The Effect of Tactile Feedback on Mental Workload During the Interaction with a Smartphone

Peter Rasche[1(✉)], Alexander Mertens[1], Christopher Schlick[1], and Pilsung Choe[2]

[1] Chair and Institute of Industrial Engineering and Ergonomics of RWTH Aachen, Aachen 52062, Germany
p.rasche@iaw.rwth-aachen.de

[2] Department of Mechanical and Industrial Engineering, Qatar University, Doha, Qatar
pchoe@qu.edu.qa

Abstract. This empirical study examines the adequacy of tactile feedback to present status information about the progress of Internet-based services on mobile devices and possibilities to compensate age-related changes in users performance. Therefore the user experience of mobile browsing was compared using three different vibration signals and two different levels of process times. In this experiment the participants had to perform two tasks simultaneously. The participants experienced six different (combinations treatments) permutations in treatment with regard to 'vibration type' and 'process time.' The user experience was measured by the Technology Acceptance Model and the subjective mental workload by the NASA Task Load Index using a questionnaire. The experiment revealed that a short vibration signal at the end of a process is capable of increase the user experience. Therefore, 'perceived enjoyment' as well as 'perceived usefulness' improved. However, the characteristic factor 'mental workload' decreased with usage of tactile feedback.

Keywords: Design for social development · Demographic change · Aging-appropriate design

1 Introduction

The mobile use of Internet and web application and services often leads to problems regarding interference. Raskin [1] defines interference in the context of human-computer-interaction as a trade off a user has to conduct in order to perform more than one simultaneous task, which cannot be automated (such as navigating to a desired destiny). In such situation the user has to divide his attention to cope with the tasks. Usually users' performance decreases in such situations. This problem is specially critical in the context of using mobile devices in complex situations of daily life. An example of a complex situation is a pedestrian, who uses a mobile device during the crossover of a multi-lane road. An increased risk of accidents is verified as a result of the operation of a mobile device [2]. Furthermore, the individual risk increases, if the

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user's age is considered due to age-related changes of the perception, cognition and motor skills [2]. Considering the demo graphic change, the problem of interference during operation of mobile devices is a critical problem. Internet-based services will have a growing importance for social participation, enhancing the quality of life and medical care for the aging society today and in the future. More than 50 % of the over 50-year-old women and men in Germany are already connected to the Internet by mobile devices and their barrier-free and secure access to Internet-based services. Even in complex situations of daily life, it is an extremely effective tool for a self-determined and fulfilled life [3, 4].

The problem described above can be addressed by providing features that enable users of mobile devices to focus the attention on the primary task (e.g. crossing a street) during non-productive portions of the secondary activity (e.g. loading new information during the use of Internet-based services). A state of the art solution for this problem is a loading-bar as known from stationary computers. Information about the progress of a process is passed on visually to the user. Using such an interface on a small screen increases the problem of interference and thereby exposes the user to unnecessary high stress and risk of accidents [5]. Therefore this empirical study examines, based on Brewster and King [6], whether a tactile feedback is appropriate to present the status information about the progress of data download on mobile devices and thereby could compensate age-related changes in user performance. Using an appropriate tactile feedback, the user should be able to focus on the primary task during phases in which no user interaction within the secondary task is necessary, although the user has continuous information about the status of the secondary task [1]. The term vibration-loading interface is defined in the context of this experiment as an interface presenting a visual progress bar, which is enhanced by a vibration signal.

2 Research Model

User experience is a common approach to determine whether software meets users' needs. One common and robust attempt to determine user experience is to evaluate the user's attitude toward usage of the examined technology, which is measured by the Technology Acceptance Model (TAM) [7]. It describes the influence of the technological innovation factors of 'perceived usefulness' and 'perceived ease of use' on the user's behavioral intention to use this innovation. During the last decade, this model has been modified several times to meet the constantly evolving challenges of new technologies and users' needs. It was extended by several factors, such as 'perceived enjoyment' [8] or redesigned to meet the upcoming challenges of the smartphone industry [9, 10]. As shown by all of these researches TAM is a powerful tool, which is why it will be used as basis for the research model in this experiment [11, 12]. Based on the research assumptions the dependent variables 'perceived enjoyment', 'perceived usefulness' and 'mental workload' have influence on the usage of a vibration-loading interface. The first two variables are accepted in the context of user experience and the TAM model [13–15]. The dependent variable 'perceived enjoyment' measures the users' enjoyment of the entire situation during each treatment. Therefore, it should be possible to determine a vibration-loading interface that is accepted by users in multitasking situations. The dependent variable ‘perceived usefulness’ should support this by measuring whether the users think the experienced vibration-loading interface is useful during the performance of the multitasking situation. At least, the dependent variable ‘mental workload’ should validate the measurements of the first two variables, because an enjoyable and useful vibration-loading interface is expected to decrease users’ mental workload during the experiment. This variable will be evaluated by the NASA Task Load Index will measure the subjective ‘mental workload’. The NASA TLX tool, developed by NASA in 1988, divides mental workload into six different factors. These factors are ‘mental demand,’ ‘physical demand,’ ‘time pressure,’ ‘expended effort,’ ‘achieved performance level’ and ‘experienced frustration’ [16].

