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The Impact of Video and Subtitle Speed on Subtitle Reading: An Eye-Tracking Replication Study

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Abstract

We present results of a direct replication of Liao et al.'s (2021) study on how subtitle speed and the presence of concurrent video impact subtitle reading among British and Polish viewers. Our goal was to assess the generalisability of the original study's findings on a cohort of Australian English participants. The study explored both subtitle-level and word-level effects, considering the presence or absence of concurrent video and three subtitle speeds: 12, 20, and 28 characters per second (cps). Overall, most of the original results were replicated, confirming that the presence of video and the speed of the subtitles have a measurable impact on processing across different viewer groups. Additionally, differences in how native and non-native speakers process subtitles emerged, in particular related to wrap-up, word frequency and word length effects. The paper describes the replication in detail, presents the findings, and discusses some of their implications.

Key words: subtitling, reading speed, subtitle speed, replication, concurrent video, foreign language, L2 processing.

Introduction

In today's audiovisual landscape, subtitles have become indispensable to millions of people worldwide. This trend has been driven by streaming platforms like Netflix, Amazon Prime or Disney+, and by accessibility regulations, such as the Americans with Disabilities Act and the EU Audiovisual Media Services Directive. Subtitles do not only aid deaf and hard-of-hearing populations, but also assist hearing speakers grappling with unclear audio, rapid speech, or challenging accents (Díaz Cintas & Remael, 2021; Zajechowski, 2022). They are also indispensable for non-native speakers to understand foreign content, and are often used for language learning purposes (Vanderplank, 2016; Wang & Pellicer-Sánchez, 2022).

Despite the ubiquity of subtitles and the growing body of research on subtitle processing, we still know little about how different viewer groups engage with subtitled content, in particular how the very presence of moving images and increasing subtitle speeds affect viewers' processing and comprehension. Research into subtitle processing in general, and subtitle speed in particular, dates back to the 1980s and continues until today (d'Ydewalle et al., 1985; d'Ydewalle et al., 1987; Jensema, 1998; Koolstra et al., 1999; Szarkowska and Gerber-Morón, 2018; Kruger et al., 2022; Szarkowska et al., 2021). However, the generalisability of these findings is hindered by variations in methodologies, audiovisual genres, video lengths, viewer demographics, eye movement metrics, speed calculations, or subtitle types.

Our study addresses this gap by conducting a direct replication, as defined by LeBel et al. (2018), of the research by Liao et al. (2021). Our goal is to determine whether the results obtained in the original study, which focused on a sample of Australian viewers (AUS), hold true for British native speakers (UK) and L1-Polish L2-English speakers (PL). We hypothesised that Polish participants, as non-native speakers, would find the task more challenging than UK counterparts. In contrast, we expected UK participants to exhibit more consistent reading patterns and find the task less challenging. The paper describes the replication in detail, presents the findings, and discusses some of their implications.

1. Replication

By conducting a direct replication, employing the same methods and materials as the original study, we aim to advance our understanding of how diverse viewer demographics engage with subtitled videos across different regions of the world. Until recently, replication in audiovisual translation (AVT) has been uncommon (Díaz Cintas & Szarkowska, 2020). Furthermore, experimental studies in AVT have suffered from issues such as small sample sizes, selective reporting, underpowered experimental designs, small effect sizes, and simple statistical analyses, leading to the unreliability of findings in many instances. Given these challenges, even though the number of experimental eye-tracking studies on subtitling, the primary focus of this investigation, has increased in recent years, we cannot assert with complete confidence that the outcomes reported in these studies are definitive and universally applicable. Therefore, in line with the Open Science Collaboration's perspective, we believe that "there is still more work to do to verify whether we know what we think we know" (2015, p. 943).

Replication has often faced resistance from some journals, with editors rejecting papers on the grounds of lacking innovation and stating that "we already know this" (Open Science Collaboration, 2015, p. 943). However, as highlighted by Koole and Lakens (2012), replication is essential to uphold scientific progress and ensure the reliability of research findings. According to Schmidt (2009), replication stands as "one of the most important tools for the verification of facts within the empirical sciences" (p. 90). A significant impetus for the replication movement came from the Reproducibility Project undertaken by the Open Science Collaboration (2015), which conducted replications of 100 studies published in major psychology journals. The project found a striking disparity, with only 36% of replication studies yielding significant results compared to the 97% reported by the original studies. It needs to be noted, however, that this does not necessarily imply flaws in the original studies, but may be attributable to random or systematic error (Open Science Collaboration, 2015).

There are at least two possible lessons from this: firstly, replication should be integrated into the fabric of scientific research, including the field of AVT. Secondly, for studies to be replicable, researchers should adhere to the principles of Open Science and make their datasets, protocols, and results openly accessible to the research community for scrutiny. Our study aligns with these principles, and all datasets are accessible here for transparency and future research purposes.

2. The Original Study

In the original study by Liao et al. (2021), 31 native Australian English speakers watched videos without sound, accompanied by English subtitles displayed at three different speeds: 12 characters per second (cps), 20 cps and 28 cps. Each participant viewed six videos: three with moving images and subtitles (one at each speed) and three with subtitles on a black screen (again, one per speed). Eye movements were tracked, and comprehension was assessed using eight multiple-choice questions for each video (for detailed methodology, refer to the original paper).

The authors found that higher subtitle speeds, particularly at 28 cps, had a detrimental effect on comprehension. However, the presence of video enhanced comprehension regardless of subtitle speed. In terms of eye movements, increasing subtitle speeds led to fewer and shorter fixations, longer saccades, and fewer crossovers between subtitles and images, resulting in more superficial reading. Additionally, the study noted that established reading effects such as word length and word frequency (whereby longer and less frequent words are more likely to be fixated more often for longer), though still present, were modulated by subtitle speed and the presence of concurrent video. Similarly, the wrap-up effect, which involves spending more time on sentence- or clause-final words to integrate their meaning (Just & Carpenter, 1980; Warren et al., 2009) – a tendency traditionally interpreted in reading studies as reflecting higher-level processing and lexical integration (Rayner et al., 2000) – was influenced by subtitle speed and video presence.

Liao et al. (2021) found that, at the highest subtitle speeds and with video, viewers spent less time on words at the end of subtitles compared to the words in the middle – an effect the authors called a “reversed” wrap-up effect, also being the result of more words at the end of subtitles being skipped at the higher speeds. This suggests that eye movements are affected by both local processing difficulties and by global constraints caused by reduced reading time and the presence of a secondary visual task (i.e., the moving images) during viewing.

