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EUHSA: Extending Usability Heuristics for Smartphone Application

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ABSTRACT Emerging development trends in smartphone computing assist the user to enhance skills, health improvement, earning opportunities, sharing ideas, providing entertainment, and so on. Appropriate transfer of these assistances demands a vibrant appearance to a smartphone user. End users emphasize easy-to-use, ergonomics, efficiency, and visual aesthetic, among others. Measuring usability issues allows for improving these features. An inspection-based heuristics set identifies the usability issues for improving the quality of smartphone interfaces. Using suitable heuristics is highly relevant. In this paper, we present an extended and relevant set of 14 Usability Heuristics for Smartphone (EUHSA) application, where 13 heuristics were selected after cross-linking the identified usability flaws with the previously proposed heuristics through a user study with 800 students from a human–computer interaction course. An additional heuristic is proposed against uncaptured usability flaws. Furthermore, the EUHSA was validated using an expert evaluation study. Findings were compared with the previously proposed Joyce and SMASH sets of heuristics. The results explicitly justify the EUHSA and prove its effectiveness in evaluating the usability issues.

INDEX TERMS Human-computer interaction, usability experts, smartphone applications, heuristic evaluation, user interfaces.

I. INTRODUCTION

Nowadays, smartphones are used in several areas such as health, education, business, entertainment, sports, politics, social networking and others. Therefore, they have become a common user machine [1]. Development of cultured user interfaces (UI) for smartphone applications in these areas enhance user experience (UX) [2]. Assessing usability issues allows improving the quality of smartphone applications. Usability evaluation (UE) in the laboratory or field provides a mechanism to assess the usability issues. Developers fix the captured flaws and provide a refined interface to the users.

"Summative" and "Formative" are two approaches to evaluate usability. In Summative style, real users perform the real tasks on some defined applications and empirically measure the usability in terms of effectiveness, efficiency and user satisfaction. Formative approach employs the experts for UE using heuristics or guidelines [3]. An inspection based heuristics set is practiced extensively to evaluate usability of application. Initially, it was designed by Molish and Nielsen in 1990, which later on refined by Nielsen in 1994 and provided ten usability heurists [4]. Heuristic evaluation became popular with the passage of time due to its effectiveness, low cost, low resource consumption and accurate results [5]. For this, heuristics should be documented properly, so to learn and practice conveniently [6]. Relevant sets of heuristics are more applicable to all types of machines ranging from desktop computers to portable devices such as smartphones or tablets. Smartphone usability gained obvious attention for its unique features particularly mobility, near field communications, multiple windows, context awareness [7] limited input/output modality, small screen size [8], varying context, interaction [9] and many others.

Human-computer interaction (HCI) researchers argued that traditional heuristics sets are not completely relevant of current smartphone and applications [5], [10], mainly due to mobile specific features. Some work has been done such as Bertini *et al.* [11], Joyce and Lilly [12], Inostroza *et al.* [13], and Humayoun *et al.* [14] for smartphone applications. However, none of the studies assured that the work is complete and comprehensively identifies usability issues related with smartphone applications. This indicates the need of research in the above-mentioned gap [15].

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For gap identification in existing literature and the development of smartphone heuristics, we followed the six stages methodology proposed by Inostroza *et al.* [16]. This process starts from identification of problem statement, literature review in the domain of interest, descriptive, correlation, explicative, validation and finally the refinement stage. For flaws identification, at third stage, we conducted an initial user study. Eight hundred undergraduate enrolled students in an HCI course performed the experimental tasks on four mobile applications including Calendar, Amazon, CNN, and Gallery. Before experimentation, we prepared participants theoretically and practically. We developed a corpus of usability issues and identifying pertinent issues. In problem description, we took help from domain experts to understand the behavior of user interaction in varied environments. We followed the procedure [17] to understand the users behavior, which impacts the user' task performance [18]. We refined the submitted information by eliminating the irrelevant, ambiguous and duplicated work and extracted valid usability issues. These flaws were crossed link with the appropriate heuristics taken from 11 sets of heuristics. These sets of heuristics are for mobile phones [19], for smartphone [12], [13], [20], [21], for specific but applicable to general mobile applications [22]-[24], for desktop but, extensively applicable to mobile paradigm [4] and for multi-touch gesture evaluation [14], [25]. The objective of this activity was to analyze whether the existing heuristics capable to cope with all these identified issues.

It was found that most of the captured usability flaws were mapped with 13 heuristics related with smartphone applications. These heuristics were mainly common in most of the studies with minor changes in heuristic names, sequence and minor definition changes. It was found that some of the usability flaws were not crossed link to any of the heuristic. These usability issues provided input-output mismatch to the user. Collaborative style was followed for defining heuristic for these uncaptured flaws. At the end, a newly defined heuristic "Avoid Misleading Relations" came out from the user study.

For validation, we executed the heuristic evaluation with twenty-four usability experts. These experts had good knowledge of heuristic evaluation, smartphone applications and HCI. We selected four mobile applications including Gallery, Geo, Calendar and Contacts and six experimental devices selected for experimentation. Evaluation study had two experimental conditions (EC) with 12 experts in each. In EC-1, we performed heuristic evaluation using EUHSA and Joyce et al. sets of heuristics, while in EC-2, we performed heuristic evaluation using EUHSA and SMASH sets of heuristics. Experts identified the usability issues and assigned the respective severity ranks. We highlighted the qualitative and quantitative analysis of collected data. This analysis comprised the comparison of sets of heuristics in the two experimental conditions and assessed their respective contribution. We also inquired from experts about the usefulness of our EUHSA. ANOVA method was used for statistical analysis of obtained results. The remaining part of this paper is structured as follows: In Section 2, we provide smartphone features and relevant literature review. In Section 3, we discuss the most relevant usability concepts related with smartphone usability, high- light the correlation between the identified flaws in a user study with the existing sets of heuristics. Further, we also provide details about the user study procedure and the way to propose the heuristics. This section also describes the methodology for realizing usability heuristics for EUHSA, the respective definitions of heuristics, and the framework for the classification these heuristics. We describe the expert-based evaluation study and highlight the qualitative and quantitative analysis of collected data. Finally, we conclude the paper in Section 4.

II. SMARTPHONE USABILITY BIBLIOGRAPHY

A. SMARTPHONE FEATURES AND ASSOCIATED USABILITY

Small screen size [24], [26]–[29]: User clicks the wrong option on small screen due to massive information. If designers put small amount of information on screen. It may lead huge possibility to lose its meaning for the users. *Limited input capabilities* [24], [26]–[29]: Inflexible and tailored gestures for interaction and virtual keyboard cause usability issues. Users simultaneously spend mental effort between the typing content and the keypad zone. *Limited computational resources* [24], [26]–[29]: Users demand that mobile devices should accomplish the task efficiently and behave like a desktop. Limited power (batteries) [24], [26]–[29]: The user has to compromise on the brightness and the connectivity of internet, which consumes more power. *Single window* [35]: Switching between the windows causes of uneasiness. *Different display resolution* [29]: Comparatively, lower resolution of smartphone resulting in lower quality images. *Buttons of mobile devices* [30]: Small buttons and labels can reduce the efficiency. *Limited and costly band- width* [26]: The problem of slow internet limits the search and other tasks. *Limited connectivity* [24], [26]–[29]: Task effectiveness, efficiency and users comfort reduces. *Wide heterogeneity*[26]: The users of smartphones must always adjust to new customs and users need to relearn meanings, actions, letters, and others. *Mobility and varying context* [9], [24], [31]: Mobility may lead to inaccuracy of data entry, effectiveness, efficiency and discomfort. *Interruption* [27], [28]: Notification and requests may cause the error and task delay. *Privacy and security* [9], [33]: The user while moving through in different situations does not feel comfortable. *No right click* [28]: It bounds the number of inputs, functions and options. *Context-awareness* [32], [33]: Context-aware mobile applications do not properly provide a usable interface to the users in varied situations.

B. LITERATURE REVIEW

Bertini *et al.* [19] developed eight usability heuristics for mobile devices. They validate the proposed work against Nielsen's 10 heuristics [4] in an evaluation study. Their heuristics mainly focused on physical interaction, ergonomics, performance and strength of the device. Few heuristics' definitions overlap, which may distract evaluators and lead to mistakes. Later on, Bertini *et al.* [11] further explored avenues and motivated the research community to develop new sets of usability heuristics. Väänänen-Vainio-Mattila and Wäljas [34] developed seven UX heuristics for mobile web services. They further executed web services evaluation study using previously established heuristics. Findings of the study identified eight main themes of service UX. This resulted in enhancing the initial set of heuristics to nine [22]. Rusu *et al.* [35] proposed a methodology to develop usability heuristics and validated using Grid computing applications. They argued that the traditional methodology does not properly support for the development of relevant sets of heuristics. Korhonen [23] developed a set of twelve usability heuristics for mobile gaming. Ponnada and Kannan [36] also validated the Korhonen set of heuristics in an expert based evaluation study. This domain specific set of heuristics were also useful to evaluate other mobile applications.

Inostroza *et al.* [16] developed eleven heuristics for usability evaluation of touch screen mobile devices. Initially, usability issues were identified in a guided inspection, and then mapping these issues with Nielsen's set of heuristics. Additional issues were analyzed and proposed a set of touch screen based usability heuristics. This preliminary set was experimentally validated against Nielsen's heuristics. On the basis of results and experts' opinion, heuristics set was revised to twelve [30]. Salazar *et al.* [37] conducted a comprehensive literature review and collected all heuristic sets. They mapped the findings with Nielsen's heuristics and identified the additional heuristics suitable for mobile devices. It was found that these heuristics sets were based on traditional heuristics except [16, 30]. Salgado and Freire [38] also conducted literature review and identified the only mobile based set of heuristics [30].

