How Older Adults Use Online Videos for Learning

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Online videos are a promising medium for older adults to learn. Yet, few studies have investigated what, how, and why they learn through online videos. In this study, we investigated older adults' motivation, watching patterns, and difficulties in using online videos for learning by (1) running interviews with 13 older adults and (2) analyzing large-scale video event logs (N=41.8M) from a Korean Massive Online Open Course (MOOC) platform. Our results show that older adults (1) are motivated to learn practical topics, leading to less consumption on STEM domains than non-older adults, (2) watch videos with less interaction and watch a larger portion of a single video compared to non-older adults, and (3) face various difficulties (e.g., inconvenience arisen due to their unfamiliarity with technologies) that limit their learning through online videos. Based on the findings, we propose design guidelines for online videos that can support older adults' learning.

CCS Concepts: • **Human-centered computing** → **Empirical studies in HCI**.

Additional Key Words and Phrases: online learning, older adults, MOOC, video learning

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1 INTRODUCTION

"*One is never too old to learn,*" "*Learning is from cradle to grave.*" As emphasized by these proverbs, lifelong learning, which spans from early childhood to older age, is crucial to one's life. Lifelong learning not only gives one a sense of personal fulfillment and satisfaction [15, 24, 32], but also enables them to adapt to a fast-evolving job market [15]. Furthermore, it strengthens a nation' s economy and prevents exclusion or marginalization of older adults [26, 32].

Among various media that could support lifelong learning, online videos are among the most popular due to their availability, scalability, and cost-effectiveness [65]. For example, video-based learning platforms, such as Massive Online Open Course (MOOC) platforms, are widely available these days. Additionally, video platforms like YouTube are offering instructional videos such as how-to videos in diverse domains (e.g., cooking, swimming, fishing).

With the rise of online video learning, a myriad of research has investigated how users use online videos for learning, which has provided insights on how to design videos and tools that further enhance the learning experience [11, 39, 50, 68]. However, older adults who are retired or in the later stages of their careers may exhibit different usage behaviors due to possible age-related factors (e.g., sensory and perceptual issues, slower processing speed, low working memory abilities) [31]. Moreover, in contrast to the younger "video generation", older adults are likely to be accustomed to one-way interaction with video (e.g., TV) [52, 76]. Thus, their use of online learning videos might be different from that of non-older adults. However, little research has examined *what, why, and how* older adults use online learning videos to

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learn. Understanding how older adults learn through online videos would be crucial to providing an appropriate aid for such a segment of the population to facilitate the use of online videos for learning.

To this end, in this paper, we aim to understand how older adults (i.e., those aged 55 or older[1]) use online learning videos in terms of (1) what videos they watch online for learning and why, (2) how they interact with online videos, and (3) what difficulties they face. We investigate these aspects through a mixed-methods approach: (1) interviews with 13 older adults (M_{age} = 65.5, SD_{age} = 6.6) who have used online videos for learning and (2) large-scale log analysis of older adults' interaction logs on a MOOC platform in comparison with those of non-older adults (41.8M interaction logs from total 108K users). We found that older adults tend to watch online videos to learn practical topics applicable to their daily lives (e.g., English conversation, cooking), while consuming fewer videos in science or engineering domains. Moreover, we identified that they (1) perform fewer video interactions (i.e., pause, jump forward/backward), (2) watch videos more repeatedly, and (3) cover a video[2] more than non-older adults. We also identified that older adults face difficulties due to (1) the characteristics of the video medium and technology and (2) video-specific issues (e.g., fast speaking pace). Based on the findings, we suggest design implications of online videos and their platforms for older adults to better pursue lifelong learning.

The contributions of this paper are as follows:

- Results from an analysis of 41.8M log events and interviews with older adults that reveal why and how older adults watch online videos for learning and the difficulties older adults face when watching online videos for learning
- Design guidelines of online videos and their platforms for older adults to have a better learning experience using online videos

2 RELATED WORK

We review previous work on (1) learning through online videos and (2) older adults in learning.

2.1 Learning through Online Videos

Watching online videos is a promising way to pursue learning. It is highly accessible compared to traditional education, with little restriction on time and location of learners [3]. Moreover, most of the online learning services are more affordable than their offline counterparts, allowing users to easily access them [66].

Although highly accessible, users who watch online videos for learning show different patterns compared to traditional classroom learning. For example, the high dropout rate of learners is known to be a chronic issue of online learning [55], and learners are known to be easily distracted in online learning [87]. Plus, online learning is often unidirectional, making it more difficult for learners to interact with instructors [30]. A number of research studies have investigated how users learn through online videos to better understand their behavior [17, 39, 50, 56]. Based on the understanding of learners and video formats, these studies provided insightful design implications into how video and video platforms could be designed. For instance, based on the watching pattern of selectively watching some parts of the video, Kim et al. suggested to summarize highlights of the video [50]. Similarly, Li et al. analyzed video interaction patterns and suggested design implications for utilizing video interaction patterns to improve learning experience [56].

[1]These ages are indicated in Korean age. Korean age considers the birth year as year 1, which is equivalent to calculating the age as $current\,year - birth\,year + 1$.
[2]We define the coverage of a video as the percentage of a video clip seen by the viewer.

Yang et al. recently introduced a video watching interface that provides learners with estimated difficulty and relevant parts of the video that are extracted from analyzing the collective interaction logs [89].

However, these studies are limited as they investigated typical users of the platform, while underrepresented user groups such as older adults take up only a small portion of the platform users [20]. To increase the accessibility of online videos, understanding how various types of learners learn using online videos is necessary. Previous work also highlighted the importance of customizing the design of video platforms for underrepresented user groups, such as visually or hearing impaired users [42, 57, 90], to improve the accessibility of video. Therefore, we investigate how older adults learn through online videos and also provide design guidelines for improving the accessibility of video learning for older adults.

2.2 Older Adults in Learning

Lifelong learning denotes learning happening throughout one's life [54]. However, it not only stresses the characteristic of 'lifelongness' (i.e., happening throughout one's life), but also 'lifewideness', covering learning in institutions, families, communities, and workplaces [8]. In fact, for older adults, informal learning—learning happening outside institutions or from systematic activities—is a more prevalent form of learning than formal or non-formal learning [83].

Since lifelong learning gives older adults the opportunities to learn fast-evolving knowledge, it is known to increase self-efficacy and keep them connected to society [4]. Plus, considering that many of them are retired or about to retire, further learning may benefit them with additional chances of extending their career [28]. Furthermore, participation in learning can also promote life satisfaction for older adults [27]. For these reasons, lifelong learning is known to increase the wellness of older adults.

However, it is known that participation in learning decreases as the age increases [59]. This could be because older adults often face physical, financial, and cognitive difficulties in pursuing lifelong learning [33, 37, 53, 69, 75]. Online learning is a potential alternative to address physical and financial difficulties: (1) online learning does not require learners to be on-site, (2) flexible time choices are available without time constraints, and (3) as low-cost instructional materials are widely available online, it may reduce financial burden [7]. As such, online learning is an attractive channel of lifelong learning for older adults.

In order to help older adults fully utilize online learning platforms, it is important to design platforms that are suitable for use by this group [5, 38, 88]. Since aging involves biological, psychological, and social changes in individuals [31], older adults' behaviors and attitudes toward online learning may be different from those of non-older adults. For example, research suggests that online learning based on the Modality Principle from Cognitive Theory of Multimedia Learning [62] — instructions should not overload the learner by using only one pathway such as visual channel — is more effective for older adults than non-older adults [81]. Furthermore, older adults' motivation toward MOOC learning differed from non-older adults; older adults' motivation to learn included improving cognition and seeking fun [88]. On the other hand, their interest level in certain topics are also different; they have higher interest in health-related topics [60, 72]. Moreover, research has found that there exist various accessibility barriers for older adults to learn online [2, 9, 14, 35, 67, 74], such as having difficulty moving to the next lesson [14].

