How Older Adults Use Online Videos for Learning

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ABSTRACT

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 MOOC platform. Our results show that older adults (1) have motivations to learn practical topics, leading to less consumption on STEM domains than non-older adults, (2) watch videos more sequentially with less interaction and watch a larger portion of a single video compared to non-older adults, and (3) face various challenges (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 catered to support older adults' learning.

CCS CONCEPTS

• **Human-centered computing** → **Human computer interaction (HCI)**; • **Applied computing** → **E-learning**; • **Social and professional topics** → **Seniors**.

KEYWORDS

online learning, older adults, MOOC, video learning

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 personal fulfillment and satisfaction [13, 21, 29], but also promotes competencies to adapt to a fast-evolving economy or job market [13]. On top of that, as individuals gain knowledge and competencies through lifelong learning, it eventually strengthens a nation's economy and prevents exclusion or marginalization of certain segments of the population, such as older adults [23, 29].

Among various media that could support lifelong learning, online videos are now one of the most pervasive methods to learn online due to their availability, scalability, and cost-effectiveness [56]. For example, video-based learning platforms, such as MOOC (Massive Open Online Course) platforms, are widely available these days. In addition, various instructional videos such as how-to videos in diverse domains (e.g., cooking, swimming, fishing, camping) are offered on video platforms, such as YouTube and Udemy.

With the increased use of online video learning, a myriad of research has investigated how learners use online videos for learning, which provided insights on how to design videos and tools that further enhance the learning experience [9, 34, 43, 59]. However, older adults, who are retired or in the later stages of their careers, may exhibit different usage behaviors of online learning video from the majority of online video learners (i.e., non-older adults) due to possible age-related attributes such as sensory and perceptual issues, slower processing speed, and low working memory abilities [28]. Moreover, in contrast to the younger "video generation", older adults are likely to be accustomed to one-way interaction with video (e.g., TV) [45, 66]. 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 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., who are 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 while watching online videos for learning. 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 data 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:

[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.

- 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

This work is built upon the previous work on (1) learning through online videos and (2) older adults in learning.

2.1 Learning through Online Videos

Online learning through watching videos is a promising way of pursuing learning. It is highly accessible compared to traditional education, with little restriction on time and location of learners [2]. In addition, most of the online learning services are free or more affordable than their offline counterparts, allowing users to easily access them [57]. Examples of platforms enabling learning with online videos not only include online video platforms designed for learning, such as MOOC platforms (e.g., edX, Coursera), but also include online video platforms (e.g., YouTube), where some viewers watch the videos and learn formally or informally. In such ways, online learning has lowered barriers to learning.

Although highly accessible, learners who watch online videos for learning show different learning patterns compared to traditional classroom learning. For example, the high dropout rate of learners is known to be a chronic issue of online learning [48], and learners are known to be easily distracted in online learning settings [75]. Plus, online learning is often one-way, making it more difficult for learners to interact with instructors [27]. Therefore, a stream of research has investigated how learners learn through online videos to better understand their behavior [15, 34, 43]. Based on the understanding of learners and video formats, these studies provided insightful design implications into how the video or video platform could be designed to increase the engagement of learners.

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 [18]. To increase the accessibility of online videos, understanding how various types of learners learn using online videos is necessary. Therefore, in this paper, we focus on how older adults learn through online videos and also provide design guidelines of online videos for learning and their platforms based on the findings.

2.2 Older Adults in Learning

Lifelong learning denotes learning happening throughout one's life [46]. 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 [6]. 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 [71].

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 [3]. Plus, considering that many of them are retired or about to retire, further learning may benefit them with additional chances of extending their career [25]. In addition, participation in learning can also promote life satisfaction for older adults [24]. For these reasons, lifelong learning is known to increase the wellness of older adults.

Despite the advantages, it is known that participation in learning decreases as the age increases [51]. This could be because older adults often face cognitive, physical, and financial difficulties in pursuing lifelong learning. Specifically, a large portion of older adults is reported to have low mobility due to their physical degeneration [65], making it difficult for them to take courses in physical classrooms. Moreover, financial deficits may also hinder older adults from pursuing lifelong learning [30, 47]. In such situations, online learning is a potential alternative with low barriers: (1) online learning does not require learners to be on-site, (2) flexible time choices are available without time constraints, and (3) as lots of low-cost materials are widely available, it may reduce financial burden [5]. 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 such a group [4, 33, 76]. Since aging involves biological, psychological, and social changes in individuals [28], older adults' behaviors and attitudes toward online learning may be different from those of non-older adults. For example, previous research revealed that older adults' motivation toward MOOC learning differed from non-older adults [76] and that their interest level on certain topics such as health-related topics may be different [52, 61]. In addition, a thread of research has found that there exist various accessibility problems and barriers for older adults to learn online [1, 7, 12, 32, 58, 64].

