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Inter-Platform Consistency Inspection Method

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ABSTRACT

Inter-platform consistency is a central inter-usability attribute in cross-platform service design. However, limited studies have investigated the importance of the different characteristics of inter-platform consistency for user experience (UX) of cross-platform services. A discounted, easy, fast inter-platform inspection method for cross-platform service design is still unavailable. In this paper, the authors present the results of a study on inter-platform service consistency using a new inspection method. Three UX experts evaluated three cross-platform services using predefined inter-platform consistency heuristics (perceptual, lexical, operational, and compositional). The evaluation yielded 287 inter-platform consistency findings (194 negative and 93 positive). The results indicated that all predefined consistency heuristics that represent inter-platform consistency characteristics are important and should be considered when designing the UX of cross-platform services. The evaluators assessed our inspection method and found it appropriate and effective.

KEYWORDS

Consistency, Cross-Platform, Inspection Method, Inter-Platform, Inter-Usability, User Experience

INTRODUCTION

Over the past three decades, a significant shift has occurred in how we interact with computers. We now have access to an unprecedented range of powerful computing devices with varying features, functions, and technical capabilities, which was not the case in the entire history of computing (Oulasvirta, 2008). As computing devices have become more widespread, users now engage with products and services on a broader range of computing platforms (hardware and software). As a result, the use of cross-platform services is expanding, and the demand for "always-on services" has been growing rapidly (Forrester Research, 2013; Lascau, Wong, Brumby, & Cox, 2019; Microsoft, 2013; Monge Roffarello & De Russis, 2021).

In the context of the proliferation of computing devices and their rapid adoption by people, many terms emerged to describe interactive systems accessible through multiple platforms. The term 'cross-platform service' is used to describe "a set of user interfaces (UIs) for a single service encompassing two or more computational platforms for interacting with the service" (Majrashi, 2016; Majrashi, Hamilton, & Uitdenbogerd, 2015). The term 'multiple user interfaces' (MUIs) is also used to describe views of the same information and services accessed by users from different platforms (Nilsson, 2006;

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Samaan & Tarpin-Bernard, 2004; Seffah & Javahery, 2005). Other terms are also used to describe cross-platform interactive systems, including 'cross-platform user interfaces' (Majrashi, Hamilton, & Uitdenbogerd, 2018; Richter, 2007), 'multiple platform user interface' (Ali, Perez-Quinones, Abrams, & Shell, 2002; Meskens, Vermeulen, Luyten, & Coninx, 2008), 'distributed user interface' (DUI) (Bång, Larsson, Berglund, & Eriksson, 2005; Gallud et al., 2011), 'cross-device user interface' (Lin & Landay, 2008; Nebeling, Mintsi, Husmann, & Norrie, 2014), 'multi-channeling' and 'cross media' (Segerståhl, 2008).

Several terms are used to describe interactions with cross-platform interactive systems, including 'cross-platform interaction' (Majrashi, Hamilton, & Uitdenbogerd, 2017), 'cross-device interaction' (Hamilton & Wigdor, 2014; Santosa & Wigdor, 2013), and 'multi-device interaction' (Raptis, Kjeldskov, & Skov, 2016; Santosa & Wigdor, 2013).

Cross-platform services allow users to perform tasks using multiple devices, such as desktop computers, smartphones, laptops, and tablets. Users currently perform different activities across devices, such as searching for information, managing finance, social networking, planning a trip, shopping online, and watching a video (Google, 2012; Jokela, Ojala, & Olsson, 2015; Microsoft, 2013).

In response to the spread of cross-platform services, multi-device adoptions, and cross-platform interactions, new research themes have emerged in the field of human-computer interaction (HCI), such as inter-usability and cross-platform or cross-device user experience (UX) (Zhang et al., 2021). Inter-usability concerns the ease of use of interactive systems when switching between them across devices (Denis & Karsenty, 2004), and cross-platform UX refers to an individual's perceptions resulting from interaction with the systems across devices (Majrashi, 2016). According to Wäljas, Segerståhl, Väänänen-Vainio-Mattila, and Oinas-Kukkonen (2010), the primary aim of the cross-platform design is to ensure that the user experience is coherent. Shin (2016) further highlighted that this emphasizes the importance of inter-usability as a crucial factor in the development and success of cross-platform services.

Inter-platform consistency, also known as cross-device consistency and inter-device consistency, has been identified as a central inter-usability element (Denis & Karsenty, 2004; Majrashi, 2016; Majrashi, Hamilton, & Uitdenbogerd, 2016a, 2016b; Majrashi et al., 2017; Rodrıguez, 2019; Sánchez-Adame, Mendoza, Meneses Viveros, & Rodríguez, 2019). Inter-platform consistency concerns how the UI designs and contents of the same system are consistent across platforms or the consistency of the user experience across multiple platforms (Burny & Vanderdonckt, 2022; Gajos, Wu, & Weld, 2005; Guerra-Manzanares & Välbe, 2022; S. Kang & Kim, 2007; Paternò & Santoro, 2012).

Prior studies recommend maintaining inter-platform consistency through several interface components across platforms (Denis & Karsenty, 2004; Majrashi, 2016). However, it has been argued that although inter-platform consistency is an important inter-usability attribute, interface components across platforms cannot and should not be entirely consistent at all levels (Wäljas et al., 2010). Nevertheless, there is a lack of studies on the impact of inter-platform consistency on cross-platform UX to determine which aspects are essential for enhancing the UX of cross-platform services. Therefore, one aim of this study is to address this research gap.

As an emergent interaction mode, cross-platform interaction requires new or customized evaluation methods and metrics to support cross-platform design (Antila & Lui, 2011; Majrashi, 2016). As an example, the need for new methods has been taken into account by Majrashi, Hamilton, Uitdenbogerd, and Al-Megren (2020), who built an assessment model for testing cross-platform usability (inter-usability), and Väänänen-Vainio-Mattila and Wäljas (2009), who developed an expert evaluation method for the UX of cross-platform web services. Consistency inspection is among the main usability inspection methods in the traditional usability engineering life cycle (Nielsen, 1994b). Heuristic evaluation is considered a discount usability engineering method. Studies have found that it is an efficient method for finding usability issues in user interfaces (Jeffries, Miller, Wharton, & Uyeda, 1991; Mack & Nielsen, 1994). However, a consistency inspection method for the inter-usability,

as an emergent theme in the domain, is still unavailable. Therefore, this study aims to develop and assess an inter-platform consistency inspection method.

