand averages revealed different ERP patterns for incongruent perfectives and incongruent imperfectives. Incongruent perfectives elicited negative-going effects, whereas incongruent imperfectives elicited positive-going effects. One possible explanation is that sentences with the adverb "already" in combination with an imperfective form (e.g., "When I came back, she was already stacking shelves"), are not necessarily ungrammatical. Such a reading is grammatically acceptable, but does not fit the preceding context, which always indicated that a person had started an action. Another possible interpretation of such a sentence in HZJ is that the action has just begun, because the same sign can have the meaning "just" or "right now". However, in the debriefing, participants often noted that the combination of the adverb "already" with a predicate with an ongoing meaning is not correct. By contrast, incongruent conditions in which the adverb "still" preceded a perfective predicate lead to truly ungrammatical sentences, regardless of the preceding context. Both observations were confirmed by HZJ consultants during stimuli preparation.

Further evidence that both types of violations resulted in processing costs was provided by RTs, which were significantly longer for both verbs and classifiers under incongruent conditions. However, although only the incongruent imperfective condition represented a true grammatical error, there was no significant difference in RTs between incongruent imperfective and incongruent perfective conditions, suggesting that they were equally difficult to process.

Statistical analyses confirmed the visual inspection of the grand averages. Namely, significant effects for perfective verbs occurred from the first time window analyzed, 100-300 ms post sign onset, and lasted up to 700 ms at the midline and up to 1000 ms at the lateral sites. The

Aspect × Congruence interaction had the highest effect size (η^2_p = .78) in the 300-500 ms time window, indicating that the effect was largest, compared to 100-300 (η^2_p = .40), 500-700 (η^2_p = .61), and 700-1000 ms time windows (η^2_p = .55). This interaction was primarily driven by differences in the perfective condition, as no significant pairwise comparisons were found for the imperfective conditions. Topographic maps indicate that the negativity peaked in the 500-700 ms time window, which is confirmed by the largest mean difference between incongruent and congruent perfectives (M = -3.07 μV), with a broad distribution.

The early onset of this broad negativity can be interpreted as Anterior Negativity (AN) associated with prediction violation detection. A similar effect was reported by Yano (2018) for aspectually incongruent vs. congruent sentences in Japanese, although they used a manipulation of telicity by aspectual coercion, as opposed to the manipulation of grammatical aspect used here. Yano (2018, p. 721) suggests that sustained AN may consist of several components, each reflecting a different process. More specifically, AN in the early stage (300-500 ms post stimulus onset) might reflect error in prediction of aspectual information, while AN in the later time windows (500-700 ms) might be related to the subsequent stages of the reinterpretation process. However, in the study by Yano (2018), they interpreted the negative-going amplitude at the central electrodes as reflecting reinterpretation, i.e., the second part of prediction-related AN, although the effect was not topographically distributed anteriorly. In this experiment with HZJ, the negativity was also broadly distributed, so the negativity observed in the later time window may reflect repair processes corresponding to the second phase of AN. Moreover, the negativity peaked in the 500-700 ms range, confirming the interpretation that it reflects this second phase.

Bott (2010) also observed a sustained anterior negativity in German sentences with aspectual coercion in the 500-900 ms post stimulus onset time window. This effect was interpreted as an index of working memory LAN, due to its sustained nature. Bott (2010) explains that LANs limited to 300-500 ms typically reflect morphosyntactic processing, whereas sustained LANs indicate working memory updating.

On the other hand, significant effects for imperfective verbs started later, from a time window of 500-700 ms, at both central and lateral sites and lasted until 1300 ms for lateral sites, and until 1000 ms post sign onset for central sites. In addition, the topographic maps show broad positivity across central and parietal sites, with a peak in the 700-1000 ms time window (M = 2.12 μV). Taken together, this pattern of ERP effects is consistent with the P600 component. In the literature on aspectual processing, P600 has been reported in several studies using different aspectual manipulations. Bott (2010) observed the P600 for German sentences containing an aspectual mismatch elicited by participles that lead to unresolvable aspectual mismatch.

Furthermore, P600 has been reported in a study on Chinese Mandarin by Hao et al. (2021). In their study they included congruent and incongruent combinations of progressive marker *zhe* and state verbs one the one hand, and with achievement verbs on the other. Hao et al. found "N400-like" effect followed by the P600 time-locked to aspect marker onset, with additional AN time locked to the word after aspect marker, suggesting that both semantic and syntactic processing systems are included in resolution of such aspect violations.

In SL studies, P600 was reported in two studies that used the agreement violation paradigm, one for ASL (Capek et al., 2009), and the other for DGS (Hänel-Faulhaber et al., 2014). In these studies, agreeing verbs were directed to a spatial location where no referents were introduced (so-called unspecified verb agreement), or when the sign was directed to the signers instead of a specific location (so-called reversed agreement). Both types of violations resulted in biphasic ERP responses (LAN and P600), reflecting integration and/or syntactic reanalysis and repair. Taken together, results from the Experiment 1 suggest that incongruent imperfectives in HZJ were processed less as prediction violations and more as integration or repair process, consistent with P600. Interestingly, although adverb *still* constraints aspectual form of the following predicate, no early effects were observed. This is consistent with the interpretation of this effect as reflecting reanalysis rather than prediction.

When grand averages for handling classifier predicates are compared to those for verbs, pattern of differences between perfective and imperfective predicates is visually quite similar. As was the case for verbs, incongruent perfective classifiers also elicited more negative-going amplitudes, while incongruent imperfective classifiers elicited positive-going deflections. Statistical analyses confirmed these visual impression. Namely, significant effects were observed for perfective classifiers since the earliest time window, 100-300 ms, and they lasted until 700 ms for midline sites and until 1300 ms for lateral sites. Again, the effect size for interaction Aspect × Congruence was the largest in the 300-500 ms time window (η^2_p = .75). This effect was largely attributable to differences in the perfective condition, as no significant pairwise comparisons emerged for the imperfective condition in that time window. Visual inspection of topographic maps suggest that difference in amplitude between incongruent and congruent perfective classifiers was the largest in the 500-700 ms time window, confirmed by mean difference of -3.76 μV.

Imperfective classifiers were significant from the 500-700 at midline sites and from 700-1000 over lateral sites, both until 1000-1300 ms time window. Topographic maps reveal that positivity was the largest in the 700-1000 ms time window, which is supported by the largest mean difference between incongruent and congruent imperfective classifiers ($M = 2.12$ µV).

The observed negativity for perfective classifiers is comparable to the effect reported by Krebs et al. (2021), who investigated neural correlates of classifier processing in ÖGS signers. More specifically, they compared the processing of two word orders: Subject-Verb-Object (SVO), the basic word order in ÖGS, and Object-Subject-Verb (OSV). They found that OSV sentences elicited negative-going amplitude around 400 ms post stimulus onset, namely, the N400. The authors argue that the N400 reflects increased cognitive load during the processing of non-basic word order. That finding is consistent with the results of this study on HZJ, that verbs and classifiers are processed in the same manner, i.e. that signers process handling classifiers linguistically, despite their greater iconicity.

To summarize, the ERP results indicate that Signers process perfective and imperfective verbs differently. They are also sensitive to incongruencies between the adverb and the following predicate, as evidenced by longer RTs and a more negative amplitude for perfective predicates and a more positive amplitude for imperfective predicates. However, the evidence for the prediction is limited. Early effects of incognruence (100-300 ms time window) were only significant for perfective verbs and classifier predicates, as they showed early onset negativity that persisted until later time windows, indicating the AN and prediction violation, but no significant later positivity effects that would indicate syntactic reanalysis. Imperfective predicates, on the other hand, did not show early negativity, but they did show positive-going effects with centro-parietal distribution consistent with the P600, for both verbs and classifier predicates.

5.2. Processing based on experience in visual modality

The second experiment investigated how visual-perceptual skills in non-signing population relate to perception of visual linguistic events. The same stimuli were used as in the Experiment 1 in order to investigate whether non-signers (Gamers and Controls) can recognize linguistically coded event structure when predicate signs are embedded into sentences, thus making the task more complex compared to previous studies that focused on isolated signs (Strickland et al., 2015; Krebs et al., 2023).

Visual-perceptual abilities were operationalized by the Perceptual Reasoning Index (PRI) of the Wechsler Adult Intelligence Scales (WAIS). Comparison of three groups showed that the Gamers outperformed the Control group (p = .014), but performed just as well as the Signers (p = .535). The Signers also did not differ significantly from the Control group (p = .245).

Unexpectedly, the Signers group did not perform significantly better than the Control group. Importantly, these two groups were matched for age, sex, years of education and handedness, so common confounding factors could be controlled. In other words, this finding suggests that visuospatial abilities in the Signers group are not superior to those of the Control group, at least when measured with PRI from WAIS. As Signers are bimodal bilinguals, i.e. they have been exposed to HZJ from birth, it was expected that they would outperform the control group and perform comparably to Gamers, in line with the literature. Yet, none of the known studies used the PRI to compare the performance of the groups, as was the case in this study. However, mental image generation task by Emmorey et al. (1993) draws on similar underlying processes. The authors investigated how deaf native signers, hearing native signers and hearing non-signers perform in generation of mental image. They found that both deaf and native signers were faster than hearing non-signers, although all three groups were equally accurate. This study suggests that early SL exposure provides some benefit in terms of speed but not overall accuracy in complex visual abilities.

Although the Signers group did not significantly outperform the Control group, their performance on the PRI was comparable to that of the Gamers. In terms of visual experience, signers can be considered an expert group in visual perceptual abilities, similar to action video game players (AVGPs). It is well established in the literature that playing action video games, i.e. playing 1st/3rd person shooters or action RPG video games (characteristics used as inclusion criteria for selecting Gamers) can enhance visual-perceptual abilities (Bediou et al., 2018). Furthermore, Cretenoud et al. (2021) found that sensitivity to peripheral cues and the honeycomb illusion is positively related to players' rank. In other words, players with a higher rank tend to perform better on such tasks than AVGPs with a lower rank. In this study, Gamers scored significantly higher than the Control group on visual-perceptual reasoning, consistent with existing literature on AVGP's visual abilities. Importantly, this thesis is the first study to compare Signers and AVGPs directly, and the finding their performance was statistically equivalent is notable. It raises the possibility that Signers, like AVGPs, may benefit from domain-specific visual expertise. The lack of significant difference between Signers and Controls may be due to limited statistical power. Future studies with larger samples could further explore whether Signers show perceptual reasoning advantages over non-signing peers.

The behavioral results from the EEG experiment indicate that both non-signing groups track the visual form of the signs regardless of the congruency between adverbs and the predicates. Although participants in the non-signing groups did not know any sign language, it was assumed that they would rely on movement features of a sign preceding the predicate, i.e., an adverb. In HZJ, the adverb ALREADY is signed with a movement that has a sharp ending. In contrast, the adverb STILL is signed without such a movement and involves a repetition. Therefore, it was assumed that they would show different patterns behaviorally for when a sharply ending movement (ALREADY) is followed by the same sharply ending movement (perfective forms), as opposed to a repetitive, slower movement typical of imperfective predicates. Instead, the pattern of their responses suggests that they focused mainly on the visual form of the predicates, rather than on the congruence between adverb and verb speed of movement, as they rated predicates from all conditions containing a perfective form as having a completed action.

This also matches information that non-signers provided in the post-experiment debriefing. When asked if they had a strategy for deciding which videos showed a completed or ongoing action, all responded that they relied on the movement features of the last sign, even though they had not been told what to look for in videos. This result is comparable to the findings of Strickland et al. (2015) and Krebs et al. (2023), who reported that non-signers are able to visually recognize telicity in several unrelated SLs in isolated signs. Although telicity is a semantic feature, it is visible in SLs at the phonological level (Wilbur, 2008). While this study on HZJ did not examine telicity but the grammatical aspect, the results could be comparable considering that the two seem to be conflated in HZJ (Malaia & Milković, 2021).

As for the EEG part of Experiment 2, statistical analysis of EEG data did however show a significant Aspect × Congruence interaction for verbs at lateral ROIs in all analyzed time windows for Gamers and in all but last window for Controls. This indicates that the size and direction of the congruency effect depended on the aspectual form, suggesting that even non-signers are sensitive to such combinations. Moreover, a distinct ERP pattern emerged for perfective versus imperfective predicates: perfectives elicited more negative amplitude, whereas imperfectives elicited more positive amplitude.

This aspect-based difference suggests that aspectual marking recruits different neurocognitive processes. Perfectives, that mark a completed and/or bounded event, appear to be processed by non-singers in a similar way to the telic verbs described in Krebs et al. (2023). These verbs have an inherent boundary or end-point and are characterized by velocity deceleration or change at the phonological level (Malaia et al., 2013), which may increase processing load, as reflected in greater negativity. Taken together, these results show that even in non-signers, aspectual distinctions modulate ERP responses, with perfectives eliciting stronger negativity, consistent with the telicity effects observed in previous research.

When statistically comparing the two non-signer groups, mixed ANOVA with Group as a between-subjects factor yielded limited evidence of group differences. Of the 10 time windows analyzed (five for each predicate type), in only one did the significant Congruence × Group interaction also have significant pairwise comparisons. More specifically, Gamers showed a more negative amplitude for verbs in the 100-300 ms time window, but since the p-value after applying the Bonferroni correction for multiple comparisons was .046, the overall trend may indicate that there are no significant pairwise comparisons.

Overall, there is limited evidence that the superiority Gamers show in visual-perceptual abilities (mean difference 14 points between gamers and controls) provides an advantage in visual event perception. Another possible reason why their advantage in general visual-perceptual abilities may not be useful in tasks involving the perception of complex visual stimuli such as an SL is the greater complexity of motion in a natural SL compared to everyday motion. By using the optical flow method, which quantifies changes in pixel positions between two video frames, Borneman et al. (2018) have shown that ASL has greater information content compared to non-linguistic visual motion such as placing apples on a table.