At the medium speed of 20 cps, Liao et al. (2021) found that time spent fixating individual words in subtitles decreased, while average saccade lengths remained unaffected. However, at 28 cps, word fixation time decreased further, implying an impact on parafoveal preview, while saccade length and word skipping increased. This suggested a shift from local, word-based decisions about word skipping towards more global heuristics, such as skipping short words but fixating longer words as subtitle speed exceeded 20 cps.

Additional findings from the original experiment described in Liao et al. (2021) are reported by Kruger et al. (2022). They observed that as subtitle speed increased, more words were skipped or left unread, fewer words were re-fixated, and there was an increase in subtitles not read to completion. Together, these findings suggest that excessive speed may not afford sufficient time to resolve ambiguity or handle processing challenges.

The findings above were used by the authors to formulate a framework for eye-movement control in multimodal reading, termed the "multimodal integrated-language framework". This framework, based on Reichle's (2020) computational model of reading, accommodates non-textual visual and auditory input. The framework posits that viewers can track a limited number of previously identified objects in the video while reading subtitles in a pre-attentive visual processing stage. This enables these objects to be linked with the propositional content stored in working memory, derived from subtitle information, thus forming the evolving situation model. In essence, the framework suggests that the inherent limitation of attention requiring serial allocation can be circumvented by concurrently monitoring previously identified objects while reading subtitles. This component of the framework, as argued by the authors, is compatible with Paivio's (1971) dual-coding theory, which posits that presenting information in more than one modality benefits comprehension and learning. Consequently, subtitle information and video content complement each other, explaining the enhanced comprehension even at the fastest subtitle speed when video is present.

The current replication study seeks to further validate this framework by offering additional evidence to assess its general applicability.

3. Method

The same audiovisual materials and subtitles were used as in the original study. Unless otherwise stated, the same experimental procedure and data analysis protocols were also followed (see Liao et al., 2021, for more details).

3.1. Design

The study has a 2 (video: present or absent) x 3 (subtitle speed: 12, 20 and 28 cps) within-participant design. Video and speed conditions were counterbalanced, and the order of video presentation was randomised.

3.2. Participants

Participants were 51 native English speakers from the UK (Female=33, Male=13, Non-binary=4; M_{age}=21.49, *SD*=2.84, range=18–33) and 42 native Polish speakers (Female=34, Male=8; M_{age}=23.12, *SD*=3.52, range=18–33). The average English proficiency of the Polish participants, as measured by the online LexTALE test (Lemhöfer & Broersma, 2012), was 79.08 (*SD*=10.38), ranging from 62.5 to 100, which roughly corresponds to C1 and C2 CEFR proficiency (Council of Europe, 2018).

When asked about the frequency of watching English movies with English subtitles, Australian participants in the original study reported an average of 2.78 (*SD*=1.96) on a 1–7 scale, where 1 represented the lowest familiarity and 7 the highest (Kruger et al., 2022, p. 221). This indicated that

they had limited exposure to subtitling. In contrast, in our study, subtitling was the preferred type of audiovisual translation for both UK and PL participants (90.2% for UK participants and 92.9% for PL). Furthermore, when asked about watching English-language content with English subtitles, they reported average ratings of 5.75 (*SD*=1.65) and 5.86 (*SD*=1.64), respectively, overall demonstrating their high level of familiarity with subtitling.

3.3. Stimuli

Six videos of approximately nine minutes each from the BBC documentary *Planet Earth* were used. The videos had a similar duration (9–10 min), number of subtitles (80–84), number of words (607–681) and readability scores. Readability scores were calculated using the Flesch Reading Ease score (Graesser et al., 2014) in the Coh-Metrix tool (McNamara et al., 2010). The soundtrack was removed from all video clips to eliminate the influence of the audio on processing and to allow for the consistent manipulation of subtitle speed, which would have otherwise caused asynchronies with the sound, thereby introducing undesirable confounds.

3.4. Apparatus

Eye-movements were collected using an EyeLink Portable Duo in the UK and a desktop EyeLink 1000 Plus Eye Tracker (SR-Research, Ontario, Canada) in Poland. Data were recorded binocularly at a 1000 Hz sampling rate, using a target sticker for remote tracking with the Portable Duo and a chinrest to minimise head movement with the 1000 Plus.

3.5. Procedure

On arrival, both UK and PL participants signed informed consent forms, completed a questionnaire regarding their subtitling-related preferences and habits[1], and took the LexTALE English Proficiency Test (Lemhöfer & Broersma, 2012).

After calibration (9-point with EyeLink 1000 Plus and 13-point with EyeLink Portable Duo, as per manufacturer's recommendations), participants watched the clips. At the end of each clip, they answered the same comprehension questions as in the original experiment. The experiment lasted approximately two hours, including two 5-minute breaks after the second and fourth clip. Before each video, calibration was checked and the eye-tracker was recalibrated if necessary.

[1] The questionnaires, together with summary tables for all modelling results, data analysis scripts, graphs and figures, can be accessed in the Replication Pack available with this paper: https://osf.io/jw9my/?view_only=ed855d93ef004a4fbed0a28a56cabbeb

3.6. Analyses

Following the original study, subtitle-level and word-level analyses were performed. Subtitle-level analyses focused on two macro interest areas: the subtitle region and the video region. The eye-tracking measures examined were mean fixation duration (MFD), total fixation number, mean saccade length, and number of crossover saccades between subtitles and video. At the word level, we examined gaze duration and total fixation times to assess the impact of word frequency and length. Gaze duration is the sum of all fixations on an interest area during first-pass reading, and reflects early lexical processing, while total times reflect relatively late processes (e.g., lexical integration), as they include fixations and regressions across all reading passes. To assess wrap-up effects, we examined eye behaviour on subtitle-final words by looking at total times as well as word skipping probability, which refers to whether a word was fixated or not during first-pass reading.

To enable a direct comparison to the original study, fixations shorter than 60 ms or longer than 800 ms were excluded. Eight Polish and fourteen British participants were excluded due to data quality (see Replication Pack for exclusion details), resulting in analysable eye-tracking data from 34 PL and 37 UK participants.

Data were analysed via (Generalised) Linear Mixed Effect Models in R (version 4.1.2). In the global (subtitle-level) analyses, subtitle speed and video condition were entered in the models as fixed effects together with their interactions. In the word-level analyses (the results of which are available as Supplementary Materials owing to space limitations), word frequency, word length and related interactions were also added as predictors. In the wrap-up analyses, word location was also considered to assess behaviour on subtitle-final words. Random effects for both participants and items were added to the models, the items being either whole subtitles or individual words. Maximal structures were fitted first, and trimmed according to the parsimonious mixed-model approach (Bates et al., 2015). Contrast coding was applied (*contr.sdif* function in R), variables were log-transformed where required, and the *emmeans* package was used to further compare pairs of means after fitting the models. Finally, the significance threshold was adjusted to p = .0125 (0.05/4) using the Bonferroni correction for multiple comparisons, to avoid critically inflating false positive rates (von der Malsburg & Angele, 2017).