Multi-platform interactions can be sequential (working on an interrelated task using different devices at different times) or simultaneous (working on a single task using more than one device at the same time) (Google, 2012). Figure 1 shows a conceptual example of user interaction in sequential and simultaneous modes. In the sequential mode, a user can use a mobile phone to browse clothing products and, when deciding on a specific product, switch to a laptop at a different time to purchase it. The time between the transition from one device to another can be short or long in the sequential interaction. In the simultaneous mode, a user can use a mobile phone and a laptop to view and compare two different flight options simultaneously. In this study, we consider these two different interaction modes when investigating the effect of different consistency characteristics on the UX of cross-platform services using our proposed inter-platform consistency inspection method.

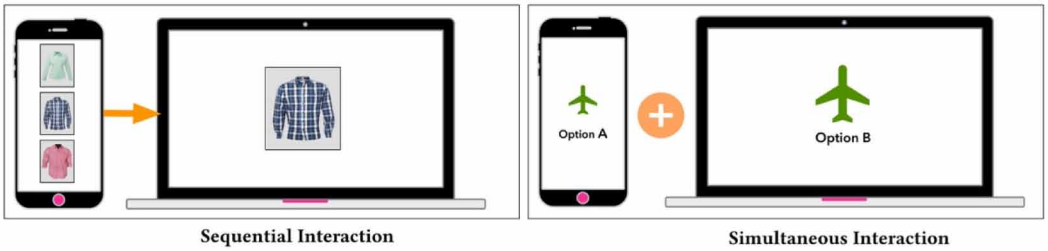
The explosion of research topics on cross-platform interactions has led to using different terminology. For example, different prefixes (e.g., cross, multi, inter) are combined with specific words such as platform, device, and modal. Brudy et al. (2019) contributed a taxonomy to create a unified terminology and understanding in cross-device research. In their taxonomy, 'cross-platform' refers to "the development of interfaces that run on different device form factors and operating system platforms". Other terms that are used with a similar meaning to 'cross-platform' are 'multiplatform' and 'cross-modal'. For this study, we use 'cross-platform service' to refer to a set of UIs for a single service on two or more computational platforms. We also use 'inter-platform consistency' to refer to the consistency of the UIs of the same system across platforms. The prefix 'inter' highlights the interconnectivity dimension of software products across platforms.

In summary, this study primarily explores how specific consistency characteristics affect the UX of cross-platform services in sequential and simultaneous interaction modes. It also investigates the extent to which the inspection method developed in this study is appropriate for evaluating inter-platform consistency.

RELATED WORK

Many studies have been conducted on UX and inter-usability of cross-platform services (Denis & Karsenty, 2004; Gomes, Boon, & Hoeber, 2022; J.-S. Kang & Lee, 2018; Majrashi, 2019; Majrashi et al., 2016a, 2016b, 2017; Pyla, Tungare, & Pérez-Quinones, 2006; Rodrıguez, 2019; Shin, 2016; Wäljas et al., 2010). Studies on cross-platform UX often emphasize the importance of consistency as a key element. Some studies identified it as the factor most affecting cross-platform UX (Majrashi et al., 2016a, 2016b, 2017). It has also been found and argued that consistency supports continuity and seamless transition when transferring a task to a different device (Denis & Karsenty, 2004; Majrashi, 2016). An early study also showed that the consistency priorities approach for multi-device UI design resulted in better impressions than the fitting-to-a-screen approach when performing similar tasks

Figure 1. Two different modes in multiplatform interaction context



on different devices (de Oliveira & da Rocha, 2007). Consistency is also one of the 3C framework elements (consistent, continuous, and complementary) considered the building blocks of a multi-device design (Levin, 2014).

Denis and Karsenty (2004) suggested that maintaining consistency is important at various levels if it does not contradict technical or operational limitations. They identified four levels of consistency: perceptual (information's appearance and structure), lexical (labels of user interface elements), syntactical (operations that serve the same purpose), and semantic (data and functionality). Similarly, Majrashi (2016) identified consistency requirements that should be considered across devices at different levels, including appearance, operational, and lexical consistency.

While consistency is crucial in cross-platform design, Wäljas et al. (2010) argue that complete consistency is unattainable and inappropriate due to technological differences. Instead, they suggest achieving consistency at certain levels, such as appearance and language. In addition, it has been acknowledged that enforcing consistency in certain aspects may not always result in a positive user experience. For example, Majrashi et al. (2016b) found that users may not necessarily prefer a uniform look and feel across different devices.

Majrashi (2019) also investigated the user performance on cross-device menu interfaces and found that consistency of menu item orders is an important factor for the efficient and accurate relocation of menu item targets after the transition from one device to another. However, he found that the consistency of menu layouts (horizontal vs. vertical) does not largely affect user performance when switching between devices. Therefore, Majrashi's study suggested that inter-device consistency should be associated with real user needs and behaviors.

Väänänen-Vainio-Mattila and Wäljas (2009) conducted a study with the primary aim of developing an expert evaluation method for the UX of cross-platform services. They synthesized initial heuristics and asked three UX experts to use them to evaluate three cross-platform web services. The results of the evaluations were used to refine the initial heuristics. In their study, consistency emerged primarily as a topic under a main heuristic called service usability. However, specific aspects of consistency were not comprehensively addressed or discussed.

In general, most of the related studies show the importance of inter-platform consistency as a key cross-platform UX element, but there is still a need to examine the effect of the different aspects of inter-platform consistency on cross-platform UX. In addition, an inter-platform consistency inspection method for evaluating inter-platform consistency across platforms is absent. This study attempts to fill these gaps.

METHOD

This section represents our inter-platform consistency inspection method, which combines essential elements required to evaluate the inter-platform consistency of cross-platform services. By integrating the expertise of UX evaluators, a set of inter-platform consistency heuristics, and a systematic evaluation process that accounts for multi-platform interaction aspects (e.g., sequential and simultaneous interactions, changing of device order in the sequential interaction, and period between interactions), the method provides an evaluation framework for the inter-platform consistency of cross-platform services.

We employed the method to evaluate the inter-platform consistency of three cross-platform services across two devices. The method's aim was twofold. First, to investigate the effect of inter-platform consistency aspects on cross-platform UX. Second, to evaluate the suitability of the method for inspecting inter-platform consistency.