The similar direction of ERP waveforms in the groups of non-signers compared to Signers (perfective predicates – negativity, imperfective predicates – positivity) is in line with previous studies that found that non-signers are able to discriminate signs based on telicity, i.e. the visual form of the signs (Krebs et al., 2023; Strickland et al., 2015). This apparent transparency of visual events is accounted by the Event Visibility Hypothesis (Wilbur, 2008). Telic signs have encoded internal end-point or boundary which is phonologically realized as a change in phonological parameters, such as handshape aperture from [open] to [closed]. Atelic signs, on the other hand, are those that do not have internal end-point and do not show change at the phonological level. In this study on HZJ, predicates were chosen based on their verbal aspect form (perfective – imperfective). However, perfective and imperfective predicates in HZJ are realized following the same phonological principles that have been previously described for telicity (Malaia & Milković, 2021; Milković, 2011). The results of this study with HZJ sentences demonstrate that non-signers are able to extract these features not only from isolated signs, as used in previous studies, but also in continuous signed sentences.

Furthermore, these results fit into the Multiscale Information Transfer (MSIT) framework proposed by Blumenthal-Dramé and Malaia (2018). The MSIT, a modality-independent framework, includes low-level and high-level processing of the visual or auditory signal that can be interpreted across different domains (Blumenthal-Dramé and Malaia, 2018, p. 13). For example, when non-signers watch a sign language, they can only process it at a lower level and rely on general event segmentation abilities. This was quantified in an fMRI study by Malaia et al. (2013), which showed that when watching sign language, only cortical areas for motion processing are active in the non-signing group. By contrast, signers show activation limited to language processing. The study emphasizes that "while all participants operate on the same perceptual information, it is only familiarity with the language which allows low-level perception of motion differences in the signal to be transferred as information to higher, language-based processing scales (e.g. phonology, semantics, and syntax)" (Blumenthal-Dramé and Malaia, 2018, p. 5). Moreover, Malaia et al. (2023) found that both Austrian signers and non-signers engage in predictive processing when watching Austrian SL, however those predictions operate on different levels, as explained by the MSIT. In their study, Malaia et al. (2023) recorded EEG while the participants watched Austrian SL sentences. Univariate Feature Selection algorithm for feature analysis revealed different patterns of EEG features for the two groups. Signers showed activation in linguistic processing areas (left frontal), while for non-signers spatial processing areas were more relevant (right hemisphere). Nevertheless, both groups showed activity in lower frequency bins, thus suggesting involvement of predictive mechanisms.

To summarize, the Gamers in Experiment 2 showed higher visual-perceptual abilities when measured by the Perceptual Reasoning Index, compared to the Control group who neither played action video games or knew a sign language. This finding is consistent with previous research with action video game players. However, this advantage did not translate to the ERP findings. While both groups showed significant Aspect × Congruence interactions, group comparisons revealed limited evidence of a gamer advantage, suggesting that the general visual-perceptual advantage does not extend to the processing of complex visual stimuli such as a sign language. Taken together, these results indicate that non-signers, regardless of their visual-perceptual abilities, recruit low-level perceptual mechanisms when perceiving aspect-containing movements in sign language, consistent with the EVH and MSIT.

5.3. Short-term memory and working memory abilities in relation to prediction

In Experiment 3, several verbal and spatial STM and WM tasks were used in order to assess its relationship to processing of visual linguistic and non-linguistic events. Verbal STM was measured using the longest span in the Digit Span Forward task, while the longest span in the Corsi-block Tapping task was used as a measure of spatial STM. The ANCOVA for Digit Span Forward, with age included as a covariate, showed that the main effect of group approached significance, with a moderate effect size (η^2_p =.101), suggesting that a larger sample size might reveal meaningful group differences. Given the moderate effect sizes, it is possible that the study was underpowered to detect all but the strongest group effects. The current study confirms the findings of Emmorey et al. (2017), who found no statistically significant differences between deaf and hearing signers and hearing non-signers on a Letter Span task in which participants were asked to repeat a sequence of auditorily presented English letters, and ASL fingerspelled letters.

In contrast, all three groups in this study performed similarly on the Corsi Block-Tapping task, as there was no main effect of group (p = .168). Although the Gamers were significantly younger than the other two groups, age was statistically controlled for in the analysis, suggesting that the group differences in STM or WM performance were not due to age.

The literature to date provides conflicting evidence for the effects of early exposure to SL on STM and WM tasks, while there is more consistent evidence for better performance in AVGPs compared to their non-gaming peers. The lack of significant group differences on the Corsi Block-Tapping task between hearing signers and non-signers in the present study is consistent with previous findings, although previous research has mainly focused on Deaf signers (Emmorey et al., 2017; Marshall et al., 2015; McFayden et al., 2023). However, Emmorey et al. (1993) found that Deaf native signers performed better in the maintenance of visual images, compared to hearing native signers and hearing non-signers, suggesting better visual STM. This suggests that sensory deprivation, rather than experience with a visual language, may play a more important role. The present results support this interpretation, as Signers' performance was comparable to that of the Control group.

With regard to complex memory abilities, i.e. tasks requiring both retention and manipulation of information, the Operation Span and Digit Span Backwards tasks were used to obtain a measure of verbal WM, while the Rotation Span task assessed spatial WM. An ANCOVA with age as a covariate revealed a significant main effect of group on the Operation Span task

(p = .026). Pairwise comparisons also showed that Gamers performed significantly better than the Control group (p = .034). Gamers and Signers performed similarly, although the comparison approached significance (p = .058), suggesting a trend. No significant difference was found between Signers and the Control group (p = 1.00). In contrast, the ANCOVA for the Digit Span Backward task showed no significant effect of group (p = .124), indicating similar verbal WM performance in the groups.

In spatial WM, group differences were evident in the Rotation Span task (p = .035), although post hoc comparisons did not reveal any statistically significant differences. The comparison between the Gamers and the Control group approached significance (p = .059), suggesting a possible trend, while Signers performed similarly to the Gamers and the Controls.

These results are consistent with previous research suggesting that, apart from the STM advances mentioned above, AVGPs also perform better than non-gamers on non-verbal WM tasks. Recent evidence for this comes from a study by Campbell et al. (2024). They found that AVGPs performed better than non-gamers on spatial WM tasks involving learning efficiency and error monitoring. More specifically, AVGPs were faster but showed comparable accuracy – a pattern also observed by Emmorey et al. (1993) in a mental image generation task.

Conversely, there is increasing evidence that native signers do not consistently outperform non-signers on complex non-verbal WM tasks. For example, Emmorey et al. (2017) found that both Deaf and hearing signers performed comparably to hearing non-signers. The same result was previously reported by Marschark et al. (2016), who found equal scores on the Symmetry Span task for Deaf signers, hearing signers and hearing non-signers.

The results suggest that the cognitive benefits observed in Gamers may extend beyond spatial processing to verbal working memory and reasoning, suggesting a domain-general improvement. In contrast, Signers showed no evidence of improved performance in either domain, which may suggest that visual language exposure without concomitant sensory deprivation does not lead to broader cognitive benefits. This contrast between Gamers and Signers highlights the role of task-specific demands and type of experience in shaping cognitive abilities.

Correlation analyses between STM/WM scores and EEG amplitude revealed that Signers with higher verbal STM span showed greater amplitude for imperfective classifiers in the earliest time window (100-300 ms) at the central site. This suggests that native bimodal bilingual signers recruit verbal STM resources when processing imperfective, i.e. ongoing, actions, possibly reflecting the processing cost of violated prediction by incongruent sentences (Gathercole, 2007; Trapp et al., 2021).

In the Control group, the visuospatial STM span measured with the Corsi Block-Tapping task correlated positively with ERP amplitudes in two later time windows: posterior activity in the 300-500 ms time window and central activity in the 700-1000 ms time window, both for imperfective classifiers. These correlations suggest that non-signing participants rely more heavily on visual-spatial resources when processing classifiers. Their performance on the Corsi Block-Tapping task, as well as their average visuospatial abilities, could be due to a lack of experience in processing more complex visual stimuli (in contrast to Gamers), so they had to rely more on general cognitive resources.

Interestingly, two correlations between verbal WM and ERP amplitudes were found in the Gamers group. More specifically, Operation Span correlated negatively with posterior ERP response to perfective classifiers in the early time window of 100-300 ms, suggesting that higher verbal WM capacity allows for less effortful processing of perfective, i.e., telic/bounded signs, which have previously been shown to be more complex than atelic predicates (Malaia et al., 2012). In contrast, Digit Span Backward was found to correlate positively with amplitude in the central ROI for imperfective classifiers in the late 1000-1300 ms time window. The correlations observed in two late time windows in both Controls and Signers at central and posterior sites may reflect the allocation of resources required to process predicates without a visual end-point (Krebs et al., 2023).

To summarize, Experiment 3 investigated the relationships between STM and WM and the processing of visual linguistic and non-linguistic events. Significant main effects of group were found in both verbal and spatial WM task performance. Signers and Controls showed no significant differences in performance on STM and WM tasks, but Gamers showed advantages on measures of verbal WM, consistent with previous evidence that action video game experience helps improve general cognitive abilities. In contrast, SL experience without sensory deprivation did not lead to benefits in domain-general abilities, consistent with studies showing signers do not necessarily perform better than non-signers on non-verbal, i.e. spatial WM tasks. Correlation analyses also showed a group-specific use of memory resources during EEG processing of HZJ classifiers (no significant correlations were found with verbs). In particular, Signers drew on verbal STM for imperfectives in the earliest time window (100-300 ms). Gamers also showed a correlation in the earliest time window, but between verbal WM (Operation Span) and amplitude for perfectives, in a negative direction.

Furthermore, in the last time window analyzed (1000-1300 ms), a positive correlation was found between verbal WM (Digit Span Forward) and the amplitude for imperfectives. While these two groups showed associations with verbal abilities, Controls used visuospatial STM for processing imperfectives. The finding that Gamers show domain-general WM advantages while Signers and Controls drew on different cognitive resources during SL perception, illustrates the way in which task demands and background experience recruit different memory resources during the processing of visual events.

5.4. Limitations

There are several limitations of this study. First, although the sample size of 16 to 22 participants per group was typical of ERP studies, some effects, particularly for STM and WM skills, were marginal, i.e., not significant after correction for multiple comparisons. Second, participants may have been biased to answer that the observed action was completed, as the question at the end of each trial was "Is the action completed?" Third, classifier predicates were added as filler sentences to sentences with verbs. However, since both types of sentences followed the same structure and had the same combinations of adverbs and verbal aspect forms, this could have led participants to work strategically and notice the manipulation. In fact, many participants remarked in the debriefing that it seemed to them that sentences were repeated and that "something happens at the end of the sentences", even though all sentences were pseudorandomized and each participant saw a different order.

6. CONCLUSION

In this thesis, the processing of visual events that are linguistically encoded in HZJ was investigated using verbal aspect in three groups of participants: hearing native bimodal bilingual participants (Signers), hearing gaming non-signers (Gamers) and hearing non-gaming non-signers (Controls). It was hypothesized that the constraints induced by the adverb to determine the event time would allow aspectual prediction for native signers. The non-signing groups were hypothesized to rely on the fact that verbal aspect in sign language such as HZJ maps its phonological form to visual event perception substrates (perfective forms involve rapid deceleration of movement, whereas imperfective forms involve continuous movement without rapid deceleration). Importantly, the group of Gamers was recruited to account for the possibility that only enhanced visual-spatial abilities support the prediction of complex motion that is a sign language.

The results of the EEG experiment with Signers reveal distinct mechanisms involved in the processing of verbal aspect in HZJ. Moreover, incongruent perfective verbs and classifier predicates elicited a sustained bilateral broad negativity with early onset (100-300 ms), typically reported as an index of prediction violation. Imperfective predicates, however, did not show early effects, but only sustained positivity from 500 ms post stimulus onset, indicating a P600 effect. Response times complement ERP results, as Signers had longer response times for incongruent compared to congruent conditions across both verbs and classifier predicates, indicating processing costs at both neural and behavioral levels.

Gamers were found to have superior visual-spatial abilities compared to Controls, but comparable to Signers. Nevertheless, this advantage did not translate to processing because both groups showed early but sustained ERP effects. This suggests that higher visual-spatial abilities are not necessary for visual event segmentation, i.e. higher scores in Gamers group did not bring additional advantage. Additionally, the occurrence of early effects may support motion-based prediction, in line with the Multiscale Information Transfer framework.

Furthermore, all three groups performed similarly on STM and WM tasks, with one exception. Gamers had significantly higher scores on verbal WM compared to Controls, even when age was controlled for. Correlation analyses between STM/WM scores and ERP amplitude showed that both Signers and Gamers relied on verbal STM and WM resources, respectively, while Controls relied on spatial STM. This highlights the role of previous linguistic and advanced perceptual experience in visual modality during the processing of visual events.

In sum, this thesis demonstrates that hearing signers and non-signers are sensitive to aspectual congruence from the earliest stages of processing. However, the sources of these effects differ. For signing group, these effects appear to show linguistic prediction which was associated with verbal short-term memory capacity. Non-signing groups, on the other hand, appear to rely on motion-based processing. In action video game players, ERP amplitude was associated with verbal working memory abilities, while in the control group it was associated with spatial short-term memory. This study provides the first direct comparison of three groups of hearing participants with different experiences: native exposure to HZJ, action video game playing vs. none of two, thus enabling disassociation of linguistic vs. non-linguistic experience in the visual modality related to processing of visual events.

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8. APPENDIX A

The notation conventions used in this thesis are as follows:

IX – index or pointing sign. IX_{there} means that IX is used for establishing location. Addition of subscript letters *a, b, c, d,* or *e* indicates spatial loci in the signing space in front of the signer. If imagined as a horizontal semi-circle in front of the signer, from left to right, *a* is the leftmost locus, *e* is the rightmost, and *c* is in between. Locus *b* is between *a* and *c*, while locus *d* is between *d* and *e.*

IX_{1sg} – first person singular pronoun. By extension *you*, *he/she/it*, *we*, *you*, *they* are IX_{2sg}, IX_{3sg}, IX_{1pl}, IX_{2pl}, IX_{3pl}, respectively. For example, a third person singular pronoun signed towards a location *d* is written as $IX_{3sg\text{-}d}$.