Inostroza *et al.* [39] further refined work by performing evaluation against Nielsen's heuristics and experts' feedback. Issues identified by Nielsen's set of heuristics were more severe than proposed set of heuristics. One additional heuristic, "efficiency of use and performance", was introduced. This set in next iteration passed through evaluation study and inquiry test [13]. They asked for further validation of heuristics as there was no experimental validation in this study. Cunha *et al.* [21] compiled eleven heuristics based on Nielsen's work, analysis of previous literature and brainstorming. Their domain specific heuristics set was also applicable to mobile interfaces. Neto and Pimentel [20] used and further refined the set of heuristics described in [21]. They used inspection by simulation to understand the usability problems, categorized and associated with Nielsen's heuristics. They validated the proposed heuristics using evaluation study. Nielsen's heuristics were used for result comparison. They agreed to conduct comprehensive experimentation in future as this work lacks considering kind of interaction and contextual information. Joyce and Lilley [12] defined a set of 12 usability heuristics for smartphone applications. This set of heuristics are special in handling issues related to user's workload, varied context of use and first time usage. This set was further tested using UE [5], while comparing results with Nielsen and Bertini et al. sets of heuristics. Chuan *et al.* [40] developed usability heuristics for gestures interaction evaluation using smartphone. While Humayoun *et al.* [14] also proposed specific heuristics for evaluating multi-touch gestures in mobile applications. They adjusted 14 heuristics to make them more appropriate for smartphones and validated the set using evaluation study and compare the results with [12]. They agreed for further evaluation studies to generalize the feasibility of proposed heuristics.

Most of the above work highlighted that Nielsen's traditional set of heuristics provide basis in most of the mobile usability studies. This set was used to validate the mobile-based heuristics in various studies [12], [13], [19]. As there is no formal validation mechanism available in literature; therefore, research community compared and analyze the findings of mobile based heuristics with non-mobile based heuristics [4]. As a result, the developed sets of heuristics may not comprehensively identify the flaws using smartphone [10].

III. METHODOLOGY FOR DEVELOPING USABILITY HEURISTICS FOR SMARTPHONE APPLICATION

Several methodologies provide a mechanism to develop specific usability heuristics for mobile applications [10], [35], [41]–[45]. In our study, we followed 6 stages methodology developed by Rusu *et al.* [35], as this methodology was applied in most of the domain specific usability heuristics development studies. All other methodologies were applied only for domain specific mobile applications; whereas, this selected methodology was also validated in creating usability heuristics for touch screen based mobile devices [39], for mobile interfaces [9] and for smartphone application [13]. Quiñones *et al.* [10] further refined [35] and introduced two additional stages.

Step 1 of this selected methodology focuses to explore smartphone features and examine relevant studies of heuristic development. We covered this step in previous section. Step 2 emphases the identification of most significant features of the composed information and formalize the key concepts related with the study. Step 3 is a correlational work, in which we crossed link the usability flaws with the existing heuristics, to identify the features that usability heuristics should have and proposed an additional heuristic against pending usability flaws. In step 4, we followed the standard template to specify the usability heuristics for smartphone. Step 5 is the validation stage in which we performed heuristic evaluation with experts against SMASH and Joyce sets of heuristics. We refined the proposed heuristics based on feedback from the experts.

TABLE 1. Identification of smartphone related heuristics from studies.

Smartphone heuristics	Bertini et.al [19]	Joyce [12]	Inostroza et al. [13]	John-ston [24]	Cunha et. al [21]	Korho-nen [23]	Nielsen [4]	Chuan et al. [40]	Humayoun et al.[14]	Neto et al. [20]
SH1	1	1	1	1	9	9	1		1	9
SH2	2	2	2	8	1,5	5	2		2	1,5
SH3	8	3	5,10		6	10	5,9		5	6
SH4		4	11	5	10	12	10		8	10
SH5		5	8		8					8
SH6	7	6	9	2		2	8		7	
SH7	6	9	7	3	8	8	7	3	6	8
SH8		10								
SH9	4	11	12		4			4		
SH10	2	12	2			1		2	10,11	
SH11	6	7	6		3,11	4,11	6	1	13,15	3,11
SH12		8	3		6	6	3		3	6
SH13	3	2	4	8	3	7	4		4	3

A. STEP 2: DESCRIPTIVE STAGE

Three steps procedure was followed to ensure consistent and reliable outcomes.

- In first step, each author of this study, collected the sets of heuristics provided in literature, re-examined and identify the unique heuristics for smartphone.
- In second step, each author established their individual insights and matches the definition of each heuristic with the relevant heuristic in other sets.
- In third step, authors exchange the sheets and review the other's work.

We analyzed the definitions of each heuristic and followed the same approach as practiced in [39], [46]–[48] for comparison with all related heuristics in their respective sets. For example, we found that Bertini *et al.* [19] and SMASH [13] explicitly stated in their heuristic # 2 that "system should have the capability to sense its environment and adapt the presentation of information accordingly". Also, Joyce and Lilley [12] stated in its heuristic # 12 that "Use the camera, microphone and sensors when appropriate to lessen the user's workload". Korhonon [23] in its first heuristic stated that "camera behaves correctly", and also proposed four heuristics related with "context aware" playability [49]. Humayoun *et al.* [14] also asked for "cognitive load" in its 10th heuristic. We analyzed and combined all these similar concepts in a single heuristic. This single heuristic definition was "the system should provide contextual information wherever necessary to the concerned application, so application provides usable interface to the user. Also, the application should provide effective design to lessen the user's workload".

It was found that there were 13 heuristics related with smartphone applications in all these sets of heuristics as shown in Table 1. These heuristics were mainly common in most of the studies with minor changes in heuristic names, sequence and minor definition changes. First column of Table 1 highlights the short name (SH) of smartphone heuristics, whereas, other columns represent different studies with reference and its associated heuristic numbers. Following are the heuristics along with their respective short names.

Visibility of the system status (SH1), match between system and the real world (SH2), realistic error management (SH3), help and documentation (SH4), efficiency of use and performance (SH5), aesthetic and minimalistic design (SH6), flexibility and efficiency of use (SH7), Handling varied context of use in mobile environments (SH8), fingertip size controls and ergonomics (SH9), effective design to lessen user's workload (SH10), recognition rather than recall (SH11), user control and obviousness (SH12), consistency and standards (SH13).

B. STEP 3 CORRELATION STAGE

A smartphone application related usability flaw is associated with some specific feature of smartphone and for each such feature; there is always an association with relevant usability attribute. To identify correlation among these, we followed the four steps procedure.

- Methodology for comprehending usability flaws in a user study.
- Cross linked the flaws with existing heuristics for smartphone.
- Methodology for realizing usability heuristics against pending flaws.
- Categorizing usability heuristics to capture specific smartphone features.

1) USER STUDY ENVIRONMENT

A user study is an example of experimental research [50]. Eight hundred (800) undergraduate enrolled students in an HCI course performed the experimental tasks on some defined mobile applications and submitted the observed user related flaws. We assume for each user-related issue, the literature contains appropriate heuristic.

For user study execution, we used the platform of the Virtual University of Pakistan. This E-learning university provides knowledge to distant students at their doorstep using technology. This platform also provides opportunity to job holders to enhance their knowledge and skills in their domain of interest. This is the reason; we observed enrollment of professional students in computer science degree programs.

Amongst the participated students in the study, as shown in Figure 1, 106 participants were employed. We keenly observed their profile and found 90 participants were doing their jobs in the field of information technology. Some were teaching computer science courses in schools, while others were doing jobs in software industry related to software design and development. We assumed these participants have previously good knowledge of computing and few having expertise in UI design and development.

For experimentation, we need to prepare participants theoretically and practically. We delivered on line video lectures about HCI basics including UE concepts, smartphone features, and interaction paradigm among others for 6 weeks, delivered by renowned industry HCI expert. Participants were provided lab manuals uploaded on Learning Management System in the form of documents and recorded audio/video files for better understanding. On a regular basis, two forums were kept available for participants to discuss issues for understanding concepts. One is Moderated Discussion Board (MDB), which remained open for participants without any break. Participants asked theoretical concept related queries, which were answered. Whereas, for practical preparation, collaborative sessions using Team Viewer application remained open on alternate days for audio/video interaction. Multiple instructors took the sessions in which participants were given lab work and supported to complete the experimentation. To assess the participants' capabilities and understanding about HCI concepts, an online quiz was conducted. This quiz was a graded activity. The result of this quiz indicated that large number of participants were capable enough to execute experiment. This activity was managed by authors of this study, with the help of instructors in the HCI course.

2) STUDY SETTINGS

800 participants were given four mobile applications including CNN, Amazon, Gallery and Calendar with some defined tasks and the related description. The participants were also asked to explore applications and perform the tasks. We defined a list of two major tasks associated with each mobile application highlighted below.

a: APPLICATION 1 (CALENDAR)

Task 1.1: Add an event in your calendar mobile application. Give values to different fields like select date, place, add guests list, etc. and finally save the event.

Task 1.2: Use "Reminders" to create and view to-dos alongside your event.

b: APPLICATION 2 (GALLERY)

Task 2.1: Search the specific picture using "filter by" (events, people, scenery, food, pet etc.) from gallery application. Tap the picture you want to view and set as wallpaper. Task 2.2: Select a picture or a video from Gallery and apply different basic operations like "copy to album", "move to album", "rotate left", "rotate right", "add tag" etc.

c: APPLICATION 3 (AMAZON)

Task 3.1: Go to main page of the Amazon app; register yourself (sign up). Then, use your credentials to sign in and select search by voice option, here are things you can do with voice like "search, reorder, add to cart, track order etc.

Task 3.2: Go to the shopping page, select few items to buy, add to cart. Then modify the order and finally place the order (fill up desired fields without giving account detail and submit form).

d: APPLICATION 4 (CNN)

Task 4.1: Open the app to scan the world's top headlines and explore interactive featured stories.

Task 4.2: Quickly catch up on International, Opinions, Entertainment and other CNN coverage.

Participants used different smartphones manufactured by Samsung, iPhone, Huawei, Mobile, LG, Motorola, Lenovo, OPPO, Gfive and Infinix. After task execution, participants were asked to submit the following information: observed usability issues, the improvements suggestions with proper reason, mobile device and environment.

3) EXTRACTION AND REFINEMENT OF EXPERIMENTAL INFORMATION

There exist four different ways for the extraction of information [51]. We developed a corpus of usability issues and identifying pertinent issues. In problem description, we took help from experts (sociologist) to understand and analyze the behavior of user interaction in varied environments, because this impacts the user' task performance [18]. We also followed an approach given by Lewis *et al.* [52] to draw inferences from text-based material.