Although these studies aimed to explore how older adults learn, they are limited to certain aspects of behaviors or difficulties (e.g., motivation, accessibility issues), which may be insufficient to fully understand *what, why, and how* older adults are learning specifically using online videos. To this end, we aim to comprehensively understand how older adults learn through online videos by focusing on the following three points with both large-scale log data and in-depth interview sessions: (1) motivation, (2) video interaction patterns, and (3) difficulties.

3 METHOD

We took a mixed-methods approach, incorporating both interviews and a large-scale MOOC log analysis, to understand how older adults use online videos to learn. By analyzing older adults' video usage logs, it is possible to understand how older adults watch videos for learning from their natural behavior logs and how their behaviors differ from non-older adults. However, understanding why they show such behaviors and what difficulties they face might be limited with the log analysis alone. Thus, we conducted interviews with older adults in addition. We used an emergent mixed-methods design [21], where we first started with log analysis only and later conducted interviews to draw complementary insights. Note that the logs analyzed were collected in 2018 and the interviews were conducted in 2020.

Our research questions are as follows:

- **RQ1**: **[Motivation]** Why and what do older adults want to learn while watching online videos?
- **RQ2**: **[Watching pattern]** How do older adults watch online videos for learning?
  - **RQ2-1**: What do they consider when choosing which videos to watch?
  - **RQ2-2**: How much do they interact with the video?
  - **RQ2-3**: How and why do they watch a video repeatedly?
  - **RQ2-4**: How much of the video do they watch?
- **RQ3**: **[Difficulties]** What are the difficulties older adults face while learning through online videos and how do they try to address the difficulties?

We combined the interview and log analysis to gain a comprehensive understanding. We originally started our log analysis for RQ1 and RQ2-2. Upon realizing that exclusively relying on the log analysis provides a limited understanding of older adults' video-based learning behavior, we decided to conduct interviews to complement the findings from the log analysis. While planning the interview study, we added RQ2-1 (how they select videos to watch) and RQ3 (difficulties) as these are aspects that are essential in understanding the end-to-end process of how older adults learn with videos. These were also questions that the log analysis could not answer. We also further added RQ2-3 and RQ2-4 for clarity in reporting. After the interview, we conducted an additional log analysis to answer RQ2-3 and RQ2-4, as these are the research questions that were added later that could be also answered through log analysis in addition to the interview.

Definition of Older Adults. Although most previous studies defined *older adults* as those whose age spans 55 to 65 [29, 63], no fixed agreement exists on which chronological age could define older adults. This is because the term 'older adults' have different criteria based on their societal surroundings, ranging from family to culture or world [82].

As such, we refer to Findsen et al. [32] to define older adults as people who are having or about to have a later stage of life. Specifically, since the average retirement age in Korea was around 57 in 2018 [45], when our data was collected, we defined older adults as those who are aged 55 or older in their Korean age.

Scope of Online Videos for Learning. The goal of our research is to investigate how older adults use online videos in general for learning purposes. Since the types of online videos one can learn from vary greatly, we interviewed those who watched *any video* if they watched the video with the *purpose of learning* to capture diverse watching experiences. While granting an in-depth account of individual experiences, interview results can only capture behaviors participants remember. Thus, for a more comprehensive understanding of the landscape, we complemented interviews with a log analysis from a large-scale video platform.

We chose a MOOC platform for the log analysis, since we can ensure users of a MOOC platform watched MOOC videos for learning purposes. Most MOOC platforms, however, have several differences from other video platforms; they usually offer videos in limited styles [44] or topics and many take courses for college credits or certificates. Insights gathered from analyzing a MOOC platform would lead to a misalignment with more generic video learning experiences of our interview participants. Considering this, we chose to analyze data from K-MOOC[3] [48] in 2018 due to its breadth of topics and video styles and credit system not being adopted yet. First, K-MOOC provides videos with various topics aiming for providing lifelong learning ranging from common MOOC topics (e.g., Using Python for Big Data Analysis[4], Reading American Literature with Pictures[5]) to various topics related to daily life (e.g., Smoking and Healthy Life[6], All about My House[7], Creative People's Seven Habits[8]). Second, format-wise, they are not only limited to typical styles of MOOC videos, but include various formats such as practicing workout steps, narrative animation [44], or fictional case study [44]. Lastly, in 2018, K-MOOC has not yet adopted the Academic Credit Bank System [1]; it did not allow one to earn credits for earning a degree. In summary, we believe K-MOOC—with its broad topical coverage and lifelong learning support—can serve as a compatible source of data to complement our interviews—with more generic video learning experiences.

3.1 Interview

We recruited 13 adults aged 55 or older and who had experience watching online videos for learning within six months. We posted recruitment ads in online communities where older adults are expected to visit (e.g., online bulletin board targeted for 50s+), along with online communities where the users' parents may be in the age of older adults (e.g., online communities of colleges) to recommend their acquaintances who qualify. We tried to diversify the interviewee pool by considering their age, level of education, pre-reported frequency/amount of learning using videos and selected 13 interview participants (7 females, M_{age} = 65.5, SD = 6.6) (Table 1). All interview sessions were conducted through voice calls and lasted around 60-90 minutes. Each session was audio-recorded, and each participant received 25,000 KRW (22 USD equivalent) for their participation. The study was approved by our institution's IRB.

We conducted semi-structured interviews, where we asked (1) *personal information* (e.g., age, education degree), (2) *general experiences on learning through online videos* (e.g., motivation for learning, first time to start learning through online videos, how they got accustomed to online video interface), and (3) *experience on learning through online videos for each video they mentioned* (e.g., content/form of the video, motivation, how they watched the video, other activities they did relate to the video, difficulties they faced and how they resolved them). All interviews were transcribed and then analyzed with a thematic analysis [16, 80].

Two researchers conducted thematic analysis by first reading transcripts and noting notable patterns of behaviors or quotes. Then, we classified notes into the most relevant research question. For each research question, we classified notes into theme. To improve coherence within the theme, we iterated over the notes within each theme while re-classifying a subset of notes. Here, we discussed on the note categorization where we disagreed to reach a consensus. Finally, we labeled the themes. For RQ2-2 and RQ3, researchers agreed that there exists a need for classifying further

[3]A Korean state-led MOOC platform, which launched in 2015 with 3.6M users by the end of 2018. It offered 520 courses open for enrollment as of January 2019, spanning various subject domains (e.g., humanities, social science, engineering, natural science) offered by 92 different universities.
[4]Domain: Engineering, Level: Intensive major
[5]Domain: Humanities, Level: Basic major
[6]Domain: Medical sciences & Pharmacy, Level: Elective
[7]Domain: Engineering, Level: Elective, A course that covers how to pick a good home, how to interior the house, how to invest using house, and knowledge for house taxation
[8]Domain: Social science, Level: Elective

Table 1. Participants of the interview sessions

ID	Age	Gender	Education	Domains of videos watched for learning
P1	76	M	Master	Bible, health, English conversation
P2	65	F	Master	Biblical Hebrew, Bible, theology
P3	57	M	Master	Work-related IT field, statistics, deep learning, cookery, camping
P4	56	F	High school	Sports, health, diet, preparation for old age
P5	69	F	Doctorate	Chinese, calligraphy, DIY, musical instrument, gardening, cookery, health, life wisdom
P6	63	M	Bachelor	Photoshop, camera, Chinese, astronomy, fire safety
P7	74	F	Bachelor	Farming, cookery, sports
P8	75	M	Master	Oil painting, farming
P9	65	M	Bachelor	Counseling studies, golf, yoga
P10	57	F	High school	Stock investment, storytelling (Korean traditional stories), cookery
P11	64	M	Master	English (conversation, vocabulary), golf, fishing, billiard
P12	65	F	Bachelor	Taxation, cookery, interior architecture, health, astronomy
P13	65	F	Bachelor	English, swimming, cookery

into subthemes — to identify detailed reasons behind the identified interaction behavior themes (RQ2-2) and to further classify the high-level challenges to identify the detailed reasons behind the challenges older adults face (RQ3). Thus, we further decomposed notes in each theme into subthemes by going over the same process with when identifying the themes. Finally, one researcher re-examined the notes of themes and subthemes for coherence.