$POSS_{1sg}$ – first person singular possessive pronoun. By extension *your*, *his/hers/its*, *our*, *your*, *their* are $POSS_{2sg}$, $POSS_{3sg}$, $POSS_{1pl}$, $POSS_{2pl}$, $POSS_{3pl}$, respectively. For example, a third person singular possessive pronoun signed towards a location *b* is written as $POSS_{3sg\text{-}b}$.

SIGN – English glosses in small caps represent the closest meaning in a particular sign language. If not stated otherwise, glosses referer to Croatian Sign Language (*hrvatski znakovni jezik*, HZJ)

SIGN-SIGN – if more than one word is needed to represent a single sign, the glosses are conncected with hyphens.

S-I-G-N – fingerspelled signs are written with hyphens between letters.

SIGN++ – plus symbols indicate reduplication, i.e. repeated movement of a sign

$_{3}SIGN_{1}$ – subscript numbers indicate the direction of movement, where 1 represents the signer, while 2 and 3 are second and third person, respectively. For example $_{3\text{-}d}VISIT_{1}$ means that the sign is produced from the right side towards the signer.

$_{d}SIGN_{b}$ – subscript letters mean that the sign is produced from the location *d* towards the *b*. $_{d}COME_{b}$, for example, means that a person came to location *b* from the *d.* However, case like SEE_{b} mean that the sign is directed to location *b* from the neutral signing space. Also, $_{d}COME$ means that a person came from location *d* to neutral signing space in front of the signer.

$SIGN_{PFV}$ – verbal sign has a perfective meaning. In contrast, $SIGN_{IPFV}$ has imperfective meaning.

"action" – gestures are written in lowercase letters between quotation marks.

CL(handshape):sign-sign – a classifier sign

9. APPENDIX B

List of abbreviations

ASL = American Sign Language

ANCOVA = analysis of covariance

ANOVA = analysis of variance

AVGPs = action video game players

CODA = children of deaf adults

CPS = closure positive shift

DGS = German Sign Language

DSS = digit-symbol substitution

EEG = electroencephalography

EMG = electromyography

ERPs = event-related potentials

EST = Event Segmentation Theory

EVH = Event Visibility Hypothesis

HZJ = Croatian Sign Language

ipfv =imperfective

IVC = instantaneous visual change

L1 = first language

L2 = second language

LAN = left anterior negativity

LIBRAS = Brazilian Sign Language

LIS = Italian Sign Language

LPP = late positive potential

MSIT = Multiscale Information Transfer

MT+ = motion complex area

NGT = Sign Language of the Netherlands

ÖGS = Austrian Sign Language

pfv = perfective

PP = predictive processing

ROI = region of interest

RT = response time or reaction time

SLs = sign languages

STM = short-term memory

TID = Turkish Sign Language

WAIS = Wechsler Adult Intelligence Scale

WM = working memory

10. APPENDIX C

Sentences with lexical predicates

1. CHOOSE

A new director was elected in one company and he has to choose his assistant directors. Now he began to choose. After a month he had already chosen them.

ONE COMPANY NEW DIRECTOR, MUST CHOOSE NEW LOWER-RANK HELP DIRECTORS, NOW IX$_{3sg\text{-}d}$ START CHOOSE$_{ipfv}$…

… ONE-MONTH PASS, IX$_{3sg\text{-}d}$ ALREADY CHOOSE$_{pfv}$++

… ONE-MONTH PASS, IX$_{3sg\text{-}d}$ STILL CHOOSE$_{ipfv}$+++

… ONE-MONTH PASS, IX$_{3sg\text{-}d}$ ALREADY CHOOSE$_{ipfv}$+++

… ONE-MONTH PASS, IX$_{3sg\text{-}d}$ STILL CHOOSE$_{pfv}$++

2. ANSWER

I am a lawyer, the questioning of my client has been going on for three hours in court. He was asked the last question, he started to answer, but my cell phone rang and I left. I came back in 2 minutes and he already answered.

IX$_{1}$ LAWYER ONE PERSON$_{d}$ HELP$_{d}$, COURT THREE-HOUR INTERROGATE$_{d}$, NOW LAST ASK$_{d}$, IX$_{3sg\text{-}d}$ START ANSWER$_{ipfv}$, POSS$_{1}$ CELL-PHONE RING, IX$_{1}$ OUT$_{b}$…

… TWO MINUTE LATER $_{b}$COME-BACK, IX$_{3sg\text{-}d}$ ALREADY ANSWER$_{pfv}$+

… TWO MINUTE LATER $_{b}$COME-BACK, IX$_{3sg\text{-}d}$ STILL ANSWER$_{ipfv}$++

… TWO MINUTE LATER $_{b}$COME-BACK, IX$_{3sg\text{-}d}$ ALREADY ANSWER$_{ipfv}$++

… TWO MINUTE LATER $_{b}$COME-BACK, IX$_{3sg\text{-}d}$ STILL ANSWER$_{pfv}$+

3. CHASE-AWAY

A famous actor should come to a hotel. In the morning, a lot of people gathered to see him, but the police chased them away. In the evening, the actor arrived, and they already chased them away.

ONE FAMOUS ACTOR WILL COME$_{d}$ HOTEL, NOW MORNING PEOPLE EXCITED WANT SEE$_{d}$, BUT POLICE IX$_{3sg\text{-}d}$ CHASE-AWAY$_{ipfv}$…

… NOW EVENING, ACTOR ARRIVE, IX$_{3sg\text{-}d}$ ALREADY CHASE-AWAY$_{pfv}$+

… NOW EVENING, ACTOR ARRIVE, IX$_{3sg-d}$ STILL CHASE-AWAY$_{ipfv}$+++

… NOW EVENING, ACTOR ARRIVE, IX$_{3sg-d}$ ALREADY CHASE-AWAY$_{ipfv}$+++

… NOW EVENING, ACTOR ARRIVE, IX$_{3sg-d}$ STILL CHASE-AWAY$_{pfv}$+

4. COME

One plane is preparing to take off, but they called from the terminal that one disabled person is still coming. The pilot looked out and took notice. After 5 minutes she already came.

ONE PLANE PREPARE TAKE-OFF, IX$_{there-d}$ TELEPHONE $_{d}$LET-KNOW MORE ONE PERSON DISABILITY IX$_{3sg-d}$ COME$_{ipfv}$, PILOT LOOK$_{d}$, “ok”…

… FIVE MINUTE PASS, IX$_{3sg-d}$ ALREADY $_{d}$COME$_{pfv}$

… FIVE MINUTE PASS, IX$_{3sg-d}$ STILL $_{d}$COME$_{ipfv}$

… FIVE MINUTE PASS, IX$_{3sg-d}$ ALREADY $_{d}$COME$_{ipfv}$

… FIVE MINUTE PASS, IX$_{3sg-d}$ STILL $_{d}$COME$_{pfv}$

5. SEND-TEXT-MESSAGE

There was supposed to be a wedding tonight, but the newlyweds fell ill and have to postpone the wedding. They have to call a lot of people, so the two of them send text messages. After 15 minutes, they already sent them.

TODAY EVENING WEDDING, NEWLYWEDS ILL, FORCEDLY POSTPONE, MUST LET-KNOW A-LOT PEOPLE, TWO-OF-THEM$_{b}$ TEXT-MESSAGE SEND-TEXT-MESSAGE$_{ipfv}$+++…

… FIFTEEN MINUTE PASS, TWO-OF-THEM$_{b}$ ALREADY SEND-TEXT-MESSAGE$_{pfv}$++

… FIFTEEN MINUTE PASS, TWO-OF-THEM$_{b}$ STILL SEND-TEXT- MESSAGE$_{ipfv}$+++

… FIFTEEN MINUTE PASS, TWO-OF-THEM$_{b}$ ALREADY SEND-TEXT- MESSAGE$_{ipfv}$+++

… FIFTEEN MINUTE PASS, TWO-OF-THEM$_{b}$ STILL SEND-TEXT- MESSAGE$_{pfv}$+++

6. POST-VIDEO

My boss ordered me to post promotional videos on the website. I started doing it, and the boss went to do other things. After half an hour he came back, and I had already posted them.

BOSS ORDER$_{1}$ SHORT VIDEO ADVERTISEMENT INTERNET POST-VIDEO$_{pfv}$++… IX$_{1}$ START POST-VIDEO$_{ipfv}$++, IX$_{3sg-d}$ OUT RUN-ERRANDS…

… HALF-AN-HOUR LATER, IX$_{3sg-d}$ $_{d}$COME-BACK, IX$_{1}$ ALREADY POST-VIDEO$_{pfv}$++

… HALF-AN-HOUR LATER, IX$_{3sg-d}$ $_{d}$COME-BACK, IX$_{1}$ STILL POST-VIDEO$_{ipfv}$+++

… HALF-AN-HOUR LATER, IX$_{3sg\text{-}d}$ $_{d}$COME-BACK, IX$_{1}$ ALREADY POST-VIDEO$_{ipfv}$+++

… HALF-AN-HOUR LATER, IX$_{3sg\text{-}d}$ $_{d}$COME-BACK, IX$_{1}$ STILL POST-VIDEO$_{pfv}$++

7. COME

The students are going on their graduation trip, they got on the bus, but one student is missing. I see in the distance that he is coming, so I decided to collect passports. When I looked outside, this student had already arrived.

MIDDLE SCHOOL FINISH, TOGETHER TRIP, NOW INSIDE BUS, BUT MISS ONE STUDENT… IX$_{1}$ SEE FAR IX$_{3sg\text{-}d}$ $_{d}$COME$_{ipfv}$, IX$_{1}$ COLLECT PASSPORT…

… LOOK-OUTSIDE, IX$_{3sg\text{-}d}$ ALREADY $_{d}$COME$_{pfv}$

… LOOK-OUTSIDE, IX$_{3sg\text{-}d}$ STILL $_{d}$COME$_{ipfv}$

… LOOK-OUTSIDE, IX$_{3sg\text{-}d}$ ALREADY $_{d}$COME$_{ipfv}$

… LOOK-OUTSIDE, IX$_{3sg\text{-}d}$ STILL $_{d}$COME$_{pfv}$

8. TAKE-PILL

My grandmother takes a lot of medicine every day. This morning I gave her the pills, she started taking them, and I went to make coffee. When I came back, she had already taken them.

POSS$_{1}$ GRANDMA EVERY-DAY PILE EVERYTHING TAKE-PILL$_{pfv}$++… TODAY MORNING PILE $_{1}$CL- C-TH-ADJ: give$_{d}$, IX$_{3sg\text{-}d}$ START TAKE-PILL$_{ipfv}$++, IX$_{1}$ IX$_{there\text{-}b}$ $_{b}$MAKE COFFEE…

… A-FEW MINUTE PASS, SEE IX$_{3sg\text{-}d}$ ALREADY TAKE-PILL$_{pfv}$++

… A-FEW MINUTE PASS, SEE IX$_{3sg\text{-}d}$ STILL TAKE-PILL$_{ipfv}$+++

… A-FEW MINUTE PASS, SEE IX$_{3sg\text{-}d}$ ALREADY TAKE-PILL$_{ipfv}$+++

… A-FEW MINUTE PASS, SEE IX$_{3sg\text{-}d}$ STILL TAKE-PILL$_{pfv}$++

9. APPOINT

After the elections, the prime minister started appointing new ministers. After a month, he had already appointed them.

ELECTIONS FINISH, PRESIDENT GOVERNMENT NOW NEW MINISTER++ IX$_{3sg\text{-}d}$ START APPOINT$_{ipfv}$+++…

… ONE-MONTH PASS, IX$_{3sg\text{-}d}$ ALREADY APPOINT$_{pfv}$++

… ONE-MONTH PASS, IX$_{3sg\text{-}d}$ STILL APPOINT$_{ipfv}$+++

… ONE-MONTH PASS, $IX_{3sg\text{-}d}$ ALREADY $APPOINT_{ipfv}$+++

… ONE-MONTH PASS, $IX_{3sg\text{-}d}$ STILL $APPOINT_{pfv}$++

10. PAY-OFF

I bought a car on credit with monthly instalments of 200 euros. After ten years I have already paid it off.

BEFORE IX_1 BUY CAR CREDIT, MONTH++ TWO-HUNDRED EURO $PAY\text{-}OFF_{ipfv}$+++

… TEN-YEAR PASS, IX_1 ALREADY $PAY\text{-}OFF_{pfv}$++

… TEN-YEAR PASS, IX_1 STILL $PAY\text{-}OFF_{ipfv}$+++

… TEN-YEAR PASS, IX_1 ALREADY $PAY\text{-}OFF_{ipfv}$+++

… TEN-YEAR PASS, IX_1 STILL $PAY\text{-}OFF_{pfv}$++

11. TAKE/BRING (a child by hand)

Every Monday and Wednesday I take my son to English. I've been busy the last few Wednesdays, so Grandma took him. I was busy at work today and forgot to take him, so I quickly called my husband. He told me: "Well today is Wednesday, she has already taken him."

$POSS_1$ SON LITTLE LEARN ENGLISH, ALWAYS MONDAY WEDNESDAY IX_1 $TAKE_{IPFV}$++… BUT WEDNESDAY LAST-FEW IX_1 BUSY, GRANDMA $IX_{3sg\text{-}d}$ $TAKE_{ipfv}$++… TODAY BUSY WORK FORGET, HUSBAND ${}_1VIDEO\text{-}CALL_b$…

… ${}_bTELL_1$ TODAY WEDNESDAY, $IX_{3sg\text{-}d}$ ALREADY $TAKE_{pfv}$+

… ${}_bTELL_1$ TODAY WEDNESDAY, $IX_{3sg\text{-}d}$ STILL $TAKE_{ipfv}$++

… ${}_bTELL_1$ TODAY WEDNESDAY, $IX_{3sg\text{-}d}$ ALREADY $TAKE_{ipfv}$++

… ${}_bTELL_1$ TODAY WEDNESDAY, $IX_{3sg\text{-}d}$ STILL $TAKE_{pfv}$+

12. SHAVE

My husband and I are going to my friend's wedding today. I went to get my hair done, and he went to the barber. He told me that it was very crowded and that he didn't know how long he would have to wait. After an hour I came to the barber, and he was already shaved.