4. Results

4.1. Comprehension

Overall, comprehension accuracy amounted to 74% among UK participants and 73% among Polish participants (see Table 1), which is slightly higher than in the original study (70%). Comprehension was lower when participants were watching subtitles without the video compared to the condition with the video across all speeds, confirming the positive impact of the moving images on comprehension accuracy. Adding video had a significant positive effect on comprehension accuracy

(PL: $z = 4.081$, $p < 0.001$; UK: $z = 4.276$, $p < 0.001$). Unlike in the original study and contrary to our expectations, subtitle speed had no significant impact on comprehension accuracy in either the UK or the PL group (see Figure 1). Unlike in the original analysis, no interaction between the Speed and Video conditions was found.

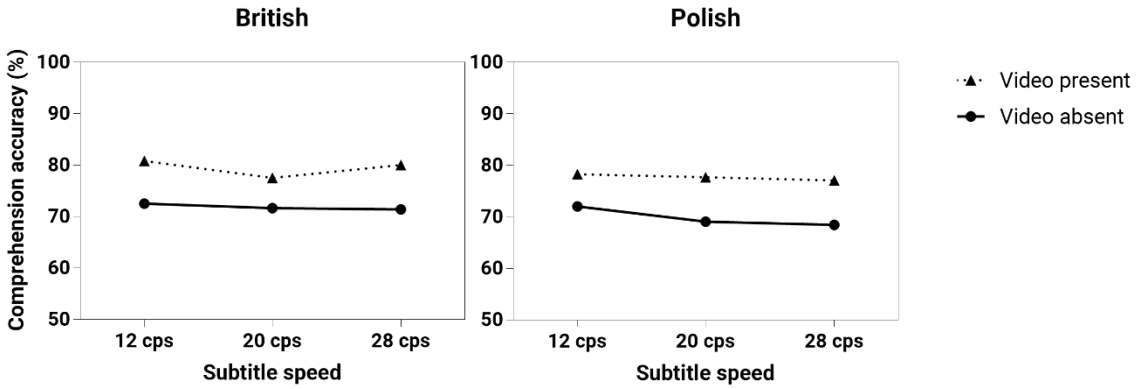
Table 1

Comprehension Accuracy by Speed and Video Condition

	12 cps		20 cps		28 cps	
	Video present	Video absent	Video present	Video absent	Video present	Video absent
UK	79.94 (40.09)	70.57 (45.63)	75.52 (43.05)	69.79 (45.97)	77.86 (41.57)	70.31 (45.74)
PL	78.27 (41.29)	72.02 (44.95)	77.67 (41.70)	69.04 (46.29)	77.08 (42.09)	68.45 (46.53)

Figure 1

Comprehension Accuracy by Subtitle Speed and Video



4.2. Subtitle-Level Eye-Tracking Analyses

To enable comparisons with the original study, we excluded from the eye-tracking analyses three UK and four PL participants whose comprehension score for at least two of the videos was below 40%. Figures 2–3 and Tables 2–5 provide descriptive statistics and graphs for subtitle-level eye-movement analyses on subtitle and video regions as well as model summaries.

Table 2

Descriptive Statistics for Subtitle-Level Eye-Movement Measures (UK Participants)

		Mean Fixation Durations (ms)		Mean Saccade Length (degrees)		Total Number of Fixations		Number of Crossovers
Video presence	Subtitle speed	Subtitle Region (SD)	Video Region (SD)	Subtitle Region (SD)	Video Region (SD)	Subtitle Region (SD)	Video Region (SD)	Subtitle/Video (SD)
Absent	12 cps	253 (57)	291 (160)	3.62 (2.60)	3.73 (2.71)	10.10 (3.68)	0.68 (1.53)	1.67 (1.16)
Absent	20 cps	238 (62)	272 (150)	3.60 (2.24)	3.58 (2.55)	7.15 (2.41)	0.72 (1.31)	1.43 (0.84)
Absent	28 cps	227 (58)	269 (153)	3.79 (2.29)	3.97 (2.54)	5.69 (1.92)	0.59 (1.14)	1.33 (0.70)
Present	12 cps	204 (48)	334 (113)	3.73 (2.26)	4.11 (3.04)	7.97 (3.13)	3.55 (2.27)	2.21 (1.11)
Present	20 cps	200 (49)	323 (135)	3.75 (2.16)	4.34 (3.09)	6.19 (2.34)	2.06 (1.44)	1.61 (0.72)
Present	28 cps	195 (46)	307 (142)	3.81 (2.07)	4.82 (3.28)	5.50 (1.72)	1.44 (1.51)	1.30 (0.56)

Table 3

Descriptive Statistics for Subtitle-Level Eye-Movement Measures (Polish Participants)

		Mean Fixation Durations (ms)		Mean Saccade Length (degrees)		Total Number of Fixations		Number of Crossovers
Video presence	Subtitle speed	Subtitle Region (SD)	Video Region (SD)	Subtitle Region (SD)	Video Region (SD)	Subtitle Region (SD)	Video Region (SD)	Subtitle/Video (SD)
Absent	12 cps	234 (44)	259 (153)	3.09 (2.40)	2.82 (2.43)	11.40 (3.34)	0.64 (1.75)	1.32 (0.69)
Absent	20 cps	219 (42)	234 (151)	2.97 (1.91)	3.37 (2.55)	8.14 (2.15)	0.31 (0.69)	1.15 (0.46)
Absent	28 cps	214 (47)	250 (174)	3.18 (1.84)	3.32 (2.54)	6.29 (1.65)	0.33 (0.75)	1.12 (0.40)
Present	12 cps	202 (39)	333 (122)	2.90 (1.94)	3.94 (2.83)	9.66 (3.23)	2.82 (1.97)	2.00 (1.00)
Present	20 cps	196 (40)	310 (136)	2.85 (1.62)	4.59 (3.15)	7.40 (2.10)	1.67 (1.24)	1.42 (0.62)
Present	28 cps	192 (41)	289 (141)	3.05 (1.63)	4.89 (3.27)	5.82 (1.56)	1.23 (0.93)	1.17 (0.43)

Figure 2

UK Participants' Overall Viewing Behaviour as a Function of Video Presence/Absence and Subtitle Speed