3.2 Log Analysis

We analyzed event log data from K-MOOC collected in 2018 to understand how older adults use MOOC videos compared to non-older adults. Through comparison with typical users, we wanted to understand how older adults are *unique* in their way of using the videos, as it could provide insight into better designing current online videos and their platforms customized for older adults. Specifically, we took into account their video domain selection which indirectly reveals their motivation (RQ1), frequency of single interactions and watching patterns (i.e., interaction sequence) (RQ2-2), length of repeated watched parts (RQ2-3), and coverage per video (RQ2-4) as dependent variables, while age group (i.e., older adults and non-older adults) being the common independent variable of all the log analysis.

3.2.1 Data and Pre-processing. The event logs capture users' video interactions (i.e., play/stop/pause video and seek back/forward) on their interaction type, video timestamp, real-time, and user & course information, across 1.4K different courses and 51K different lecture videos (See Supplementary Material for sample logs). Data were provided from the K-MOOC platform upon the grant contract after all personally identifiable information had been anonymized. After excluding the logs with errors that are not recoverable (e.g., (1) missing certain fields describing an event (e.g., the time when an event occurred) and (2) having duplicate values for certain fields (e.g., having two different times for an event)) and extracting video-related event logs as of our purpose, 41.8M event logs were left. These video event logs included behaviors of 108K different K-MOOC users on 1,391 different courses. Among the users who provided their birth year when signing up (107K users), 4.4K users (2.8% of all users) were classified as older adults in 2018 (Figure 1).

Additionally, we also obtained sign-up information (i.e., birth year, gender, etc., which users optionally entered while signing up) of users who signed up until 2018 (3.6M users) and information of 438 courses that were open for

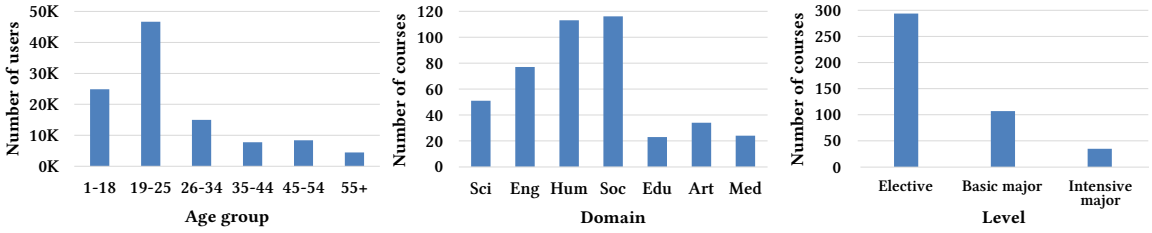

Fig. 1. Age distribution of users who watched K-MOOC videos in 2018 (left), distribution of courses by domain (middle) and level (right) offered in K-MOOC in 2018 (Sci: natural science, Eng: engineering, Hum: humanities, Soc: social science, Edu: education, Art: arts & physical education, Med: medical sciences & pharmacy)

enrollment in 2018, including course name and subject categorization. Since video length information was not stored in the database as a separate entry, we extracted the length of 23.7K videos from 476 different courses, which we were able to access at the time we crawled (April 2020).

3.2.2 RQ1: What do they want to learn while watching videos? Analyzing how older adults select courses, in which domain and level of difficulty (i.e., elective, basic major, intensive major), may give us insights into what older adults want to learn using online videos. Therefore, we analyzed how the domain selection and level selection of older adults differ from that of the non-older adults. We based the categorization of each video on K-MOOC's classification, which was determined by the instructor: seven high-level domain categories and three levels of difficulty as in Figure 1. To avoid taking cases into account where a user may have clicked a video mistakenly, we only considered the courses the user took with at least three log events (i.e., play, stop, pause, seek, changing speed, and showing/hiding captions or transcript). Then, we used logistic regression to identify the relationship between the age group (i.e., older adults and non-older adults) and whether the user will take a course in each domain category. As there exists a correlation between each case since individuals took multiple lectures and the same lecture video is watched by multiple users, we used generalized estimating equations (GEE) model [41], a statistical method used when correlation may exist in the outcome variable. We used the exchangeable correlation structure as one may watch a course at different times watching several videos, so their order of watching courses may change.

3.2.3 RQ2-2: How much do they interact with the video? Analyzing how older adults interact with the video would provide insights into how they watch a video [49]. Thus, we (1) analyzed the frequency of video interactions and (2) performed sequence clustering [84] to know the dominating interaction sequence pattern to understand how each older adult watched each video. Among various types of video interactions, we particularly focus on watch, pause, and seek forward/backward[9] for the analysis, as they have a direct connection with the flow of how users consume video content, unlike speed change or turning on/off captions or subtitles.

1. Frequency of single interactions. Even for the same jump, the intention behind performing a long jump could be different from a short jump. Thus, we subclassified each interaction into three detailed interactions based on the length or duration of the interaction. As in Table 2, the threshold between short and medium interactions is determined as 25 percentile of interaction length/duration, while the threshold between medium and long interactions is determined as 75 percentile of interaction length/duration. For 'watch' interaction, unlike other interactions like pause or seek where pause/seek interval begins with a user pressing the 'pause/seek' button, a watched interval can begin without

[9]In this paper, we define 'seek backward' as jumping to a prior part of the video and 'seek forward' as jumping to a later part of the video

Table 2. We defined 12 detailed interactions, based on the length or duration of each interaction.

Type	Detailed name of interaction	Definition
Watch	Short Watch (SW)	0.2 s ≤ Watched duration of video timestamp < 1.8 s
	Medium Watch (MW)	1.8 s ≤ Watched duration of video timestamp < 44.2 s
	Long Watch (LW)	44.2 s ≤ Watched duration of video timestamp
Pause	Short Pause (SP)	Paused duration < 1.6 s
	Medium Pause (MP)	1.6 s ≤ Paused duration < 45.0 s
	Long Pause (LP)	45.0 s ≤ Paused duration
Seek Backward	Short Seek Backward (SB)	-8.2 s ≤ Seek videotime length ≤ 0s
	Medium Seek Backward (MB)	-33.6 s ≤ Seek videotime length < -8.2 s
	Long Seek Backward (LB)	Seek videotime length < -33.6 s
Seek Forward	Short Seek Forward (SF)	0s < Seek videotime length < 9.0 s
	Medium Seek Forward (MF)	9.0s ≤ Seek videotime length < 36.6 s
	Long Seek Forward (LF)	36.6 s ≤ Seek videotime length

the user actually pressing the 'play' button at the start of the interval. Thus, we decided to ignore the cases where only watching status lasts less than 0.2 seconds. Moreover, as we are defining detailed interactions according to their length relative to the video length while the length of the videos in K-MOOC varied a lot (m = 13.5 minutes, std = 9.4 minutes), we focused only on the logs that were performed in the videos that have the length that falls into the 25 to 75 percentile of the video length distribution: 6.95 minutes to 18.07 minutes.

Then we calculated the frequency of each detailed interaction each user performs in each video. We took the following two metrics to calculate frequency to capture complementary aspects: (1) Frequency 1: number of times each detailed interaction is performed per minute; calculated by dividing the number of times each detailed interaction is performed by the total length of the corresponding video, and (2) Frequency 2: number of times each detailed interaction is performed per coverage of the video one watched; calculated by dividing the number of times each detailed interaction is performed by the coverage of the corresponding video that the learner watched at least once. For Frequency 2, we excluded cases where one's coverage of the video is less than 1% to avoid dividing by near zero.

We then used linear regression to identify the relationship between the frequency of each detailed interaction and the user's age group. This is because through RQ1 we found that older adults and non-older adults watch videos of different domains and levels of the video, where the domain and level of the video may affect the frequency of interaction. Thus, we used regression while taking domain and level of the video as regressors in the model to understand the relationship between frequency of interaction and the user's age group without these factors affecting the result. Similar to the reason explained in RQ1, we used Generalized Estimating Equations (GEE) with exchangeable correlation structure. In addition, in order to compare which detailed interaction has more frequency difference between older adults and non-older adults, we standardized the dependent variable and iterated upon the same condition.