TODAY $POSS_1$ FRIEND WEDDING, IX_1 HAIR-DO, $POSS_1$ HUSBAND $IX_{there\text{-}b}$ SHAVE… $IX_{3sg\text{-}d}$ ${}_3LET\text{-}KNOW_1$ CROWD, DON'T-KNOW TIME-TAKE…

… ONE-HOUR PASS, IX_1 $_1VISIT_d$, $IX_{3sg\text{-}d}$ ALREADY $SHAVE_{pfv}$+

… ONE-HOUR PASS, IX_1 $_1VISIT_d$, $IX_{3sg\text{-}d}$ STILL $SHAVE_{ipfv}$+++

…ONE-HOUR PASS, IX_1 $_1VISIT_d$, $IX_{3sg\text{-}d}$ ALREADY $SHAVE_{ipfv}$+++

… ONE-HOUR PASS, IX_1 $_1VISIT_d$, $IX_{3sg\text{-}d}$ STILL $SHAVE_{pfv}$+

13. INVITE

My company is organizing a charity dinner, my boss ordered me to invite 50 companies. I immediately started calling them. The boss asked me the next day how it was going, I had already invited them.

IX_{1pl} ORGANISE CHARITY DINNER, BOSS $ORDER_1$ FIFTY COMPANY++ MUST $INVITE_{pfv}$++… IX_1 IMMEDIATELY TELEPHONE $INVITE_{ipfv}$+++

… TOMORROW BOSS $_3ASK_1$ HOW, IX_1 ALREADY $INVITE_{pfv}$++

… TOMORROW BOSS $_3ASK_1$ HOW, IX_1 STILL $INVITE_{ipfv}$+++

… TOMORROW BOSS $_3ASK_1$ HOW, IX_1 ALREADY $INVITE_{ipfv}$+++

… TOMORROW BOSS $_3ASK_1$ HOW, IX_1 STILL $INVITE_{pfv}$++

14. BUY

My daughter got her first paycheck and is looking for clothes online. We watched together and she found what she liked and started shopping, and I went to cook. I came back in half an hour, and she had already bought it.

$POSS_1$ DAUGHTER RECEIVE FIRST PAYCHECK, $IX_{3sg\text{-}d}$ WANT $IX_{there\text{-}d}$ INTERNET CLOTHES BUY-MANY… TOGETHER SEE LIKE IX_{det}++ START BUY_{ipfv}+++, IX_1 $COOK_b$…

… HALF-AN-HOUR PASS $_bCOME\text{-}BACK$, $IX_{3sg\text{-}d}$ ALREADY BUY_{pfv}++

… HALF-AN-HOUR PASS $_bCOME\text{-}BACK$, $IX_{3sg\text{-}d}$ STILL BUY_{ipfv}+++

… HALF-AN-HOUR PASS $_bCOME\text{-}BACK$, $IX_{3sg\text{-}d}$ ALREADY BUY_{ipfv}+++

… HALF-AN-HOUR PASS $_bCOME\text{-}BACK$, $IX_{3sg\text{-}d}$ STILL BUY_{pfv}++

15. LEAVE

I work in a school as a cleaner. In the hall, the tournament ended and people started to disperse, so I went to get cleaning supplies. When I came back, they had already left.

IX_1 WORK SCHOOL CLEANER… $IX_{there-d}$ SPORTS-HALL TOURNAMENT FINISH, NOW PEOPLE IX_d START $LEAVE_{ipfv}$+++, IX_1 LIQUID CLEAN $HEAD\text{-}TO_b$…

… $_b$COME-BACK, IX_{3pl-d} ALREADY $_dLEAVE_{pfv}$++

… $_b$COME-BACK, IX_{3pl-d} STILL $_dLEAVE_{ipfv}$+++

… $_b$COME-BACK, IX_{3pl-d} ALREADY $_dLEAVE_{ipfv}$+++

… $_b$COME-BACK, IX_{3pl-d} STILL $_dLEAVE_{pfv}$++

16. FAIL (DECLINE/PERISH)

In one factory, there is a new management, but it's bad and the production has started to decline. Workers have been on strike for two months. Despite that, the factory has already failed.

ONE FACTORY NEW MANAGEMENT BAD, IX_d PRODUCTION START $FAIL_{ipfv}$… WORKERS TWO-MONTH STRIKE++…

… IN-VAIN, IX_d ALREADY $FAIL_{pfv}$

… IN-VAIN, IX_d STILL $FAIL_{ipfv}$

… IN-VAIN, IX_d ALREADY $FAIL_{ipfv}$

… IN-VAIN, IX_d STILL $FAIL_{pfv}$

17. LOCK

The door on my house has three locks. Now we are going on a trip, my wife is locking the door, but the last lock is stuck. I went to put the baby in the car. I came back to help her, but she had already locked up.

$POSS_1$ HOUSE DOOR HAVE THREE LOCK… IX_{1pl} PREPARE TRIP, $POSS_1$ WIFE IX_{3sg-b} $_b$LOCK, LAST $_b$STUCK… IX_1 $IX_{there-d}$ CAR BABY $LAY\text{-}DOWN_d$…

… $_d$COME-BACK $_1HELP_b$, IX_{3sg-b} ALREADY $LOCK_{pfv}$+

… $_d$COME-BACK $_1HELP_b$, IX_{3sg-b} STILL $LOCK_{ipfv}$+++

… $_d$COME-BACK $_1HELP_b$, IX_{3sg-b} ALREADY $LOCK_{ipfv}$+++

… $_d$COME-BACK $_1HELP_b$, IX_{3sg-b} STILL $LOCK_{pfv}$+

18. VACCINATE

Today, the doctor and the nurse came to my class to vaccinate the children. The nurse started to vaccinate them, and I went to the meeting. I came back in half an hour, and the nurse had already vaccinated them.

POSS$_1$ CLASS TODAY VACCINATE… DOCTOR NURSE COME, NURSE IX$_{3sg\text{-}b}$ START VACCINATE$_{ipfv}$++, IX$_1$ OUT$_d$ MEETING

… HALF-AN-HOUR PASS $_d$COME-BACK, IX$_{3sg\text{-}b}$ ALREADY VACCINATE$_{pfv}$++

… HALF-AN-HOUR PASS $_d$COME-BACK, IX$_{3sg\text{-}b}$ STILL VACCINATE$_{ipfv}$+++

… HALF-AN-HOUR PASS $_d$COME-BACK, IX$_{3sg\text{-}b}$ ALREADY VACCINATE$_{ipfv}$+++

… HALF-AN-HOUR PASS $_d$COME-BACK, IX$_{3sg\text{-}b}$ STILL VACCINATE$_{pfv}$++

19. DELIVER

I ordered a lot of clothes and shoes online; they told me it was shipped. After a week, the packages were already delivered to me.

IX$_{there\text{-}d}$ INTERNET DIFFERENT SHOE CLOTHES IX$_1$ ORDER++, IX$_d$ $_d$LET-KNOW$_1$ IX$_c$ $_d$SEND…

… ONE WEEK PASS, IX$_c$ ALREADY $_d$DELIVER$_{pfv}$+

… ONE WEEK PASS, IX$_c$ STILL $_d$DELIVER$_{ipfv}$++

… ONE WEEK PASS, IX$_c$ ALREADY $_d$DELIVER$_{ipfv}$++

… ONE WEEK PASS, IX$_c$ STILL $_d$DELIVER$_{pfv}$+

20. EXTINGUISH

Yesterday, a fire spread in Dalmatia, burning in many places, so firefighters spent the whole day putting it out. They already turned it off this morning.

YESTERDAY DALMATIA FIRE SPREAD BURN$_{DISTR}$, FIREFIGHTERS IX$_d$ WHOLE DAY PUT-OUT-WITH-A-HOSE$_{ipfv}$+++…

… TODAY MORNING IX$_d$ ALREADY EXTINGUISH$_{pfv}$++

… TODAY MORNING IX$_d$ STILL EXTINGUISH$_{ipfv}$+++

… TODAY MORNING IX$_d$ ALREADY EXTINGUISH$_{ipfv}$+++

… TODAY MORNING IX$_d$ STILL EXTINGUISH$_{pfv}$++

21. PAY

Earlier I bought a flat on credit, I pay monthly instalments of 500 euros. After 15 years, I have already paid it off.

BEFORE IX_1 TAKE CREDIT, BUY FLAT, MONTH++ 500 EURO PAY_{ipfv}+++…

… FIFTEEN YEAR PASS, IX_1 ALREADY PAY_{pfv}+

… FIFTEEN YEAR PASS, IX_1 STILL PAY_{ipfv}+++

… FIFTEEN YEAR PASS, IX_1 ALREADY PAY_{ipfv}+++

… FIFTEEN YEAR PASS, IX_1 STILL PAY_{pfv}+

22. DESTROY

One director destroys the company and commits fraud, so the union sued him. In vain, he had already destroyed it.

ONE COMPANY $DIRECTOR_b$ FRAUD $DESTROY_{ipfv}$+++, UNION SUE_d…

… IN-VAIN, $IX3_{sg\text{-}b}$ ALREADY $DESTROY_{pfv}$+

… IN-VAIN, $IX3_{sg\text{-}b}$ STILL $DESTROY_{ipfv}$+++

… IN-VAIN, $IX3_{sg\text{-}b}$ ALREADY $DESTROY_{ipfv}$+++

… IN-VAIN, $IX3_{sg\text{-}b}$ STILL $DESTROY_{pfv}$+

23. SELL (PROPERTY)

I'm moving to a new apartment, but I have too many books, so I started selling them. After a month, I already sold them.

IX_1 MOVE NEW FLAT, BUT PROBLEM BOOK A-LOT CL-B: stacked-books… IX_1 START $SELL_{ipfv}$+++

… ONE-MONTH PASS, IX_1 ALREADY $SELL_{pfv}$+

… ONE-MONTH PASS, IX_1 STILL $SELL_{ipfv}$+++

… ONE-MONTH PASS, IX_1 ALREADY $SELL_{ipfv}$+++

… ONE-MONTH PASS, IX_1 STILL $SELL_{pfv}$+

24. SEND-LETTER

A new law on inclusive benefit was passed and the Institute for Social Welfare started sending decisions to people with disabilities. After a month, they had already sent them.

NOW NEW LAW PERSON DISABILITY MONEY BENEFIT, I-D, SOCIAL-WELFARE $_{d}$INSTITUTE DECISION++ START SEND-LETTER$_{ipfv}$+++…

… TWO-MONTH PASS, IX$_{d}$ ALREADY SEND-LETTER$_{pfv}$++

… TWO-MONTH PASS, IX$_{d}$ STILL SEND-LETTER$_{ipfv}$+++

… TWO-MONTH PASS, IX$_{d}$ ALREADY SEND-LETTER$_{ipfv}$+++

… TWO-MONTH PASS, IX$_{d}$ STILL SEND-LETTER$_{pfv}$++

25. FLEE

There was a dangerous earthquake in Japan, the government announced that people living along the coast must evacuate immediately. After an hour, they had already fled.

IX$_{there\text{-}d}$ JAPAN EARTHQUAKE DANGEROUS, GOVERNMENT INFORM PEOPLE LIVE BY SEA IX$_{3pl\text{-}c}$ MUST FLEE$_{ipfv}$++…

… ONE-HOUR PASS, IX$_{3pl\text{-}c}$ ALREADY FLEE$_{pfv}$+

… ONE-HOUR PASS, IX$_{3pl\text{-}c}$ STILL FLEE$_{ipfv}$++

… ONE-HOUR PASS, IX$_{3pl\text{-}c}$ ALREADY FLEE$_{ipfv}$++

… ONE-HOUR PASS, IX$_{3pl\text{-}c}$ STILL FLEE$_{pfv}$+

26. GIVE-GIFT

Saint Nicholas came to the kindergarten and is giving gifts to the children. The principal wants to take a photo, but she doesn't have her cell phone with her, so she went to get it. When she returned, he had already shared them.

$_{b}$KINDERGARTEN SAINT-NICHOLAS COME$_{b}$, CHILDREN IX$_{3sg\text{-}b}$ GIVE-GIFT$_{ipfv}$+++ … PRINCIPAL WANT TAKE-PHOTO, NOT-HAVE-HERE CELL-PHONE, HEAD-TO$_{d}$…

… $_{d}$COME-BACK, IX$_{3sg\text{-}b}$ ALREADY GIVE-GIFT$_{pfv}$++

… $_{d}$COME-BACK, IX$_{3sg\text{-}b}$ STILL GIVE-GIFT$_{ipfv}$+++

… $_{d}$COME-BACK, IX$_{3sg\text{-}b}$ ALREADY GIVE-GIFT$_{ipfv}$+++

… $_{d}$COME-BACK, IX$_{3sg\text{-}b}$ STILL GIVE-GIFT$_{pfv}$++

27. SIGN

I am a professor, students who come to the lecture must sign the sheet. I gave them the paper, they started to sign. I forgot a book so I went to get it. When I came back, they had already signed.

IX$_1$ PROFESSOR, NOW LECTURE, STUDENTS WHO COME MUST SIGN… PAPER GIVE$_d$ IX$_{3pl\text{-}d}$ START SIGN$_{ipfv}$+++… IX$_1$ FORGET ONE BOOK, HEAD-TO$_b$...