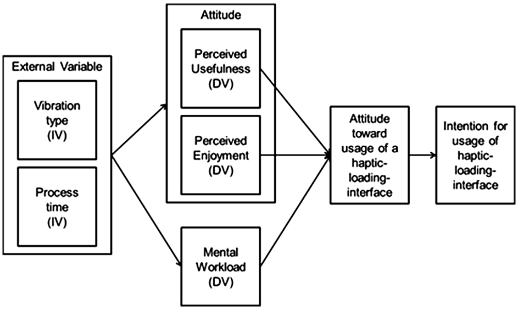

Fig. 1. Research model

To measure the influence of vibration feedback on the user experience, two independent variables were defined (see Fig. 1). The first is called ‘process time’ and the second is called ‘vibration type’ according to the research model. Roto and Oulasvirta [5] found that vibration feedback is useful for interaction pauses lasting longer than 4 s. If the process time is shorter than this, users may feel annoyed by it. To avoid this problem, the minimal process time in this experiment was set to 5 s. Beneath the 5-second process time participants experienced, a second, longer process time. The duration of the second should be longer than 10 s, as this time frame is known in the context of the 10-second-response rule among certain experts [17]. According to this rule, users shift their attention toward other things and away from the performed computer task if a process lasts longer than 10 s. It is assumed that this rule is also valid for users in a mobile environment. This is indicated by an experiment performed by Oulasvirta et al. [18]. During their experiment, smartphone users shifted their attention up to eight times away from the smartphone and back during a process depending on their mobile environment. Furthermore, it was reported by their experiment indicated that the average time a user spends glancing at the display of a smartphone also differs according to the environment [5]. On the other hand, the process time should not be too long, otherwise users could be annoyed [19]. Therefore, the second level of the independent variable ‘process time’ was 12.5 s. The second independent variable ‘vibration type’ has three levels ‘continuous vibration’, ‘end vibration’ and ‘no vibration’. The first vibration type ‘continuous vibration’ is defined as a continuous vibration signal that will last as long as the process proceeds. ‘End vibration’ is defined as a short vibration signal with fixed frequency and a duration of 500 ms. The vibration signal occurs when the process is completed and the vibration-loading interface is closed. The frequency of the vibration signals was the default vibration signal provided by the smartphone Samsung GT-S5830. The last vibration type, ‘no vibration’ is a vibration-loading interface which provides no tactile feedback. This level is used as baseline and increases the possibilities of interpreting the results of this experiment. Based on the combination of the independent variables’ levels, the mobile application simulates six different treatments with individual vibration-loading interfaces, consisting of ‘vibration type’ and ‘process time’ (see Fig. 2). Hence, participants experienced each vibration type during a long- and a short-lasting process.

		Vibration Type		
		Continuous Vibration	**End Vibration**	**No Vibration**
Process Time	**Short**	Treatment 1	Treatment 3	Treatment 5
	Long	Treatment 2	Treatment 4	Treatment 6

Fig. 2. External variables and configuration matrix

3 Methods

Participants. This experiment was carried out at Tsinghua University in Beijing, China in 2013. 30 participants (24 male and six female) with a European cultural background took part in the experiment. All participants were smartphone users who were highly familiar with Internet functions of their smartphones.

Experimental Design. This experiment evaluated the user experience of participants during the simultaneous performance of two tasks [20, 21]. The primary task was to watch a short movie, presented on a laptop (Apple MacBook Pro mid2012 OSX 10.8.2). Watching the information video should animate the participants and draw their attention away from the smartphone. Each short movie had the same duration of 2:30 min. The second task participants performed was a search task on a provided smartphone. The mobile application necessary for the search task was developed in MIT Appinventor on a MacBook Pro (2012, OSX 10.8.2) and was installed on a Samsung GT-S5830 under Android 2.2 Froyo for the experiment. To minimize the necessary number of participants, each participant experienced all six different treatments and thereby six different vibration-loading interfaces. The order of the movies was the same for every participant. However, the order of treatments was randomized for each participant. That means, no participant watched the same movie during the same treatment, nor did they perform different treatments in the same order. This was necessary, since the experiment provided no training with the mobile application. Furthermore, a random order should serve to eliminate the influence of learning effects on the results of this experiment. To underscore this approach, the participants were not informed which combination of the independent variables each treatment had. The smartphone was held in the right hand.