2. Dominating interaction sequence pattern. Although we can know how frequently older adults exhibit different interactions by analyzing individual interactions, it does not capture patterns of video watching at a macro level. There may be cases where a sequence of interactions signals a specific intent. For instance, even with the same number of Short Seek Forwards performed within a video, one could be seeking forward to look for a specific part or to skim the whole video. Thus, we analyzed the interaction *sequence* by sequence clustering method proposed by Wang et al. [84] to identify older adults' emergent video watching patterns and how they differ from those of non-older adults.

We first converted each learner's interaction logs of a video in a session to a watching pattern sequence composed of interaction units defined in Table 2. Then, we extracted every possible subsequence of length k (i.e., k-gram sequence) from the watching pattern sequence. For every two watching pattern sequences pair, we calculated the normalized frequency per subsequence that appeared in either of the two sequences. These normalized frequencies are made into an array per sequence. Next, we used polar distance between the two arrays to cluster the sequences. (Refer to Wang et al. [84] for more detailed information on sequence clustering.) We chose k as 4 in k-gram sequence as repetitiveness is captured enough in 4-gram (See Supplementary Material for details). Furthermore, similarly to analyzing the frequency of each detailed interaction, we focused only on the videos that belong to the 25 to 75 percentile of video length distribution. Then, due to time complexity, we randomly sampled a total of 20K watching sequences of a user watching a video in a session (i.e., 10K from older adults and 10K non-older adults) for sequence clustering. With the sequence clustering results, we made dummy variables for each cluster and ran GEE with a binary exchangeable correlation structure.

3.2.4 RQ2-3: How much do they watch in a repeated manner? To understand how older adults watch videos repeatedly, we extracted the sum of lengths of all the repeated watched parts. If a user watched a part three or more times, each repeated watching time was added. As the length of videos varies, we calculated the percentage of the length of all the repeated watched parts by dividing by the length of the video. Next, we used GEE model with linear regression to identify the relationship between the percentage of the repeated watch and the age group. For a similar reason with the previous analyses (RQ2-2), we also considered the domain and level of the video as factors in the model and used exchangeable correlation structure. We also took the length of videos as a factor in the model as we did not limit the analysis to a certain length of the videos.

3.2.5 RQ2-4: How much of the video do they watch? To identify how much older adults cover a video, we extracted the sum of lengths of all the watched parts, regardless of the number of times watched. Then, we derived the coverage of the video by dividing it by the length of the video. Next, we used GEE model with linear regression to identify the relationship between the coverage of a video and the user's age group in the same setting as with RQ2-3.

4 RESULTS

We present the results of the thematic analysis of the interviews and log analysis for each RQ. For the thematic analysis result, we present the identified themes of all RQs. For the log analysis, we present the result of RQ1, RQ2-2, RQ2-3, and RQ2-4.

4.1 RQ1: Why and what do they want to learn while watching online videos for learning?

4.1.1 Interview. We identified two themes on what older adults want to learn — (1) those related to their personal interests, hobby, curiosity, or needs in their daily life and (2) those related to their work.

We found that *all participants wanted to learn at least one* subject **related to their personal interests, hobbies, or needs in their daily life**. This relates to more self-directed or autonomous learning rather than required learning [6]. What they learned spanned across various disciplines, including visual arts, physical education, humanities, social sciences, and even practical life skills (Table 1). In contrast, only 3 participants said they learned a STEM subject. Some participants attributed the lack of desire to learn STEM to the difficulty of learning: "*For me, it's hard* (*to learn scientific topics*)" (P4). P7 even explicitly mentioned that they regard learning something completely new as not suitable for their age. Even among the participants who watched STEM videos, it was largely limited to the surface level (2 out

of 3 participants). For example, P12 who watched astronomy videos said: "*Although I have interest in science, I'm not interested in the theories but watch* (*science videos*) *for their awe-inspiring feelings*" (*P12*).

Four participants mentioned that they watch online videos to learn things **related to their work**, although no participant reported watching online videos solely for learning work-related materials. This is linked with required or mandated learning [6]. In this case, they were more driven by external factors, including learning something that relates to their job (e.g., speaker system development, health education, deep learning basics).

4.1.2 Log Analysis. Results show that older adults take more humanity and medical science courses while taking fewer courses in STEM, social science, and education, compared to non-older adults. This aligns with our interview result that not many older adults watch STEM domain videos. Furthermore, it aligns with previous research [47, 60] that older adults tend to like learning about health science. The *odds ratio* [13] of each domain, which indicates the ratio of the odds of older adults taking a course in a certain domain to the odds of that of non-older adults, is presented in Figure 2. For example, the odds of older adults taking natural science courses are 0.65 times that of non-older adults. Except for arts & physical education courses, there exist clear differences between the odds of older adults taking a course in a certain domain compared to those of non-older adults.

Moreover, compared to the non-older adults, older adults prefer taking elective courses over major courses. The odds ratio decreases as the level increases (elective courses: 1.14, basic major courses: 0.90, intensive major courses: 0.70) (Figure 2). This may be the result of older adults trying to learn something related to their personal interest or curiosity rather than for their work, as shown in our interview result.

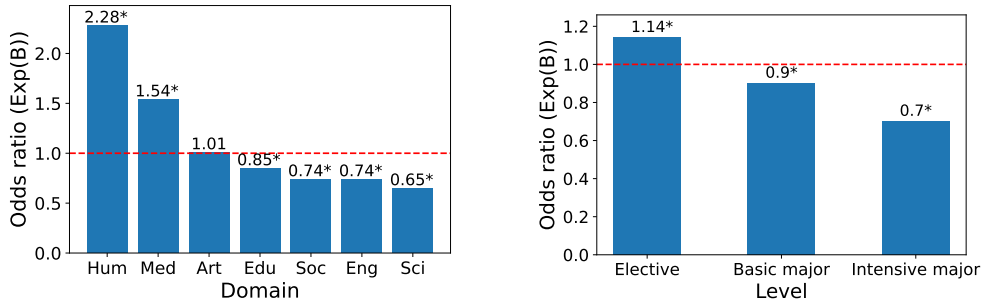

Fig. 2. Results of RQ1, which displays odds ratio for domain (i.e., Humanity, Medical sciences & Pharmacy, Arts & Physical education, Education, Social science, Engineering, Natural science) and level (i.e., Elective course, Basic major course, Intensive major course). Older adults take more humanity or medical sciences & pharmacy courses and less engineering, natural science, social science, education courses than non-older adults. They also take more elective courses and major-related courses than non-older adults. (* indicates $p < .01$)

4.2 RQ2-1: What do they consider when choosing which videos to watch?

4.2.1 Interview. The criteria for deciding what to watch have emerged as follows: (1) video metadata, (2) whether the content and level suit their expectations, and (3) whether the video is in their desired format.

Nine participants mentioned **video's metadata** (e.g., title, thumbnail, uploaded date, creator/uploader) as the main criteria for clicking the video to watch: "*If I have something I want to know, I first search their* (*i.e., prominent tax accountant's*) *channel ⋯ I don't think his delivery is better, but I can trust what he's saying*" (P12). However, some mentioned that deciding with metadata would lead to misselection. Thus, some mentioned that they would only continue watching when it fits the additional criteria (e.g., content, level, format).

Ten participants also mentioned **desired content and difficulty level of the video** as criteria for choosing video to watch. Specifically, they wanted to find a video that covers the contents that fit their level. According to P9, since the metadata do not mention whether the yoga video is for older adults, they should watch to judge whether it suits their level and stop watching if it does not. Interestingly, four participants pointed out that creator being in their age as an indicator of proper content and level: "*I don't really understand when watching cooking videos made by young people. Moreover, while I prefer cooking Korean dishes, they usually cook Western dishes.*" (P10).

Twelve participants pointed out the **desired format** as a criterion for selecting videos to watch. Their desired format includes demonstration with appropriate close-ups to how-to videos, having a feedback session, and showing more visual materials than just explaining. Interestingly, many (8 participants) favored a format that delivers the core content without adding jokes, irrelevant chats, or advertisements: "*I don't think trying to be funny or interesting is necessary. (I like it when they tell me) just the key points*" (P7).