Although these studies aimed to explore how older adults learn online, 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 while focusing on their motivation, video interaction patterns, and difficulties. 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 during the process might be limited with the data analysis alone. Thus, we conducted interviews with older adults in addition. We used an emergent mixed methods design [19], where we first started with data analysis only and later conducted interviews to draw complementary insights. Note that the data analyzed was 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 for learning?
- **RQ2**: **[Watching pattern]** How do older adults watch online videos for learning?
  - **RQ2-1**: How do they select 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 a video do they watch?
- **RQ3**: **[Difficulties]** What are the challenges older adults face while learning through online videos and how do they try to address the challenges?

We originally started data analysis with RQ1 and RQ2-2 only for RQ2. We added RQ2-1 (how they select videos to watch) and RQ3 (difficulties) while planning on the interview as these are the aspects data cannot cover. We also clarified RQ2 by segmenting it further by adding RQ2-3 and RQ2-4 for clarity in reporting and presentation. After the interview, we conducted additional data analysis on RQ2-3 and RQ2-4 according to the iterated research questions.

Definition of Older Adults. Although most previous studies defined *older adults* as those whose age spans from 55 to 65 [26, 55], no fixed agreement exists on which chronological age could define older adults. This is because chronological age is the number humans created while individuals do not have an innate biological clock [70]. Thus, the term 'older adults' could have different criteria based on their societal surroundings, ranging from family to culture or world.

As such, in this study, we refer to older adults as people who are having or about to have a later stage of life, which is similar to the qualitative definition of older adults in the previous work [29]. Specifically, as the average retirement age in Korea was around 57 in 2018 [38], when our data was collected, we defined older adults as those who are aged 55 or older in their Korean age. Similarly, we refer to *non-older adults* as those below 55.

Scope of Online Videos for Learning. The types of online videos one can learn from vary greatly. For example, an individual can learn from not only videos created for educational purposes, but also from online videos that may be created for other purposes (e.g., entertainment, relaxation). Thus, in order to include such various sources of learning, we interviewed those who watched *any video* if they watched the video with the *purpose of learning*. Yet, for data analysis, we decided to focus on an educational video platform (i.e., MOOC), as we cannot ensure whether older adults watched a certain video for learning from other platforms such as YouTube with the data logs.

3.1 Interview

To understand how older adults learn using online videos through interviews, we recruited 13 older adults aging above 55 in their age who had experience watching online videos for learning within six months. We posted recruiting advertisements on online communities where older adults are expected to visit (e.g., online bulletin board targeted for 50s+, online community for trading secondhand cars), along with online communities where the users' parents may be in the age of older adults (e.g., online communities of several colleges, online communities for gig work/part-time jobs) to recommend their acquaintances who qualify. While selecting among the applicants, we tried to diversify the interviewee pool by considering their age, level of education, pre-reported frequency/amount of learning using online videos. Table 1 shows information about the 13 older adults who participated in our interviews (7 females, M_{age} = 65.5, SD = 6.6). Due to COVID-19, 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.

We conducted a series of semi-structured interview sessions, 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 learning 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, which were then analyzed with a thematic analysis [14]. Specifically, we conducted a thematic analysis with the following process: (1) read transcripts and make notes, (2) classify notes into the most relevant research question, and then for each research question (3) identify high-level groups while going over the notes, (4) categorize notes into high-level groups, (5) categorize the notes in each high-level group into groups, (6) iterate over the categories of the notes while readjusting and revising the groups, and (7) re-examine the groups and categories. The first six phases were conducted by two researchers while the last phase was done by one researcher. In phase 6, the two researchers discussed together on the note categorization where they have different opinions to reach a consensus.

3.2 Data Analysis

We analyzed the event log data of K-MOOC, a Korean MOOC platform[3] [41], 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 insights 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 data analysis.

3.2.1 Data and Pre-processing. We used event logs collected by the K-MOOC platform for a year (2018), which capture users' video interactions (i.e., play/stop/pause video and seek back/forward)

[3] A Korean state-led MOOC platform, which launched in 2015 with 3.6M users by the end of 2018. It offered 520 courses as of January, 2019, spanning various subject domains (e.g., humanities, social science, engineering, natural science) offered by 92 different universities.

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

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). All personally identifiable information had been anonymized upon our access to the data. 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 or user id) and (2) having duplicate values for certain fields such as 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 offered their year of birth when signing up (107K users), 4.4K users (2.8% of all users) were classified as older adults in 2018 (Figure 1).