It was found that participants experienced activities including lying, sitting, standing, walking, attending a lecture, and few others. Location was classified into home, study center, class room, market, workstation, garden and few others. We found that most of the participants' responses indicated that they used smartphone in a sitting situation and mostly at home. When these participants experienced in other locations, then these places were familiar to them. Total number of participants and the quality of their submitted work in the form of grades is shown in Figure 2. For the extraction of user related issues from participants' submissions, we categorized the information in three formats. 1) submissions containing one application 2) submissions with two applications, and 3) submissions with 3 or 4 applications. First type in which participants didn't put relevant effort contains 60% of submissions, as shown in Figure 2. They argued that they tried but couldn't succeed to identify the usability issues at satisfactory level. Second type of submissions included 23% participants, who put effort, but their work was incomplete. Third type of submissions constitutes 17% participants, worked in a good manner. They followed the procedure and mostly findings were relevant and justified. For refinement of information,

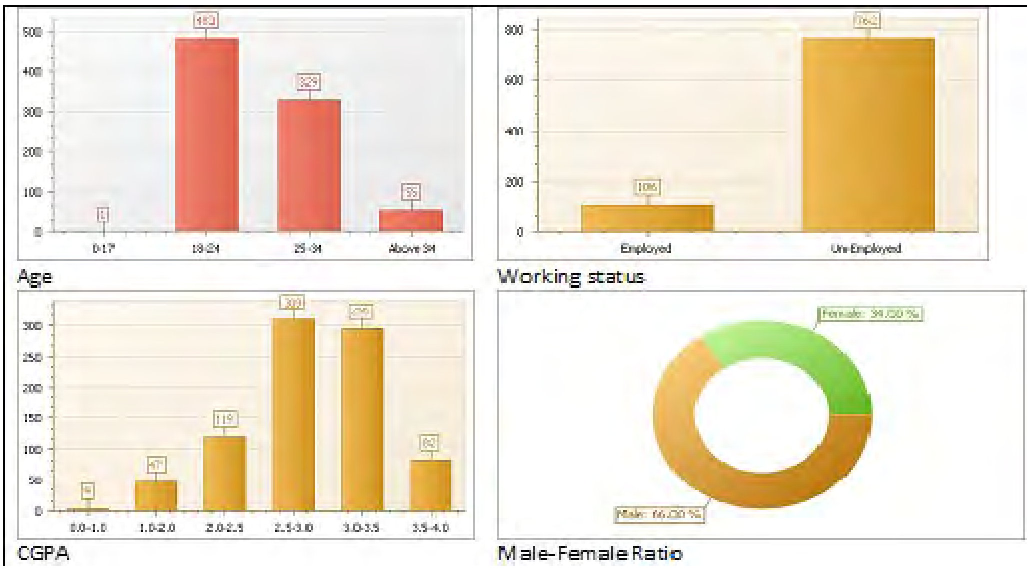

FIGURE 1. Users' profile.

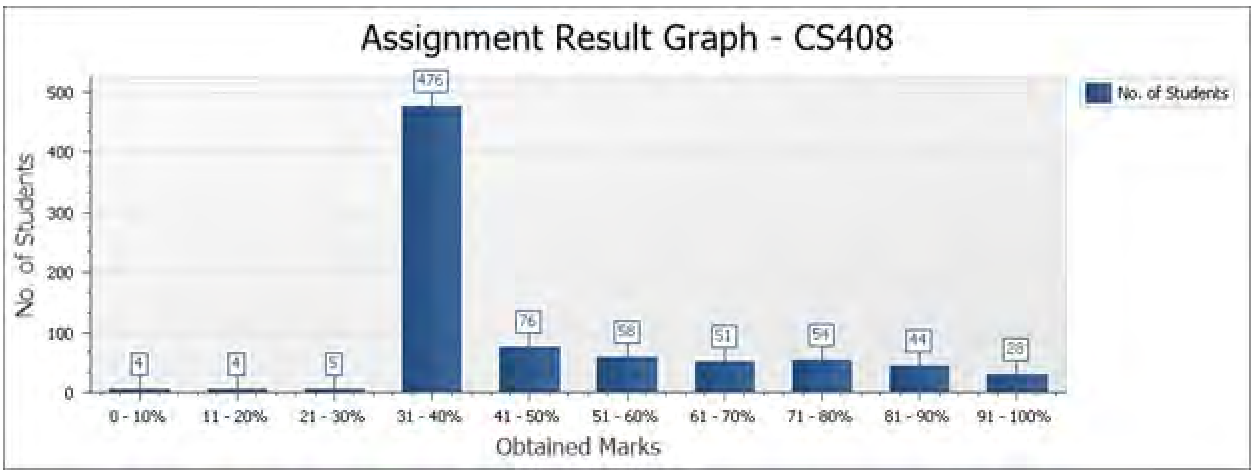

FIGURE 2. Students testing performance.

we neglected any grammatical/syntax related mistake and focused only on the core part of problem statement. Some user-defined problems were not clear and few were beyond the scope, which were discarded. We also eliminated the irrelevant, ambiguous and duplicated work for further refinement.

To ensure valid, transparent and consistent outcome, each author of this study also considered the following scenarios in a similar fashion.

- There were cases in which multiple participants' observed same user related issues in varied environments, and they suggested multiple improvement proposals. We believe that all such issues may have different impacts but, evaluated against a single heuristic. For example, participants set event alarm at a given time in Calendar mobile application. Now, there were cases in which participants moved around in some noisy environments and couldn't listen to alarm mainly due to low volume of built in ring tone. This happened in multiple situations while shopping in the market, walking on the road and others. They reported user related issues that mobile applications don't adapt according to environment and suggested varied improvement. We counted similar cases as a single entity.
- Smartphones have different layout, screen sizes, resolution values, available sensors, and others. So, a single usability issue may also have different impact in different smartphones. We counted similar cases as a single entity and put all these in the same set.
- Due to the subjective nature of each participant, there is a possibility that same issue may have multiple improvement suggestions. We added all these in a single category.

Then each author of this study described the usability issues considering all parameters and shared a consolidated file to other, for review and developed a refined list.

TABLE 2. Cross linked the identified user related issues with the available Heuristics.

Usability issues from calendar mobile application	Backlog heuristics	Number of identified usability issues from four mobile applications
For an event, Invite the guest and sent an email to guest. But, there was no visible feedback, whether, email has been sent to guest or not? We need to open the Gmail and verify.	Visibility of the system status [9, 12-14, 19, 21, 23, 25, 36, 39, 53]	17
"Create event" Dialog box contains some unnecessary information	Aesthetic and the minimalist design [9, 12-14, 19, 21, 23, 25, 36, 39, 53]	7
"Delete Event" option wasn't visible on displayed UI. User needs to scroll down to visualize.	Recognition rather than recall [9, 12-14, 19, 21, 23, 25, 36, 39, 53]	13
When user opens the "year view" and selects a particular date. Mostly it is selected wrong because of small control size. Also, selected date isn't ergonomically fit.	Fingertip size controls and Ergonomics [9, 12, 13, 39]	8
Created an event at 10:40PM. Event start time is 10:25PM and two alarms were set 5 minute before and at the time of event. No error message was displayed.	Realistic error management [9, 12-14, 19, 21, 23, 25, 36, 39, 53]	12
Takes extra steps when setting the "notification" in the reminder.	Efficiency of use and performance [9, 12, 13, 39]	10
There were two alerts named as "First Alert" and "Second Alert" used for event creation. User assumes that second alert option will inform the user later on after first alert. But, this isn't the case. It is just time dependent. Arrangement and names don't match with the real world.	Match between system and the real world [9, 12-14, 19, 21, 23, 25, 36, 39, 53]	14
There was no events in calendar app, so, "search" option should be disabled/ explicitly stated that no event is there" before search, to lessen the user's workload.	Effective Design to lessen the user's workload [12, 13, 19]	9
Similar functions weren't close to each other's.	Consistency and standards status [9, 12-14, 19, 21, 23, 25, 36, 39, 53]	15
End user lost control of task execution starting point after accomplishment.	User control and obviousness [9, 12-14, 19, 21, 23, 25, 36, 39, 53]	18
Reminder ring tone is set by default and the user can't change it. This isn't audible in the noisy area.	Handling varied context of use in mobile environments [12, 19]	7
End user selects" time zone" in the "Reminder", there is given a drop down list. Where user can perform the task using plus and minus time instead of the area or country. No shortcut is given for expert user.	Flexibility and efficiency of use [9, 12-14, 19, 21, 23, 25, 36, 39, 53]	8
Open the "memories" tag to add up new memory. User didn't find any clue from where to add up past memories	Help and documentation [9, 12-14, 19, 21, 23, 25, 36, 39, 53]	13

4) CROSS LINKED THE CAPTURED FLAWS WITH EXISTING HEURISTICS FOR SMARTPHONE

In third step, we crossed link the identified usability issues with appropriate heuristics taken from 11 sets of heuristics. These sets of heuristics are for mobile phones [19], for smartphone [12], [13], [20], [21], for specific mobile apps but applicable to general mobile applications [22]–[24], for traditional desktop systems, but extensively applicable to mobile paradigm [4] and for multi-touch gesture evaluation [14], [25]. The objective of this activity was to analyze whether the existing heuristics capable to cope with all these identified issues. Table 2 highlights some of the reported user related issues linked with the available heuristics.

As shown in Table 2, for these reported usability issues, backlog contains heuristics; however, there were few usability issues, which remained unallocated. Participants observed that applications provided input-output mismatch. Initially, this phenomena was observed especially in image searching/sorting using Gallery mobile application.

Some examples of such flaws in Gallery and Calendar are:

In Gallery mobile application,

1) View the image, press the "Edit" option, make no changes, and then press the "Done" option. Again open the same image for edit. Interface displays the "Revert" option. As we didn't make any edit in the image. Then, application shouldn't provide "Revert" option as an output. This is input-output mismatching.
2) Search "Birthday" images using search option. Application displays absolutely different images to user. This is input-output mismatching.
3) Select the video and drag up to see the "Related videos", which weren't matched with the input.
4) Open the "past memories" and press the search option. Application displays the same interface, where we can search ordinary images instead of past memories.