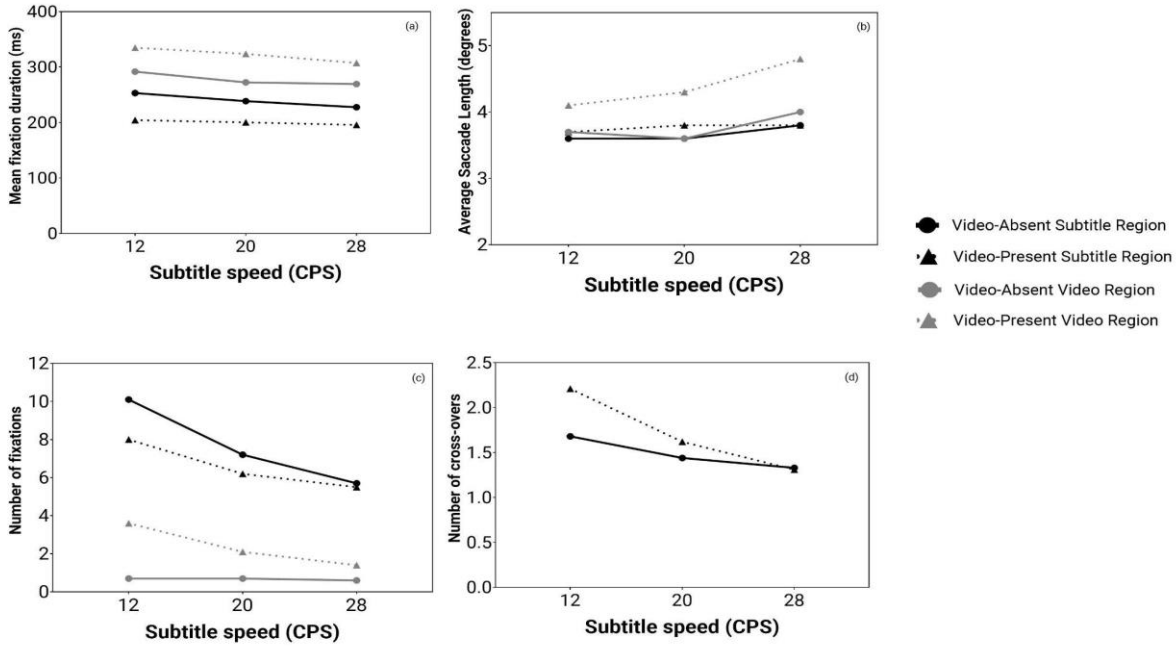


Figure 3

Polish Participants' Overall Viewing Behaviour as a Function of Video Presence/Absence and Subtitle Speed

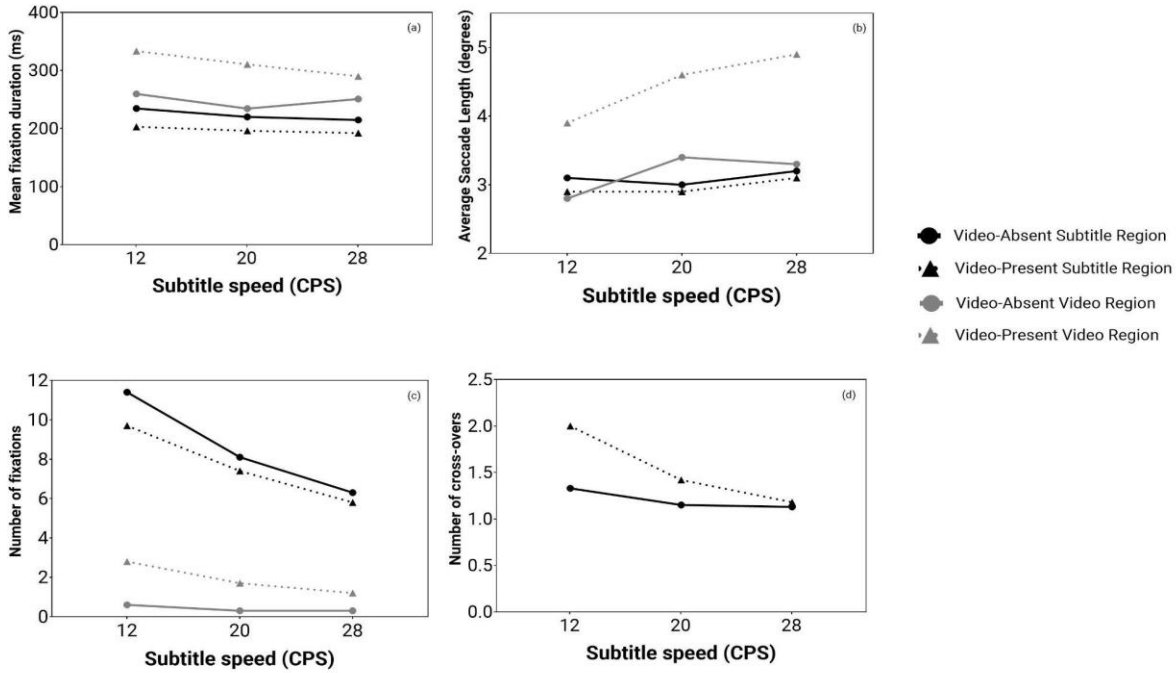


Table 4

LMMs Results for Subtitle-Level Analyses (UK)