…$_b$COME-BACK, IX$_{3pl\text{-}d}$ ALREADY SIGN$_{pfv}$++

…$_b$COME-BACK, IX$_{3pl\text{-}d}$ STILL SIGN$_{ipfv}$+++

…$_b$COME-BACK, IX$_{3pl\text{-}d}$ ALREADY SIGN$_{ipfv}$+++

…$_b$COME-BACK, IX$_{3pl\text{-}d}$ STILL SIGN$_{pfv}$++

28. SELL (x-th-adj)

My daughter has grown and has too many toys that just sit there. Our apartment is small and there is a lack of space, so I started selling them on the Internet. After a month, I already sold them.

POSS$_1$ DAUGHTER GROW-UP, TOYS PILE SIT-THERE, POSS$_1$ FLAT SMALL NO-SPACE, $_d$INTERNET TOYS IX$_1$ START SELL$_{ipfv}$+++…

… ONE-MONTH PASS, IX$_1$ ALREADY SELL$_{pfv}$+

… ONE-MONTH PASS, IX$_1$ STILL SELL$_{ipfv}$+++

… ONE-MONTH PASS, IX$_1$ ALREADY SELL$_{ipfv}$+++

… ONE-MONTH PASS, IX$_1$ STILL SELL$_{pfv}$+

29. PULL-OUT

One man started to drown in the sea, but another man swam and started to pull him out. I saw it and ran for help. When we returned, the man had already pulled it out.

IX$_{there\text{-}b}$ SEA ONE MAN START-TO-DROWN, OTHER MAN SWIM$_b$ TRY PULL-OUT$_b$… IX$_1$ SEE$_b$ RUN$_d$ CALL$_d$ HELP…

… $_d$TOGETHER-COME-BACK$_b$, IX$_{3sg\text{-}b}$ ALREADY PULL-OUT$_{pfv}$+

… $_d$TOGETHER-COME-BACK$_b$, IX$_{3sg\text{-}b}$ STILL PULL-OUT$_{ipfv}$+++

… $_d$TOGETHER-COME-BACK$_b$, IX$_{3sg\text{-}b}$ ALREADY PULL-OUT$_{ipfv}$+++

… $_d$TOGETHER-COME-BACK$_b$, IX$_{3sg\text{-}b}$ STILL PULL-OUT$_{pfv}$+

30. BREAK-THROUGH

I live in Istria and the highway is always crowded because the second tube of the Učka tunnel takes a long time to break through. Last year I moved to America. Now I came back for Christmas and saw that they had already broken it.

IX$_{1}$ LIVE IX$_{there-b}$ ISTRIA, ALWAYS CROWD HIGHWAY BECAUSE TUNNEL U-Č-K-A OTHER DIRECTION ONE COMPANY$_{d}$ LONG BREAK-THROUGH$_{ipfv}$+++… LAST YEAR IX$_{1}$ MOVE IX$_{there-b}$ AMERICA…

… NOW CHRISTMAS $_{b}$COME, SEE$_{d}$ IX$_{3sg-d}$ ALREADY BREAK-THROUGH$_{pfv}$+

… NOW CHRISTMAS $_{b}$COME, SEE$_{d}$ IX$_{3sg-d}$ STILL BREAK-THROUGH$_{ipfv}$+++

… NOW CHRISTMAS $_{b}$COME, SEE$_{d}$ IX$_{3sg-d}$ ALREADY BREAK-THROUGH$_{ipfv}$+++

… NOW CHRISTMAS $_{b}$COME, SEE$_{d}$ IX$_{3sg-d}$ STILL BREAK-THROUGH$_{pfv}$+

31. MEET

I am a teacher and a new student from Ukraine came to my class. The children started to get to know each other, but the director invited me outside for a short time to make arrangements. When I came back, they had already met.

IX$_{1}$ TEACHER, POSS$_{1}$ CLASS NEW STUDENT COME-FROM UKRAINE, CHILDREN IX$_{3pl-c}$ START MEET$_{ipfv}$+++… PRINCIPAL $_{3d}$INVITE$_{1}$ SHORT ARRANGEMENT$_{d}$…

… $_{d}$COME-BACK, IX$_{3pl-c}$ ALREADY MEET$_{pfv}$++

… $_{d}$COME-BACK, IX$_{3pl-c}$ STILL MEET$_{ipfv}$+++

… $_{d}$COME-BACK, IX$_{3pl-c}$ ALREADY MEET$_{ipfv}$+++

… $_{d}$COME-BACK, IX$_{3pl-c}$ STILL MEET$_{pfv}$++

32. TIDY-UP

My daughter's birthday is today, her friends will come to celebrate, but her room is a mess. She started cleaning, and I went to the store. When I came back, she had already cleaned it.

POSS$_{1}$ DAUGHTER TODAY BIRTHDAY, POSS$_{3sg-b}$ FRIENDS WILL GATHER CELEBRATE BUT POSS$_{3sg-b}$ ROOM MESSY, IX$_{3sg-b}$ START TIDY-UP$_{ipfv}$+++ IX$_{1}$ LEAVE$_{d}$ STORE…

… $_{d}$COME-BACK, IX$_{3sg-b}$ ALREADY TIDY-UP$_{pfv}$++

… $_{d}$COME-BACK, IX$_{3sg-b}$ STILL TIDY-UP$_{ipfv}$+++

… $_{d}$COME-BACK, IX$_{3sg-b}$ ALREADY TIDY-UP$_{ipfv}$+++

… $_{d}$COME-BACK, IX$_{3sg-b}$ STILL TIDY-UP$_{pfv}$++

33. GIVE-BIRTH

My wife is pregnant with twins, and her water broke. I rushed her to the hospital. After two hours, she already gave birth.

POSS$_1$ WIFE PREGNANT TWINS CL-5: big-belly, WATER BREAK, TWO-OF-US$_b$ URGENT GO-TO-HOSPITAL$_b$…

… TWO-HOURS PASS, IX$_{3sg-b}$ ALREADY GIVE-BIRTH$_{pfv}$+

… TWO-HOURS PASS, IX$_{3sg-b}$ STILL GIVE-BIRTH$_{ipfv}$+++

… TWO-HOURS PASS, IX$_{3sg-b}$ ALREADY GIVE-BIRTH$_{ipfv}$+++

… TWO-HOURS PASS, IX$_{3sg-b}$ STILL GIVE-BIRTH$_{pfv}$+

34. TRANSLATE

The English teacher gave my son a punishment for tardiness, he has to translate 30 sentences. When he returned home, he began to translate them. After an hour I checked how it was going, he had already translated them.

TEACHER ENGLISH GIVE PUNISHMENT POSS$_1$ SON BECAUSE SLACK-OFF, IX$_{3sg-d}$ MUST THIRTY SENTENCES TRANSLATE… $_d$COME HOME, START TRANSLATE$_{ipfv}$+++…

… ONE-HOUR LATER, IX$_1$ CHECK, IX$_{3sg-d}$ ALREADY TRANSLATE$_{pfv}$+

… ONE-HOUR LATER, IX$_1$ CHECK, IX$_{3sg-d}$ STILL TRANSLATE$_{ipfv}$+++

… ONE-HOUR LATER, IX$_1$ CHECK, IX$_{3sg-d}$ ALREADY TRANSLATE$_{ipfv}$+++

… ONE-HOUR LATER, IX$_1$ CHECK, IX$_{3sg-d}$ STILL TRANSLATE$_{pfv}$+

35. TRANSLATE

I am preparing to move to Germany, but first I need to translate the documents. I sent them for translation and it was agreed that they should start translating. After a week I visited them, they had already translated.

IX$_1$ PREPARE MOVE$_d$ GERMANY, BUT FIRST DOCUMENT++ MUST TRANSLATE$_{PFV}$+… SEND$_b$ AGREEMENT IX$_{3sg-b}$ START TRANSLATE$_{ipfv}$+++…

… ONE WEEK PASS, IX$_1$ VISIT$_b$, IX$_{3sg-b}$ ALREADY TRANSLATE$_{pfv}$+

… ONE WEEK PASS, IX$_1$ VISIT$_b$, IX$_{3sg-b}$ STILL TRANSLATE$_{ipfv}$+++

… ONE WEEK PASS, IX$_1$ VISIT$_b$, IX$_{3sg-b}$ ALREADY TRANSLATE$_{ipfv}$+++

… ONE WEEK PASS, IX_1 $VISIT_b$, $IX_{3sg\text{-}b}$ STILL $TRANSLATE_{pfv}$+

36. BOARD

The students are getting ready for the trip, getting on the bus. The teacher forgot the list, so he went to the school to get it. When he returned, the students had already boarded the bus.

$IX_{there\text{-}b}$ SCHOOL CHILDREN PREPARE JOURNEY EXCURSION, NOW BUS $IX_{3pl\text{-}c}$ $BOARD_{ipfv}$+++…

TEACHER FORGET PAPER LIST, HEAD-TO_b…

… $_b$COME-BACK, $IX_{3pl\text{-}c}$ ALREADY $BOARD_{pfv}$++

… $_b$COME-BACK, $IX_{3pl\text{-}c}$ STILL $BOARD_{ipfv}$+++

… $_b$COME-BACK, $IX_{3pl\text{-}c}$ ALREADY $BOARD_{ipfv}$+++

… $_b$COME-BACK, $IX_{3pl\text{-}c}$ STILL $BOARD_{pfv}$++

11. APPENDIX D

Sentences with classifier predicates

1. CL-C: reach-thick-object (a thick book)

The history teacher wants to take down a thick book from a high shelf, he tries to reach it. A student approached him to help him, but the teacher already took it off himself.

ONE TEACHER HISTORY TEACH, $IX_{3sg\text{-}b}$ WANT BOOK SHELF HIGH CL-C: $\text{reach-thick-object}_{ipfv}$+++

… ONE STUDENT $_{d}$COME HELP, $IX_{3sg\text{-}b}$ ALREADY CL-C: $\text{reach-thick-object}_{pfv}$++

… ONE STUDENT $_{d}$COME HELP, $IX_{3sg\text{-}b}$ STILL CL-C: $\text{reach-thick-object}_{ipfv}$+++

… ONE STUDENT $_{d}$COME HELP, $IX_{3sg\text{-}b}$ ALREADY CL-C: $\text{reach-thick-object}_{ipfv}$+++

… ONE STUDENT $_{d}$COME HELP, $IX_{3sg\text{-}b}$ STILL CL-C: $\text{reach-thick-object}_{pfv}$++

2. CL-C: put-round-object (a bread loaf)

I work in a store, a new colleague has arrived. He is putting the bread on the shelves, but he is very slow, so I asked him if he needed help, he said no, he would do it himself. I said "OK" and went to sweep. In 10 minutes I saw that he had already putt everything on the shelf.

IX_1 WORK $IX_{there\text{-}d}$ STORE, COME NEW WORKER… SHELF BREAD $IX_{3sg\text{-}d}$ CL-C: put_{ipfv}+++, IX_1 $_{1}ASK_{d}$ NEED HELP, NO, $ALONE_{role\text{-}shift\text{-}b}$, "AH" IX_1 $SWEEP_{b}$…

… TEN MINUTE PASS, $_{1}SEE_{d}$ $IX_{3sg\text{-}d}$ ALREADY CL-C: $\text{put-round-object}_{pfv}$++

… TEN MINUTE PASS, $_{1}SEE_{d}$ $IX_{3sg\text{-}d}$ STILL CL-C: $\text{put-round-object}_{ipfv}$+++

… TEN MINUTE PASS, $_{1}SEE_{d}$ $IX_{3sg\text{-}d}$ ALREADY CL-C: $\text{put-round-object}_{ipfv}$+++

… TEN MINUTE PASS, $_{1}SEE_{d}$ $IX_{3sg\text{-}d}$ STILL CL-C: $\text{put-round-object}_{pfv}$++

3. CL-C: stack-square-objects (a stack of bills)

The police seized a lot of smuggled money at the border. Now they are preparing for filming the journalists, the policeman is stacking a lot of banknotes. The journalists came, and he told them to wait outside for 15 minutes. When they returned, he had already put all banknotes.

$IX_{there\text{-}d}$ BORDER POLICE STOP MONEY SMUGGLE SEIZE… NOW PREPARE PRESS RECORD, POLICE-MAN_{d} TABLE CL_{SASS}: stack-papers CL-C: stack_{ipfv}+++… PRESS COME $_{b}COME_{d}$, $IX_{3sg\text{-}d}$ $_{d}TELL_{b}$ WAIT $OUTSIDE_{d}$ FIFTEEN MINUTE…

… $IX_{3pl\text{-}b}$ $_{b}$COME-BACK, $IX_{3sg\text{-}d}$ ALREADY CL-C: $\text{stack-square-objects}_{pfv}$++

… IX$_{3pl\text{-}b}$ $_{b}$COME-BACK, IX$_{3sg\text{-}d}$ STILL CL-C: stack-square-objects$_{ipfv}$+++

… IX$_{3pl\text{-}b}$ $_{b}$COME-BACK, IX$_{3sg\text{-}d}$ ALREADY CL-C: stack-square-objects$_{ipfv}$+++

… IX$_{3pl\text{-}b}$ $_{b}$COME-BACK, IX$_{3sg\text{-}d}$ STILL CL-C: stack-square-objects$_{pfv}$++

4. CL-FLAT-O: pull-thin-object (a thin book)

I have a pile of books in my room, I need one from the bottom, but I can't get it out. I called my brother for help, but he was gone for a long time. When he came, I had already pulled it out.

POSS$_{1}$ ROOM BOOK CL$_{SASS}$: pile, IX$_{1}$ NEED LAST CL-FLAT-O: pull$_{ipfv}$+++, CALL$_{d}$ BROTHER$_{d}$ HELP, NOT-HERE$_{d}$, “ah” IX$_{1}$ TRY CL-FLAT-O: pull-thin-object$_{ipfv}$+++…

… $_{d}$COME, IX$_{1}$ ALREADY CL-FLAT-O: pull-thin-object$_{pfv}$+

… $_{d}$COME, IX$_{1}$ STILL CL-FLAT-O: pull-thin-object$_{ipfv}$+++

… $_{d}$COME, IX$_{1}$ ALREADY CL-FLAT-O: pull-thin-object$_{ipfv}$+++

… $_{d}$COME, IX$_{1}$ STILL CL-FLAT-O: pull-thin-object$_{pfv}$+

5. CL-FLAT-O: give-flat-object (a consent paper)

Students from my class are going to the graduation trip, I had one student hand out a paper for parental consent and went out to answer the phone. When I came back, the student had already distributed them.