In addition to the event logs, we also obtained sign-up information (i.e., information including birth year, gender, level of education, etc., which the users optionally entered when they sign up) of users who signed up until 2018 (3.6M users) and information of 438 courses ran in 2018, including course name and subject categorization, from K-MOOC. 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 older adults want to learn while watching online videos for learning? 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 domain and level categorization of videos on K-MOOC's classification, which classifies each course into seven high-level domain categories: natural science, engineering, humanities, social science, education, arts & physical education, medical sciences & pharmacy (Figure 1-domain), which are then classified into three levels: elective, basic major, and intensive major courses (Figure 1-level; 2 cases of no classification or multiple classifications were excluded). To prevent 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 [36], 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 older adults interact with the video? Analyzing how older adults interact with the video would offer insights into how they watch a video [42]. Thus, we (1) analyzed the frequency of video interactions and (2) conducted sequence clustering 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[4] for the analysis, as they have a direct connection with the flow of how users consume the video contents, 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. To understand how frequently older adults perform each interaction, we classified each interaction into three detailed interactions based on the length or duration of the interaction as shown in Table 2. The criteria of categorizing each interaction were built upon the distribution of the interaction length or duration; the threshold between short and medium interaction is determined as 25 percentile of interaction length/duration, while the threshold between medium and long interaction is determined as 75 percentile

[4]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

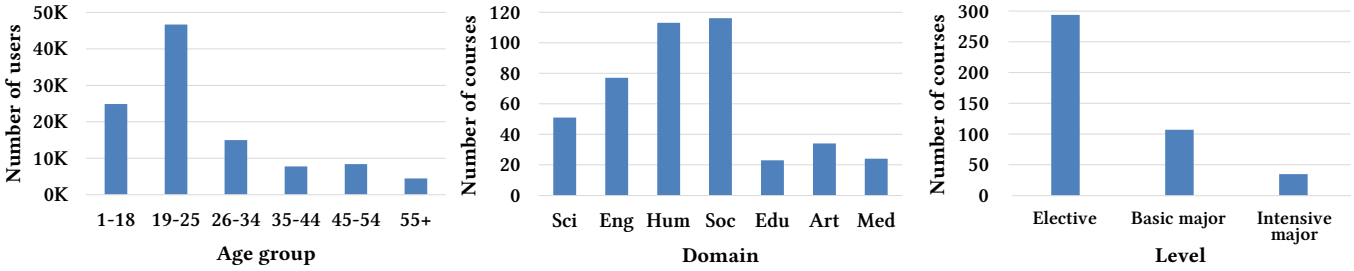

Figure 1: Age distribution of users who watched K-MOOC videos in 2018 (left), distribution of courses by domain (middle) and level (right) offered in K-MOOC in 2018 (Sci: natural science, Eng: engineering, Hum: humanities, Soc: social science, Edu: education, Art: arts & physical education, Med: medical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

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 the user actually pressing the 'play' button at the start of the interval. As such, 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: 417 seconds (approximately 7 minutes) to 1084 seconds (approximately 18 minutes).

Based on our definition of detailed interaction, we calculated the frequency of each detailed interaction each user performs in each video. Here, we took the following two metrics to calculate the frequency of each detailed interaction to capture complementary aspects: (1) Frequency 1: the number of times each detailed interaction is performed per minute, which is calculated by dividing the number of times each detailed interaction is performed by the total length of the corresponding video, and (2) Frequency 2: the number of times each detailed interaction is performed per coverage of the video one watched, which is 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 the second frequency metric, we excluded cases where the coverage of the video one watched is less than 1 percent 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. As the domain and level of the video may affect the frequency, we also considered them as factors in the model. Similar to the reason explained in RQ1, we used generalized estimating equations (GEE) with exchangeable correlation structure. In addition, to compare which detailed interaction has more frequency difference between older adults and non-older adults, we standardized the dependent variable and iterated in 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 example, only by analyzing a sequence of interactions can we differentiate the case of skimming the whole video from the case of finding a specific part several times, as the two sequences may show the same number of seek forward interactions. Thus, we used sequence clustering [72] to identify older adults' emergent video watching patterns and how they differ from those of non-older adults. For this, we first converted each learner's interaction logs of a video in a session to a watching pattern sequence composed of 12 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 of each subsequence that appeared in either of the two sequences into an array per each sequence. Next, polar distance [72] between the two arrays was calculated, which represents the similarity between the two sequences that are later used for clustering the sequences. Here, we chose k as 4 in k-gram sequence after testing with different values of 4, 6, and 8. We decided k as 4 as the repetitiveness is captured enough in 4-gram. In addition, similar to analyzing the frequency of each detailed interaction, we only focused on the videos that belong to the 25 to 75 percentile of video length distribution. Then, due to the 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 through data analysis, we extracted the sum of lengths of all the repeated watched parts. If the learner watched 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.

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

3.2.5 RQ2-4: How much of a video do they watch? To identify how much older adults cover a video through data analysis, 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 RESULT

We present the result of the thematic analysis of the interviews and data analysis for each RQ.