		Subtitle Region				Video region			
Measures	**Contrasts**	**β**	**SE**	**t**	**p**	**β**	**SE**	**t**	**p**
Mean Fixation Duration	Intercept	5.361065	0.016471	325.488	**<.0001*** **	5.58495	0.01453	384.467	**<.0001*** **
	Video (Present-Absent)	-0.174216	0.010005	-17.413	**<.0001*** **	0.21248	0.02187	9.713	**<.0001*** **
	Speed (20-12cps)	-0.043129	0.005891	-7.322	**<.0001*** **	-0.05624	0.01431	-3.930	**<.0001*** **
	Speed (20-28cps)	-0.035041	0.005698	-6.150	**<.0001*** **	-0.05342	0.01707	-3.130	**0.003** **
	Video x Speed (20-12cps)	0.035278	0.015595	2.262	0.030	-0.01202	0.02538	-0.474	0.635
	Video x Speed (28-20cps)	0.038175	0.015262	2.501	0.017	-0.03592	0.02535	-1.417	0.156
Mean Saccade Length	Intercept	1.156e+00	2.102e-02	54.998	**<.0001*** **	1.135e+00	2.846e-02	39.873	**<.0001*** **
	Video (Present-Absent)	5.763e-02	1.260e-02	4.573	**<.0001*** **	1.985e-01	4.471e-02	4.439	**<.0001*** **
	Speed (20-12cps)	2.394e-02	9.483e-03	2.524	0.016	4.262e-02	2.273e-02	1.875	0.060
	Speed (20-28cps)	4.109e-02	9.607e-03	4.277	**<.0002*** **	6.587e-02	2.409e-02	2.735	**0.006** **
	Video x Speed (20-12cps)	-1.114e-02	8.865e-03	-1.256	0.209	9.089e-03	4.370e-02	0.208	0.835
	Video x Speed (28-20cps)	-3.615e-02	1.007e-02	-3.591	**<.0004*** **	5.632e-02	4.609e-02	1.222	0.221
Total Fixation Number	Intercept	7.089e+00	1.754e-01	40.412	**<.0001*** **	1.530e+00	8.420e-02	18.166	**<.0001*** **
	Video (Present-Absent)	-1.079e+00	1.814e-01	-5.948	**<.0001*** **	1.637e+00	1.535e-01	10.667	**<.0001*** **
	Speed (20-12cps)	-2.337e+00	1.663e-01	-14.053	**<.0001*** **	-7.475e-01	1.104e-01	-6.773	**<.0001*** **
	Speed (20-28cps)	-1.135e+00	9.650e-02	-11.762	**<.0001*** **	-3.477e-01	5.907e-02	-5.887	**<.0001*** **
	Video x Speed (20-12cps)	1.200e+00	7.959e-02	15.082	**<.0001*** **	-1.476e+00	5.484e-02	-26.914	**<.0001*** **
	Video x Speed (28-20cps)	7.793e-01	8.078e-02	9.648	**<.0001*** **	-5.993e-01	5.567e-02	-10.766	**<.0001*** **
Number of Crossovers	Intercept	1.53657	0.04338	35.418	**<.0001*** **				
	Video (Present-Absent)	0.32568	0.06404	5.085	**<.0001*** **				
	Speed (20-12cps)	-0.38002	0.04694	-8.096	**<.0001*** **				
	Speed (20-28cps)	-0.17810	0.03076	-5.791	**<.0001*** **				
	Video x Speed (20-12cps)	-0.41939	0.04405	-9.520	**<.0001*** **				
	Video x Speed (28-20cps)	-0.25939	0.04155	-6.244	**<.0001*** **				

Table 5

LMMs Results for Subtitle-Level Analyses (PL)

		Subtitle Region				Video region			
Measures	**Contrasts**	**β**	**SE**	**t**	**p**	**β**	**SE**	**t**	**p**
Mean Fixation Duration	Intercept	5.326244	0.015318	347.708	**<.0001*** **	5.49576	0.02640	208.173	**<.0001*** **
	Video (Present-Absent)	-0.123348	0.008063	-15.298	**<.0001*** **	0.30771	0.03286	9.363	**<.0001*** **
	Speed (20-12cps)	-0.049965	0.007325	-6.821	**<.0001*** **	-0.09994	0.01411	-7.083	**<.0001*** **
	Speed (20-28cps)	-0.025045	0.005254	-4.767	**<.0001*** **	-0.04541	0.01430	-3.175	0.001
	Video x Speed (20-12cps)	0.029948	0.011830	2.531	0.016	0.01437	0.02824	0.509	0.610
	Video x Speed (28-20cps)	0.006198	0.009168	0.676	0.503	-0.07951	0.02862	-2.778	0.005
Mean Saccade Length	Intercept	9.412e-01	2.067e-02	45.531	**<.0001*** **	1.077e+00	3.837e-02	28.080	**<.0001*** **
	Video (Present-Absent)	-1.673e-02	8.555e-03	-1.956	0.059	3.130e-01	5.841e-02	5.359	**<.0001*** **
	Speed (20-12cps)	1.189e-02	8.775e-03	1.355	0.184	1.406e-01	3.091e-02	4.548	**<.0001*** **
	Speed (20-28cps)	7.407e-02	8.668e-03	8.546	**<.0001*** **	-1.607e-03	3.529e-02	-0.046	0.963
	Video x Speed (20-12cps)	-1.135e-02	7.942e-03	-1.429	0.153	-8.996e-04	6.221e-02	-0.014	0.988
	Video x Speed (28-20cps)	-6.483e-03	9.067e-03	-0.715	0.474	1.237e-01	7.073e-02	1.748	0.080
Total Fixation Number	Intercept	8.120e+00	1.544e-01	52.592	**<.0001*** **	1.171e+00	6.224e-02	18.816	**<.0001*** **
	Video (Present-Absent)	-9.932e-01	1.098e-01	-9.050	**<.0001*** **	1.478e+00	1.015e-01	14.563	**<.0001*** **
	Speed (20-12cps)	-2.767e+00	1.450e-01	-19.085	**<.0001*** **	-7.385e-01	9.814e-02	-7.525	**<.0001*** **
	Speed (20-28cps)	-1.712e+00	1.097e-01	-15.602	**<.0001*** **	-2.098e-01	5.084e-02	-4.127	**<.0001*** **
	Video x Speed (20-12cps)	1.025e+00	7.003e-02	14.641	**<.0001*** **	-8.213e-01	4.550e-02	-18.048	**<.0001*** **
	Video x Speed (28-20cps)	2.150e-01	7.008e-02	3.069	**0.002 ** **	-4.526e-01	4.553e-02	-9.940	**<.0001*** **
Number of Crossovers	Intercept	1.35181	0.02100	64.383	**<.0001*** **				
	Video (Present-Absent)	0.34507	0.04151	8.314	**<.0001*** **				
	Speed (20-12cps)	-0.36372	0.03722	-9.771	**<.0001*** **				
	Speed (20-28cps)	-0.13051	0.02606	-5.007	**<.0001*** **				
	Video x Speed (20-12cps)	-0.42612	0.04121	-10.341	**<.0001*** **				
	Video x Speed (28-20cps)	-0.21926	0.04075	-5.381	**<.0001*** **				

4.2.1. Mean Fixation Duration (MFD)

In both PL and UK analyses, like in the original study, MFD was longer in the video region compared to the subtitle region. We found a main effect of both video and speed on MFD (Table 4 and Table 5).

In the subtitle region, the presence of video resulted in a significant reduction in MFD compared to the video-absent condition. MFD also decreased with speed across both video conditions in all three cohorts. No interactions between speed and video were found in either the UK or PL cohorts after applying the Bonferroni correction for multiple comparisons, unlike in the AUS cohort, where the interaction was significant at both speed intervals.

Results are similar in the video region across all three cohorts: adding video produced a significant increase in MFD in the video region, and increasing speed led to a significant MFD reduction, with the only significant interaction registered for the PL cohort at the highest speeds, showing that for PL viewers there was less difference in MFD on the video region between 20 and 28 cps when the video was not displayed.

4.2.2. Mean Saccade Length

As in the original study, both PL and UK participants made longer saccades when looking at the video region than when reading the subtitles.