Apparatus. The environment of this experiment was challenging in terms of minimizing the effects of environmental disturbance. The participants were provided with headphones to avoid the possibility of hearing the vibration signal or other environmental sounds. The whole laboratory setting is shown in Fig. 3. The used application provided six different vibration-loading interfaces. The implemented vibration-loading interface presented a visual process-progress bar, which was improved by a vibration signal depending on the independent variable ‘vibration type’. The interface stayed visible as long as the independent variable ‘process time’ corresponded to the treatment defined. Further, the application should require mental involvement of its users, which was achieved by asking the users to accomplish a search task. This task was based on a certain question the users were presented with in the application during the experiment. The answer of each question was presented after the user completed the right search path within the application. The search paths were designed according to a search path of an Internet search on a desktop computer. The search task simulates the use of different webpage links to achieve a certain page or information. Since this experiment focused on the user experience of vibration-loading interfaces, the user-based input was minimized to clicking certain buttons during the search task. Three screens within the application, which provided six different buttons from which to choose, were established to further increase mental effort. These screens are called search screens in the following Figure (see Fig. 3). All the presented buttons on these screens were related to the answer to the asked search question. The user selected one of these buttons depending on their opinion. To make it more realistic and to increase the mental demand, a time limit of five seconds per screen was implemented. By selecting the necessary buttons on the different screens, users created the needed search path. After pushing a button, the users experienced the treatments’ vibration-loading interface and were referred to the next screen. To ensure that each screen was viewed, participants had to confirm each screen by at least one button click. To simulate a realistic scenario of mobile browsing, a certain ‘trial and error’ possibility within the desired application was implemented, and users could make use of the common backward button of an Android phone to navigate. If the users had used the backward button, they would experience the vibration-loading interface to make the simulation of mobile browsing as realistic as possible. In this process, a search task with a high number of mistakes might influence the user’s opinion in an unintended way because of the disproportional experience of the certain interface. Therefore, users were led to an error screen after they experienced the vibration-loading interface if they chose the wrong button. The error-screen then asked users to start the entire treatment over. Further, the implementation of the error screen should prevent misuse of the backward function, since the number of possible search paths is limited within the application and thus mental involvement is substitutable by a high number of button clicks [22]. To avoid an accumulation of error screens, the search task was defined as easy as possible without neglecting mental involvement. The following figure shows a schematic illustration of the defined search paths within the application (see Fig. 3).

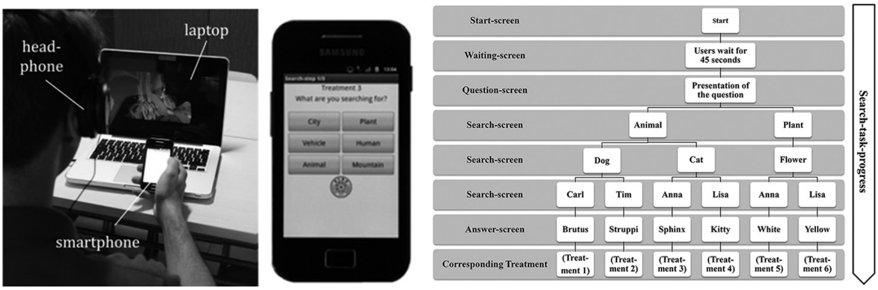

Fig. 3. Laboratory setting during the experiment (left), Search screen within the mobile application (middle) and schematic illustration of search paths implemented in the mobile application (right).

Questionnaire. The questionnaire consisted of eight pages and was divided into three main stages with 81 questions in total. The first stage asked participants three questions about their mobile Internet usage via a smartphone and demographic background data in terms of age, gender and handedness. The second stage posed questions designed to evaluate the two categories of user experience, which refer to the dependent variables of ‘perceived enjoyment’ and ‘perceived usefulness.’ Both variables were assessed by three similar questions based on the corresponding categories of the TAM model. The questions provided a 7-likert scale for the participants to rate their answers. Further questions were modified during a pre-test to make them more understandable to participants [23]. In addition to these questions, this stage also contained questions related to the NASA TLX to measure the subjective mental workload of each treatment. The third stage of the questionnaire provided space for further comments of the participants on the experiment or their experiences.