Cross-Platform Services and Devices

For this study, we selected three cross-platform services: Amazon (Figure 2), Facebook (Figure 3), and TripAdvisor (Figure 4). Using a sample of three interfaces or services is common in related studies

Figure 2. Amazon cross-platform service (desktop, website, and mobile application)

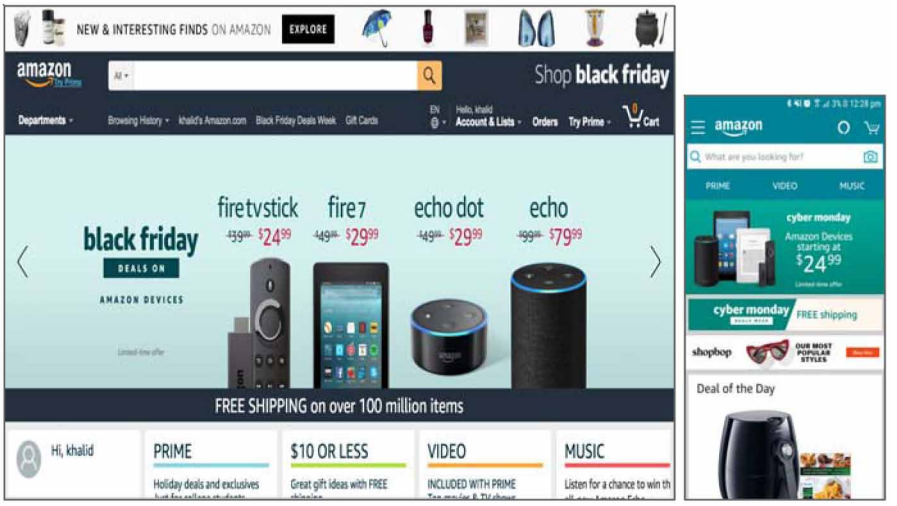
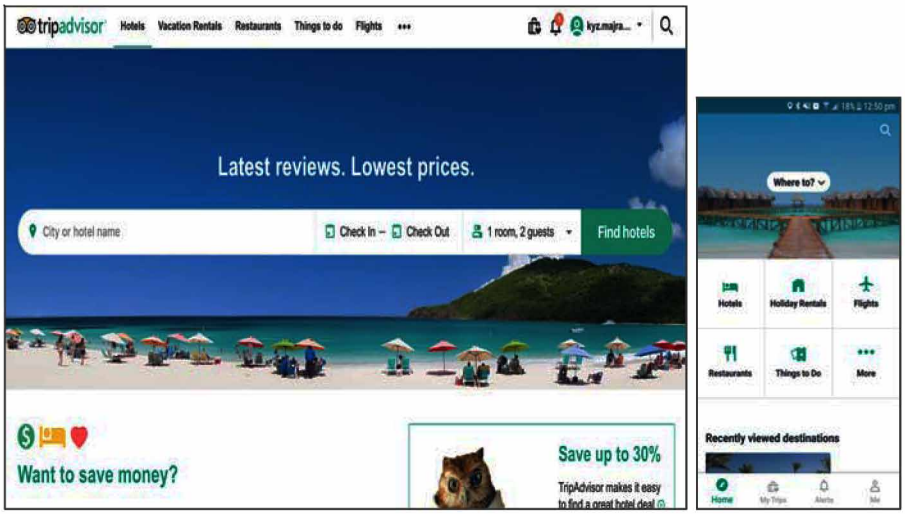


Figure 3. Facebook cross-platform service (desktop, website, and mobile application)

(see e.g., Väänänen-Vainio-Mattila & Wäljas, 2009). Amazon allows users to search for, browse, and buy products online. Facebook provides several features to its users, including "liking," tagging, posting, adding friends, uploading photos, creating and managing groups, and editing privacy settings. TripAdvisor offers advice from real travelers and various travel choices, such as accommodation.

The selected services are from different domains (social networking, online shopping, and travel). Users who frequently engage in cross-platform activities commonly interact with services in these domains (Google, 2012). The services tend to apply complementary levels of redundancy where the interactive systems on all devices have a zone of shared data and functions, but one or more of the devices offer(s) access to data or functions that are inaccessible on the other device(s). This is the most common configuration for cross-platform services (Denis & Karsenty, 2004).

Figure 4. TripAdvisor cross-platform service (desktop, website, and mobile application)



Amazon, Facebook, and TripAdvisor services are available across devices (personal computer [PC] and mobile phone). The device categories (PC/laptop and mobile phone) are commonly used in both cross-platform sequential and simultaneous interaction modes (Google, 2012). Our study adopted these two devices for the evaluation of the three services.

Initial Set of Inter-Platform Consistency Heuristics

We synthesized and described the inter-platform consistency heuristics based on a review of a set of studies (Denis & Karsenty, 2004; Majrashi, 2016; Wäljas et al., 2010) and informal analysis of cross-platform services, which is one way used for developing heuristics in the field (see, e.g., Väänänen-Vainio-Mattila & Wäljas, 2009). These heuristics represent the consistency characteristics, in which we aimed to investigate their importance for the UX of cross-platform services. In Table 1, we present the heuristics and their descriptions.

The Evaluators

The recommended number of evaluators for heuristic evaluation is three to five (Nielsen, 1994a). We recruited evaluators using an online sign-up form. Twenty professionals and researchers with UX

Table 1. The initial set of inter-platform consistency heuristics

	Heuristic	Description
CH1	: Perceptual	Interface appearance, behavior of dynamic elements, as well as the information structure. For example, consistency of colors, shapes, layout, and typefaces; behavior of buttons and menus; spatial organization of information or elements; and order of information or elements.
CH2	: Lexical	Consistency of labels of user interface objects.
CH3	: Operational	Consistency of operations when accomplishing the same goals.
CH4	: Compositional	Consistency of content (data and function).
CH5	: Not Related	The finding is not related to the predefined heuristics (CH1, CH2, CH3, and CH4).

and usability backgrounds signed up to take part in our study. However, we selected only three UX experts, who matched our participation criteria, to participate in the evaluation process (E1 = Evaluator 1, E2 = Evaluator 2, and E3 = Evaluator 3). Examples of the criteria are that the UX expert should have a previous engagement in a UX expert review process and at least 4–5 years of experience in UX design or research. The three UX experts evaluated each service. The experts used and evaluated the services in their contexts. All evaluators had 4–5 years of experience in UX research and design. Their study programs included computer science, software engineering, and HCI. The evaluators primarily worked in industries from the government to education and software.

The evaluators' previous experience with the evaluated services varied. All of them had more than three years of experience with the Amazon desktop website but had no experience with the Amazon mobile application. They had over three years of experience with the Facebook desktop website and mobile application. As regards the TripAdvisor service, they had no experience with it across devices. We considered these varieties of experience an advantage since the evaluations would generate findings based on different prior experiences.

The Heuristic Evaluation Process

In the preparation phase, we sent the consistency heuristics to the evaluators with a detailed explanation of each heuristic. We also included an explanation of sequential and simultaneous interaction. In addition, we provided them with evaluation instructions and a tool we developed for recording positive and negative findings. The evaluators were encouraged to ask questions if needing any clarifications. They were also provided links to the cross-platform services (websites and the latest version of mobile applications) that they were asked to evaluate.