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

4.1.1 Interview. We found that all interview participants wanted to at least learn one subject related to their personal interests, hobby, curiosity, or needs in their daily life. What they learn spanned variously across arts & physical education (e.g., yoga, oil painting, photography, calligraphy), humanities & social science (e.g., English conversation, Chinese, Bible study), and skills related to day-to-day life (e.g., how to invest, cooking, health-related information, fishing, farming, how to use tents). Science and engineering were also included, albeit very few (3 participants); some participants attributed the lack of learning in these domains to the difficulty of learning: *"For me, it's hard (to learn scientific topics), so I'm rather interested in things I can relate to or utilize in my life"* (P4). One participant (P7) even explicitly mentioned that they regard learning something completely new as not suitable for their age. Even for those who did watch scientific videos, the need for watching such videos was highly limited to the surface level (2 out of 3 participants), such as fulfilling their curiosity by appreciating astronomical scenes. P12 mentioned: *"Although I have interest in science, I'm not interested in the theories but watch due to the awe-inspiringness".*

Participants also mentioned that they watched online videos to learn things related to their work (4 participants), although no participant solely learned work-related material through online videos. In this case, they were more driven by external factors, which includes learning something that relates or may relate to their job (e.g., speaker system development, health education, deep learning basics).

4.1.2 Data Analysis. Results of data analysis indicate that older adults take more humanity and medical science & pharmacy courses while taking fewer courses in engineering, natural science, social science, and education compared to non-older adults. This aligns with findings from previous research [40, 52] that older adults like learning health and medical knowledge. The *odds ratio* [11] 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 that of non-older adults.

Moreover, the result indicates that compared to the non-older adults, older adults prefer taking elective courses over major courses. The odds ratio of each level is presented in Figure 2. The odds ratio decreases as the level increases; the odds ratio is 1.14 for elective courses, 0.90 for basic major courses, and 0.70 for intensive major courses.

4.2 RQ2-1: How do older adults select videos to watch to learn?

4.2.1 Interview. While the channels the participants use to access videos were diverse, criteria for deciding what to watch has emerged as follows: (1) the video's metadata, (2) whether the content and level suits their expectation, 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

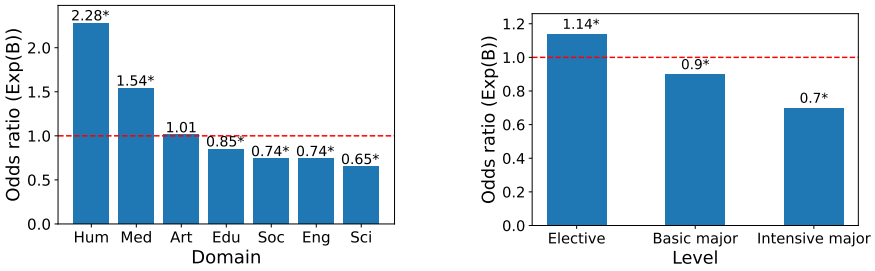

Figure 2: Results of RQ1, which displays odds ratio for domain (i.e., Humanity, Medical sciences & Pharmacy, Arts & Physical education, Education, Social science, Engineering, Natural science) and level (i.e., Elective course, Basic major course, Intensive major course). Older adults take more humanity 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 $p < .01$)

only continue watching when it fits the additional criteria (e.g., content, level, format).

Participants (10 participants) also mentioned desired content and difficulty level of the video as criteria to choose which video to watch. Specifically, they wanted to find a video that covers the contents that fit their level. According to P9, as the metadata does not mention whether the yoga video is for seniors who are older than 60, they need to watch to judge whether it suits their level and quit 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 (so I watch videos from creators who are in the same age group)"* (P10).

Many participants (12 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 images or clips than just explaining. Interestingly, many participants (8 participants) favored a format that delivers the core contents without adding jokes, irrelevant chats, or advertisement: *"I don't watch videos where YouTubers just make fun or laugh (...) I don't think trying to be funny or interesting is needed. (I like it when they tell me) just the key points"* (P7).

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

4.3.1 Interview. When asked to describe how they interact (e.g., pause, seek forward) while watching a video, eight participants replied that they do not really perform interactions a lot. This was in part because they did not find the need to interact with the video as they could understand the video content. But in some cases, this was because they did not have the need to fully understand the contents, which is linked to their motivation of watching the video (RQ1). On the other hand, it was also due to the fact that they did not know how to interact with the video or felt discomfort interacting with the video: *"I didn't know about the pausing and other functionalities … So I watch from the beginning again"* (P4).

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

We also investigated the reasons behind seeking forward, seeking backward, and pausing. They **seek forward** to skip the part (1) that covers what they already know or what they do not need or (2) that looks useless or irrelevant. They **seek backward** to (1) watch the part they missed or did not understand the part that has just passed or (2) watch again to remember the content. It could be that they forgot an important content, but some also sought back to retain the content in their memory although they did not forget at the moment. They **pause** to (1) take an accurate note or as they do not want to miss the next part while taking notes or (2) look at the part in detail as they think it is important or hard: *"If the movement (of Chinese calligraphy) passes too fast, I can't see. In such cases, I watch it in a paused screen to see clearly"* (P5).

4.3.2 Data Analysis.

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). Plus, the negative values of all the coefficients in Table 3 indicate that older adults perform all the detailed interactions less than non-older adults.