4.3 RQ2-2: How much do they interact with the video?

4.3.1 Interview. We identified emerging themes of (1) not performing many interactions overall and (2) performing seek forward, seek backward, or pause time to time, where the former took most proportion. Thus, we report the subthemes that represent the reasons behind the first emergent theme.

When asked to describe how they interact (e.g., pause, seek forward) with the video while watching it, eight participants replied that they **do not really perform many interactions overall**. This was in part because they did not find it necessary as they could understand the video content but also because they did not need to fully understand the content, which is linked to their motivation of watching the video (RQ1). Moreover, they did not interact with the video because they did not *know how* to interact with the video or felt uncomfortable interacting with the video. P4 mentioned, "*I didn't know about pausing or other functionalities ⋯ So I watch (the video) from the beginning again.*"

Particularly for the seek forward interaction, six participants said they do **not mostly seek forward at all**. The most prominent reason was that they prefer not to miss or skip anything. P1 said: "(*Even if I watch a video several times, if I seek forward, I feel like I'm learning less even though it may save some time.*" Similarly, P9 mentioned: "(*Although I'm only looking for a certain part in a video,) I watch it from the beginning without seeking forward. It is because I want to know everything ⋯ (It's also because, even if I am knowledgeable about the other part of the contents,) explanation styles across lecturers may vary*".

4.3.2 Log Analysis. We report results from analyzing (1) frequency of video interactions and (2) dominant interaction sequence patterns.

1. Frequency of single interactions. We found that older adults perform significantly fewer interactions while watching online videos for learning compared to non-older adults (Table 3). Moreover, the negative values of all coefficients in Table 3 indicate that older adults perform all detailed interactions less than non-older adults. This aligns with our interview result of older adults not performing interactions a lot.

To identify which interaction has a larger frequency difference between older adults and non-older adults, we standardized the dependent variable and ran the model again, whose result is shown in the last column of Table 3. Moreover, older adults tended to perform large seek forwards much less compared to non-older adults. This may be the result of not performing seek forward as they do not want to miss anything as seen in the interview. They also exhibit short watches much less than long watches compared to non-older adults. As the watched interval was defined by watched

Table 3. Results of RQ2-2-1: distribution and the result of linear model regression using GEE for Frequency 1 (i.e., number of times each detailed interaction is performed per minute) (top) and Frequency 2 (i.e., number of times each detailed interaction is performed per coverage of the video one watched) (bottom). For example, the coefficient of age group being 55+ for Short Watch (SW) is -0.120, which means compared to non-older adults, the number of times Short Watch (SW) performed per minute by older adults is on average 0.120 times/minute smaller, while the average of whole users being 0.17 times/minute. Moreover, the number of times Short Watch (SW) is performed per coverage of the video one watched by older adults is on average 0.162 times/covered minute smaller, while the average of whole users being 0.2 times/covered minute (* indicates $p < 0.01$). (Note that some averages of detailed interaction appear to be similar between older adults and non-older adults, but it could be due to the fact that each group (older adults and non-older adults) has a different distribution of watching videos in terms of levels and domains, while these factors also significantly affect the interaction frequency.)

Detailed Interaction	Avg. & Std. for all	Avg. & Std. for older adults	Avg. & Std. for non-older adults	B (Coefficient of age group being 55+)	B (Coefficient of age group being 55+ after standardizing dependent variable)
SW	0.17 / 0.51	0.05 / 0.19	0.18 / 0.53	-0.120 *	-0.237 *
MW	0.29 / 0.63	0.24 / 0.66	0.30 / 0.63	-0.069 *	-0.108 *
LW	0.13 / 0.15	0.13 / 0.12	0.13 / 0.15	-0.002 *	-0.013 *
SP	0.04 / 0.36	0.02 / 0.09	0.05 / 0.38	-0.022 *	-0.061 *
MP	0.12 / 0.39	0.10 / 0.40	0.12 / 0.39	-0.032 *	-0.082 *
LP	0.05 / 0.10	0.05 / 0.09	0.05 / 0.10	-0.003 *	-0.031 *
SB	0.04 / 0.17	0.02 / 0.10	0.04 / 0.18	-0.018 *	-0.107 *
MB	0.08 / 0.22	0.05 / 0.16	0.08 / 0.22	-0.030 *	-0.139 *
LB	0.04 / 0.11	0.03 / 0.08	0.04 / 0.11	-0.012 *	-0.109 *
SF	0.10 / 0.48	0.07 / 0.37	0.10 / 0.49	-0.064 *	-0.053 *
MF	0.10 / 0.53	0.09 / 0.34	0.20 / 0.54	-0.098 *	-0.177 *
LF	0.09 / 0.19	0.05 / 0.14	0.09 / 0.19	-0.042 *	-0.225 *

Detailed Interaction	Avg. & Std. for all	Avg. & Std. for older adults	Avg. & Std. for non-older adults	B (Coefficient of age group being 55+)	B (Coefficient of age group being 55+ after standardizing dependent variable)
SW	0.20 / 0.79	0.04 / 0.27	0.22 / 0.82	-0.162 *	-0.205 *
MW	0.20 / 0.40	0.11 / 0.30	0.21 / 0.41	-0.097 *	-0.243 *
LW	0.03 / 0.03	0.03 / 0.03	0.03 / 0.03	-0.001 *	-0.038 *
SP	0.03 / 0.24	0.01 / 0.07	0.03 / 0.25	-0.016 *	-0.067 *
MP	0.04 / 0.12	0.03 / 0.11	0.04 / 0.12	-0.016 *	-0.131 *
LP	0.01 / 0.05	0.01 / 0.04	0.01 / 0.05	-0.003 *	-0.057
SB	0.02 / 0.18	0.01 / 0.09	0.02 / 0.19	-0.012 *	-0.066 *
MB	0.04 / 0.23	0.02 / 0.11	0.05 / 0.24	-0.026 *	-0.113 *
LB	0.03 / 0.18	0.02 / 0.10	0.04 / 0.19	-0.019 *	-0.099 *
SF	0.07 / 0.98	0.03 / 0.26	0.07 / 1.02	-0.041 *	-0.042 *
MF	0.21 / 1.03	0.06 / 0.52	0.22 / 1.07	-0.148 *	-0.140 *
LF	0.17 / 0.66	0.07 / 0.39	0.18 / 0.68	-0.105 *	-0.161 *

segment without pause or seek interaction, this also strengthens the interview result of older adults not performing interactions overall.

2. Dominating interaction sequence patterns. We identified seven sequence clusters along with the top three sequence patterns that are prevalent in each cluster, distinguishing the cluster from other clusters (Table 4). We also grouped sequences that were not included among the seven clusters as Cluster *Etc.*. The odds ratio of each cluster in Table 4 indicates the ratio of the odds of older adults watching a video in the pattern of the corresponding cluster to the odds of that of non-older adults. For example, the odds of older adults watching with the dominating pattern of consistent medium or long seek forwards (i.e., MF & LF) without watching (i.e., MF-MF-MF-MF or LF-MF-MF-MF or MF-MF-MF-LF) are 0.634 times that of non-older adults.

We found that older adults watch in a different watching sequence compared to non-older adults; the odds ratio was significantly different except for Cluster 4. Among those, only Cluster 5 (i.e., repeated long-term watching and long-term pause), had higher odds of older adults watching in that pattern than non-older adults. This indicates that older adults are more likely to watch in a longer pace just pausing for a long time once in a while. Results also show that older adults are less likely to watch in a constant skipping or skimming manner (Cluster 2, 3, 6). This also strengthens our interview result that older adults do not prefer missing anything in addition to single interaction analysis (Section 4.3.2.1). Moreover, the odds of older adults watching in a pattern that is not common enough so that it does not belong to any clusters were around two times higher than that of non-older adults (Cluster Etc.). This indicates that they are more likely to watch in sequences that are not frequently watched by others.

4.4 RQ2-3: How and why do they watch a video repeatedly?

4.4.1 Interview. A lot of participants (11 participants) reported that they watch videos repeatedly, where three themes emerged as reasons behind rewatching: (1) to follow the videos, (2) to remind themselves of the contents, and (3) to learn and understand the contents more thoroughly.