In order to eliminate the learning effects of using new devices for the evaluation, the evaluators were instructed to use their own devices when evaluating the cross-platform services. All evaluators used a MacBook Pro 13-inch (running OS X Sierra) and the Google Chrome browser to access the desktop websites of the services. In this study, the MacBook device was referred to as a PC since our tool classified both PCs and laptops as PCs. Two evaluators used the Apple iPhone 7 (running iOS 11), and one used the Samsung Galaxy S6 (running Android 8.0 Oreo) to operate the mobile applications of the services. In this study, the two types of mobile devices are referred to as mobile phones.

Evaluators were given seven days to evaluate all services assigned to them. We encouraged them to use the services comprehensively, including all the main features offered by the services. They were asked to use the services in their usual contexts. They were instructed to use the services on both PC and mobile phones and interact with them sequentially and simultaneously. In the sequential interaction, we encouraged them to evaluate the services by considering the period between interactions, both short (e.g., after seconds or minutes) and long (e.g., after hours or days). The evaluators were also encouraged to use interfaces of each service in different orders to simulate real users' behavior during the cross-platform interaction (Google, 2012), as well as to identify inter-platform consistency issues that may be associated with each specific order (Majrashi, 2016).

The evaluators were also encouraged to evaluate the three services at different times (a day between evaluations) to prevent the possible influence of overlapping experiences between services. Each evaluator was instructed to assess services in a different order to minimize the effect of service order on evaluation (Table 2).

Table 2. Service evaluation order

Evaluator	Order of Services		
1	Amazon	Facebook	TripAdvisor
2	TripAdvisor	Amazon	Facebook
3	Facebook	TripAdvisor	Amazon

The evaluators were asked to note all positive and negative findings of consistency affecting the cross-platform UX and label them with the related heuristic (CH1 to CH4), which is a common heuristic evaluation practice (see e.g.,Väänänen-Vainio-Mattila & Wäljas, 2009). They were instructed that if they thought a certain finding was unrelated to one of the predefined heuristics, they should mark it with CH5. They were asked to consider their positive and negative experiences and their expectations of how a specific inter-platform consistency characteristic might affect the cross-platform UX of other users. We described the positive finding as "consistency or inconsistency in a specific aspect that leads to a positive experience for the evaluator and/or an expected positive experience for other users." Similarly, we explained the negative finding as "consistency or inconsistency of a specific aspect that leads to a negative experience for the evaluator and/or an expected negative experience for other users." That is, inconsistency might not always lead to a negative experience, and consistency might not always result in a positive experience.

Evaluators were also asked to rate the severity of each consistency problem based on a three-level rating adopted from Sauro (2013) and customized for our study: minor (problem might cause some hesitation or slight irritation when switching between devices), moderate (problem might cause occasional task failure for some users or delays when switching between devices and moderate irritation), or critical (problem might lead to task failure when switching between devices or cause users extreme irritation). In addition, evaluators noted whether they encountered the finding during the sequential or simultaneous interaction modes.

The following figures are screenshots from the tool used by the evaluators. The tool included a section for recording general information about the evaluators, their background and experience, the reviewing period, the evaluated service and interfaces, and the devices used for the evaluation (Figure 5), a section for describing: interaction modes, type of findings, heuristics, severity levels, and order of devices in the sequential interaction (Figure 6), a section for recording findings (Figure 7), and a section for an automatic display of the evaluation results (Figure 8).

EXPERT EVALUATION OF THE METHOD

Expert evaluation can be used for evaluating usability inspection methods. In a related study, Väänänen-Vainio-Mattila and Wäljas (2009) asked UX experts to evaluate the suitability of their evaluation method for the UX of cross-platform services after using the method to evaluate actual services. Similarly, we asked the evaluators (the UX experts) to evaluate the suitability of our method. To gather their feedback, they received a questionnaire to comment on the method, including the heuristics and the evaluation process. We sent the questionnaire before the evaluation period so that they could comment on the method during the evaluation process to ensure that they would report more accurate information about the method. An evaluator could have forgotten important information

Figure 5. A section in the tool for collecting general information

Reviewer's name:		Platform 1 (i.e. MacBook Pro 15inc: OS X El Capitan):
Reviewer's E-mail:		User interface 1 (i.e. Desktop Website):
Cross-platform service (e.g., Amazon, Facebook, TripAdvisor):		Previous experience with the user interface 1 (e.g., no experience, 1 month, 2 months, 1 year, 2 years ...etc.) :
Reviewer study major (i.e. computer science, information technology, HCI):		Platform 2: (i.e. Samsung Galaxy s6: Android 8.0)
Reviewer experience in the field of UX design or UX/HCI research (i.e. 2 months, 1 year, 2 years ...etc.):		User interface 2 (i.e. Mobile App):
Review period (i.e. 7 Dec 2017 to 15 Dec 2017)		Previous experience with user interface 2 (e.g., no experience, 1 month, 2 months, 1 year, 2 years ...etc.) :

Figure 6. A section in the tool for describing interaction modes, the type of findings, heuristics, severity levels, and the order of devices

Interaction Modes		
#	Mode	Description
1	Sequential	Working on an interrelated task using different devices at different times (see the instructions file for examples of sequential tasks).
2	Simultaneous	Working on a single task using more than on device at the same time. (see the instructions file for examples of simultaneous tasks).

Findings	
Type	Description
Positive	Consistency or inconsistency of a specific aspe experience for the evaluator and/or an expecte other users.
Negative	Consistency or inconsistency of a specific aspe experience for the evaluator and/or an expecte other users.

Heuristics		
Heuristic Code	Heuristic	Description
CH1	Perceptual	It concerns consistency of interface appearance, behavior of dynamic elements, as well as the structure of information across devices. For example, consistency of colors, shapes, layout and typefaces, behavior of buttons and menus, spatial organization of information/elements, and order of information/elements, etc.
CH2	Lexical	It concerns consistency of the labels of corresponding user interface objects across devices (e.g., the labels of the corresponding menu items, buttons across devices)
CH3	Operational	It is about consistency of operations of the same goal across devices (e.g., operations or steps to find a specific information across devices).
CH4	Compositional	It refers to the consistency of content (data and function) across devices (e.g., the availability of sort function in all user interfaces across devices).
CH5	Not Related	Finding is not related to any of the pre-defined heuristics (CH1, CH2, CH3, CH4).

Severity Rating		
#	Scale	Descri
1	Minor	Might cause some hesitatio switching between devices.
2	Moderate	Might cause occasional task delays when switching betw irritation.
3	Critical	Might lead to task failure wl devices or cause user extrem

Order of Devices in Sequential Interact	
PC to Mobile	The evaluator starts the task on **PC** and then continue the task.
Mobile to PC	The evaluator starts the task on **Mobile devi** to continue the task.