5) View the status of an album. Application shows 1165 photos in that album, whereas the correct figure was 1109 photos and 145 videos.
6) Copy the image from one album to another, edit only in the new album, whereas changes reflected in parent album. This is input- output mismatching.
7) When we rotate the picture in the editing window, picture is rotated by zoomed in and out occurs. Only rotation is required instead of zoom in.
8) If we delete a picture from a folder which has only one picture, the folder is also deleted. This is also input-output mismatching.

In Calendar mobile application,

1) Check the Islamic date mentioned on calendar app interface. It was mentioned 3rd, whereas actual date was 4th. This is misleading the user. Application should change the Islamic date at sunset time instead of at 12:00AM.
2) Click on "Today" option, to see events. Output interface highlighted information containing all upcoming events with title "January", whereas interface also contains events in February, March, and April etc.
3) When same name "events" available in the event list with different values in them, and the user searches that particular event by name, then UI displays only one event and don't display other. As both events are available, then, application should display output accordingly.

5) METHODOLOGY FOR REALIZING USABILITY HEURISTICS FOR SMARTPHONE

In previous sub-section, we crossed link the usability issues and assigned appropriate heuristics from backlog in a collaborative way. Same collaborative style will be observed while defining heuristic for smartphone computing. By exploiting the analysis of related usability issues along with associated data including mobile device, environment and others we carried out the below highlighted activities.

- Each author of this study was asked to follow [54]–[56] an approach and analyze the extracted pending usability issues from an initial user study. Each author described and generalized the usability flaws, to define heuristic. Then, we compared the listed extracted 13 heuristics and a newly defined heuristic, with general sets of usability heuristics for smartphone. Similar activity was performed in previous studies [39, 46–48] for proposed work.
- Each of the authors of this study compared his own developed set of usability heuristics with that of other, to produce a new consolidated list.
- This is the refinement phase, in which we arranged a discussion meeting to form a single consolidated table of EUHSA for mobile computing. Then, for further refinement, this consolidated list of heuristics was shared with 10 industry experts in a meeting session. These HCI experts provided feedback and adjusted accordingly.

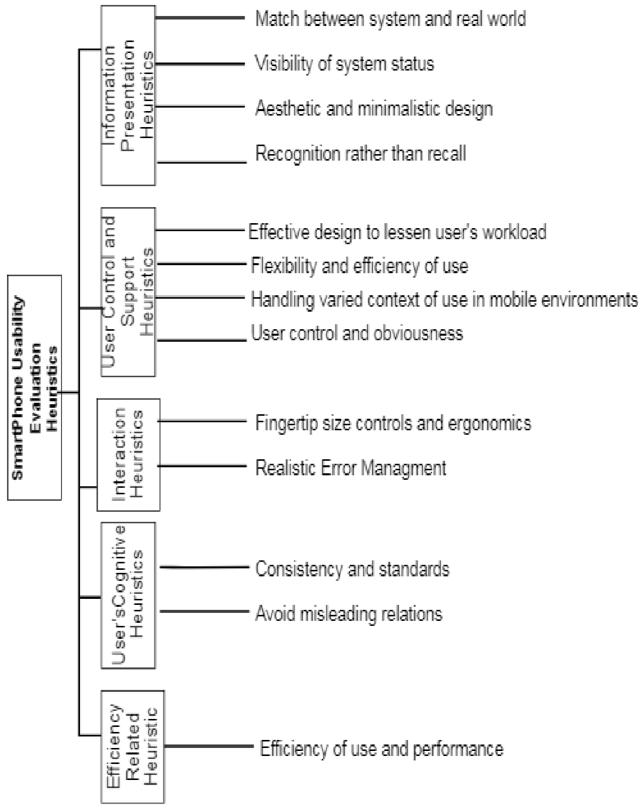

FIGURE 3. **Framework for classification of EUHSA heuristics.**

Finally, we developed 14 usability heuristics, in which thirteen were taken from previous literature and one newly developed heuristic "Avoid Misleading Relations". This heuristic is the extension of existing literature.

6) CATEGORIZE THE USABILITY HEURISTICS TO CAPTURE CERTAIN SPECIFIC SMARTPHONE FEATURES

Following steps were taken for the classification of EUHSA

- In first step, each author of this study categorized smartphone features and associated with the developed set of heuristics.
- In second step, authors exchanged and reviewed each other's work for consistent outcome.

We found that all smartphone usability heuristics were linked with five categories. Each category with underlying heuristics are described below and shown in Figure 3.

1) Information Presentation features: This category contains features associated with the smartphone presentation and information.
2) Interaction features: This category deals with the interaction between the user and smartphone.
3) User's Cognitive features: Category associated with the user's mental model/perception to perform any specific task.
4) User's Control and Support: This category contains features that provide control and support to the user during and after completion of any specific task.

5) Efficiency related features: This category contains aspects associated with the efficiency of the task accomplishment.

C. STEP 4. EXPLICATIVE STAGE

Following are the definitions of EUHSA ranging from P1 to P14.

1) VISIBILITY OF THE SYSTEM STATUS

The smartphone should keep the user informed about all processes and state changes through feedback and in a reasonable time. Feedback should facilitate user in under- standing the device's behavior.

a: EXPLANATION

When a user performs any specific task, there occurs some state changes in application or smartphone behavior. All such changes should be visible and communicated to the user. There are some situations in which the user doesn't initiate the task, but system provides feedback in case of audio messages, low battery status and others. System provides feedback in different forms including sound, light color changes and others.

b: EXAMPLE

Battery is showing the status that it is left 72%. Similarly, interface provides current status of network connectivity, signal strength and weather conditions as shown in Figure 4.

FIGURE 4. Visibility of the system status.

c: BENEFITS

Users feel comfort and react accordingly upon precise feedback. Users well aware about any application or system state changes within time limit.

d: PROBLEM

There are many different types of feedback in which the user's familiarity with all these does matter. Message sound generates against text messages, notifications, Whatsapp messages/audio, and others. So, different sounds recognition and familiarity among other types of feedback become difficult to understand and differentiate.

2) P2. MATCH BETWEEN SYSTEM AND THE REAL WORLD

The smartphone should express users' language instead of system oriented designs and technicalities. The smartphone should present the information in a natural and balanced way. Smartphone should follow the real world pacts.

a: EXPLANATION

Displayed Information is of images, text, icons, titles, font, style, and color scheme among others. All such information should follow conventions and should present according to the situation. It is observed that due to non- effective color scheme, looks difficult for users to select any specific option/ icon. So, system should design keeping in view environment variance. Use of color scheme and combination should conform to community belief, values, culture and environment as well as to enhance UX.

b: EXAMPLE

Battery status and weather conditions in Figure 5 shows symbol of battery (bin) and clouds resembles respectively and according to the real world.

FIGURE 5. Match between system and the real world.

c: BENEFITS

Logical and natural arrangement of information supports every user to let it understand easily and perform the task efficiently. Also, real world conventions support to perform task free from errors.

d: PROBLEMS

Real world conventions vary due to different of beliefs, culture, conventions and others. So, possibly, due to subjective nature, this heuristic identifies a flaw but, that wouldn't be a flaw by some other community.

3) P3. REALISTIC ERROR MANAGEMENT

Users may not always be precise in performing the task on mobile devices due to many reasons, such as small screen size, kind of interaction etc. Application should provide mechanism to prevent from error as well as display error message with proper diagnosis and suggest suitable solution.

a: EXPLANATION

System should provide proper security mechanism in case of sudden exit from the application domain, removing SIM/battery/sudden shutdown due to battery end up. In all such situations, system should provide a proper error message which highlights the consequences of the action and also provide a way to target situation in a good manner. When battery level goes down at a certain level, smartphone inform the user to take appropriate action such as enabling the power saving mode to save data and for long time usage.

b: EXAMPLE

Smartphone displays error prevention mechanism, when the user wants to install or update application in case of low space. System also suggests appropriate solution to get free space in a good way as shown in Figure 6.

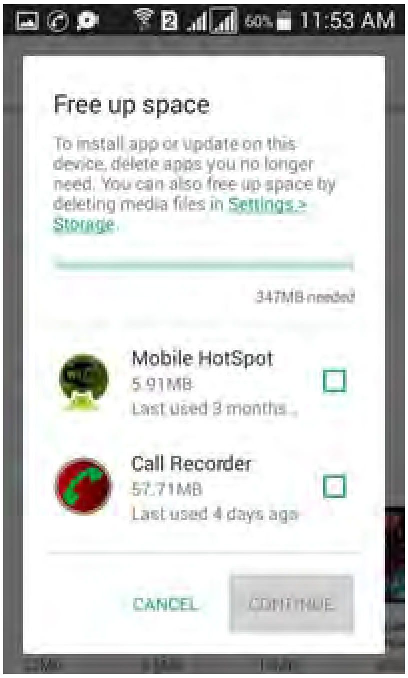

FIGURE 6. Realistic error management.

c: BENEFITS

Error prevention leads to enhance user comfort and less time to complete the task. Clear and recognizable error messages support the user to handle the situation just like a technician and recover from the error.

d: PROBLEMS

This heuristic instructs the user to understand the nature and type of error and how to use the system to come out of the danger situation. All this demands to know the workflow of the system. This may be less helpful for the naïve users.

4) P4. HELP AND DOCUMENTATION

The smartphone application should provide documentation and help focused on the user's current task.

a: EXPLANATION

Due to small screen size, designers put fewer information on screen. It may lead huge possibility to lose its meanings for the user. That's why, system should support the user to understand and execute the current task effectively and efficiently. One possible support is to provide proper help and documentation in an effective way. System should provide help and documentation with less cognitive work- load and context switching. Help and documentation may not necessarily organize in different menu setup or tab in mobile paradigm. System should support the user and provide help in the form of clues about next steps of task accomplishment.

b: EXAMPLE

It is clear from the Figure 7, that smartphone provides proper help, when the user wants to display next image. Clear steps are mentioned to perform the current task. Another example is while using amazon mobile app, an option to add an item in the cart gives a tip to press and drag the item at specific place.

FIGURE 7. Help and documentation.

c: BENEFITS

Proper help supports the user to accomplish the task effectively and efficiently. This heuristic also provides support to the user to get complete understanding of the system and can execute task with less error.

d: PROBLEMS

This heuristic supports the user about how to execute the current task for proper accomplishment. So, for naïve user, it is relatively difficult to understand and recognize.