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 in Table 3. The result shows that older adults tend to perform seek forwards with a larger seek gap much less frequently compared to non-older adults, and exhibit short watches much less frequently than long watches compared to non-older adults.

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 $p < 0.01$)

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 *

2. Dominating interaction sequence patterns. We identified seven clusters from sequence clustering, numbered from 1 to 7 in Table 4, along with the top three sequence patterns that are prevalent in each cluster, distinguishing the cluster from other clusters. We also grouped sequences that were not included among the seven clusters as *Etc.* cluster. The odds ratio of each cluster, indicating 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, is presented in Table 4. 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 of that of non-older adults.

We found that older adults watch a video in a different watching sequence from that of non-older adults. The odds of older adults watching in a certain pattern were significantly different from that of non-older adults in all clusters except for cluster 4. Among the remaining clusters, only cluster 5, which represents repeated long-term watching and long-term pause, had higher odds of older adults watching in that pattern than non-older adults. Older adults are likely to watch less in a pattern that belongs to the rest of the clusters which are either accompanying constant forwarding (cluster 2, 3, 6) or watching with relatively shorter-term watching

(cluster 1, 7). From this, we can infer that older adults are less likely to watch in a skipping or skimming manner or while interacting (i.e., pausing or seeking back/forward) frequently throughout the video. 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 2 times higher than that of non-older adults. 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. We could identify a lot of reports from participants (11 participants) that they watch videos repeatedly, where three themes emerged as reasons behind rewatching. First, participants watched videos repeatedly before starting to follow the actions in the video.

Interestingly, among the participants who wanted to follow the video, many participants (6 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 the video. Once they become familiar with a specific video, they reported that they also stick to that video for a long time and follow the video over and over, without easily shifting onto another video: *"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"* (P9).

Second, 11 participants reported that they rewatch videos to remind themselves of the contents. Among them, some (8 participants) reported that they rewatch when they forget some contents, while others (3 participants) were reported to watch repeatedly, worrying that they would forget the contents someday 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, participants (7 participants) added that they would rewatch to fully learn and understand the contents. They considered that rewatching a video repeatedly is crucial to learning: *"I'd download the video and rewatch as currently (i.e., after watching) it's not fully mine"* (P11). Similarly, P6 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 Data Analysis. Overall, rewatching patterns were not identified as frequent for both older and non-older adults. As Figure 3 shows, the majority of learners watched videos (93.1%) with rewatching happening in less than one-tenth of the video length, indicating 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 the case of watching a video multiple times is rare.

Nonetheless, the 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 a video do they watch?

4.5.1 Interview. Excluding factors such as their circumstance (e.g., time to cook) or content/level, whether they watch a video until the end or drop out in the middle depended on their tendency of watching videos. Seven participants reported that they have a tendency to watch until the end and would never or 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 all 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). 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 part.

4.5.2 Data Analysis. We found that the age group is a significant predictor of video coverage; older adults cover significantly more for 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 shown in Figure 4 also shows a similar result. While the median (50 percentile) of the coverage distribution was 91.9% for older adults, it was 59.1% for non-older adults. This indicates that more than half of the older adults cover more than 90% of the video once they start watching the video, which is much more than non-older adults. Moreover, dropping out early, 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.

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

4.6.1 Interview.

1. Challenges 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).

First, their unfamiliarity with technologies makes learning online difficult for them. Although many mentioned that they were 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).

Table 4: Results of RQ2-2-2: Sequence clustering result and the odds ratio of older adults for each cluster. Percentile refers to how common the cluster is.

Cluster	Patterns	Percentile	Exp(B) ($p < 0.01$)	Cluster	Patterns	Percentile	Exp(B) ($p < 0.01$)
1	MP MW MP MW MW MP MW MP MP MW LP LW	13.6%	0.758	5	LW LP LW LP LP LW LP LW LW LP LW SP	7.1%	1.257
2	MW MF MW MF MF MW MF MW MW MF SW MF	11.4%	0.492	6	MF MF MF MF LF MF MF MF MF MF MF LF	5.3%	0.634
3	MW LF MW LF LF MW LF MW LF MW LF SW	8.9%	0.562	7	SP SW SP SW SP SW MP MW SW MP MW SP	2.3%	0.477
4	MB MW MB LW MW MB LW MB MB LW MB LW	8.0%	Not significant	etc.	-	43.3%	2.014