Figure 7. A section in the tool for recording findings

Evaluation Findings

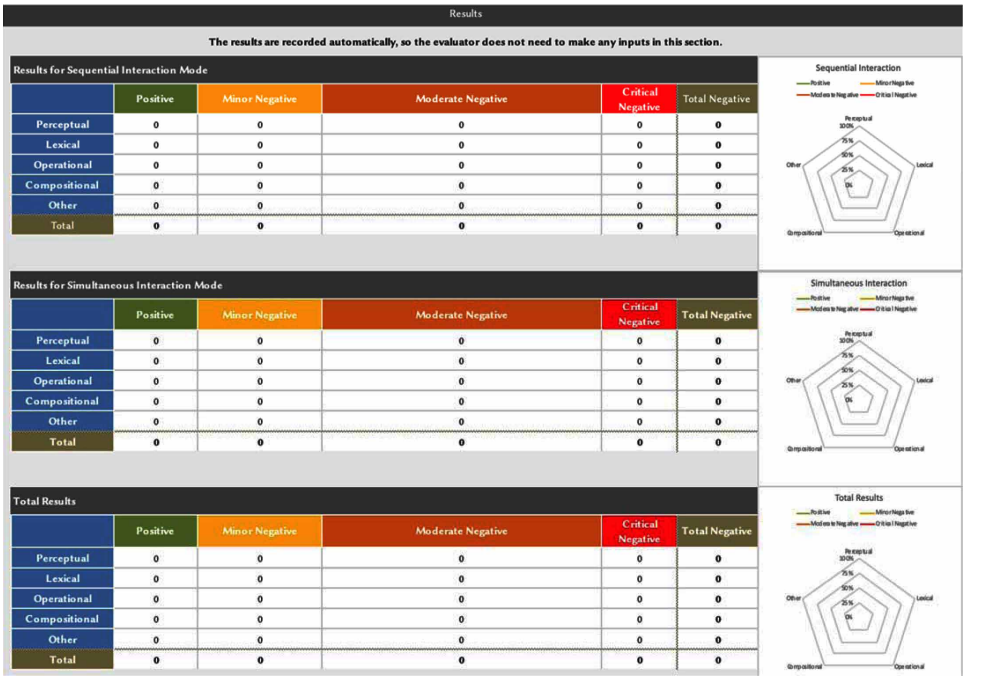
Please don't delete the examples, and start recording the findings after the examples.

#	Order of Devices (only if the interaction mode is sequential)	Interaction Mode	Consistency Heuristic	Findings	Positive or Negative Finding	Severity Rating (only if the finding is negative)	Any additional comment
Example #1		Simultaneous	Lexical	Inconsistency of labelling the submit button.	Negative	Moderate	
Example #2	Mobile to PC	Sequential	Perceptual	Consistency of ordering menu items	Positive		
Example #3		Simultaneous	Compositional	All functions experienced in the desktop website were available on the mobile interface.	Positive		
Example #4	PC to Mobile	Sequential	Operational	Each interface across devices provide different number of operations for achieving the same goal.	Negative	Minor	
1							
2							
3							
4							

about the method if we asked them to comment after completing their evaluation of the services. The questionnaire involved questions to assess the method in terms of:

- Appropriateness of the inspection method for assessing inter-platform consistency.
- Effectiveness of the method for identifying positive and negative consistency findings.
- The extent to which the heuristics are complete and easy to understand, and whether there is any redundancy in the heuristics.
- Challenges, constraints, or difficulties while using the method for assessing inter-platform consistency.
- The importance of evaluation in two interaction modes (sequential and simultaneous).
- The importance of changing the order of devices during the sequential evaluation.

Figure 8. The result section in the tool


Results

The results are recorded automatically, so the evaluator does not need to make any inputs in this section.

Results for Sequential Interaction Mode

	Positive	Minor Negative	Moderate Negative	Critical Negative	Total Negative
Perceptual	0	0	0	0	0
Lexical	0	0	0	0	0
Operational	0	0	0	0	0
Compositional	0	0	0	0	0
Other	0	0	0	0	0
Total	0	0	0	0	0

Sequential Interaction

Results for Simultaneous Interaction Mode

	Positive	Minor Negative	Moderate Negative	Critical Negative	Total Negative
Perceptual	0	0	0	0	0
Lexical	0	0	0	0	0
Operational	0	0	0	0	0
Compositional	0	0	0	0	0
Other	0	0	0	0	0
Total	0	0	0	0	0

Simultaneous Interaction

Total Results

	Positive	Minor Negative	Moderate Negative	Critical Negative	Total Negative
Perceptual	0	0	0	0	0
Lexical	0	0	0	0	0
Operational	0	0	0	0	0
Compositional	0	0	0	0	0
Other	0	0	0	0	0
Total	0	0	0	0	0

Total Results

- The length of the evaluation.
- Satisfaction about the tool used for recording the findings.

RESULTS AND DISCUSSION

Interaction Modes

The evaluation of all services resulted in 287 findings related to inter-platform consistency. This large number of findings generally means that inter-platform consistency is an important element for cross-platform UX. Table 3 shows examples of our findings in sequential and simultaneous interaction modes.

Out of the 287 findings, the evaluators reported 154 (53.66%) findings associated with the sequential interaction mode. Table 4 shows the number of positive, minor negative, moderate negative, and critical negative findings associated with the inter-platform consistency heuristics (CH1–CH5) identified in the sequential interaction mode for all services. The number of findings associated with the predefined heuristics (CH1–CH4) is 140, representing around 90% of the total findings (see Figure 9). This result means that our heuristics (perceptual, lexical, operational, and compositional) covered most consistency aspects. The findings reported under CH5 (not related to predefined heuristics) were those involving more than one consistency aspect, which can fit under more than one predefined consistency heuristic. These are called composite findings.

The findings were more associated with CH2 (lexical) and CH3 (operational) for Amazon. For Facebook and TripAdvisor, the findings were more associated with CH1 (perceptual) and CH4 (compositional). Examining the data in Table 4 does not reveal consistent patterns that allow judging whether specific heuristics or inter-platform consistency aspects are more important than others. This lack of patterns could be interpreted to mean that all heuristics are important and that the design of the different services may result in different numbers and types of findings associated with the heuristics.