5) P5. EFFICIENCY OF USE AND PERFORMANCE

Different steps and concepts involve in defining the task accomplishment should contain the minimum set of requirements.

a: EXPLANATION

Smartphone should support the users to perform their respective tasks by providing refined and an abstracted interface to the user. System should explicitly provide basic application functionality, focused on users' objective. A task accomplishment requires system resources including processing capabilities, battery, number of steps, mental effort and others. Complex task requires comparatively more resources than a simple task.

b: EXAMPLE

If the user disconnect the call with ''A'', after conversation. After some time, if the user dials to another person, let's say ''B''. Then, following steps are required to initiate the call. Press the dialed button, this results in opening up the previous caller interface (not necessary), from there, the user need to go back with only ''search'' option. Another extra step is to cancel/delete the previously searched option, then find the contact number of ''B'' to call. Finally, press the dialed button. These extra steps further add up, if the dialer is busy in some other activity or moving.

c: BENEFITS

Users comfort level goes up and intended to use the application in the future.

d: PROBLEMS

Possibly, one task accomplishment steps are minimum for an evaluator, while other raised question. So, it's a subjective in nature.

6) P6. AESTHETIC AND MINIMALIST DESIGN

Dialogues should not contain information which is irrelevant or rarely needed.

a: EXPLANATION

The application should provide aesthetically pleasant in- teraction, controls, icons, contents and others to the user. So they can avoid negative UX and feel joyness while performing the task.

b: EXAMPLE

An auto movement of cursor to the next field rather than scrolling enhances user experience. Similarly, when the user closes application, system should support the user in task accomplishment. But, the displayed dialogue box contains additional and irrelevant information in the form advertisement, which enhances negative UX as shown in Figure 8.

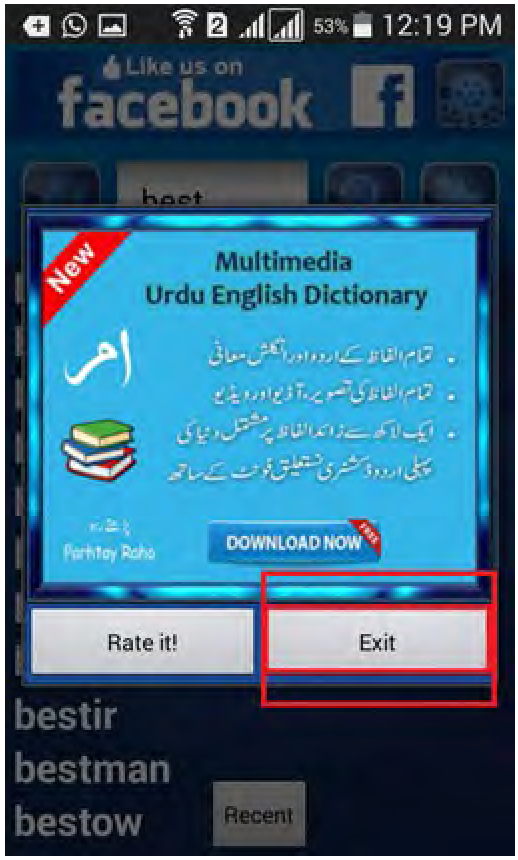

FIGURE 8. **Aesthetic and minimalistic design.**

c: BENEFITS

Minimum and aesthetically pleasant interface leads to better performance and increase comfort level.

d: PROBLEMS

Different evaluators may have different interpretations due to the subjective nature of this heuristic.

7) P7. FLEXIBILITY AND EFFICIENCY OF USE

System should provide shortcuts and configuration options for naïve and expert users to speed up interaction.

a: EXPLANATION

Experienced users may prefer to configure gestures as per their own requirements (e.g., double tapping on a particular area for direct zoom-in a specific part of the map). Similarly, short keys are available for different operations to speed up interaction. Users can also customize various operations according to requirements. System also provide shortcut to mute all calls, stop vibration of incoming calls, alarms and timers, when the device is flipped.

b: EXAMPLE

Figure 9 shows that enabling the Wi-Fi by just flip the screen from the top and select the Wi-Fi icon. In the second way,

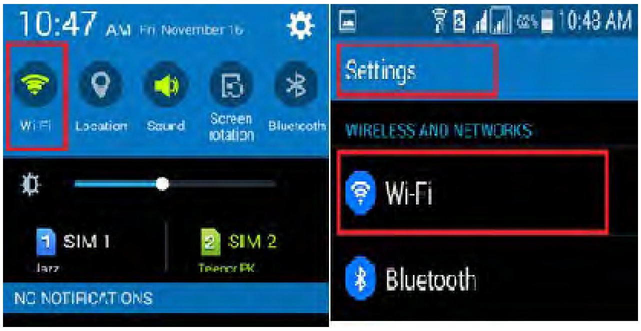

FIGURE 9. Flexibility and efficiency of use.

Wi-Fi is turned on with some additional steps including "open the setting menu and then turning on Wi-Fi.

c: BENEFITS

Users can accomplish the task efficiently and establish a sense of ownership.

d: PROBLEMS

Each user has its own requirements and wants to customize accordingly. So, it is a difficult task for designers to accommodate all such users with full capacity.

8) P8. HANDLING VARIED CONTEXT OF USE IN MOBILE ENVIRONMENTS

Smartphone application should provide a simple and effective way to interact in different context of use, by providing a suitable interface highly acceptable for users.

a: EXPLANATION

Possible constraints are: auditory due to noise, visually due to bad light, shaking hands due to motion, or less focused due to social interaction. An effective interaction in these contexts of use facilitates the user to provide large controls, multi-modal input/output and subtle animation to accomplish task. System should also provide a usable setting of important functions of mobile application especially. It is observed that sometimes, due to movement, text is not readable on UI. It may be due to the use of improper color scheme and/or brightness restricts clear visibility, etc.

System should support by putting a dot on some event/part of an application to improve the readability.

b: EXAMPLE

By default, audio sound settings of ring tone is not audible in motion, due to noisy environment. Ring tone should be audible and further support with vibration can enhance UX as shown in Figure 10.

c: BENEFITS

Users perform the task efficiently in varied context of use.

FIGURE 10. Handling varied context of use in mobile environment.

d: PROBLEMS

Evaluators may get confuse this heuristic with "match between system and the real world".

9) FINGERTIP SIZE CONTROLS AND ERGONOMICS

Smartphone should provide layout of the UI controls with enough margins, located at some recognizable places and fit to use.

a: EXPLANATION

While in motion, user mistakenly presses icon/button because of congestion which may lead to another unwanted situation. The system should provide enough margins to get fingertip size control. Holding smartphone with one hand and using the same hand thumb to interact with control elements will provide more ease to the user.

b: EXAMPLE

"Save" and "Add" controls for events are very far from the single hand. So it requires second hand to save the event as shown in Figure 11, which is less ergonomically usable.

c: BENEFITS

User's performance increases, when buttons are placed at some recognizable places and definitely easy to use.

FIGURE 11. Fingertip size controls and ergonomics.

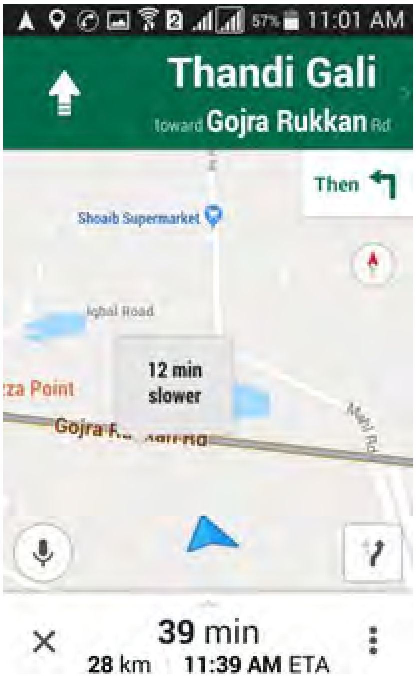

FIGURE 12. Effective design to lessen user's workload.

d: PROBLEMS

One problem when executing this heuristic in the case of users with special needs. Evaluators should analyze each such case separately.

10) P10. EFFECTIVE DESIGN TO LESSEN THE USER'S WORKLOAD

System should provide contextual information wherever necessary to the concerned application to provide usable interface to the user.

a: EXPLANATION

As the user's objective is difficult to determine directly so context cues are used, to help infer this information and to inform an application for how best to support the user. System should also follow gestalt continuation law to engage the user by providing continuity from one object to another from UI. While in motion, it is observed that users engage in multiple activities simultaneously and perform context switching according to the need. This requires more cognitive load to perform the task. Gestalt continuation law provides support to design interface, where one object link up to next object and so on. It supports the user to read properly and help to accomplish the task.

For example, send message task has several steps like: open the app, write up the text, and enter/find the contact (receiver) and press the "send" button. In mobility, if these steps link up with each other, users can comfortably accomplish the task.

b: EXAMPLE

The map application in Figure 12 supports users in traveling from one location to other by providing contextual information about the traffic condition, current place and routing information to lessen the workload.

c: BENEFITS

User gets support in task accomplishment and better understanding of the system.

d: PROBLEMS

Evaluators may get confuse in exercising this heuristic with match between system and the real world.

11) P11. RECOGNITION RATHER THAN RECALL

The smartphone should offer visible actions, options and objects in order to avert operators to remember information from one part of the dialog to another.

a: EXPLANATION

System should provide recognizable multi-touch gestures while interacting with mobile application. Users while using double tap, slide, flick, two finger rotation, pinch in/out and many others, feel that these gestures will help to accomplish task in an effective manner. Make it sure to eliminate gesture ambiguity for significant gestures to be more usable according to touch targets, size and placement. Similarly, due to limited short term memory of users, system should also provide support in other parts.