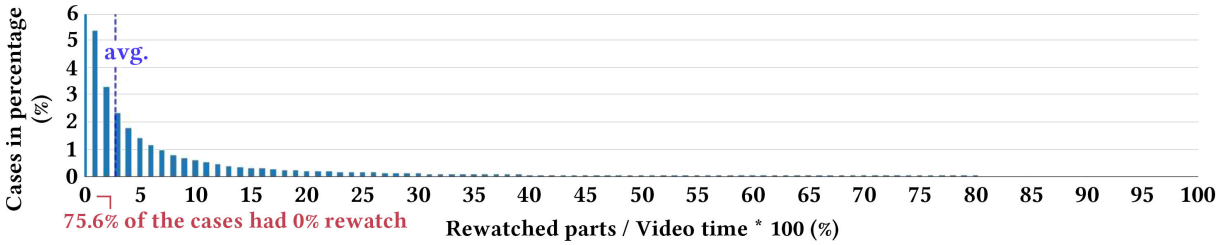

Figure 3: Distribution of the total length of rewatched parts in the unit of the corresponding video time percentage for all learners in K-MOOC. Rewatched part percentage was rounded to the nearest whole number in percentage. The blue line indicates the average video time percentage of the rewatched part. As 75.6% of the cases were when the learner watched a video with almost no rewatching (i.e., rewatching less than 0.5% of the video), the y-axis is limited to 6% to better represent the remaining part of the distribution.

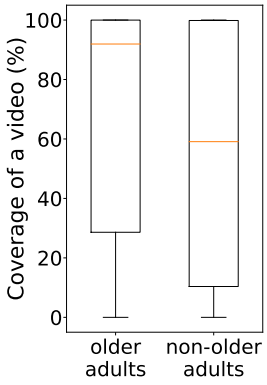

Figure 4: Box plot of the distribution of video coverage for both older adults and non-older adults. The orange line indicates the average coverage for each group. From the distribution, we can notice that older adults are likely to cover a video more than non-older adults.

Participants also 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 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 around 20 minutes pass as I have to watch with my glasses on"* (P13). They also had difficulty interacting with the video. Some (3 participants) showed difficulty although they knew how to use the features (e.g., *"When I watch with the computer, I control using the mouse, but when I watch with my small-screened phone, I just watch. I cannot control it well"* (P5)), while some (6 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 watched by reopening the page and watching again from the beginning.

In addition, older adults also reported discomfort due to problems arising from a specific video:

- **Lack of explanation on the background knowledge**. Six participants expressed difficulty due to the lack of background knowledge required for watching the video. They

especially faced difficulty as they were unfamiliar with domain-specific jargon, jargon used by non-older adults, loanwords, or words spoken in a 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 any experience of higher education, they feel the difficulty even in the streets and everywhere. They work hard to study which word is used when"*.

- **Visual or auditory problems in videos**. They also had difficulty due to the visual or auditory-related problems in the 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 reading glasses. When young people do it (i.e., make a video), it's inconvenient"* (P10). Aligning with these difficulties, many participants (8 participants) preferred watching on a bigger screen: *"We don't have a computer. I can't buy a laptop though watching with a computer would be comfortable ... (When watching videos related to stocks through phone,) I must enlarge the chart view to see the bar graphs. I cannot see (the graph) in a glance"* (P10). They also mentioned difficulties arising 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 of videos**. They had complaints about the structure or flow of some videos, for example, being plain without any emphasizing. Many (7 participants) were especially dissatisfied due to verbose structure, irrelevant chats, advertising in the video. This was critical to them so that they included compactness as a criterion while selecting videos to watch.

2. How older adults address the challenges. Participants took different actions when they confronted difficulties: they (1) sought external help, (2) searched external resources, or (3) gave up trying to resolve the issue. Participants mentioned that they seek help from others to resolve various problems (e.g., when they do not understand the content or a specific term, or when they face technical problems), most of which (4 participants) sought help in-person from their family members or acquaintances rather than interacting online by using the commenting system or Q&A boards: *"As we cannot interact back and forth (through video), I write down things to ask to the tax accountant that I know"* (P12). When we asked P12 whether they do not 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 other than their acquaintances (e.g., service center, TAs) through phone calls, but expressed dissatisfaction: *"Whenever I call (the CS center), the line is busy, … and the TAs are not available. … Once I get through the line, they were blunt while explaining … They cannot possibly think that I don't even know this"* (P13).

In some cases, they searched external resources (e.g., dictionaries, other videos/books, web search) mostly when they did not know a term or content, but rarely when they faced technical problems. However, 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 were because they felt tiresome to look for it or because they do not think that it is essential to know to move on. In other cases, they gave up after failing to seek external help or search for external sources: *"I was going to ask my kid (on how to go back to the previous lecture), but as she seems busy, I just moved on. … When I ask my acquaintances, they don't really care. I know that I wouldn't get it although they explain as I'm not familiar with technologies. But still, I feel bad that I didn't get appropriate help (so that I had to drop the open university)"* (P13).

5 DISCUSSIONS

In this section, we discuss possible attributes that might have led to the results of our analysis while relating with previous studies on how older adults learn as well as discussing the generalizability of our results. Based on the insights and results of our analysis, we offer design guidelines for online videos and platforms targeted to older adults' learning. Finally, we discuss the limitations of our study.