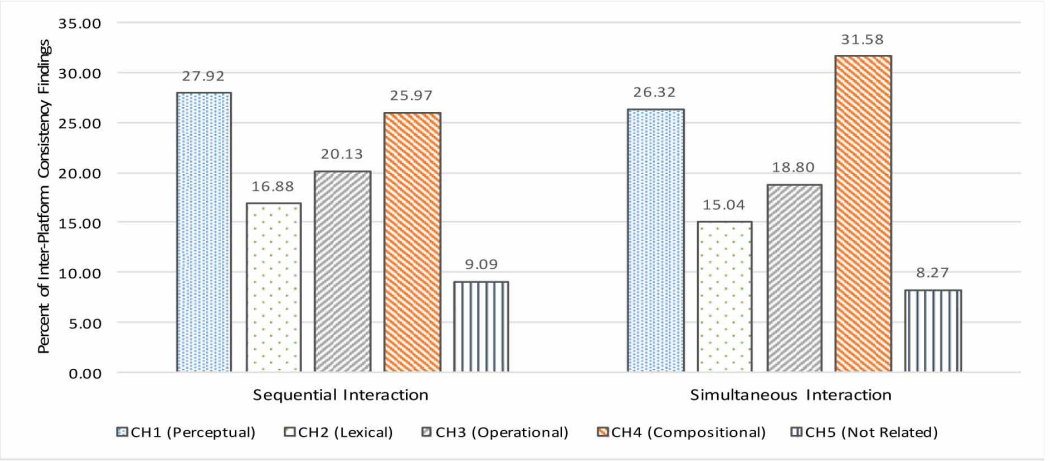
Table 3. Examples of inter-platform consistency findings. A = Amazon, F = Facebook, TA = TripAdvisor.

Mode	Device order	Heuristic	Finding	Type	Severity level
Sequential	PC to Mobile	CH1	"The search results for the same search query are not ordered consistently across the two terminals." (A)	Negative	Minor
Sequential	PC to Mobile	CH4	"I like the feature used in Amazon for searching for products by taking their photo. This feature is on the mobile app, and I would not expect to see it on the PC website because it is associated with the mobile device capability. So, I would say it is a good inconsistency." (A).	Positive	-
Sequential	Mobile to PC	CH2	"The label for the gift card menu item is different." (A).	Negative	Moderate
Simultaneous	-	CH4	"There was inconsistency in showing drafted status. I created a drafted status on the mobile, and when I switched using the PC to add an image to the status, I could not find the drafted status, so I went to check the notification to find it, but it did not appear in the notification window, although it appeared in the notification in the mobile app." (F).	Negative	Critical
Simultaneous	-	CH3	"The number of steps is slightly different when trying to show all restaurants on a map." (TA).	Negative	Minor

Table 4. Number of findings associated with inter-platform consistency heuristics in sequential interaction mode for all services

		Positive	Negative				Total Findings
			Minor	Moderate	Critical	Total	
Amazon	CH1 (Perceptual)	3	3	7	1	11	14
	CH2 (Lexical)	3	6	6	6	18	21
	CH3 (Operational)	1	3	7	12	22	23
	CH4 (Compositional)	3	2	4	2	8	11
	CH5 (Not related)	2	3	0	0	3	5
	Total	12	17	24	21	62	74
Facebook	CH1 (Perceptual)	4	2	3	0	5	9
	CH2 (Lexical)	1	1	1	0	2	3
	CH3 (Operational)	2	0	1	1	2	4
	CH4 (Compositional)	6	1	0	2	3	9
	CH5 (Not related)	3	2	1	0	3	6
	Total	16	6	6	3	15	31
TripAdvisor	CH1 (Perceptual)	11	7	2	0	9	20
	CH2 (Lexical)	0	1	1	0	2	2
	CH3 (Operational)	1	1	1	1	3	4
	CH4 (Compositional)	12	2	1	5	8	20
	CH5 (Not related)	2	1	0	0	1	3
	Total	26	12	5	6	23	49
Total		54	35	35	30	100	154

Figure 9. Percentage of inter-platform consistency findings associated with heuristics in each interaction mode



The number of findings identified in the simultaneous interaction mode was 133 (46.34%) out of the 287 findings. Table 5 presents the number of positive, minor negative, moderate negative, and critical negative findings associated with the inter-platform consistency heuristics (CH1–CH5) identified in the simultaneous interaction mode for all services. Of these, 122 findings are associated with the predefined heuristics (CH1–CH4). This number represents around 92% of the total findings (133), which is similar to the findings in the sequential interaction mode (see Figure 9). This finding suggests that the predefined heuristics also cover most of the findings in the simultaneous interaction mode. Similar to our finding in the sequential interaction mode, the findings reported under CH5 in the simultaneous interaction mode were positive or negative findings with more than one consistency aspect associated with more than one predefined heuristic. For Amazon, the findings were more associated with CH3 (operational) and CH4 (compositional). For Facebook and TripAdvisor, the findings were more associated with CH1 (perceptual) and CH4 (compositional). This result is partially consistent with our findings as regards the sequential interaction mode.

The overall results across the different evaluated services showed that the findings were more associated with CH1 (perceptual) and CH4 (compositional) than CH3 (operational) and CH2 (lexical) in both sequential and simultaneous modes. In the sequential mode, the total number of findings was 43 for CH1 (perceptual), 40 for CH4 (compositional), 31 for CH3 (operational), 26 for CH2 (lexical), and 14 for CH5 (not related). In the simultaneous mode, the total number of findings was 42 for CH4 (compositional), 35 for CH1 (perceptual), 25 for CH3 (operational), 20 for CH2 (lexical), and 11 for CH5 (not related). However, although lower numbers of findings are associated with CH3 (operational) and CH2 (lexical consistency) in both sequential and simultaneous modes, it is difficult to judge that these heuristics are at a lower level of importance than CH1 (perceptual) and CH4 (compositional) heuristics. This distinction occurs as many factors can affect the results. For instance, the number of evaluated user interface design cases within specific tasks related to the operational and lexical heuristics can be lower than those related to the other heuristics. In addition, the number of consistency aspects covered by each heuristic differs (Table 1), which can influence the number of findings per heuristic.

Order of Devices

As mentioned earlier, evaluators were instructed to interact with the services in different orders of devices in the sequential interaction mode. For Amazon, Facebook, and TripAdvisor, 67.56%, 41.93%, and 36.73% of the findings that the evaluators reported were associated with the "PC to

Table 5. Number of findings associated with inter-platform consistency heuristics in simultaneous interaction mode for all services

		Positive	Negative				Total Findings
			Minor	Moderate	Critical	Total	
Amazon	CH1 (Perceptual)	1	3	5	0	8	9
	CH2 (Lexical)	1	1	2	2	5	6
	CH3 (Operational)	6	0	5	4	9	15
	CH4 (Compositional)	3	3	7	5	15	18
	CH5 (Not related)	2	1	0	0	1	3
	Total	13	8	19	11	38	51
Facebook	CH1 (Perceptual)	2	3	2	6	11	13
	CH2 (Lexical)	3	1	5	0	6	9
	CH3 (Operational)	1	0	5	2	7	8
	CH4 (Compositional)	1	0	2	11	13	14
	CH5 (Not related)	4	1	1	0	2	6
	Total	11	5	15	19	39	50
TripAdvisor	CH1 (Perceptual)	7	5	0	1	6	13
	CH2 (Lexical)	2	1	2	0	3	5
	CH3 (Operational)	1	1	0	0	1	2
	CH4 (Compositional)	4	2	3	1	6	10
	CH5 (Not related)	1	1	0	0	1	2
	Total	15	10	5	2	17	32
Total		39	23	39	32	94	133

Mobile" interaction sequence, and 32.43%, 58.06%, and 63.26% with the "Mobile to PC" sequence, respectively (see Figure 10). Our in-depth investigation of the findings in each sequence showed that more than half of the problems associated with each interaction sequence for each investigated service are unique, indicating the necessity for evaluating inter-platform consistency through interacting with the services in different orders of devices.