First, participants watched videos **to follow the videos, while most of them repeatedly watched video before starting to follow** the actions in the video. Interestingly, among the participants who wanted to follow the video, six participants reported that they did not follow the video while simultaneously watching it. Instead, they preferred to rewatch the videos repeatedly until they could ultimately follow the video without watching it. They also reported that they also stick to that video for a long time and follow the video repeatedly, before shifting to another video. P9 said, "*I watch videos repeatedly until I can do the workout completely by myself without watching ⋯ There are only one or two videos that I have completely understood. For one video, I even watched for about 20 times.*" .

Second, 11 participants reported that they rewatch videos **to remind themselves of the contents**. Among them, eight participants reported that they rewatch when they forgot some contents, while others reported that they watch repeatedly since they worry they would forget the contents later: "*I usually watch around 3 to 6 times. Now my memory got worse (than when I was young). Although I think I'm better than others in my age.*" (P1).

Lastly, seven participants added that they would rewatch **to fully learn and understand the contents more thoroughly**. They considered that rewatching a video repeatedly is crucial to learning. P11 said, "*I'd download the video and rewatch, as (even after watching) it's not fully mine.*" P6 also said, "*Even though I try to watch all the details, I can't understand everything by only watching once ⋯ By watching again after some time has passed, I can notice something that I haven't noticed before.*"

4.4.2 Log Analysis. Overall, neither older nor non-older adults showed rewatching pattern frequently. The majority of learners watched videos (93.1%) with rewatching happening in less than one-tenth of the video length, indicating

Table 4. Results of RQ2-2-2: Sequence clustering result and the odds ratio of older adults for each cluster. Per each cluster, top three sequence patterns that are prevalent in each cluster, which distinguish the cluster from other clusters are presented. Percentile refers to how common the cluster is.

Cluster # (Percentile)	Patterns	Pattern Explanation	Exp(B) ($p < 0.01$)
Cluster 1 (13.6%)	MP-MW-MP-MW MW-MP-MW-MP MP-MW-LP-LW	medium-lengthed watching with intermittent medium pause	0.758
Cluster 2 (11.4%)	MW-MF-MW-MF MF-MW-MF-MW MW-MF-SW-MF	medium-lengthed watching with intermittent medium-lengthed forwarding	0.492
Cluster 3 (8.9%)	MW-LF-MW-LF LF-MW-LF-MW LF-MW-LF-SW	medium-lengthed watching with intermittent long-lengthed forwarding	0.562
Cluster 4 (8.0%)	MB-MW-MB-LW MW-MB-LW-MB MB-LW-MB-LW	medium or long-lengthed watching with intermittent medium-lengthed backwarding	not significant
Cluster 5 (7.1%)	LW-LP-LW-LP LP-LW-LP-LW LW-LP-LW-SP	long-lengthed watching with intermittent long pause	1.257
Cluster 6 (5.3%)	MF-MF-MF-MF LF-MF-MF-MF MF-MF-MF-LF	constant medium or long-lengthed forwarding without watching	0.634
Cluster 7 (2.3%)	SP-SW-SP-SW SP-SW-MP-MW SW-MP-MW-SP	short-lengthed watching with intermittent short pause	0.477
Cluster Etc. (43.3%)	-	-	2.014

that the vast majority just rewatch small parts of the video. Moreover, only 0.4% of the cases rewatched more than 100% of the video, implying that watching a video multiple times was rare.

Nonetheless, age group was a significant predictor of how much the learner rewatched a video; older adults rewatched significantly more than non-older adults do. The GEE result indicates that older adults are expected to rewatch 6.24 seconds ($p < 0.01$) more of a video than non-older adults for a video of the same domain, level, and video length.

4.5 RQ2-4: How much of the video do they watch?

4.5.1 Interview. We identified three emerging themes that affect older adults to drop out of a video or not: (1) **circumstance** not being suitable to keep watching (e.g., time to cook), (2) **content or level** not suitable or as expected (e.g., level of yoga being too difficult), and (3) their **tendency of watching videos until the end**. Since the first two themes are obvious reasons behind drop out even among non-older adults [36], below we focus on the third theme.

Seven participants reported that they have a tendency to watch until the end and would rarely drop out in the middle: "*I always watch from the beginning to the end ⋯ It's because, after I watch it all, I can then conclude* (*whether*

the video is useful)" (P10), "*I always watch everything due to my desire to learn ⋯ (Although the lecture gets boring, I watch it all) because I'm not watching the lectures for eight hours a day. I only watch for one or two hours*" (P10).

4.5.2 Log Analysis. We found that the age group is a significant predictor of video coverage; older adults cover significantly more of a single video than non-older adults do. The GEE result indicated that older adults are expected to cover 12.24% ($p < 0.01$) more than non-older adults for a video with the same domain, level, and video length. The distribution of the coverage also shows a similar result (Figure 3): for more than half of the cases, older adults covered more than 90% of the video once they started watching the video, which is much more than non-older adults. Moreover, dropping out without even watching 10% of the video, is much more common among non-older adults than older adults, taking up to around one-fourth of the non-older adults' logs.

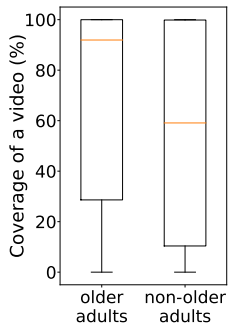

Fig. 3. Box plot of the distribution of video coverage for both older adults and non-older adults. The orange line indicates the average coverage for each group. From the distribution, we can notice that older adults are likely to cover a video more than non-older adults.

4.6 RQ3: What are the difficulties they face while learning through online videos and how do they try to address the difficulties?

4.6.1 Interview.

1. Difficulties older adults face. From the interview, participants reported that they face difficulties due to (1) the characteristics of the video medium and technology itself and (2) video-specific issues (e.g., small fonts).

Interviewees mentioned the challenges arising from the **characteristics of the video medium and technology itself**:

- **Unfamiliarity with technologies** made learning online cognitively difficult for them. Although many mentioned that they were more familiar with using smartphones and personal computers than their peers, their learning was often accompanied by inconvenience, got halted, or even restricted as they had the fear of using technology or were unable to do what they wanted to do with technology: "*I started using YouTube for less than a year ago. Previously, I thought I cannot do such things* (*e.g., using YouTube*) *at my age* (*so didn't even think of starting to use it*)." (P13); "*We are the generation where we used to look into printed manuals to get familiar with something. But now there's no* (*physical*) *manual and it's all stored in the phone. For us, I hope at least there's a two or three-page-long table of contents where they point out where to look at to know how to do something.*" (P5).
- Participants had difficulty due to the **characteristics of the video medium itself**. Still, some of them mentioned that video is an appropriate medium considering their relatively low visual acuity and eye fatigue as

(1) it is multimedia with visuals and audio and (2) missing one scene does not critically affect the overall understanding due to the context. In contrast, they also mentioned that long watching sessions are physically hard for them due to their visual/auditory ability and physical strength: "*Learning* (*through video*) *is hard since the view gets blurred and my eyes hurt after 20 minutes as I have to watch with my glasses on*" (P13). They also had cognitive difficulty interacting with the video. Three participants showed difficulty although they knew how to use the features: "*When I watch with the computer, I control using the mouse, but when I watch with small-screened phone, I just watch. I cannot control it well.*" (P5). Six participants had difficulty as they did not properly know about the interaction function either partially or entirely. For example, P1 did not know about the concept of pausing or seeking so they reopened the page and rewatched the video from the beginning.