In the subtitle region analyses, the main difference between the three cohorts pertained to the impact of video. Unlike fixation duration and number, saccade length in the PL cohort was not significantly affected by the presence or absence of video, just as in the AUS cohort. In contrast, for the UK cohort saccade length increased on the subtitle region.

In the subtitle region, subtitle speed had a significant effect on saccade length only at the highest speed in all three cohorts. Specifically, as subtitle speed increased from 20 cps to 28 cps, saccade length increased as viewers made longer saccades trying to read the rapidly disappearing subtitles. There was no significant interaction between speed and video in the subtitle region analysis in the AUS and PL cohorts. In the UK cohort, however, a significant Video × Speed interaction was observed at the highest speed. Further examination of pairs of means indicated that, in the UK cohort, the effect of speed on saccade length in the subtitle region was more pronounced without video.

In the video region, the main difference between the three cohorts was in the effect of speed. While video presence positively affected mean saccade length on the video region across all three cohorts, subtitle speed led to longer saccades in the video region only when going between 12 and 20 cps in both AUS and PL cohorts. In the UK cohort, however, saccade length in the video region was significantly higher only between 20 and 28 cps. No significant interaction was found between speed and video in the video region analysis across all cohorts.

4.2.3. Total Number of Fixations

Overall, gaze behaviour in both subtitle and video regions was very similar across all three cohorts. Like the original AUS participants, UK and PL viewers made more fixations on subtitles than on video (AUS 7.4 vs. 1.3; UK 7.1 vs. 1.54; PL 8.12 vs. 1.17).

The presence of video emerged as a significant predictor for the number of fixations in both subtitle and video regions, a pattern consistent across UK, PL and AUS participants. As viewers engaged with two sources of meaningful input (images and subtitles), they made fewer fixations on subtitles when video was present compared to the video-absent condition.

We also found a significant effect of subtitle speed on the number of fixations in the subtitle region: as speed increased, the number of fixations on the subtitles decreased in both video-present and video-absent conditions. Similarly, in the video region, as speed increased, fixations also decreased across both video conditions.

In line with the original analyses, significant interactions between video and speed conditions were also found in both video conditions for both UK and PL participants. Although subtitle speed had an impact on the number of fixations in both video conditions, the observed effect was more pronounced in the video-absent condition, which more closely resembles the reading of printed text.

4.2.4. Number of Crossovers

For all viewers, the number of crossover saccades between the subtitle and video regions was significantly higher when the video was present compared to when it was absent, reflecting the saliency of the moving images. Moreover, as subtitle speed increased, the number of crossovers significantly decreased. In all three analyses significant interactions were found, albeit with differences. Further examination of the UK and PL means showed that the effect of subtitle speed on crossover counts was most visible with video, but also without video at lower speeds (12 cps and 20 cps). In the original analysis, on the other hand, subtitle speed had significant effects on crossover counts only when the images were displayed.

4.3. Word-Level Eye-Tracking Analyses

4.3.1. Word Frequency and Length Effects: Gaze Durations

Similar to the original study, PL and UK analyses revealed main effects for all four fixed factors (see Tables 6–9 in Supplementary Materials attached to this paper). First, gaze durations had a direct relationship to word length: as length increased, so did gaze durations. Second, gaze durations had an inverse relationship with subtitle speed and word frequency: as speed and frequency increased, gaze durations significantly decreased (Figures 4 and 5). Finally, adding video meant a significant decrease in gaze durations on the words in the subtitles.

Just like in the original study, UK and PL results were modulated by interactions. An interaction was confirmed between word length and frequency in both native cohorts (AUS and UK), as longer words with lower frequency attracted longer gaze durations, but not in the PL cohort after the Bonferroni correction. Moreover, unlike in the original analysis, where only one three-way interaction was found (Length × Frequency × Video), PL and UK analyses revealed different significant interactions. A significant Length × Frequency × Speed interaction was found only between 12–20 cps in both UK and PL data. Pair-wise comparisons showed that frequency and length effects were particularly pronounced at the lowest speed (12 cps) and became attenuated as speed increased. In the PL cohort, a significant Length × Speed × Video interaction was also found between 12–20 cps, but not between 20–28 cps. Further examination of pairs of means revealed that at the highest speed for the Polish participants, the effects of word length were still present (with viewers spending more time reading longer words), but they were attenuated and less affected by the presence of the video.

4.3.2. Word Frequency and Length Effects: Total Times

Similar to gaze duration, we found main effects for all four predictors. First, total times had a direct relationship to word length: viewers spent more time fixating longer words. Second, total times were inversely proportional to speed and word frequency: as speed and frequency increased, total times significantly decreased (see Figures 4 and 5). Total times also decreased when video was added.

Word frequency interacted with speed across all speed levels in the PL cohort but not the UK cohort. In comparison, for the AUS cohort it was only significant going from 12 to 20 cps, suggesting that word frequency effects may be more perceivable by non-native speakers than native speakers, especially at higher speeds.

In all three cohorts there were also Length × Video interactions, whereby longer words led to higher total times when video was absent. A Length × Speed interaction was found in all three cohorts between 12–20 cps, indicating that the effects of increasing speed on total times were more evident with longer words. Moreover, a Length × Frequency interaction was observed in all three cohorts, with larger frequency effects for longer words. Finally, a Video × Speed interaction also emerged in

all three analyses, with the addition of video resulting in steadily decreasing total times spent reading words across all three speeds in the two native cohorts, whereas in the non-native PL cohort the decrease in total times was more pronounced between 12 and 20 cps.

Figure 4

LMM-adjusted Word Length and Word Frequency Effects for UK Participants as a Function of Video Presence/Absence and Subtitle Speed, with Gaze Durations in Panel (A) and Total Times in Panel (B). Word Frequency is Based on the Zipf Scale in the SUBTLEX-UK Corpus.