IX$_{1}$ TEACHER, POSS$_{1}$ CLASS PREPARE EXAM TRIP, PARENT MUST SIGN CONSENT… NOW ONE STUDENT IX$_{3sg\text{-}b}$ PAPERS CL-FLAT-O: give-flat-object$_{ipfv}$+++… IX$_{1}$ OUT$_{d}$ TELEPHONE…

… $_{d}$COME-BACK, IX$_{3sg\text{-}b}$ ALREADY CL-FLAT-O: give-flat-object$_{pfv}$++

… $_{d}$COME-BACK, IX$_{3sg\text{-}b}$ STILL CL-FLAT-O: give-flat- object$_{ipfv}$+++

… $_{d}$COME-BACK, IX$_{3sg\text{-}b}$ ALREADY CL-FLAT-O: give-flat- object$_{ipfv}$+++

… $_{d}$COME-BACK, IX$_{3sg\text{-}b}$ STILL CL-FLAT-O: give-flat-object$_{pfv}$++

6. CL-FLAT-O: give-flat-object (a diploma)

My son graduated and today he has a graduation ceremony at the university. After the ceremony, we will go to a restaurant for lunch. The presiding officer hands out diplomas, but he is old and quite slow. After an hour, he had already handed them.

POSS$_{1}$ SON STUDY FINISH, IX$_{there\text{-}b}$ CEREMONY DIPLOMA CL$_{SASS}$: square-objects CL-FLAT-O: give-flat-object$_{ipfv}$+++… LATER POSS$_{1}$ FAMILY CELEBRATE, BUT IX$_{3sg\text{-}b}$ PERSON CL-FLAT-O: give-flat-object, LONG-TIME CL-FLAT-O: give-flat-object$_{ipfv}$+++

… ONE-HOUR PASS, $IX_{3sg\text{-}b}$ ALREADY CL-FLAT-O: give-flat-object$_{pfv}$++

… ONE-HOUR PASS, $IX_{3sg\text{-}b}$ STILL CL-FLAT-O: give-flat-object$_{ipfv}$+++

… ONE-HOUR PASS, $IX_{3sg\text{-}b}$ ALREADY CL-FLAT-O: give-flat-object$_{ipfv}$+++

… ONE-HOUR PASS, $IX_{3sg\text{-}b}$ STILL CL-FLAT-O: give-flat-object$_{pfv}$++

7. CL-BABY-O-FLAT-EXT: take-out-thin-object (lettuce)

The child eats a sandwich for breakfast, but he doesn't like lettuce, so he immediately started to take it out. Father warned him and turned to make coffee. After that he saw that the child had already taken it out.

NOW MORNING, ONE $CHILD_d$ EAT SANDWICH, BUT $IX_{3sg\text{-}d}$ NOT-LIKE GREEN LETTUCE, IMMEDIATELY CL-BABY-O-FLAT-EXT: take-out-thin-object$_{ipfv}$+++ … FATHER WARN, TURN $MAKE_b$ $COFFEE_b$…

… THEN SEE_d, $IX_{3sg\text{-}d}$ ALREADY CL-BABY-O-FLAT-EXT: take-out-thin-object$_{pfv}$+

… THEN SEE_d, $IX_{3sg\text{-}d}$ STILL CL-BABY-O-FLAT-EXT: take-out-thin-object$_{ipfv}$+++

… THEN SEE_d, $IX_{3sg\text{-}d}$ ALREADY CL-BABY-O-FLAT-EXT: take-out-thin-object$_{ipfv}$+++

… THEN SEE_d, $IX_{3sg\text{-}d}$ STILL CL-BABY-O-FLAT-EXT: take-out-thin-object$_{pfv}$+

8. CL-BABY-O-FLAT-EXT: give-thin-object (a flower)

Today is Women's Day. In one company, they remembered to give roses, the director is now distributing them. The secretary wanted to take a photo, but as he left his mobile phone in the office, he went to get it. When he returned, the director had already given them.

TODAY DAY WOMEN… ONE COMPANY REMEMBER WANT GIVE++ ROSE, DIRECTOR $IX_{3sg\text{-}b}$ NOW CL-BABY-O-FLAT-EXT: give-thin-object$_{ipfv}$+++… SECRETARY WANT TAKE-PHOTO, NOT-HAVE-HERE MOBILE-PHONE, $HEAD\text{-}TO_d$...

… $_d$COME-BACK, $IX_{3sg\text{-}b}$ ALREADY CL-BABY-O-FLAT-EXT: give-thin-object$_{pfv}$++

… $_d$COME-BACK, $IX_{3sg\text{-}b}$ STILL CL-BABY-O-FLAT-EXT: give-thin- object$_{ipfv}$+++

… $_d$COME-BACK, $IX_{3sg\text{-}b}$ ALREADY CL-BABY-O-FLAT-EXT: give-thin- object$_{ipfv}$+++

… $_d$COME-BACK, $IX_{3sg\text{-}b}$ STILL CL-BABY-O-FLAT-EXT: give-thin-object$_{pfv}$++

9. CL-BABY-O-FLAT-EXT: take-out-small-objects-with-fingers (peas)

I cooked pea soup, gave my son a plate, but my son doesn't like peas and he started taking it out of the plate. I waved my hand and went to check the stove. When I came back, he had already taken it out.

IX$_1$ COOK SOUP HAVE PEA, GIVE$_d$ SON EAT, BUT IX$_{3sg-d}$ NOT-LIKE EAT, IMMEDIATELY CL-BABY-O-FLAT-EXT: take-out-small-objects-with-fingers$_{ipfv}$+++, “well”, IX$_1$ CHECK $_b$COOK…

… $_d$COME-BACK, IX$_{3sg-d}$ ALREADY CL-BABY-O-FLAT-EXT: take-out-small-objects-with-fingers$_{pfv}$++

… $_d$COME-BACK, IX$_{3sg-d}$ STILL CL-BABY-O-FLAT-EXT: take-out-small-objects-with-fingers$_{ipfv}$+++

… $_d$COME-BACK, IX$_{3sg-d}$ ALREADY CL-BABY-O-FLAT-EXT: take-out-small-objects-with-fingers$_{ipfv}$+++

… $_d$COME-BACK, IX$_{3sg-d}$ STILL CL-BABY-O-FLAT-EXT: take-out-small-objects-with-fingers$_{pfv}$++

10. CL-S: give-cylindrical-object (an ice-cream cone)

At the children's birthday party, father gives out ice creams to the children. Mom said they can't have it before lunch because now they're going to eat pizza. Father overheard that; he already gave them away.

CHILDREN CELEBRATE BIRTHDAY, FATHER IX$_{3sg-b}$ ICE-CREAM CL-S: give-cylindrical-object$_{ipfv}$+++… MOM SAY STOP, NOW PIZZA…

… OVERHEAR, IX$_{3sg-b}$ ALREADY CL-S: give-cylindrical-object$_{pfv}$++

… OVERHEAR, IX$_{3sg-b}$ STILL CL-S: give-cylindrical-object$_{ipfv}$+++

… OVERHEAR, IX$_{3sg-b}$ ALREADY CL-S: give-cylindrical-object$_{ipfv}$+++

… OVERHEAR, IX$_{3sg-b}$ STILL CL-S: give-cylindrical-object$_{pfv}$++

11. CL-S: give-cylindrical-object (a bouquet)

An actor friend invited me to the premiere of the play, later there will be a gathering. After the play, the actors came on stage, the director is giving them bouquets, and I went outside to smoke. When I came back, he had already given them.

POSS$_1$ FRIEND ACTOR $_3$INVITE$_1$ NEW PLAY WATCH, FINISH LATER GATHERING… ACTING FINISH, NOW ACTOR++ IN-LINE, DIRECTOR IX$_{3sg\text{-}d}$ FLOWER CL-S: give-cylindrical-object$_{ipfv}$+++, IX$_1$ OUT$_b$ SMOKE…

… $_d$COME-BACK, IX$_{3sg\text{-}d}$ ALREADY CL-S: give-cylindrical-object$_{pfv}$++

… $_d$COME-BACK, IX$_{3sg\text{-}d}$ STILL CL-S: give-cylindrical-object$_{ipfv}$+++

… $_d$COME-BACK, IX$_{3sg\text{-}d}$ ALREADY CL-S: give-cylindrical-object$_{ipfv}$+++

… $_d$COME-BACK, IX$_{3sg\text{-}d}$ STILL CL-S: give-cylindrical-object$_{pfv}$++

12. CL-S: move-cylindrical-object (a gear lever)

Father started the car in the garage and went to put the transmission in gear, but it got stuck. He told me to call the workman, so I went out to make a phone call. When I got back, he had already put the transmission into gear.

IX$_{there\text{-}b}$ GARAGE, FATHER$_b$ CAR START, GEAR-LEVER STUCK, CL-S: move-cylindrical-object$_{ipfv}$+++… $_{3b}$TELL$_1$ WORKMAN CALL, IX$_1$ OUT$_d$ TELEPHONE…

… $_d$COME-BACK, IX$_{3sg\text{-}b}$ ALREADY CL-S: move-cylindrical-object$_{pfv}$+

… $_d$COME-BACK, IX$_{3sg\text{-}b}$ STILL CL-S: move-cylindrical-object$_{ipfv}$+++

… $_d$COME-BACK, IX$_{3sg\text{-}b}$ ALREADY CL-S: move-cylindrical-object$_{ipfv}$+++

… $_d$COME-BACK, IX$_{3sg\text{-}b}$ STILL CL-S: move-cylindrical-object$_{pfv}$+

13. CL-BENT-5: give-round-object (an apple)

I brought a group of tourists to visit the oldest orchard in Croatia. The owner started giving them apples as a gift. I wanted to take a photo, but I forgot my mobile phone on the bus, so I went to get it. When I came back, he had already given them.

IX$_1$ LEAD ONE GROUP TOURISTS VISIT$_b$ ORCHARD, IX$_{here}$ CROATIA OLDEST ORCHARD VISIT… IX$_{3sg\text{-}b}$ OWNER GIFT APPLE CL-BENT-5: give-round-object$_{ipfv}$+++, IX$_1$ WANT TAKE-PHOTO, FORGET MOBILE-PHONE $_d$BUS, HEAD-TO$_d$…

… $_d$COME-BACK, IX$_{3sg\text{-}b}$ ALREADY CL-BENT-5: give-round-object$_{pfv}$++

… $_d$COME-BACK, IX$_{3sg\text{-}b}$ STILL CL-BENT-5: give-round-object$_{ipfv}$+++

… $_d$COME-BACK, IX$_{3sg\text{-}b}$ ALREADY CL-BENT-5: give-round-object$_{ipfv}$+++

… $_d$COME-BACK, IX$_{3sg\text{-}b}$ STILL CL-BENT-5: give-round-object$_{pfv}$++

14. CL-BENT-5: give-round-object (a chocolate egg)

Santa Claus came to the hospital and he is giving chocolate eggs to the children. It was agreed earlier that a journalist would come to film, but he informed me that he got lost somewhere, so I went to help him. When we returned, he had already gave them.

IX$_{\text{there-b}}$ HOSPITAL COME SANTA CLAUS, IX$_{\text{3sg-b}}$ CHOCOLATE EGG CHILDREN CL-BENT-5: give-round-object$_{\text{ipfv}}$+++… BEFORE ARRANGE JOURNALIST FILM, $_{\text{3d}}$LET-KNOW$_{\text{1}}$ LOST WANDER, IX$_{\text{1}}$ GO$_{\text{d}}$ HELP…

… $_{\text{d}}$TOGETHER-COME-BACK, IX$_{\text{3sg-b}}$ ALREADY CL-BENT-5: give-round-object$_{\text{pfv}}$++

… $_{\text{d}}$TOGETHER-COME-BACK, IX$_{\text{3sg-b}}$ STILL CL-BENT-5: give-round- object$_{\text{ipfv}}$+++

… $_{\text{d}}$TOGETHER-COME-BACK, IX$_{\text{3sg-b}}$ ALREADY CL-BENT-5: give-round- object$_{\text{ipfv}}$+++

… $_{\text{d}}$TOGETHER-COME-BACK, IX$_{\text{3sg-b}}$ STILL CL-BENT-5: give-round-object$_{\text{pfv}}$++

15. CL-BENT-5: give-round-object (a bauble)

I am a teacher and for Christmas I bought baubles for the students, everyone will get one. Another colleague came to help me give them to students, but I had to go to the toilet. When I came back, she had already distributed them.

IX$_{\text{1}}$ TEACHER, BUY CHRISTMAS BAUBLES, GIFT CHILDREN EACH GET ONE… ANOTHER$_{\text{b}}$ TEACHER $_{\text{3b}}$HELP$_{\text{1}}$ TOGETHER CL-BENT-5: give-round-object$_{\text{ipfv}}$+++, IX$_{\text{1}}$ HAVE-TO-GO TOILET$_{\text{d}}$…

… $_{\text{d}}$COME-BACK, IX$_{\text{3sg-b}}$ ALREADY CL-BENT-5: give-round-object$_{\text{pfv}}$++

… $_{\text{d}}$COME-BACK, IX$_{\text{3sg-b}}$ STILL CL-BENT-5: give-round-object$_{\text{ipfv}}$+++

… $_{\text{d}}$COME-BACK, IX$_{\text{3sg-b}}$ ALREADY CL-BENT-5: give-round-object$_{\text{ipfv}}$+++

… $_{\text{d}}$COME-BACK, IX$_{\text{3sg-b}}$ STILL CL-BENT-5: give-round-object$_{\text{pfv}}$++

16. CL-X-TH-ADJ: turn-handle (a screwdriver)

My family bought a new wardrobe, father and I put it together and he is screwing the parts. I went to the store to buy us something to eat. When I came back, he had already screwed it up.