Participants also reported discomfort due to **video-specific issues**:

- **Lack of explanation on the background knowledge**. Six participants expressed cognitive difficulty due to the lack of background knowledge required for watching. They especially faced difficulty as they were unfamiliar with domain-specific jargon, jargon used by non-older adults, loanwords, or words spoken in foreign language. P8, who had a graduate degree, said: "*Some words are mixed with English ... I don't have difficulty* (*while watching a video*) *as I know English. But to those who didn't have higher education, they feel the difficulty even in the streets and everywhere. They work hard to study which word is used when.*" . Similarly, previous work also indicated jargon as one of the major hurdles for older adults to utilize information on the Internet [25].
- **Visual or auditory problems in videos**. They also had cognitive and physcial difficulty due to visual or auditory-related problems of a video. Problems not only arise from the bad filming or editing of the video, but also due to the small fonts or figures: "*They put small letters on the screen so I needed to put on my glasses. When young people do it* (*i.e., make video*)*, it's inconvenient.*" (P10). Eight participants also preferred watching on a bigger screen: "*We don't have a computer. I can't buy a laptop though watching with computer would be comfortable ...* (*When watching videos related to stocks through phone,*) *I must enlarge the chart to see the bar graphs.*" (P10). Moreover, they had difficulties due to letters shown for a short time and fast speaking pace: "*Young people are fast, but as we get old we talk slow and see slow. To me, they* (*i.e., letters*) *pass away so quick that I cannot see ... They talk too fast*" (P7). Some also pointed out unclear voices: "*Some YouTubers speak in an unclear tone and some just use computer voice, but for news, we use people who can speak in a way anyone can listen to without repulsion.*" (P7).
- **Distracting structure or flow**. They faced cognitive discomfort due to the structure or flow of some videos, e.g., being plain without any emphasizing. Seven participants were especially dissatisfied due to verbose structure, irrelevant chats, advertisements in the video. This was critical to them so that they included compactness as a criteria while selecting videos to watch (RQ2-1).

2. How older adults address the difficulties. Participants (1) sought help from others, (2) searched external resources, or (3) gave up trying to resolve the issue. Participants mentioned that they **sought help from others** if, for example, they did not understand the content or they faced technical problems). Most of them sought help from their family members or acquaintances rather than interacting online through the commenting system or Q&A boards: "(*As videos are uni-directed,*) ⋯ *I can only ask the tax accountant that I know.*" (P12). When asked whether they read or write comments for questions, P12 said: "*Comments are just for fun. I don't think they'll be helpful to me so I don't look at the comments and just ask the tax accountant.*" Several participants (5 participants) mentioned that they also tried reaching out to others beyond just their acquaintances (e.g., service center, teaching assistants) through phone calls

but expressed dissatisfaction. P13 said: "*Whenever I call (the service center), the line is busy, ⋯ and the TAs are not available. ⋯ Once I get through the line, the TAs are very blunt while explaining ⋯ They cannot possibly think that I don't even know this.*"

In some cases, they **searched external resources** such as dictionaries, other videos/books, web search when they did not know a term or content, but they rarely did the same when they faced technical problems. Only a few *searched* on the Internet, as many were not accustomed to the search function, although they mentioned that they were more familiar with technologies than others of their age.

However, there were many cases (6 participants) when they would **give up** trying to resolve the problem or just move on without trying. Some gave up because they felt it to be too much of a burden to look for the information or because they did not think that it was essential to know. Others gave up after failing to seek external help or search external sources. P13 mentioned: "*I was going to ask my kid (on how to go back to the previous lecture), but since she seemed busy, I just moved on. ⋯ When I ask my acquaintances, they don't really care. I know that I wouldn't get it even though they explain as I'm not familiar with technology. I feel bad that I didn't get appropriate help (so I had to drop the open university degree).*"

5 DISCUSSIONS

We discuss our interpretation of the results, design guidelines for online videos and platforms targeted to support older adults' learning, and the limitations of our study.

5.1 Interpretation of the Results

We discuss the similarities and differences between our quantitative and qualitative results and possible explanations for the results.

5.1.1 Older adults want to learn subjects related to their interest or life (RQ1). According to our qualitative results, what older adults want to learn depended more on their personal interest or needs in their life and less on jobs. This shows a clear contrast with non-older adults, as non-older adults tend to have strong career-related or educational motivations for learning [85], while older adults who are retired or about to retire may lack such motivations. This may be the reason behind our quantitative result — they watch more (1) videos on humanities and health and (2) easier videos than non-older adults (Figure 2). Both our quantitative and qualitative results showed that few older adults preferred to learn STEM subjects. In fact, STEM subjects were the subjects that older adults took the least compared to non-older adults (Figure 2). In the interview, many participants attributed the reason to the difficulty of learning STEM subjects. Considering that older adults prefer videos that (1) suit their level (RQ2-1) and (2) relate to their life, lack of STEM videos with easy explanation that relates to their interest could be the reason why they watch less STEM videos.

5.1.2 Older adults select videos based on the level and format (RQ2-1). Older adults regarded the level of videos to be a critical factor while selecting videos. Our RQ1 results also support this, as they actually watch more easy-level videos and fewer hard-level videos than non-older adults (Figure 2). This may be due to their previous watching experiences of finding many videos to be not fitting them, which could be seen from our results: due to the level not fitting them, they dropped out of the video (RQ2-4) or faced difficulties (RQ3). Interestingly, they used instructor's age being similar as a way to estimate the level and used as a criterion for choosing videos. This could be partially because the instructor in the same age group could have explained the material easily by being in their shoes. However, it could be also because older adults may have viewed the perceived difficulty to be easier; thinking that they can also learn it just like

the instructor of the same age group. Previous research also suggests that learners prefer instructors who share the same characteristics as them (e.g., gender, race, ethnicity, age) [19, 23, 34, 73].

Older adults also preferred videos that are concise and free of jokes, impromptu segments, and irrelevant chatter. This also aligns with the previous study, which argues that the preferred types of online courses are different between older adults and non-older adults: older adults prefer videos of professor lecturing, while younger learners prefer videos involving interactive learning [76].

5.1.3 Older adults interact less with videos and skim or skip less (*RQ2-2*). Results show that older adults generally interact less with videos. This could be due to generational differences. While older adults are familiar with passive watching (e.g., TV), non-older adults including the net generation or digital natives are known to be more familiar with interactive media [52, 76]. Thus, older adults' mental model of 'online video' could be different [77]. Moreover, sequence clustering results show that they are more likely to watch in patterns that are not common (Cluster Etc.). This may be partially because older adults are not familiar with video interactions.

Older adults tend to watch a video in a linear fashion rather than skipping forward, which also attributes to higher video coverage (RQ2-4). Research suggests that the digital environment brought changes to people's reading behaviors; non-older adults who are familiar with the web environment, which provides a vast amount of information, are likely to have a habit of skimming content [58, 86]. Our results indicate that this difference in skimming behavior is not only limited to reading, but also video watching for learning.

5.1.4 Older adults watch videos repeatedly (*RQ2-3*). Qualitative results showed that older adults watch videos repeatedly. Many participants who rewatched the video while following how-to videos wanted to first know all the steps and then follow the video. This is in contrast to how general users watch, which is by following the video in the mid of watching or segmenting the video into chunks to follow it [79]. Therefore, older adults may have watched a video repeatedly since the procedural knowledge of a whole video is beyond their working memory capacity. Moreover, older adults' pattern of watching repeatedly to fully understand the contents before starting an action may reflect that older adults tend to be reflective learners (i.e., prefer understanding things before acting) compared to non-older adults who are rather active learners (i.e., prefer getting into action and experience immediately when they are learning) [43, 52, 61, 78].

While the log analysis also showed that older adults rewatch significantly more than non-older adults, the difference was small, since the amount of rewatching was small for both age groups. This could be due to the fact that the log analysis was based on MOOC platform, while the amount of rewatching differs according to the type of videos [10] and the format of the videos (lecture vs. tutorial) [39]. Moreover, since K-MOOC videos are organized by courses with multiple videos, this may have fostered users to proceed to the next video instead of rewatching the video. P13 reported they watch videos in a repeated manner for learning swimming in YouTube, while rarely repeating while learning English by taking courses on open university to follow the course schedule.

5.1.5 Older adults watch a larger portion of a single video (*RQ2-4*). Our quantitative results revealed that older adults watch more parts of a video than non-older adults. Our qualitative results reveal the possible reason behind this: their tendency to watch videos until the end. This tendency to cover more parts of the video was also in line with the reason why many older adults do not want to seek forward (RQ2-2): wanting to learn without missing any parts. Another reason could be due to their watching pattern: not many watch with skimming the video through constant seek forwards compared to non-older adults (Cluster 2, 3, 6 in Table 4). This may explain the reason why there were

many non-older adults who watched less than only 10% of the video compared to older adults. We suspect this to be also relevant with non-older adults being accustomed to bite-sized content, thus their average attention span being shorter [46].