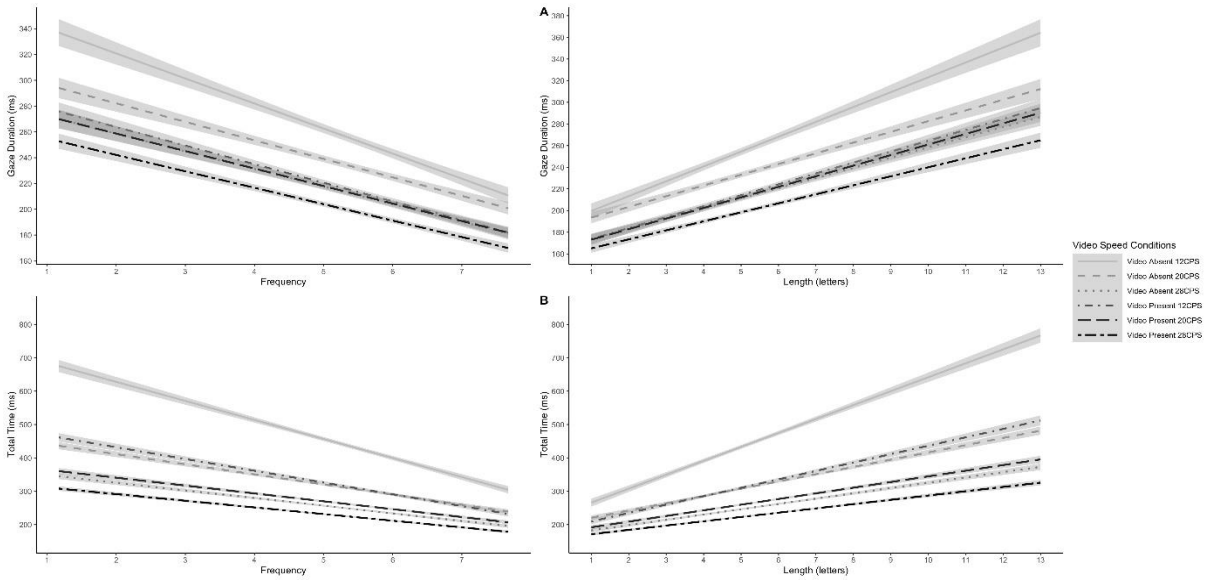
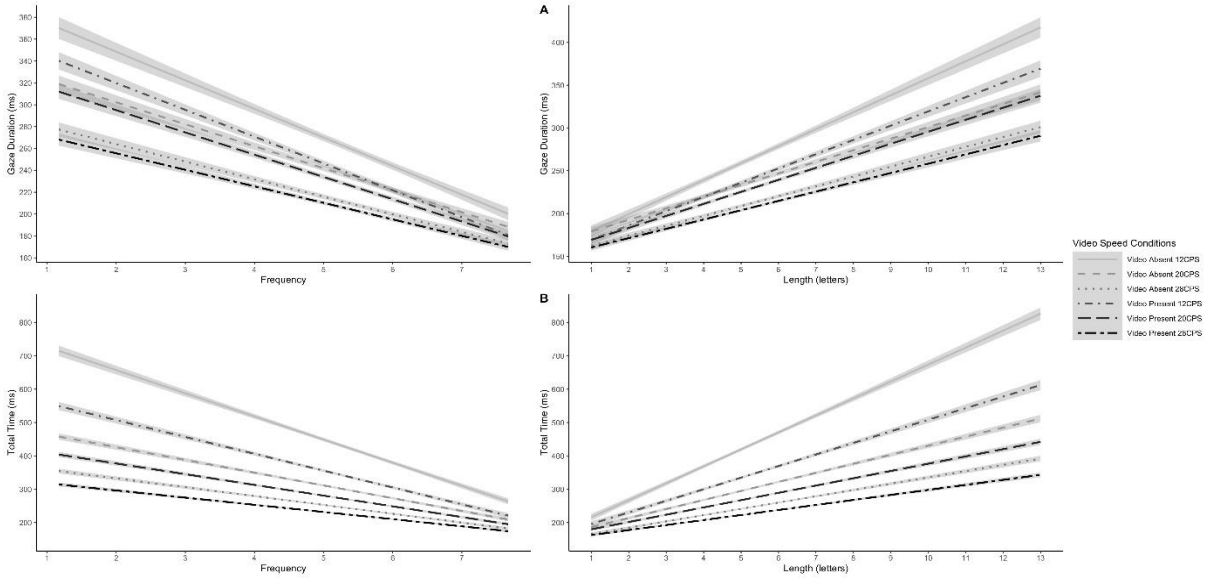


Figure 5

LMM-adjusted Word Length and Word Frequency Effects for PL Participants as a Function of Video Presence/Absence and Subtitle Speed, with Gaze Durations in Panel (A) and Total Times in Panel (B). Word Frequency is Based on the Zipf Scale in the SUBTLEX-UK Corpus.



4.3.3. Wrap-Up Effects: Total Times

To assess wrap-up effects, we compared total fixation times on words in subtitle-final vs. middle position. Consistent with prior analyses, speed and video had significant main effects in all cohorts. In the AUS and UK analyses, no significant main effect of word location was found. In the PL analysis, however, a main effect was found for location, indicating that, unlike the two native cohorts, the non-native cohort displayed a significant reduction of reading times in subtitle-final words.

A significant Video × Speed interaction was observed in all analyses for all three cohorts at all speed intervals. A Location × Speed interaction was significant between 12–20 cps for the UK cohort, 20–28 cps for the PL cohort, and across all speeds in the original AUS cohort. A Location × Speed × Video interaction was significant between 12–20 cps in the UK analysis, between 20–28 cps in the PL analysis, and across all speeds in the original analysis. Further pairwise comparisons pointed towards similarities across all cohorts: without video, a "traditional" wrap-up effect was observed at 12 cps but not at the two highest speeds, and with video, no wrap-up effect was found, as total times on subtitle-final words instead became shorter, possibly because the words disappeared too quickly to be read.

4.3.4. Wrap-Up Effects: Word Skipping Probability

In the UK model, video was a significant predictor of skipping rates: when video was present, skipping significantly increased, suggesting that UK viewers – like AUS viewers – dedicated more time to the images when these were present, in turn skipping more words in the subtitles. In the PL analysis, on the other hand, video did not have a significant main effect on skipping rates, i.e., whether the video was present or not, viewers tended to skip words in comparable amounts. Subtitle speed had more clear-cut effects across all cohorts: as speed increased, skipping rates also increased significantly.

In this analysis, there were no main effects of location alone on skipping rates across cohorts. Location initially did display such an effect for the PL cohort – mirroring the wrap-up analysis of total times above – but the effect became non-significant after Bonferroni correction.

In all analyses, significant Location × Video and Location × Speed interactions were found. Additionally, in the UK cohort only, the three-way Location × Speed × Video interaction was also significant across all speeds. Further Location × Video pairwise comparisons showed that subtitle-final words were skipped more often when the video was present across all three cohorts, suggesting that viewers had less time to read subtitles to completion while following the moving images, whereas the opposite applied to mid-position words, which were skipped less often in the presence of video. Pairwise comparisons of the Location × Speed interactions showed that, across all cohorts, subtitle-final words displayed clearer speed-related effects, and were increasingly skipped as speed increased.