5.1 Interpretation of the Analysis Results

5.1.1 Older adults and STEM video learning. Both quantitative and qualitative analyses showed that older adults prefer to learn STEM subjects through online videos less than non-older adults. The difference in motivation between older adults and non-older adults for watching online videos in the STEM domain may explain this result: while career-related, personal, educational motivations exist for general learners [73], older adults who are retired or about to retire may have little external motivations. Previous work which investigated the learning needs of older adults also found that the needs were rather day-to-day life-related similar to our findings; although their needs also included technical skills and knowledge, most of them were regarding using equipment to make life easier (e.g., using ATM, VCR) [61]. Moreover, though older adults may want to learn STEM subjects out of curiosity, interview results imply that they may not learn due to their perception that it is hard to learn. Thus, for the dissemination of STEM domains to older adults, *scientific online videos* should pursue greater accessibility at the cost of a certain level of complexity and accuracy [17].

5.1.2 Older adults and their video selection criteria. One of the criteria older adults have for choosing videos was whether the level of the videos suits their level, while quite many participants explicitly pointed out that whether the instructor/creator is of their age group to be an indicator of the criteria. A stream of research also offered that learners prefer instructors who share the same characteristics (e.g., gender, race, ethnicity) in traditional learning settings [16, 20]. Particularly for age, previous studies revealed

that learners prefer to learn from the instructor of the same age group [31, 63]. They speculated the reason behind the circumstance as sharing similar values within the cohort [31]. Our research adds to such threads of research in that for older adults, age may act as an indicator of speculating the difficulty of the video, which is one of the important criteria for choosing videos to watch.

Another criterion was that many older adults prefer videos that are concise without jokes, impromptu flow, or irrelevant chats. This also aligns with the previous study which argues that preferred types of online courses are different between older adults and non-older adults; older adults prefer videos of professor lecturing, while younger students prefer videos involving interactive learning [66].

5.1.3 Older adults interact less with videos and skim or skip less. Results show that older adults overall interact less with videos. This could be due to generational differences. While older adults are familiar with passive watching (e.g., television), non-older adults including the net generation or digital natives are known to be more familiar with interactive and immersive media [45, 66]. Thus, older adults' mental model of 'online video' could be different [67]. Moreover, sequence clustering results (RQ2-2) show that they are more likely to watch in patterns that are not common. This may also be the result of older adults not being familiar with video interactions.

Older adults watch a video sequentially rather than jumping forward for skimming or skipping content. Research suggests that their digital environment brought changes in reading behaviors: non-older adults who are familiar with the web environment which provides a vast amount of information are likely to have a reading habit of skimming [50, 74]. Our results indicate that skimming behavior being less prevalent in older adults may not only apply to reading, but also to video watching.

5.1.4 Older adults watch a larger portion of a single video. Both our interview and data analysis results show that older adults tend to watch more parts of a video than non-older adults. This is in line with previous work, which found that older learners tend to visit more course materials (i.e., lectures, problem sets, and exams) in a course [35]. We presume that older adults are likely to cover more contents of a video as they are accustomed to watching TVs or videotapes where they usually watch linearly without much interaction such as skipping forward. In addition, this could be because non-older adults are accustomed to bite-sized content and their average attention span is reported to get shorter [39]. These factors might have contributed to the age differences in the video coverage.

5.1.5 Older adults watch videos repeatedly. Interview results showed that older adults watch videos repeatedly. Interestingly, most participants rewatched the video to follow the how-to videos since they want to first know all the steps then follow the video. This is in contrast to following the video while watching or segmenting the videos into chunks and then following in the mid of watching, which are how general learners are expected to learn through how-to videos [69]. Therefore, older adults may have watched a video repeatedly since the procedural knowledge in the video is beyond their working memory capacity. Moreover, older adults' pattern of watching repeatedly to fully understand the contents before starting 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) [37, 45, 53, 68].

While the data analysis also showed that older adults rewatch significantly more than non-older adults, the difference was only expected to be 6.24 seconds, since the amount of rewatching was small for both age groups as in Figure 3. This might stem from the fact that the data analysis was done on log data of a MOOC platform, while the amount of rewatching differs according to the type of videos [8] and the format of the videos (lecture vs tutorial) [34]. Since K-MOOC platform is oriented to more conceptual or declarative knowledge than how-to videos, learners in K-MOOC, regardless of their age, might have shown less repeated watching pattern. Moreover, K-MOOC videos are organized by courses with multiple videos in contrast to independent single videos, which could have affected the rewatching behavior. P13 reported that they watch videos in a repeated manner for learning swimming in YouTube, while rarely repeating and rather skipping forward for learning English by taking courses on open university to follow the course schedule.

5.2 Generalizability of the Results

Although our interviews were not limited to experience with certain types of videos, since our data analysis was based on analyzing watching logs of MOOC videos, the result may be different from that of other types of videos (e.g., YouTube videos). There are many characteristics that distinguish MOOC videos from other videos. The inherent characteristics of a video may also affect how older adults watch the video. For example, MOOC videos are usually organized in a course format, which consists of several videos in a continuous manner. This is partially revealed in the difference in our quantitative and qualitative results about how older adults watch videos repeatedly (which is addressed in Section 5.1.5), as the qualitative analysis was not restricted to MOOC videos.