5.2 Design Guidelines

Based on our results, we present design guidelines for online videos and platforms targeted to support older adults' learning.

5.2.1 *Authoring videos that align with what older adults need.*

Considering topics of their interest: Our results show they like to learn those related to their personal interests, curiosity, or needs in their daily life (RQ1). Since they are relatively interested in humanities and medical subjects, **authoring diverse videos on these subjects** is needed. On the other hand, they watch fewer videos on STEM subjects (RQ1). However, this does not mean STEM videos should be created less, as there are many benefits for learning STEM subjects [18, 38]. Instead, considering their interest (RQ1) and level (RQ2-1), **more accessible STEM videos should be created that link to their interest** in health/medical domain, hobby, or life.

Matching their level: Our results suggest that older adults prefer to learn by watching a video that matches their level (RQ2-1), while they tend to watch more elective-level videos than major-level videos compared to non-older adults (RQ1). Therefore, the **actual level of the material should match their desired level** of the video. This also includes giving enough explanation on the background knowledge needed, as they reported that this is one of the difficulties they face (RQ3). Moreover, efforts are needed to **decrease the perceived level of the content**. For instance, considering our results that older adults relate creators/lecturers being their age to the level of videos matching their desired level (RQ2-1), including older adults while authoring videos that can be perceived as difficult (e.g., STEM videos) can help. Another possibility is to more strictly follow Multimedia Learning Theory [62]. As the working-memory ability [31] of older adults may have decreased, following the theory to effectively utilize working-memory capacity could ultimately lower the perceived difficulty of the video.

5.2.2 *Creating older adults-friendly videos.*

Making videos compact: Previous work has suggested making videos shorter is desired because users generally tend to drop out more from longer videos [50]. **Making shorter videos** is equally or even more important to older adults. This is because they are likely to face physical and cognitive difficulty from long watching sessions (RQ3), while their video consumption pattern shows they do not seek forward or skim the video unlike non-older adults (RQ2-2). One method of making the videos compact could be to reduce jokes, irrelevant chats, or advertisements in the middle, as many value **compact information delivery** over making the video funny or interesting (RQ2-1). Especially for procedural videos (e.g., exercise video), since many older adults have a tendency to watch the video several times before following it (RQ2-3) unlike general users [79], **segmenting them into multiple videos** may help. Previous work also suggested this guideline for novice learners to allow them to freely pace the video with a pause or play interaction [12]. We suggest the same guideline applies to older adults.

Increasing accessibility of visual and auditory elements: Our results indicate that older adults undergo difficulties due to visual or auditory elements in the video (RQ3). Therefore, as suggested by the design guidelines of MOOCs for older adults [2, 14, 67, 74], **automatically adjusting the size of the visuals** can be helpful. In addition to automated adjustments, similar to mobile-friendly MOOC design guidelines [51], **enabling users to easily customize** the enlargement of visual elements in the video could be helpful. Also, from our results (RQ3), we suggest automatically **slowing down the pace of visuals** shown only for a short time. For audio, as suggested by previous work, our results

(RQ3) also show that the **speed of the speech** should be slowed down [35] and **the audio quality should be high** to be heard clearly [2, 74]. Furthermore, since older adults may not be familiar with voices younger generations are relatively used to (e.g., computer-generated voice) (RQ3), enabling an **option to change the voice to the one they feel is clear** could be needed.

Increasing the delivery of the video content: Although design guidelines on the accessibility of video elements for older adults have been much investigated [2, 14, 67, 74], design guidelines on how the video content should be delivered so that videos could be more accessible to older adults have not been much explored. However, **delivering the video content better** to older adults could further increase the accessibility of the video. Our results show that older adults reported difficulty due to lack of background knowledge and language (e.g., jargon, foreign language phrases), while most do not search the Internet due to the unfamiliarity with a search engine (RQ3). Therefore, if the text or audio of a video includes such phrases, we suggest **automatically providing substitute words or relevant information links** for older adults.

5.2.3 Creating older adults-friendly video platforms.

Recommendation engine specialized for older adults: While video recommendation takes a huge portion in how users access videos [22], the cost of recommending a video that the user would not like is higher for older adults than for non-older adults. This is because they have a higher chance to waste their time watching the video although they do not like it due to their watching pattern of being less likely to seek forward or skim the video (RQ2-2) nor drop out in the middle (RQ2-4). Especially since older adults more easily experience physical difficulties from long watching (RQ3), this cost is fatal. Thus, among various metrics to evaluate recommendation algorithms, **reducing false positives** would be a relatively more important metric when designing recommendation engines targeted at supporting older adults. To address the **cold start of recommendation** engine specialized for older adults, considering our results on what they watch and how they choose videos (RQ1, RQ2-1) can be beneficial. Moreover, similar to how Liu et al. proposed a video search interface with video accessibility metrics designed for visually impaired people [57], developing a **metric to evaluate video accessibility specialized for older adults** is necessary. We believe our results on the difficulties older adults face from video-specific issues (RQ3) could guide the design of the metric. This metric could then be augmented for recommendation engines for older adults. Furthermore, when presenting the recommendation results, different metadata could be needed for older adults: presenting **metadata that represents the video contents better**, instead of those that could only grab their attention. This is because our results show that they heavily rely on video's metatdata for choosing videos to watch, although it often leads to misselection (RQ2-1). Therefore, metadata shown to older adults should be more carefully designed.

Providing appropriate support: Since older adults are unfamiliar with video medium, some not knowing the existence of video interaction such as seek forward (RQ3), providing **clearer instructions on the video interface** can help. Especially, since methods for video interaction are continuously evolving [71], it is necessary to understand common interaction patterns of different age groups and provide appropriate instructions that introduce the new video platform features relative to their norm of using video interfaces. Moreover, our results indicate that many older adults give up resolving the difficulty they face, which can sometimes lead to cease of pursuing learning (RQ3). Thus, channels are needed for opportune technological support or help with the content. Since most older adults did not utilize online channels (e.g., Q&A boards, chatbots) for resolving difficulties (RQ3), **offering instructions for utilizing online channels and offering offline channels** (e.g., phone calls, in-person support) is needed.

5.3 Limitations

There are several limitations of our study. First, we conducted interviews with Korean older adults and analyzed data extracted from a Korean MOOC platform. As cultural differences in learning can be either exaggerated [40, 64] or minimized [64, 70] as one ages, further analysis in different settings might be required in terms of generalizability.

Second, we used interaction data from the K-MOOC platform, which could be different from learning from other video platforms (e.g., YouTube). As explained in Section 5.1.4), this could have led to the difference in our quantitative and qualitative results on how older adults watch videos repeatedly. Moreover, the result of which subjects older adults take videos may be different from other video platforms. Although K-MOOC platform provides many courses on practical contents besides courses on theoretical contents, the distribution of domains can be different from other platforms. Thus, the general tendency, such as older adults watching STEM domain videos less, could be not much different with other video platforms, but specific numbers of the distribution may be different.

Third, there exists a time gap between the two data streams we used for our mixed-methods approach; the log data we analyzed was collected in 2018 (pre-COVID-19), while we conducted interviews in 2020 (during COVID-19). Although previous research [91] shows that COVID-19 does not have a major impact on how learners learn a course online, COVID-19 may have changed how they watch a single video.

Lastly, our paper did not consider differences among older adults. Since there may exist differences depending on various factors (e.g., age, educational degree, gender) [88], we call for future research to investigate these factors.

6 CONCLUSION

We investigated how older adults use online videos for learning with a mixed-methods approach. We also presented design guidelines for online videos that aim to support older adults' learning. Since online videos are a prevalent medium for online learning, providing adequate support based on how older adults learn is needed to increase the accessibility of learning through online videos. We believe that our work could enable going beyond the current one-size-fits-all of online videos to better support older adults' learning.

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