5. General Discussion

By conducting this study, we aimed to replicate Liao et al.'s (2021) findings on the impact of subtitle speed and the presence or absence of moving images on multimodal reading behaviours. We also sought to confirm whether these findings, initially observed in Australian English native speakers, also apply to English native speakers in the UK and Polish speakers reading subtitles in English as an L2. Overall, results from the original study were successfully replicated, further confirming that effects of the presence of video and varying subtitle speed are robust and consistent in both native and non-native populations.

5.1. Comprehension

Our findings, in line with the original study, show that the inclusion of video enhances comprehension by providing valuable visual context for the narrative. However, the authors of the original study found it surprising that the presence of video improved comprehension, given the redundancy principle outlined in cognitive load theory (Diao & Sweller, 2007) that attention to two simultaneous input sources (video and subtitles) would hinder comprehension. In contrast, we contend that the finding does not in fact contradict the redundancy principle, because the video cannot really be considered redundant in relation to subtitles. Unlike the spoken dialogues and corresponding subtitles – which may be identical or near-identical and thus indeed redundant – the images are often not showing exactly and exclusively what is conveyed through the subtitles, which might themselves provide additional information related to the object depicted on screen. Therefore, we would argue that the images should be considered complementary, rather than redundant. It is therefore not surprising that participants demonstrated higher comprehension after viewing the images, as they serve to enhance understanding rather than duplicate information.

Interestingly, unlike in the original study, higher subtitle speeds did not lead to a significant reduction in comprehension among our participants. This outcome might be attributed to the fact that, unlike the original AUS participants, both PL and UK viewers were accustomed to reading subtitles, and thus to integrating information in multimodal reading situations. Previous exposure to subtitles is known to impact the subtitle reading process, with less experienced viewers struggling more than those who are familiar with subtitling (Jensema, 1998; Szarkowska & Gerber-Morón, 2018). Moreover, given the previously discussed complementary role of the images, it is also possible that our participant cohorts were able to exploit the video to a greater extent to support their comprehension at the fastest subtitle speed, although this remains to be tested empirically.

Additionally, we need to acknowledge limitations related to the construction of comprehension questions in the original study. These questions combined comprehension and mnemonic elements, occasionally requiring participants to recall specific details, numbers, or exact subtitle wording. This means that conclusions on the impact of speed on comprehension cannot be established reliably as it was confounded with memory.

5.2. The Impact of Video and Subtitle Speed on Eye Movements

Both video presence and subtitle speed significantly influenced viewing patterns for all participants. In the subtitle-level analyses, viewers consistently prioritised subtitle reading over moving images, which is evident from more fixations on the subtitles compared to the video. When video was present, viewers engaged with the moving images, as evidenced by longer MFD and saccades in the video region. Our results align with previous research on differences in scene perception and reading, where reading typically involves more frequent, shorter fixations and shorter saccades (Rayner, 2009).

Fixation numbers and durations on subtitles decreased with video presence and increasing speed. At 28 cps, subtitle reading became more uniform, with viewers making similar numbers of fixations in both video conditions and fewer crossovers between subtitles and images due to limited time. At this speed, viewers might lack time for vital cognitive processes during reading, such as resolving linguistic ambiguity, confirming meanings, and integrating words with prior context.

The highest speed resulted in longer saccade lengths in the subtitle region, as viewers rushed to finish subtitles before they disappeared. This confirmed a consistent effect of speed on eye movements. However, unlike for fixation duration and number, saccade length in the subtitle region was influenced by video presence only in the UK cohort, not in the PL and AUS cohorts. This was likely due to their proficiency in multimodal reading, which enabled them to adjust their viewing behaviour more efficiently, making longer saccades to get to the end of the subtitles more quickly, to process the images. The reason Polish participants, equally versed in multimodal processing, did not make longer saccades is likely because they were reading in a foreign language, which demands more thorough processing of subtitle words, regardless of video presence.

In the word-level analyses, we confirmed – in line with the original study – the existence of two well-established effects from reading research in subtitle reading: word length and word frequency (Clifton et al., 2016). Word length and frequency are two of the “Big Three” in lexical processing (the third being predictability, which we did not test here). These effects were pronounced in subtitle reading without video at the slowest speed, akin to static text reading. However, adding moving images and raising subtitle speed reduced these effects, confirming the role of subtitle speed and video presence as overarching constraints on reading behaviour.

5.3. Wrap-Up Effects

Interesting differences between reading static text and reading subtitles emerged with regard to the wrap-up effect (Rayner et al., 2000). In the context of subtitling, the effect was manifested in prolonged reading times on subtitle-final words at the slowest speed (12 cps) when video was absent. However, at the highest speed with video present, all viewers spent less time on words at the end of

the subtitles compared to words in the middle. This suggests that subtitles disappeared too quickly to be fully processed, potentially disrupting higher-level integration.

Differences in the wrap-up effect were particularly evident in the Polish cohort, where word position (final vs. middle) had an effect on the total times these participants spent reading subtitles. PL participants exhibited a notable decrease in total reading times for subtitle-final words, even when accounting for subtitle speed and video presence. These total reading times reflect post-lexical integration processes, implying that non-native viewers may encounter challenges in processing subtitles comprehensively compared to their native counterparts. These difficulties could be attributed to processes like mentally converting linguistic representations of clauses and sentences into propositional representations, which may not be as automated for non-native speakers (Segalowitz & Hulstijn, 2005). This suggests that L2-English viewers may read at a slower pace, requiring more time to grasp word meanings and adjust their mental representations before reading subtitles to completion.

A note on the wrap-up effect in subtitling is warranted. In traditional reading, wrap-up typically occurs at the end of sentences or clauses, and is influenced by punctuation (Warren et al., 2009). However, subtitles do not always align with clauses or sentence boundaries, and thus may not always comprise self-contained units ending with punctuation. Even when a subtitle forms a complete sentence, the wrap-up effect can be affected by the presence of a subtitle that follows immediately afterwards, potentially disrupting integration. It is also possible that post-lexical integration continues after a subtitle disappears, particularly if no other subtitle immediately follows. Consequently, further exploration of wrap-up effects in multimodal reading, taking into account sentence-subtitle overlap, is necessary for a comprehensive understanding of how higher-level sentence processing and integration unfold as subtitles appear and disappear.

6. Conclusions

This study replicated Liao et al.'s (2021) main findings, confirming the impact of subtitle speed and video presence on eye movements across diverse participant groups, reaffirming the robustness of these effects at both subtitle and word levels in both native and non-native populations. Our results also highlighted the negative impact of excessive subtitle speed (above 20 cps): at 28 cps, viewers struggled to keep up with rapidly disappearing subtitles, often missing subtitle-final words, affecting the experience of watching subtitled audiovisual content.

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