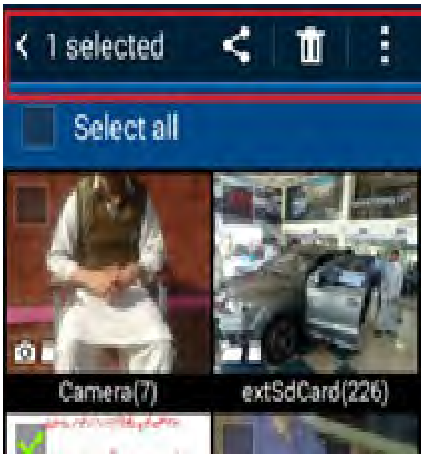

FIGURE 13. Recognition rather than recall.

b: EXAMPLE

Delete icon (bin) is visible and recognizable for users as shown in Figure 13.

c: BENEFITS

Reduce mental effort and fewer chances for error.

d: PROBLEMS

Evaluators may get confuse in exercising this heuristic with'' effective design to lessen the user's workload''.

12) P12. USER CONTROL AND OBVIOUSNESS

System should facilitate users to protect information by providing undo/redo options and provide clearly an ''emergency exits'' to leave unwanted positions. These options should be available preferably through a physical button or equivalent.

a: EXPLANATION

System should ensure user's control and obviousness especially in modification/deletion of any important information. Users can easily manage the application and resource consumption conveniently. System should support users to navigate comfortably across the application.

b: EXAMPLE

Placing a pattern or fingerprint identification makes it possible that no unauthorized person can access any personal information as shown in Figure 14.

c: BENEFITS

Users feeling of ownership can enhance UX and they can perform the task efficiently.

d: PROBLEMS

This heuristic provides an insight to repair an error and provides control to users to let it work with their own needs. So, this heuristic may not overlap with ''flexibility and efficiency of use''.

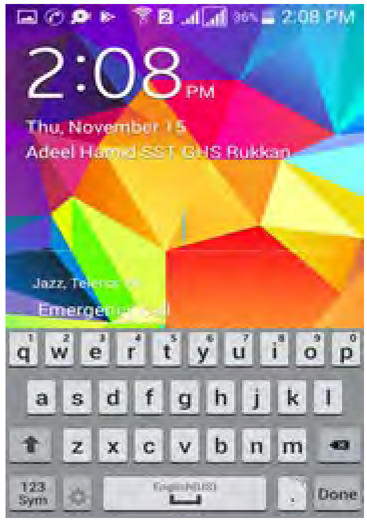

FIGURE 14. User control and obviousness.

13) P13. CONSISTENCY AND STANDARDS

The smartphone should follow the well-known conventions, allowing the user to do things in a familiar, standard and consistent way.

a: EXPLANATION

Every application contains similar functions. These similar functions put together with same layout design. This is the reason; users feel comfort and efficiently perform the task. Same options can deploy at different UIs of mobile application. These should also have same designed mechanics to provide easy to use interaction. These conventions and standards should also shadow in different devices of same manufacturers.

b: EXAMPLE

For example, Gallery mobile application contains pictures, where we can edit/modify/insert/delete any image as shown in Figure 15.

c: BENEFITS

Consistent options help users to get familiarity, easy to learn and memorization. This will certainly increase task efficiency, minimize errors and increase user satisfaction.

d: PROBLEMS

Evaluators may get confuse in exercising this heuristic with ''match between system and the real world.

14) P14. AVOID MISLEADING RELATIONS

The system should provide outcome, as it is intended to design. Avoid input-output mismatching especially, in image based sorting/searching.

a: EXPLANATION

It is human psychology that when users perform the task, they expect some response. There is always a relationship between

FIGURE 15. Consistency and standards.

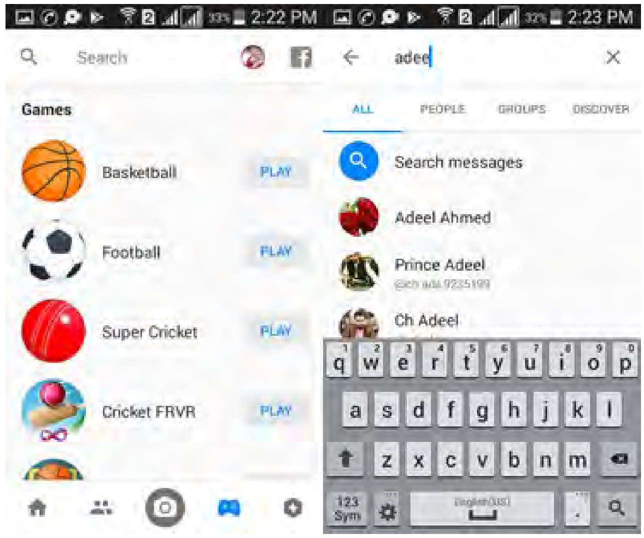

FIGURE 16. Avoid misleading relations (a) Avoid misleading relations (b).

an action and reaction. This action in mobile paradigm is similar to initiating a specific task. This specific task may include searching/sorting images/ items, editing the image/information, event creation among others.

Designers of mobile application development provide an appropriate outcome, in response to specific initiation. While designing such outcomes, users' expectations should be considered to provide a refined and useful interface. When a designer develops a search option to let it search images of different types such as birthday images, wedding images and others. Then, the user upon searching should find outcome as it is intended to design. Users should feel comfort while getting UI. Design support efficiently the extraction mechanism, so users shouldn't wonder whether a particular concept means the same thing in different situations. Similarly, when users sort items using "filter by" option in any specific mobile application and ask the system to display related items. Generated output should match with the input.

b: EXAMPLE

When a user presses the game icon as shown in Figure 16 (a), it shows the games to play. But when the user searches a particular game to play, interface shows the contact list instead of games list as shown in Figure 16 (b).

c: BENEFITS

Users will feel comfort while accessing information and reduce errors. Efficiency of task accomplishment will increase and reduce mental effort. Users will not be frustrated and intended to use further.

d: PROBLEMS

Avoid misleading relations heuristic shouldn't confuse with consistency and standards.

D. STEP 5. VALIDATION USING EVALUATION STUDY

We conducted an evaluation study to find the practicability of our EUHSA for smartphone and application. We selected the sets of heuristics developed by Joyce and Lilley [12] and Inostroza *et al.* [13] for comparison. These two sets of heuristics were also known as "Joyce" and "SMASH" respectively. The core purpose of this evaluation study was to investigate how many usability issues can be found while applying these sets of heuristics. We assumed that the evaluators would be able to identify more usability flaws using EUHSA compared to the heuristics previously developed by Joyce and SMASH.

1) EXPERIMENTAL DESIGN

Experimental study contains various design parameters explained below:

a: PARTICIPANTS AND MATERIALS

We executed the heuristic evaluation study with twenty-four usability experts. Twelve were designing UIs in software houses for more than two years of experience. Previously they had also experienced of designing and developing mobile applications. Seven experts were working as soft- ware engineer and designer of mobile applications with three years of working experience. These experts have good knowledge about HCI. Five experts have no experience but, they were executing their postgraduate research work in UE of mobile applications. Academically, fifteen of these usability experts were registered students of postgraduate research study in the domain of HCI and software engineering. Other nine were students of "HCI" undergraduate course at the Department of Computer Science and Information Technology, Virtual University of Pakistan. We assume, these participants as usability experts have good knowledge about heuristic evaluation, smartphone applications and HCI. We decided to choose easily available, easy to use and more popular smartphone applications for evaluation. We selected four mobile application including Gallery, Geo, Calendar and Contacts. There were six experimental devices selected for experimentation, whose related description is shown in the Table 3.

TABLE 3. Experimental devices description.

Device manufacturer	Device model	Operating System (O.S) and Version
Apple	Iphone 6	iOS 8.0 16/128GB
	Iphone 6s	iOS 9.0
Samsung	Galaxy S6	Android "Lollipop" with TouchWiz 5.0
	Galaxy S5	Android 2.3.6 "Gingerbread" with TouchWiz UI 3.0/4.0
Huawei	Huawei Y5	Android 6.0 Marshmallow
	Huawei Y6	Android 8.0 (Oreo); EMUI 8

We arranged the following material for the usability experts including consent form, post evaluation questionnaire for inquiry test, "EUHSA", "Joyce" and "SMASH" sets of heuristics and Nielsen's severity ranking [57].

b: EXPERIMENTAL CONDITIONS

Two experimental conditions were related with evaluation study.

Condition 1: 12 experts performed heuristic evaluation through EUHSA and Joyce sets of heuristics, while using Nielsen's severity rating scale to "Calendar" and "Contacts" mobile applications.

Condition 2: 12 experts performed heuristic evaluation through EUHSA and SMASH sets of heuristics, while using Nielsen's severity rating scale to "Gallery" and "Geo" mobile applications.

c: PROCEDURE

Each evaluator was assigned one of the two experimental conditions by following the procedure.

We formed four groups of evaluators in each experimental condition and assigned work in a systematic way to lessen the learnability impact and biasness.

Total number of evaluators divided into two equal groups A and B. Group A was further divided equally to A1, A2, A3 and A4. Whereas B was equally divided into B1, B2, B3 and B4. Each group contains 3 experts. This further distribution was on equal basis. There were two iterations in each experimental condition. Six experimental devices were assigned to 6 experts in first iteration, whereas, in second iteration, each expert wasn't assigned the same experimental device. Pseudo code of this procedure for evaluators belonging to group "A" is illustrated below:

First Iteration:

Assign, A1+A2 = EUHSA set of heuristics && A3+A4 = Joyce set of heuristics

Assign, A1 and A3 = Calendar application &&, A2 and A4 = Contacts application

Second Iteration

Assign, A1+A2 = Joyce set of heuristics && A3+A4 = EUHSA set of heuristics

Assign, A1 and A3 = Contacts application && A2 and A4 = Calendar application

Submit experimental results

Similarly, for evaluators of group "B", we have the following procedure of group formation.

Assign, B1+B2 = EUHSA set of heuristics && B3+B4 = SMASH set of heuristics

Assign, B1 and B3 = Geo && B2 and B4 = Gallery

Second Iteration

Assign, B1+B2 = SMASH set of heuristics && B3+B4 = EUHSA set of heuristics

d: PRE-EVALUATION SESSION

Experts were welcomed in the evaluation study and explained the purpose and testing procedure. Tasks were defined of the four mobile applications highlighted above in user study section, also instructed to explore the mobile applications. We trained the evaluators to fully understand the EUHSA, Joyce and SMASH sets of usability heuristics. Multiple instructors were connected with evaluators for this task. Evaluator's queries were replied using MDB and Team Viewer.

e: EVALUATION SESSION

UE is an example of observational research [50]. We conducted an evaluation study to find the practicability of our EUHSA for smartphone application. Experts in each experimental condition executed the UE according to the above highlighted procedure, identified the usability issues and assigned the respective severity ranks. During evaluation, each expert was requested to "think aloud". Experts raised question during evaluation was answered properly.