POSS$_{\text{1}}$ FAMILY BUY NEW WARDROBE, FATHER TWO-OF-US$_{\text{b}}$ PUT-TOGETHER, NOW IX$_{\text{3sg-b}}$ CL-X-TH-ADJ: turn-handle$_{\text{ipfv}}$+++… IX$_{\text{1}}$ OUT$_{\text{d}}$ SOMETHING BUY EAT…

… $_{\text{d}}$COME-BACK, IX$_{\text{3sg-b}}$ ALREADY CL-X-TH-ADJ: turn-handle$_{\text{pfv}}$++

… $_{\text{d}}$COME-BACK, IX$_{\text{3sg-b}}$ STILL CL-X-TH-ADJ: turn-handle$_{\text{ipfv}}$+++

… $_{\text{d}}$COME-BACK, IX$_{\text{3sg-b}}$ ALREADY CL-X-TH-ADJ: turn-handle$_{\text{ipfv}}$+++

… $_d$COME-BACK, IX3_{sg-b} STILL CL-X-TH-ADJ: turn-handle$_{pfv}$++

17. CL-X-TH-ADJ: handle-a-handle (a sword)

I'm watching a historical film in the cinema, two knights are fighting, one good, the other evil. The good one fought and fenced for a long time. I got bored of that, so I went to buy popcorn. When I came back, the good one already pierced the evil one.

IX$_{there-d}$ CINEMA, IX$_1$ WATCH HISTORY FILM, TWO KNIGHT, ONE$_b$ GOOD$_b$, OTHER$_d$ EVIL$_d$, CLASH… IX3_{sg-b} LONG FIGHT CL-X-TH-ADJ: handle-a-handle$_{ipfv}$, IX$_1$ FED-UP, OUT$_d$ BUY POPCORN…

… $_d$COME-BACK, IX3_{sg-b} ALREADY CL-X-TH-ADJ: handle-a-handle$_{pfv}$

… $_d$COME-BACK, IX3_{sg-b} STILL CL-X-TH-ADJ: handle-a-handle$_{ipfv}$

… $_d$COME-BACK, IX3_{sg-b} ALREADY CL-X-TH-ADJ: handle-a-handle$_{ipfv}$

… $_d$COME-BACK, IX3_{sg-b} STILL CL-X-TH-ADJ: handle-a-handle$_{pfv}$

18. CL-X-TH-ADJ: throw-small-object (a marble)

My brother and I are playing in the sandpit in the park, throwing a bunch of pickles into the hole. Dad invited us for ice cream, but my brother stayed to play, and I went with dad. When we returned, my brother had already put them in.

IX$_{there-d}$ PARK SAND AREA, BROTHER$_d$ TWO-OF-US PLAY MARBLE PILE HOLE CL-X-TH-ADJ: throw-small-object$_{ipfv}$+++… FATHER $_3$LET-KNOW$_1$ COME-ON ICE-CREAM, BROTHER$_d$ MORE PLAY CL-X-TH-ADJ: throw-small-object, HE-I$_b$ GO$_{there-b}$…

… $_b$TOGETHER-COME-BACK, IX3_{sg-d} ALREADY CL-X-TH-ADJ: throw-small-object$_{pfv}$++

… $_b$TOGETHER-COME-BACK, IX3_{sg-d} STILL CL-X-TH-ADJ: throw-small-object$_{ipfv}$+++

… $_b$TOGETHER-COME-BACK, IX3_{sg-d} ALREADY CL-X-TH-ADJ: throw-small-object$_{ipfv}$+++

… $_b$TOGETHER-COME-BACK, IX3_{sg-d} STILL CL-X-TH-ADJ: throw-small-object$_{pfv}$++

19. CL-S: lift-cylindrical-object (a barbell)

At the gym, my friend is lifting a heavy weight. I want to record it, but since I left my mobile phone behind, I rushed to get it. When I came back, he had already lift it up.

IX$_{there-d}$ GYM, POSS$_1$ FRIEND IX3_{sg-d} WEIGHT HEAVY CL-S: lift-cylndrical-object$_{ipfv}$… IX$_1$ WANT FILM, FORGET MOBILE-PHONE IX$_{there-b}$ RUSH$_b$…

… $_b$COME-BACK, IX3_{sg-d} ALREADY CL-S: lift-cylndrical-object$_{pfv}$

… $_{b}$COME-BACK, IX$_{3sg-d}$ STILL CL-S: lift-cylndrical-object$_{ipfv}$

… $_{b}$COME-BACK, IX$_{3sg-d}$ ALREADY CL-S: lift-cylndrical-object$_{ipfv}$

… $_{b}$COME-BACK, IX$_{3sg-d}$ STILL CL-S: lift-cylndrical-object$_{pfv}$

20. CL-S: place-big-cylindrical-object (a sunshade)

I'm lying and sunbathing on the beach. A family came right next to me, and a man was trying to put up a sunshade. I was hot so I went to buy ice cream. When I came back, he had already set it up.

IX$_{there-d}$ SEA, IX$_{1}$ SUNBATHE LIE… ONE FAMILY COME RIGHT-NEXT-TO-ME$_{d}$, MAN IX$_{3sg-d}$ SUNSHADE CL-S: place-big-cylindrical-object$_{ipfv}$… IX$_{1}$ HOT, HEAD-TO$_{b}$ ICE-CREAM…

… $_{b}$COME-BACK, IX$_{3sg-d}$ ALREADY CL-S: place-big-cylindrical-object$_{pfv}$

… $_{b}$COME-BACK, IX$_{3sg-d}$ STILL CL-S: place-big-cylindrical-object$_{ipfv}$

… $_{b}$COME-BACK, IX$_{3sg-d}$ ALREADY CL-S: place-big-cylindrical-object$_{ipfv}$

… $_{b}$COME-BACK, IX$_{3sg-d}$ STILL CL-S: place-big-cylindrical-object$_{pfv}$

21. CL-S: pull-cylindrical-object (a bell rope)

My company installed a new bell in the church. The priest went to test if it worked and pulled the rope, but it got stuck. A colleague went to get his boss. When they returned, he had already pulled it.

IX$_{there-d}$ CHURCH, POSS$_{1}$ COMPANY NEW BELL BELL-TOWER INSTALL, NOW PRIEST IX$_{3sg-d}$ TRY CL-S: pull-cylindrical-object$_{pfv}$, BUT STUCK CL-S: pull-cylindrical-object$_{ipfv}$, WORKMAN CALL$_{b}$ BOSS…

… $_{b}$TOGETHER-COME-BACK, IX$_{3sg-d}$ ALREADY CL-S: pull-cylindrical-object$_{pfv}$+

… $_{b}$TOGETHER-COME-BACK, IX$_{3sg-d}$ STILL CL-S: pull-cylindrical- object$_{ipfv}$+++

… $_{b}$TOGETHER-COME-BACK, IX$_{3sg-d}$ ALREADY CL-S: pull-cylindrical- object$_{ipfv}$+++

… $_{b}$TOGETHER-COME-BACK, IX$_{3sg-d}$ STILL CL-S: pull-cylindrical-object$_{pfv}$+

22. CL-X-TH-ADJ: bring-object-with-handles (a tray)

The husband is bringing breakfast to bed on a tray. I saw that he was walking slowly and went to brush my hair. When I came back, he had already brought it.

BREAKFAST POSS$_{1}$ HUSBAND IX$_{3sg-b}$ TRAY FOOD PILE CL-X-TH-ADJ: bring-object-with-handles$_{ipfv}$ +++ IX$_{there-d}$ ROOM EAT CL-X-TH-ADJ: slowly-bring-object-with-handles$_{ipfv}$+++, $_{1}$SEE$_{b}$, TIME $_{e}$COMB…

… $_{e}$COME-BACK, IX$_{3sg-b}$ ALREADY CL-X-TH-ADJ: bring-object-with-handles$_{pfv}$+

… $_{e}$COME-BACK, IX$_{3sg-b}$ STILL CL-X-TH-ADJ: bring-object-with-handles$_{ipfv}$+++

… $_{e}$COME-BACK, IX$_{3sg\text{-}b}$ ALREADY CL-X-TH-ADJ: bring-object-with-handles$_{ipfv}$+++
… $_{e}$COME-BACK, IX$_{3sg\text{-}b}$ STILL CL-X-TH-ADJ: bring-object-with-handles$_{pfv}$+

23. CL-X-TH-ADJ: bring-object-with-handles (a pot)

At the Labour Day party in the park, I'm preparing the food, and the helpers are bringing a big pot. I saw them and decided that there was still time to cut the food. After a few minutes, the workers already brought it.

IX$_{there\text{-}d}$ PARK PARTY LABOUR DAY, IX$_{1}$ PREPARE COOK, POSS$_{1}$ COLLEAGUE IX$_{3pl\text{-}d}$ HELP BIG POT CL-X-TH-ADJ: bring-object-with-handles$_{ipfv}$+++… IX$_{1}$ SEE$_{d}$, TIME CHOP…
… A-FEW MINUTE PASS, IX$_{3pl\text{-}d}$ ALREADY CL-X-TH-ADJ: bring-object-with-handles$_{pfv}$+
… A-FEW MINUTE PASS, IX$_{3pl\text{-}d}$ STILL CL-X-TH-ADJ: bring-object-with-handles$_{ipfv}$+++
… A-FEW MINUTE PASS, IX$_{3pl\text{-}d}$ ALREADY CL-X-TH-ADJ: bring-object-with-handles$_{ipfv}$+++
… A-FEW MINUTE PASS, IX$_{3pl\text{-}d}$ STILL CL-X-TH-ADJ: bring-object-with-handles$_{pfv}$+

24. CL-X-TH-ADJ: pull-flat-object (a zipper)

My little son and I are getting ready to go to the park, he has put on a jacket, but the zipper of the jacket is stuck. I asked him if he wanted help, he said no, he would do it himself. I said "ok" and went to prepare a backpack. When I came back, he had already zipped it up.

POSS$_{1}$ SON LITTLE PREPARE TWO-OF-US OUT$_{d}$ PARK, IX$_{3sg\text{-}d}$ JACKET-PUT-ON, BUT PROBLEM ZIPPER CL-X-TH-ADJ: pull-flat-object$_{ipfv}$+++… $_{1}$ASK$_{d}$ HELP$_{d}$, NO HIMSELF, "AH WELL" IX$_{1}$ GO BACKPACK THINGS-PUT-IN…
… $_{b}$COME-BACK$_{d}$, IX$_{3sg\text{-}d}$ ALREADY CL-X-TH-ADJ: pull-flat-object$_{pfv}$+
… $_{b}$COME-BACK$_{d}$, IX$_{3sg\text{-}d}$ STILL CL-X-TH-ADJ: pull-flat- object$_{ipfv}$+++
… $_{b}$COME-BACK$_{d}$, IX$_{3sg\text{-}d}$ ALREADY CL-X-TH-ADJ: pull-flat- object$_{ipfv}$+++
… $_{b}$COME-BACK$_{d}$, IX$_{3sg\text{-}d}$ STILL CL-X-TH-ADJ: pull-flat-object$_{pfv}$+

25. CL-FLAT-O: insert-thin-object (a paper)

Dad found an old typewriter and is wondering if it works. I see that he is trying to put paper for a long time, so I went to the toilet. When I came back, he had already inserted it.

DAD FIND OLD TYPE-WRITER, CHECK WORK… IX$_{1}$ $_{1}$SEE$_{b}$ IX$_{3sg\text{-}b}$ PAPER CL-FLAT-O: insert-thin-object$_{ipfv}$+++, IX$_{1}$ OUT$_{d}$ $_{d}$TOILET…

… $_{d}$COME-BACK, IX$_{3sg\text{-}b}$ ALREADY CL-FLAT-O: insert thin object$_{pfv}$+

… $_{d}$COME-BACK, IX$_{3sg\text{-}b}$ STILL CL-FLAT-O: insert thin object$_{ipfv}$+++

… $_{d}$COME-BACK, IX$_{3sg\text{-}b}$ ALREADY CL-FLAT-O: insert thin object$_{ipfv}$+++

… $_{d}$COME-BACK, IX$_{3sg\text{-}b}$ STILL CL-FLAT-O: insert thin object$_{pfv}$+

26. CL-FLAT-O: pull-thin-object (a paper)

The paper jammed in the printer at work. My colleague started to take out the paper, and I hastily left for the meeting. When I came back, he had already pulled it out.

IX$_{there\text{-}d}$ WORK PRINTER PAPER STUCK CL-FLAT-O: pull-thin-object$_{ipfv}$… COLLEAGUE IX$_{3sg\text{-}b}$ HELP CL-FLAT-O: pull-thin-object$_{ipfv}$+++, IX$_{1}$ RUSH OUT$_{d}$ MEETING…

… $_{d}$COME-BACK, IX$_{3sg\text{-}b}$ ALREADY CL-FLAT-O: pull-thin-object$_{pfv}$+

… $_{d}$COME-BACK, IX$_{3sg\text{-}b}$ STILL CL-FLAT-O: pull-thin- object$_{ipfv}$+++

… $_{d}$COME-BACK, IX$_{3sg\text{-}b}$ ALREADY CL-FLAT-O: pull-thin- object$_{ipfv}$+++

… $_{d}$COME-BACK, IX$_{3sg\text{-}b}$ STILL CL-FLAT-O: pull-thin-object$_{pfv}$+

27. CL-FLAT-O: insert-thin-object (dough)

Mom and I are making pasta. I'm turning the handle, and she's inserting the dough, but the machine got stuck. I went to get grandmother to help us. When we came back, she had already inserted it.