Problem Severity

Each negative finding or problem was classified by the evaluators as minor, moderate, or critical. The sequential interaction mode had 100 negative findings, with 35 problems classified as minor, 35 as moderate, and 30 as critical (see Figure 11). In the simultaneous interaction mode, out of the 94 problems, 23 were classified as minor, 39 as moderate, and 32 as critical (see Figure 11).

On examining the problems with different severity levels for the three evaluated services across the two modes (Tables 4 and 5), we notice that there are no specific patterns associated with a specific severity level. These results confirm that inter-platform consistency problems can occur at different levels of severity, indicating that different consistency aspects should be considered when designing cross-platform services. When comparing problems of each severity level across the predefined heuristics (CH1–CH4), we found a similar lack of patterns showing associations between heuristic(s) and level(s) of severity across services. For example, evaluators reported more

Figure 10. Percentage of inter-platform consistency findings per interaction sequence of device for each service

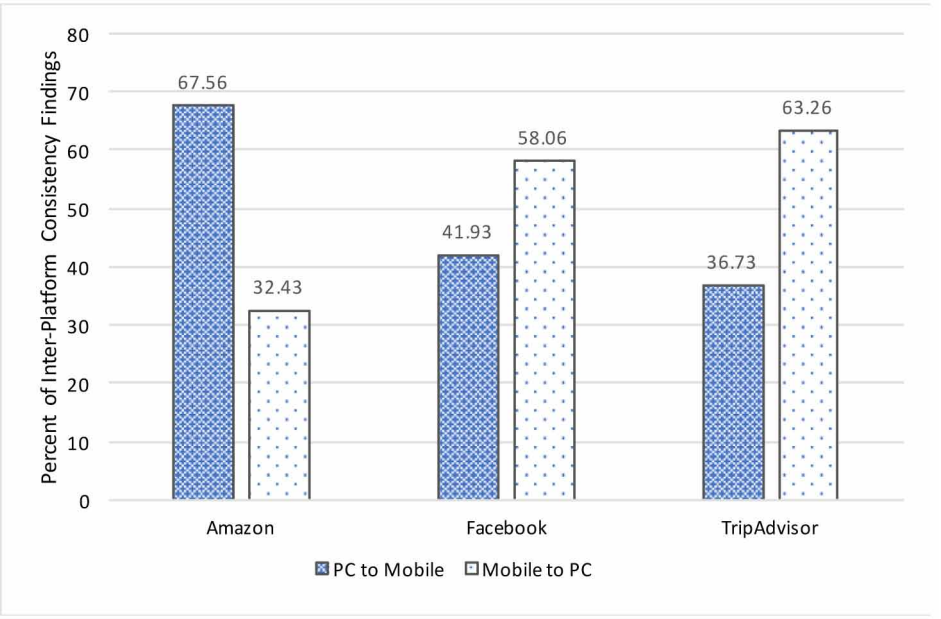
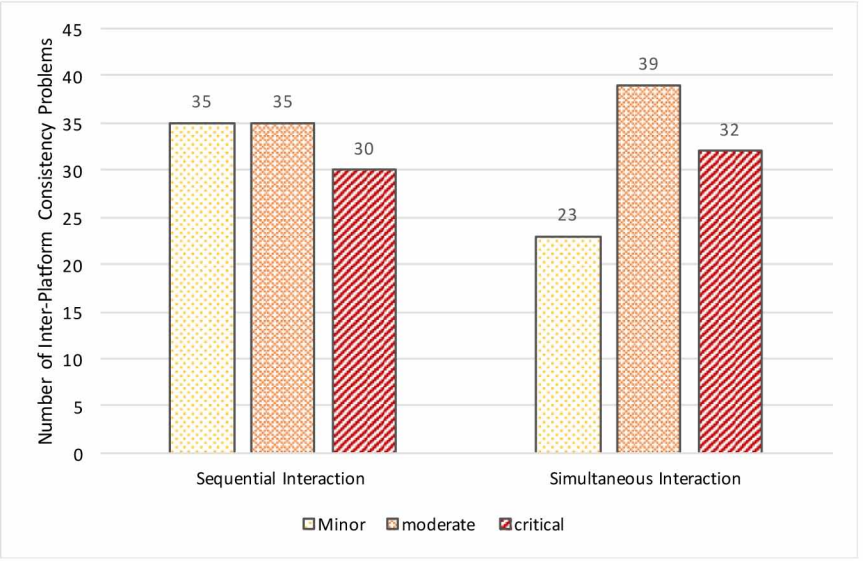


Figure 11. Number of minor, moderate, and critical inter-platform consistency problems in each interaction mode



critical negative findings associated with CH3 (operational) for the Amazon service but not for the other evaluated services (Facebook and TripAdvisor). Therefore, it is difficult to judge that problems related to operational consistency can be more critical than problems related to perceptual, lexical, or compositional consistency.

Positive and Negative Findings

Of the 287 findings in this study, 194 were negative and 93 were positive. Figure 12 shows the number of positive and negative findings related to inter-platform consistency in each interaction mode. The negative findings are more than the positive findings for each service across the two interaction modes, with the exception of TripAdvisor in the sequential interaction mode. Generally, having many positive and negative findings indicates that both types of findings should be considered when evaluating inter-platform consistency.