2) DATA ANALYSIS

This section highlighted the qualitative and quantitative analysis of collected data. This analysis comprised the comparison of heuristic evaluation of EUHSA, Joyce and SMASH sets of heuristics in their respective experimental conditions.

a: NUMBER OF USABILITY FLAWS COMPARISON

From Table 4 and Table 5, it indicates that the EUHSA identified more user related issues in the heuristic evaluation of four mobile applications. By comparing the EUHSA and SMASH heuristics in Table 4, we found that 18 issues were common in exercising "Gallery" application and 12 issues were common in "Geo" application. There were 11 and 4 flaws identified by additional EUHSA heuristics in "Gallery" and "Geo" applications respectively. Similarly, there were 5 and 3 unique flaws identified by SMASH using "Gallery" and "Geo" applications respectively.

Similarly, by comparing the EUHSA and Joyce heuristics in Table 5, we found that 13 issues were common in exercising "Calendar" application and 14 issues were common in "Contact" application. There were 6 and 4 flaws identified by

TABLE 4. Number of identified usability issues (EUHSA vs. SMASH).

	Gallery	Geo	Total
EUHSA	29	16	45
SMASH	23	15	38

TABLE 5. Number of identified usability issues (EUHSA vs. Joyce).

	Calendar	Contacts	Total
EUHSA	19	18	37
JOYCE	14	15	29

TABLE 6. Usability flaws, mean value and severity of EUSHA and SMASH.

	EUHSA			SMASH		
	Gallery	Geo	Mean %	Gallery	Geo	Mean %
cosmetics	6	2	4	4	3	3.5
minor	11	7	9	9	7	8
major	12	7	9.5	10	5	7.5
Catastrophe	0	0	0	0	0	0
Total flaws	29	16	22.5	23	15	19

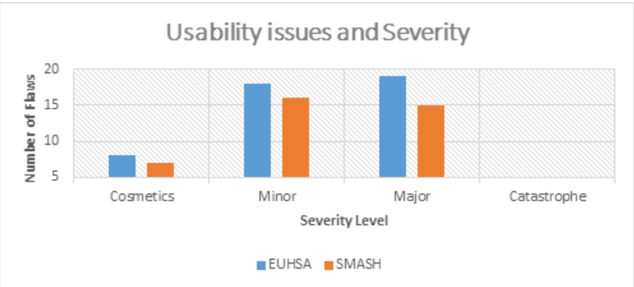

FIGURE 17. Usability flaws, severity and distribution.

TABLE 7. Usability flaws, mean value and severity of EUSHA and Joyce.

	EUHSA			Joyce		
	Contacts	Calendar	Mean%	Contacts	Calendar	Mean %
cosmetics	1	2	1.5	3	2	2.5
minor	10	8	9	6	5	5.5
major	7	9	8	6	7	6.5
Catastrophe	0	0	0	0	0	
Total Flaws	18	19	18.5	15	14	14.5

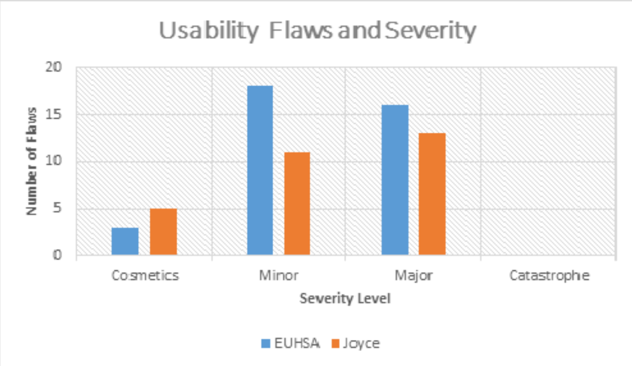

FIGURE 18. Number of flaws, severity and distribution.

additional EUHSA heuristics in "Calendar" and "Contact" applications respectively. Similarly, there was 1 unique flaw identified by Joyce in each application.

Although, each expert put effort and captured violations in good number. But, there were similar flaws using the specific set of heuristics with specific mobile application. We eliminated the duplication within a single set of heuristics and formed a unique set of usability flaws presented in Table 4 and 5. According to experts' opinion, these four mobile applications are renowned, practiced and evolved for many years, that's why; we can say that these applications have comparatively less number of usability issues.

b: SEVERITY OF USABILITY PROBLEMS AND DISTRIBUTION

As shown in figure 17 and Table 6, the percentage mean value for both applications including Geo and Gallery, the EUHSA and SMASH set of heuristics produced equally distributed severity value of identified issues. On the other hand, when we compared the values in Table 7 and figure 18, the Joyce set of heuristics produced more equally distributed mean value as compared to the EUHSA heuristics. In both applications calendar and contacts, EUHSA heuristics produced above 90% identification in minor and major level. There were some common findings in both experimental conditions. No catastrophe issue was detected. Major identified issues fall in minor and major levels. Each set of heuristics identified fewer cosmetic issues in calendar and contacts applications.

In order to see the contribution of each heuristic, there requires further analysis. This is illustrated in Figure 19 and 20. Analysis concludes of how a specific heuristic from the EUHSA and SMASH sets are fare enough to detect usability issues at different severity levels. It is clear from the Figure 19 that the EUHSA are more appropriate in detecting flaws than the SMASH heuristics. It is observed that some relevant heuristics from both sets contributed same. These heuristics are *visibility of the system status*, *match between system and the real world*, *realistic error management*, *efficiency of use and performance*, and *user control and obviousness*. When we inquired from experts, they replied that these heuristics' definition and explanation were same in both sets. This is the reason that experts' findings were similar.

There were few heuristics from SMASH, whose findings were different from the relevant heuristics of EUHSA set. Heuristic number 7 "aesthetic and minimalistic design" contributed more than the corresponding same heuristic of EUHSA set. Similarly, heuristic number 8, 9 and 10 of SMASH are "customization and shortcut", "physical interaction and ergonomics" and "minimize the user's memory load" respectively, contributed slightly more than the corresponding EUHSA heuristics.

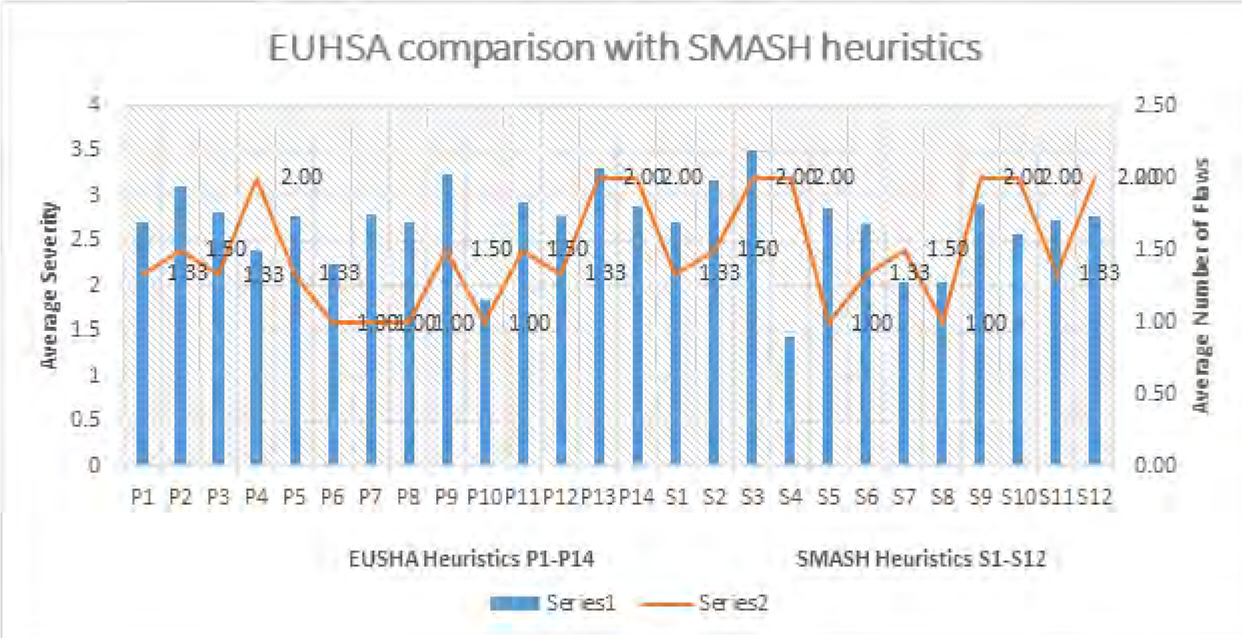

FIGURE 19. Contribution of each heuristic in EUSHA and SMASH sets:Flaws and severity.

TABLE 8. Average severity, Standard Deviation and Average Flaws (EUHSA vs. SMASH).

	EUHSA	SMASH
Average Severity	2.74	2.62
Standard Deviation (Severity)	0.41	0.55
Average number of Flaws	1.42	1.58

When we analyzed and compared the definition of these related heuristics. We found that corresponding heuristics are conceptually same. No semantic difference was found in any of the EUHSA heuristics. Upon inquiring from experts and detailed analysis, it was found that SMASH heuristics were easy to understand, short but comprehended definitions. It was easy for experts to recall suitable heuristic definition immediately after the identification of flaw. Secondly, these heuristics were defined in a way that experts didn't face the problem of heuristic overlapping.

Some EUHSA heuristics contributed more as there was no competitor heuristics in the SMASH heuristics. These heuristics were "avoid misleading relations" and "handling varied context of use in mobile environments". Although, heuristic number 2 of SMASH slightly overlap with handling varied context of use in mobile environments" and instructs to adapt the UI according to situation. But, it wasn't explicitly describing various context of use and the way to deal with.

Table 8 highlights the overall position of EUHSA and SMASH set of heuristics. Average number of flaws produced by EUHSA heuristics is less than SMASH value. Although, actual number of flaws captured by EUHSA is greater than SMASH set of heuristics; however, average severity of EUHSA is higher than SMASH and reduced value of standard deviation also depicts good results for EUHSA heuristics.