MOTHER IX$_{1}$ TOGETHER MAKE PASTA, MACHINE IX$_{1}$ SPIN, MOTHER IX$_{3sg\text{-}d}$ CL-FLAT-O: insert-thin-object$_{ipfv}$, STUCK CL-FLAT-O: struggle-insert-thin-object$_{ipfv}$+++… IX$_{1}$ CALL GRANDMA$_{b}$ HELP…

… $_{b}$TOGETHER-COME-BACK, IX$_{3sg\text{-}d}$ ALREADY CL-FLAT-O: insert-thin-object$_{pfv}$+

… $_{b}$TOGETHER-COME-BACK, IX$_{3sg\text{-}d}$ STILL CL-FLAT-O: insert-thin-object$_{ipfv}$+++

… $_{b}$TOGETHER-COME-BACK, IX$_{3sg\text{-}d}$ ALREADY CL-FLAT-O: insert-thin-object$_{ipfv}$+++

… $_{b}$TOGETHER-COME-BACK, IX$_{3sg\text{-}d}$ STILL CL-FLAT-O: insert-thin-object$_{pfv}$+

28. CL-BENT-5: put-round-objects (baubles)

My wife and I are going to a friend's house today, she wants to give them an Advent wreath with baubles, she is making it now. I saw that she was slow and that we were running late, so I went to start the car to warm it up. When I came back, she had already put it together.

TODAY POSS$_1$ WIFE TWO-OF-US$_b$ VISIT FRIEND, IX$_{3sg-b}$ WANT CHRISTMAS WREATH GIVE-GIFT, NOW CL-BENT-5: put-round-objects$_{ipfv}$+++… IX$_1$ SEE SLOW, TIME LATE, HEAD-TO$_d$ CAR$_d$ START$_d$ WARM$_d$…

… $_d$COME-BACK, IX$_{3sg-b}$ ALREADY CL-BENT-5: put-round-objects$_{pfv}$++

… $_d$COME-BACK, IX$_{3sg-b}$ STILL CL-BENT-5: put-round- objects$_{ipfv}$+++

… $_d$COME-BACK, IX$_{3sg-b}$ ALREADY CL-BENT-5: put-round- objects$_{ipfv}$+++

… $_d$COME-BACK, IX$_{3sg-b}$ STILL CL-BENT-5: put-round-objects$_{pfv}$++

29. CL-BENT-5: press-round-objects (a cake mould)

Mom and I are baking cakes. She rolled out the dough and is now pressing the moulds, and I went to the cellar to get the jam. When I came back, she had already pressed them all.

MOTHER IX$_1$ TWO-OF-US$_b$ MAKE CAKE… IX$_{3sg-b}$ ROLL, NOW CL-BENT-5: press-round-objects$_{ipfv}$+++, IX$_1$ CELLAR TAKE$_d$ JAM…

… $_d$COME-BACK, IX$_{3sg-b}$ ALREADY CL-BENT-5: press-round-objects$_{pfv}$++

… $_d$COME-BACK, IX$_{3sg-b}$ STILL CL-BENT-5: press-round- objects$_{ipfv}$+++

… $_d$COME-BACK, IX$_{3sg-b}$ ALREADY CL-BENT-5: press-round- objects$_{ipfv}$+++

… $_d$COME-BACK, IX$_{3sg-b}$ STILL CL-BENT-5: press-round-objects$_{pfv}$++

30. CL-BENT-5: stack-round-object (glasses in dishwasher)

We had a lot of friends for lunch today, and when they left there were a lot of dishes left. My husband quickly put the plates in the washing machine, now he is still putting the glasses. I asked if he needed help, he said no, he would do it himself. In a few minutes he had already put them together.

TODAY MANY-FRIENDS $_2$VISIT$_1$ LUNCH, FINISH, DISH PILE… POSS$_1$ HUSBAND IX$_{3sg-d}$ DISH-WASHER PLATE STACK-QUICKLY, NOW GLASS CL-BENT-5: stack-round-object$_{ipfv}$+++, IX$_1$ ASK$_d$ HELP$_d$, TELL NO, HIMSELF…

… A-FEW MINUTE PASS, IX$_{3sg-d}$ ALREADY CL-BENT-5: stack-round-object$_{pfv}$++

… A-FEW MINUTE PASS, IX$_{3sg-d}$ STILL CL-BENT-5: stack-round- object$_{ipfv}$+++

… A-FEW MINUTE PASS, IX$_{3sg-d}$ ALREADY CL-BENT-5: stack-round- object$_{ipfv}$+++

… A-FEW MINUTE PASS, IX$_{3sg-d}$ STILL CL-BENT-5: stack-round-object$_{pfv}$++

31. CL-FLAT-B-TH: bring-big-angular-object (a fridge)

I bought a refrigerator and ordered delivery. I also paid extra to have it delivered because I live on the 5th floor without an elevator. They informed me that they had arrived and were now carrying. I saw them down the stairs and decided that I still had time to make coffee. When I came back, they had already brought it.

BUY NEW FRIDGE, ORDER $_{d}$DELIVERY, BUT PROBLEM, FIFTH FLOOR, NO LIFT… $_{3d}$LET-KNOW$_{1}$ NOW $_{d}$COME, TWO WORKMEN IX$_{d}$ CL-FLAT-B-TH: bring-big-round-object$_{ipfv}$+++… IX$_{1}$ SEE-DOWN STAIRWELL, TIME MAKE$_{b}$ COFFEE…

… $_{b}$COME-BACK$_{d}$, IX$_{d}$ ALREADY CL-FLAT-B-TH: bring-big-round-object$_{pfv}$+

… $_{b}$COME-BACK$_{d}$, IX$_{d}$ STILL CL-FLAT-B-TH: bring-big-round-object$_{ipfv}$+++

… $_{b}$COME-BACK$_{d}$, IX$_{d}$ ALREADY CL-FLAT-B-TH: bring-big-round-object$_{ipfv}$+++

… $_{b}$COME-BACK$_{d}$, IX$_{d}$ STILL CL-FLAT-B-TH: bring-big-round-object$_{pfv}$+

32. CL-FLAT-B-TH: bring-big-angular-object (a box)

Today there is a food festival in the park. Workers bring boxes, but the car park is far away. The boss saw that they were bringing the last, biggest box and continued to prepare the food. After a few minutes, the workers already brought it.

TODAY IX$_{there-b}$ PARK FESTIVAL FOOD COOK… WORKMEN BOX CL-FLAT-B-TH: bring-big-round-object$_{ipfv}$+++, BUT CAR PARKING-LOT FAR$_{d}$… BOSS SEE$_{d}$ LAST BOX BIGGEST CL-FLAT-B-TH: bring-big-round-object$_{ipfv}$+++, “ok” PREPARE…

… A-FEW MINUTE PASS, IX$_{d}$ ALREADY CL-FLAT-B-TH: bring-big-round-object$_{pfv}$+

… A-FEW MINUTE PASS, IX$_{d}$ STILL CL-FLAT-B-TH: bring-big-round-object$_{ipfv}$+++

… A-FEW MINUTE PASS, IX$_{d}$ ALREADY CL-FLAT-B-TH: bring-big-round-object$_{ipfv}$+++

… A-FEW MINUTE PASS, IX$_{d}$ STILL CL-FLAT-B-TH: bring-big-round-object$_{pfv}$+

33. CL-FLAT-B-TH: bring-angular-object (a plank)

Work begins on the construction site and workers bring planks. They carry the back board very slowly. The boss saw them and yelled at them to speed up, and just then his mobile phone rang and he answered. When he finished, he saw that the workers had already brought it.

IX$_{there\text{-}d}$ CONSTRUCTION-SITE START BUILD, WORKMEN WOOD CL$_{SASS}$: PLANKS $_{b}$CL-FLAT-B-TH: bring-angular-object$_{ipfv}$… LAST IX$_{b}$ SLOW CL-FLAT-B-TH: bring-angular-object$_{ipfv}$+++… BOSS SEE$_{b}$ YELL COME-ON, RING ANSWER-TELEPHONE$_{d}$…

… FINISH, $_{d}$SEE$_{b}$, IX$_{b}$ ALREADY CL-FLAT-B-TH: bring-angular-object$_{pfv}$+

… FINISH, $_{d}$SEE$_{b}$, IX$_{b}$ STILL CL-FLAT-B-TH: bring-angular-object$_{ipfv}$+++

… FINISH, $_{d}$SEE$_{b}$, IX$_{b}$ ALREADY CL-FLAT-B-TH: bring-angular-object$_{ipfv}$+++

… FINISH, $_{d}$SEE$_{b}$, IX$_{b}$ STILL CL-FLAT-B-TH: bring-angular-object$_{pfv}$+

34. CL-B-TH: stack-flat-objects (clothes)

I finished ironing a lot of clothes. Now my son is putting it in the closet, and I went to the store. When I came back, he had already put it away.

CLOTHES PILE IX$_{1}$ IRON FINISH… NOW POSS$_{1}$ SON IX$_{3sg\text{-}b}$ WARDROBE CLOTHES CL-B-TH: stack-flat-objects$_{ipfv}$+++, IX$_{1}$ OUT$_{d}$ STORE…

… $_{d}$COME-BACK, IX$_{3sg\text{-}b}$ ALREADY CL-B-TH: stack-flat-objects$_{pfv}$++

… $_{d}$COME-BACK, IX$_{3sg\text{-}b}$ STILL CL-B-TH: stack-flat-objects$_{ipfv}$+++

… $_{d}$COME-BACK, IX$_{3sg\text{-}b}$ ALREADY CL-B-TH: stack-flat-objects$_{ipfv}$+++

… $_{d}$COME-BACK, IX$_{3sg\text{-}b}$ STILL CL-B-TH: stack-flat-objects$_{pfv}$++

35. CL-B-TH: bring-flat-objects (tablecloths)

There will be a wedding at the hotel tonight. My colleague and I are preparing the hall; he is bringing tablecloths so I asked him if he needed help. He said no need, so I went outside to smoke. When I came back, he had already brought them.

TODAY IX$_{there\text{-}d}$ HOTEL TONIGHT HAVE WEDDING… POSS$_{1}$ COLLEAGUE TWO-OF-US$_{d}$ PREPARE, IX$_{3sg\text{-}d}$ TABLECLOTH $_{d}$CL-B-TH: bring-flat-objects$_{ipfv}$+++… IX$_{1}$ $_{1}$ASK$_{d}$ HELP$_{d}$, IX$_{3sg\text{-}d}$ $_{d}$TELL$_{b}$ NO, IX$_{1}$ OUT$_{b}$ SMOKE…

… $_{b}$COME-BACK$_{d}$, IX$_{3sg\text{-}d}$ ALREADY CL-B-TH: bring-flat-objects$_{pfv}$+

… $_{b}$COME-BACK$_{d}$, IX$_{3sg\text{-}d}$ STILL CL-B-TH: bring-flat-objects$_{ipfv}$+++

… $_{b}$COME-BACK$_{d}$, IX$_{3sg\text{-}d}$ ALREADY CL-B-TH: bring-flat-objects$_{ipfv}$+++

… $_{b}$COME-BACK$_{d}$, IX$_{3sg\text{-}d}$ STILL CL-B-TH: bring-flat-objects$_{pfv}$+

36. CL-B-TH: stack-flat-objects (bed linen)

I work in a bed linen store. Now the goods have been delivered, so my colleague and I are putting them on the shelves. We had one more box left, my colleague said she would put it herself, and I went to make coffee. When I came back, she had already put it on shelves.

IX_1 WORK IX_{here} STORE BED-LINEN BUILDING… NOW $ORDER_d$ NEW $_d$DELIVER, COLLEAGUE $IX_{3sg\text{-}b}$ $TWO\text{-}OF\text{-}US_b$ SHELF CL-B-TH: $stack\text{-}flat\text{-}objects_{ipfv}$, LEFT ONE BOX, $IX_{3sg\text{-}b}$ HERSELF SHELF CL-B-TH: $stack\text{-}flat\text{-}objects_{ipfv}$+++, IX_1 $MAKE_d$ COFFEE…

… $_d$COME-BACK, $IX_{3sg\text{-}b}$ ALREADY CL-B-TH: $stack\text{-}flat\text{-}objects_{pfv}$++

… $_d$COME-BACK, $IX_{3sg\text{-}b}$ STILL CL-B-TH: $stack\text{-}flat\text{-}objects_{ipfv}$+++

… $_d$COME-BACK, $IX_{3sg\text{-}b}$ ALREADY CL-B-TH: $stack\text{-}flat\text{-}objects_{ipfv}$+++

… $_d$COME-BACK, $IX_{3sg\text{-}b}$ STILL CL-B-TH: $stack\text{-}flat\text{-}objects_{pfv}$++

12. CURRICULUM VITAE

Tomislav Radošević completed his master's degree in Speech and Language Therapy at the University of Zagreb Faculty of Education and Rehabilitation Sciences in 2017. During the master's program, he received an award for the best poster presentation at the 6th Student Congress of Neuroscience *NeuRi 2016* for presenting an overview of studies on sign language processing using the event-related potentials method. After a short period at the Association for the Deaf and Hard of Hearing of the City of Zagreb, he worked as a speech and language therapist in the field of neurorehabilitation at the Special Hospital for Medical Rehabilitation Krapinske Toplice. In 2019, he joined the Department of Hearing Impairments at the University of Zagreb Faculty of Education and Rehabilitation Sciences as an assistant, where he currently works. Since graduating, he has completed several scientific workshops on EEG acquisition and analysis of event-related potentials, as well as several professional workshops on standardized language testing, interventions with deaf clients, dysphagia and neurogenic communication disorders.

He has published five scientific papers:

1. Olujić Tomazin, M., Radošević, T., & Hrastinski, I. (2025). Linguistic skills and text reading comprehension in prelingually deaf readers: A systematic review. *Journal of Speech, Language, and Hearing Research*, *68*(3), 1277–1310. https://doi.org/10.1044/2024_jslhr-24-00512
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