Aside from that, the result of in which domains older adults take videos (Figure 2) may be different from other video platforms. Although we could infer that older adults are less inclined to watch videos for learning STEM subjects from both of our quantitative and qualitative results, there may exist differences in other domains from other video platforms. As the MOOC platform that we analyzed has more videos that cover theoretical contents than practical contents (e.g., English conversation, yoga, oil painting), domains such as social science and arts & physical education may have attracted fewer older adults in the MOOC platform that we analyzed than other video platforms.

5.3 Design Guidelines of Online Videos for Learning and the Platforms

5.3.1 Lowering the barrier to learning STEM subjects for older adults. To accommodate more older adults to learn STEM subjects, STEM videos should arouse their interest or curiosity. For instance, arousing scientific interest by having the videos relate to their interest in health/medical domain, hobby, or real-world applications can

lower the barrier of learning STEM subjects. Plus, lowering the level of videos is required, in terms of both actual and perceived levels of content. Considering our results that older adults relate creators/lecturers in the same age group to the level of videos, including older adults while producing STEM videos can also help lower the barrier of learning the STEM subjects.

5.3.2 Importance of recommendation over search. For older adults, providing personalized recommendations is crucial, considering that older adults face difficulties fully utilizing web search. For example, P1, who said was interested in learning science or engineering subjects related to daily life, even asked the interviewer to recommend such video several times during the interview. Moreover, our results show that once older adults start watching a video, they are less likely to drop out, skim, or skip the contents, despite their relatively short watching time due to their visual/auditory ability and physical strength. This implies that it is more important for older adults than non-older adults to lessen the false positives when building recommendation algorithms in online learning video platforms.

5.3.3 Reflecting older adults' watching patterns and difficulties while designing or editing video content and organization. Our results imply that authoring or modifying online videos with consideration of older adults' watching patterns and their difficulties is needed. Considering that older adults are inclined to watch videos repeatedly, face difficulties in interacting with the video, and actually interact less with the video, segmenting procedural videos into more granular actions may be needed for older adults. For example, rather than providing multiple exercise actions in one video, it could be more effective to automatically segment the video and provide a small number of actions in each video. Previous research showed that novice learners may benefit more from system-paced segmentation of procedural videos than allowing learners to freely pace the video with pause or play interactions [10]. Likewise, automatic segmentation of the video may be effective for older adults.

Moreover, content creators should consider difficulties older adults face while authoring or modifying the video for learning. First, older adults reported difficulty due to the lack of background knowledge and language (e.g., jargon, loanwords, foreign language phrases) assumed and used in a video. Previous work also pointed out jargon as one of the major hurdles for older adults to utilize information on the Internet [22]. Thus, platform-wise, if a video includes such phrases, automatically providing the substitute wordings or explanations for older adults is encouraged. Second, enabling visual enlargement of small-sized texts or images in the video to fit the user's preference and environment (e.g., whether the user has a small screen) [44] is recommended.

5.3.4 Providing appropriate technical or instructional support. For older adults to better utilize online videos for learning, it is crucial to address the difficulty they face due to their unfamiliarity with online video interfaces or technologies. First, providing instructions or manuals for older adults to get acquainted with the online video platform is needed. This is because older adults are not familiar with current user interfaces that often incorporate navigational hierarchy [62]. Although a recent study suggests that more older adults are now likely to try trial-and-error than before [60], our results reveal that many older adults still are not familiar with it [49]. Second, enabling opportune support when they face problems in using online videos is needed. Video learning platforms can offer channels such as phone calls or in-person support than just Q&A boards or chatbots.

5.4 Limitations

There are several limitations of our study. First, we ran interview sessions with Korean older adults and analyzed data extracted from a Korean MOOC platform. Since there may exist cultural differences in how older adults learn using online videos in other countries [54], further analysis in different settings might be required in terms of generalizability.

Second, we utilized interaction data from the K-MOOC platform, which mainly offers lecture videos in a course form offered by professors at universities, each of which consists of multiple lecture videos. Therefore, our data analysis result may be different from that of older adults watching other types of online videos (e.g., how-to videos on YouTube). Moreover, there exist log errors in the K-MOOC usage data of which we removed or tried to recover prior to the analysis. Although we tried our best to remove or recover such errors, there still may exist log errors that are not identifiable.

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 [77] 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 focused on behaviors and difficulties of learning using online videos of that of general older adults without considering the differences among older adults. Since there may exist differences depending on various factors (e.g., age, educational degree, gender) [76], we call for future research to investigate these factors for detailed results.

6 CONCLUSION

We investigated how older adults use online videos for learning with a mixed-methods approach. Based on the result, we also present design guidelines for online videos that aim to support older adults' learning. Since online videos are a prevalent medium of learning online, providing adequate support considering how older adults learn is needed to increase the accessibility of learning through online videos. As such, 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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