Procedure. Each experiment began with a participant choosing a random order for the six treatments of the experiment. An oral introduction to the experiment and the handling of the application was presented afterwards. This introduction, informed the participants that they had to write down the answer found for each search task in the questionnaire. The participants were also informed about the 5-second time limit of the application. After this introduction, participants began to see the movie and to use the application simultaneously. First, the application showed a waiting screen of 45 s to allow participants the chance to become involved with the presented movie. Following this, the application gave a short vibration signal (duration: 500 ms) to inform users that they could continue with the search task. The next step was to choose the random sorted treatment the application should perform. Afterward, the search question was presented, which participant had to confirm with a button click. The following three screens were the earlier-described search screens with six different buttons. If participant chose the right search path in the search screens, they were finally led to the answer screen. This screen displayed the answer to the search question. During a correctly performed search process the participants experienced the vibration-loading interface a total of five times. After completing the search task and watching the corresponding movie, participants completed the designated portion of the questionnaire. During this time, the application was rebooted to handle the next treatment, and the movie on the laptop was changed. In total, each participant watched six movies and performed six different search tasks, each time with a different combination of the independent variables.

4 Results

Descriptive Statistics. To provide an overview of the results of this experiment, Table 1 presents the descriptive statistics for the dependent variables evaluated. As the results show "end vibration" is for all dependent variables the best choice. The evaluation of the dependent variable "perceived enjoyment" reveals that "continuous vibration" is less enjoyable then "no vibration". But the participants evaluated "continuous vibration" as well as "no vibration" in both cases higher in terms of "perceived usefulness" than the baseline. The evaluation of the subjective mental workload shows that the usage of a continuous and no vibration signal leads to a high mental workload.

Table 1. Descriptive statistics of perceptions and 'mental workload'

Process time	Vibration type		Perceived enjoyment (points/7)	Perceived usefulness (points/7)	Mental workload (points/150)
short	continuous-vibration	Mean	4.98	5.10	47.93
		SD	1.677	1.359	13.901
	end-vibration	Mean	5.96	6.08	41.07
		SD	1.113	0.834	13.814
	no-vibration	Mean	5.12	2.43	51.20
		SD	1.723	1.617	21.157
long	continuous-vibration	Mean	5.06	5.08	50.87
		SD	1.452	1.453	14.012
	end-vibration	Mean	5.74	5.72	41.47
		SD	1.246	1.257	13.796
	no-vibration	Mean	5.32	2.13	49.60
		SD	1.615	1.432	18.713

N = 30 for each combination of process time and vibration-type.

t-Test and Repeated Measures ANOVAs. The internal consistency of the questionnaire used was investigated by the Cronbach's Alpha test (Cronbach, 1951).The calculated coefficients were all higher than 0.700 and ranged from 0.839 to 0.921 (0.921 for 'perceived enjoyment', 0.839 for 'perceived usefulness' and 0.858 for 'mental workload'). Therefore, the questionnaire was statistically significant for internal reliability and convergence validity.

t-Tests as well as repeated measurement ANOVAs were performed by SPSS to prove the hypotheses. The Mauchly's Test of Sphericity was performed to verify the necessary statistical assumptions. For all three dependent variables, this test was not significant ($p > 0.05$; $N = 30$), so a repeated measures ANOVA could be used for each variable. The repeated measures ANOVA was performed three times, independently for each dependent variable. In the first ANOVA, the influence of the independent variables on the dependent variable ‘perceived enjoyment’ was examined. The result showed that only the vibration-type significantly influenced the ‘perceived enjoyment’ (df = 2, F = 6,0908, p = 0.002). The variable ‘process time’ as well as the interaction of the variables ‘vibration type’ and ‘process time’ had no significant influence on the ‘perceived enjoyment’ according to the ANOVA performed (df = 1, F = 0,023, p = 0.880 for ‘process time’ and df = 2, F = 0,455, p = 0.637 for the interaction). The second variable examined by a repeated measurement ANOVA was ‘perceived usefulness.’ The results showed that only ‘vibration type’ significantly influenced this variable (df = 2, F =73,391, p < 0.001). The results for ‘process time’ showed no significance at α = 0.05 (df = 1, f = 3,175, p = 0.085). For the interaction of the independent variables no significant influence was discovered (df = 2, F = 1,009, p = 0.371). The third dependent variable, which was examined with a repeated measurement ANOVA, was ‘mental workload’. The results of this ANOVA showed that only ‘vibration type’ significantly influenced ‘mental workload’ (df = 2, f = 9,153, p < 0.001). The independent variable ‘process time’ (df = 1, F = 0,092, p = 0.764) and the interaction of these variables (df = 1, F = 1,019, p = 0.367) had no significant influence on ‘mental workload’ according to the results of this ANOVA.