It is clear from Figure 20, that the EUHSA heuristics are more appropriate in detecting flaws and respective severity ratings than the Joyce heuristics. It was observed the very close contribution in terms of flaws identification and aver- age severity ratings of some relevant heuristics in both sets. These heuristics are "realistic error management (J3), user control and obviousness (J8), flexibility and efficiency of use (J9), handling varied context of use in mobile environments (J10) and fingertip size controls and ergonomics (J11)".

There were few heuristics from Joyce set, whose findings are higher than the EUHSA set of heuristic. These heuristics were J7 and J12. Heuristic number 7 of Joyce set identified three flaws in which two flaws were about to memorize the interface elements rather than providing an intuitive display and this hinders easy to learn. In third problem, next steps of task accomplishment were not obvious. This part was missing in our EUHSA heuristic. J12 also identified major flaws which couldn't capture by the relevant EUHSA heuristic. When we compared the definition of both heuristics, it was found that Joyce's heuristic was easy to understand. Example and explanation was also comprehensive and easily applicable as compared to the relevant EUHSA heuristic. We defined the EUHSA heuristic again in a simple and easy way. This is also concluded from qualitative data from expert's opinion.

One EUHSA heuristic contributed more as there was no competitor heuristic in the Joyce set. This was "avoid misleading relations (P14)". Some EUSHA heuristics contributed high than their related Joyce heuristics. These were

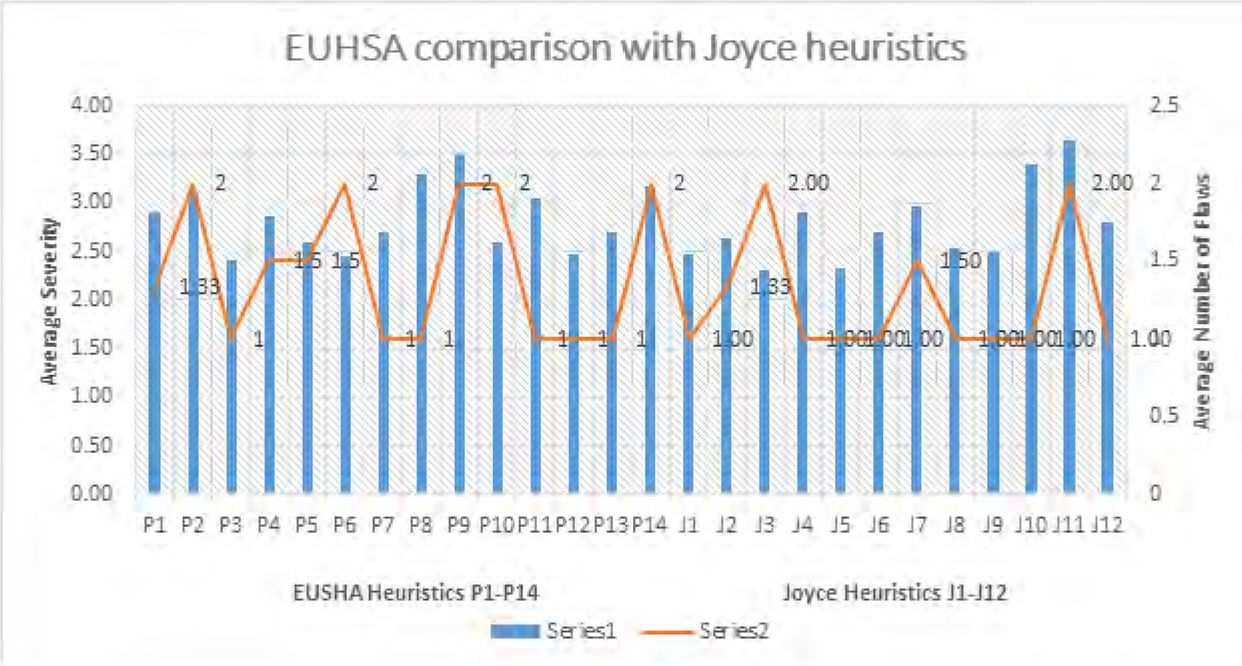

FIGURE 20. Contribution of each heuristic in EUSHA and Joyce sets:Flaws and severity.

TABLE 9. Average Severity, Standard Deviation and Average Flaws (EUHSA vs. Joyce).

	EUHSA	Joyce
Average Severity	2.84	2.76
Standard Deviation (Severity)	0.32	0.41
Average number of Flaws	1.45	1.24

visibility of the system status (P1), match between system and the real world (P2), help and documentation (P4). These heuristics were comparatively well explained and some additional minor concept.

Table 9 depicts overall position of both sets of heuristics. It is clear that EUHSA heuristics results better than Joyce in terms of average number of flaws, average severity and severity standard deviation.

c: Most and Least frequently used Heuristics and usability Flaws among all sets

There were three most frequently used heuristics including ''Visibility of the system status'', ''Efficiency of use and performance ''and ''User control and obviousness'' among all sets.

In first heuristic, visibility of the system status, most frequently occurred usability flaw was'' end users weren't properly given feedback about state changes during or after task completion''. Whereas, in ''Efficiency of use and performance'' most frequently occurred flaws were about ''end user passes through some additional steps for task completion''. In third heuristic ''User control and obviousness'', most frequently occurred flaws were about that'' application didn't provide proper user control to end user for effective task completion''.

Designers of mobile applications need to be focused in these perspectives to ensure quality interfaces. Least frequently used heuristic among all sets of heuristics was ''Flexibility and Efficiency of use''.

d: TOP SCORER EUHSA HEURISTIC

There was high contribution of newly EUHSA heuristic ''avoid misleading relations'' in identifying usability flaws at individual level. This heuristic was missing in Joyce and SMASH sets and not considered earlier.

E. STEP 6: REFINEMENT STAGE

Participants were asked to actively involved in an inquiry test and give valuable feedback about four dimensions: utility (D1), clarity (D2), easy to use (D3) and necessity of further evaluation checklist (D4). Total 24 Experts were there in the inquiry test. A five-point Likert-scale was used to grade each heuristic, ranging from Strongly Agree (5) to Strongly Disagree (1). ANOVA method was applied to analyze the grading values and the way to understand the variation among the opinions of the 24 experts. The p-value in Table 10, indicates that there are no substantial variances amongst evaluators' perception on the set of EUHSA in all four dimensions (D1, D2, D3 and D4).

An Average perception of evaluators in all four dimensions (D1, D2, D3 and D4) is highlighted in Table 11. It indicates that users' perception is somewhat agreed that EUHSA are easy to use, efficient, easy to learn and understand.

TABLE 10. Study of variances in D1, D2,D3 and D4 (significance level $\alpha = 0.05$).

Dimension	p-value
D1	0.110225
D2	0.02067701
D3	0.01080506
D4	0.02846857

TABLE 11. Average perception values for EUSHA heuristics.

Heuristic	D1	D2	D3	D4
P1	4.05	4.15	3.90	3.95
P2	4.21	4.20	4.00	3.98
P3	4.10	4.00	4.07	4.05
P4	4.03	4.20	3.90	4.20
P5	4.10	4.05	4.05	4.00
P6	4.13	4.10	4.21	4.10
P7	4.21	4.32	4.30	4.20
P8	4.30	4.20	4.10	3.95
P9	3.90	3.78	3.75	4.20
P10	3.95	4.10	4.00	4.30
P11	4.02	4.15	4.05	4.02
P12	4.25	4.10	4.10	3.95
P13	4.15	4.30	4.18	4.20
Average	4.10	4.12	4.04	4.08

TABLE 12. Correlation coefficients between average perception scores.

	D1	D2	D3	D4
D1	1	0.816921	0.785391	0.8142
D2	0.816921	1	0.78944	0.45324
D3	0.785391	0.78944	1	-0.48145
D4	0.8142	0.45324	-0.48145	1

This value also indicates that there is a need for additional evaluation elements to identify more usability related flaws in the said context.

The correlation coefficients between averages (see Table 12) show that there is a significant and positive correlation between D2 and D3 with score value 0.78. It indicates when a heuristic is perceived as clear, then, it is also perceived as easy to use.

There is a definite and significant correlation between D3 and D1 with the value 0.785391. It indicates that when a heuristic is perceived as easy to use then, the heuristic is useful and vice versa.

There is a negative correlation between D3 and D4 with the negative value, which indicates when users perceive difficult to use any heuristic, then, there is a need of additional checklist.

Upon experts' feedback about each heuristic utility and usefulness, we observed that some heuristics should be reviewed to further refine the set of EUHSA heuristics. We incorporated the feedback in our EUHSA set presented in in section 3 at ''Explicative Stage''.

IV. CONCLUSION AND FUTURE WORK

Any popular and well-earned mobile application such as What Sapp, Facebook, Amazon and others must have good usability. Research community always engage to develop tools for capturing usability issues in current mobile applications by developing relevant sets of usability heuristics. In the literature, each methodology used for the development of suitable set of heuristics divided in two major parts i.e. Propose the heuristics and its validation. Usability issues identified during user testing can provide a baseline to understand the type and nature of issues. This identification further refined and transformed into reliable set of heuristics. Previous studies including [12, 13, 19], and others rely on past data and proposed their respective sets of heuristics and validated accordingly. The uniqueness of this study is the identification of user related issues with the help of 800 participants in a user study. We analyzed these issues and mapped with the heuristics sets of existing literature. In a way, we proposed a reliable set of 14 usability heuristics (EUHSA) for smartphone and application.

In the literature, there exist different ways to propose heuristics, but, still lacking to formalize the validation mechanism. Experimentation is the popular validation strategy. This mechanism focuses to compare the identified usability issues and respective severity levels. In this study, we also followed the same procedure to validate the EUHSA and further refined using an inquiry test. We found that the EUHSA are fairly developed and an effective apparatus to measure the usability of smartphone applications. Although, we validated the set of heuristics against SMASH and Joyce sets of heuristics and found appropriate, however, further validation at large scale may perform.

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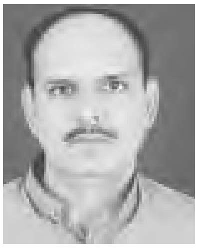

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