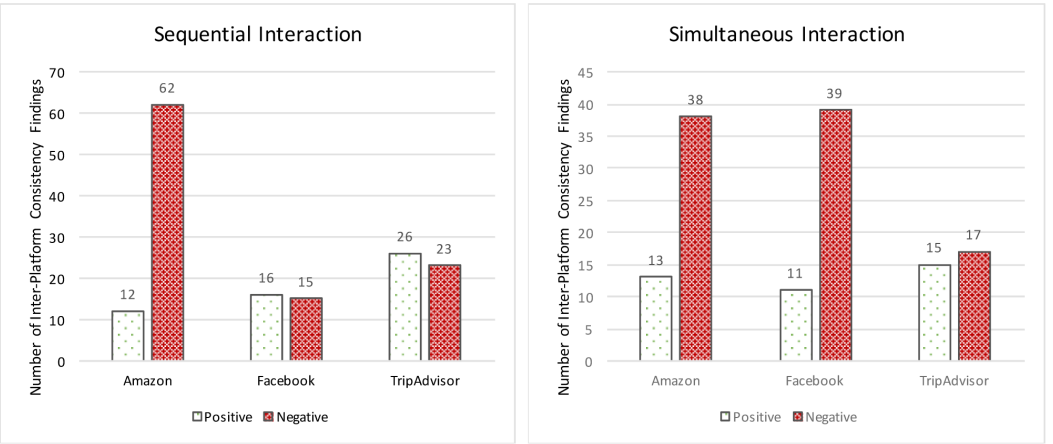
Our analysis of the findings, categorized as positive and negative, showed that both types involved results related to the consistency and inconsistency of system components. Among the positive findings, 96% of the results were related to consistency, and 4% were related to inconsistency. Among the negative findings, 97% of the problems were related to inconsistency, and 3% were related to having some interface components consistent across devices. These results confirmed our definitions of positive and negative findings and proved that inter-platform inconsistency might not always lead to a negative experience, and inter-platform consistency might not always result in a positive experience. Therefore, positive and negative consistency and positive and negative inconsistency must be considered when inspecting the inter-platform consistency of cross-platform services.

Results of Expert Evaluation of the Method

As mentioned previously, the evaluators assessed our inter-platform consistency inspection method using a questionnaire. In general, all evaluators agreed that the method was appropriate. Using a Likert scale ranging from 1: "Not at all Effective" to 7: "Extremely Effective," all evaluators rated the effectiveness of the method for identifying positive and negative findings related to inter-platform consistency, as 6 on the scale, which is labeled "Very Effective." The evaluators assessed the heuristics and agreed that they are complete and that there is no redundancy between them. However, E2 mentioned that it would be easier for the evaluator to understand the heuristics if these were classified further or if some had low-level classifications to cover consistency sub-aspects. E3 also elaborated on the composite problem with more than one consistency aspect, which can be associated with more than one heuristic. The evaluator argued that these problems should be placed under CH5 because some problems cannot be broken into subproblems.

The evaluators also commented on the ease of understanding of the evaluation method. E2 stated: "It only took me around 30 minutes to understand it, including the use of the tool." E3 commented: "At first, I tried to read them slowly and clearly before I started, but after that, it was so clear." As regards

Figure 12. Number of inter-platform consistency positive and negative findings in each interaction mode



the importance of evaluation by considering the two interaction modes (sequential and simultaneous), the evaluators agreed on the importance of evaluating services in the two modes. E1 elaborated on this aspect and suggested that tasks should be chosen carefully for each mode by considering the interaction characteristics of the mode. Another evaluator recommended using different tasks for each mode to eliminate the learning effects of interfaces across the interaction modes.

The evaluators also agreed on the importance of changing device order during evaluation to assess the fluency of tasks in different sequences of devices. They were also satisfied with the length of the evaluation process per service. E2 commented: "It took me around an hour to evaluate each service, which is fine." The average evaluation length recorded by E1 and E3 is around 1.5 hours and around 2 hours per service, respectively. The evaluators were also satisfied with the tool we developed for recording the findings. They also mentioned that if predefined tasks were provided, they could evaluate the services in a shorter time.

CONCLUSION AND FUTURE RESEARCH

This study investigated the extent to which specific consistency characteristics affect the UX of cross-platform services, and evaluated an inspection method developed for assessing inter-platform consistency. Three evaluators used the method to assess the inter-platform consistency of three cross-platform services. The evaluation assessed the services in two common cross-platform interaction modes (sequential and simultaneous). The evaluation resulted in 287 findings related to inter-platform consistency, with 154 (53.66%) identified in sequential mode and 133 (46.34%) in simultaneous mode. Of these, around 90% in the sequential mode and 92% in the simultaneous mode were reported under our predefined consistency heuristics (perceptual, lexical, operational, and compositional). We also found that all the predefined consistency heuristics are important because the findings are not only associated with specific heuristics. Moreover, we did not identify patterns relating to consistency heuristics with particular severity levels.

Further, we found that changing the device order when evaluating the service in the sequential interaction mode is essential because unique findings can be identified for each device sequence. The evaluation resulted in 194 negative and 93 positive findings, demonstrating that both positive and negative findings should be considered when evaluating inter-platform consistency. Our results also proved that both types of findings could involve inter-platform consistency or inter-platform inconsistency, and hence, inter-platform inconsistency might not always lead to a negative experience, and inter-platform consistency might not always result in a positive experience. The evaluators assessed our evaluation method and agreed it was appropriate and effective.

One limitation of this research is that the number of cross-platform services tested was limited to three, representing only three domains (social networking, online shopping, and travel). Another limitation of this study is that the devices used to access the cross-platform services represent only two categories: mobile and PC/laptop. As a result, the findings of this study may not be generalizable to all cross-platform services in different domains and to all devices that can be used to access the services. Therefore, future research should include a broader range of cross-platform services and devices to increase the representativeness of the findings.

Another limitation of this study is that the cross-platform services evaluated in this research tended to apply only one level of redundancy: complementary, where the interactive systems across the two devices had shared data and functions, but certain data or functions were accessible only from a specific device. Cross-platform services can also utilize different levels of redundancy: redundant, where all interactive systems across devices allow access to the same data and functions, and exclusive, whereby each interactive system on each device gives access to different data and functions. Therefore, future research is still needed to broaden our understanding of the impact of redundancy levels on the importance of specific consistency characteristics for the UX of cross-platform services.

From a scientific perspective, another limitation of this study is that only three evaluators assessed each cross-platform service. Using a limited number of evaluators may introduce potential bias and affect the reliability of the results. Furthermore, the sample of evaluators may not represent all potential evaluators, with different perspectives, which may have influenced the evaluation outcomes. Therefore, future research could expand the number of evaluators and consider utilizing a more diverse sample of evaluators to increase the reliability and generalizability of the findings. However, from a practical perspective, using only three evaluators was relatively low-cost and resulted in many inter-platform consistency findings. Therefore, future work could study the cost-effectiveness of our developed evaluation method and investigate the potential trade-offs between the cost and the reliability of the findings.

During the evaluation of our method, evaluators provided some suggestions for improvement. For example, one evaluator recommended carefully selecting tasks for each interaction mode based on its characteristics. This suggestion reflects that certain tasks may be better suited for certain modes due to differences in user interaction and device capabilities. Future research could explore this recommendation in more detail, analyzing the selection of tasks for each interaction mode and identifying how they influence the evaluation of the inter-platform consistency of cross-platform services. Another evaluator proposed providing evaluators with predefined tasks to shorten the evaluation period. Future research could investigate the use of predefined tasks and their impact on the length of the evaluation process.

AUTHOR NOTE

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