After these ANOVAs, it was still unclear whether the significant influences of the independent variables represent a positive or a negative contribution to the user experience; therefore, different t-Tests were performed as the ANOVA revealed, ‘process time’ had no significant influence on ‘perceived enjoyment.’ The t-Tests showed no significant difference between the values of ‘perceived enjoyment’ for the two process times of each vibration type. Further results showed significant differences for ‘perceived enjoyment’ during the ‘short’ process time (df = 29, t = -3,442, p = 0.002) as well as the ‘long’ process time (df = 29, t = -2,468, p = 0.020). A comparison between the treatments with a ‘continuous vibration’ signal and a ‘no vibration’ signal showed no significant differences for both levels of ‘process time’ (df = 29, t = -0,398, p = 0.694 for the ‘short’ process time and df = 29, t = -0,760, p = 0.453 for the ‘long’ process time). Thus, only the ‘end vibration’ signal had a positive effect on ‘perceived enjoyment’. In all examined cases the usage of the ‘end vibration’ signal led to the highest value in terms of ‘perceived enjoyment’ (See Fig. 4). The examination of ‘perceived usefulness’ by t-Tests proved the results of the performed ANOVA in nearly every case.

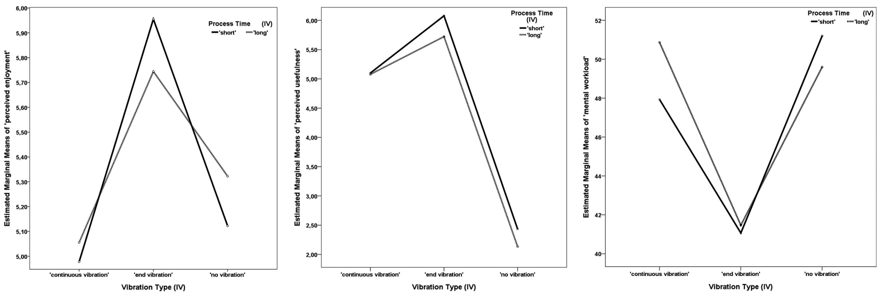

Fig. 4. Estimated Marginal Means of ‘perceived enjoyment’ (left), estimated marginal means of ‘perceived usefulness’ (middle) and estimated marginal means of ‘mental workload’ (right).

The t-Tests showed that the variation of the variable ‘process time’ had no significant influence on the measured ‘perceived usefulness’ of the vibration-loading interface employed. The value for ‘perceived usefulness’ differs by usage of the three different vibration signals, as the ANOVA had already implied. The results in Fig. 4 show that the ‘end vibration’ signal was evaluated to be the most useful vibration type, and that vibration has a positive overall effect on ‘perceived usefulness.’ What remains is the question whether the significant influences of the vibration-signals on ‘mental workload’ were positive or negative. The performed t-Tests showed that ‘mental workload’ during usage of the ‘end vibration’ signal differed significantly from the values measured during usage of the other vibration-types. The comparison between the ‘continuous vibration’ and the ‘end vibration’ signal showed significant differences ($df = 29$, $t = 2{,}807$, $p = 0.009$ for the ‘short’ process time and $df = 29$, $t = 3{,}962$, $p < 0.001$ for the ‘long’ process time). A further comparison between the ‘end vibration’ and the ‘no vibration’ signal also showed significant differences ($df = 29$, $t = -3{,}813$, $p = 0.001$ for the ‘short’ process time and $df = 29$, $t = -2{,}454$, $p = 0.020$ for the ‘long’ process time). In all of these cases usage of the ‘end vibration’ signal led to a higher mean value (see Fig. 4). Consequently, the ‘end vibration’ signal has a proven positive effect on ‘mental workload.’

5 Conclusions

As a result of this research, it is possible to extend the findings of Brewster and King [7] to the field of smartphones. It was proven that a vibration-loading interface is capable and useful in presenting the process progress on a smartphone. The ‘mental workload’ of the participants was significantly decreased. Accordingly such a vibration-loading interface is able to improve user experience.

According to the NASA TLX, the level of stress, smartphone users experience decreases. A lower level of stress results in a smaller number of attention switches between the smartphone and the mobile environment [5, 18]. In this experiment it was proven that a vibration-loading interface could decrease ‘mental workload’ and, from this, the number of attention switches also decreases. Although the experiment was staged in laboratory surroundings, the results should endure in real-life-environments as a comparison between laboratory and field testing by Kallio and Kaikkonen [24] revealed. The small number of attention switches further results in a lower distraction levels among smartphone users, which could result in higher safety of the smartphone users in a mobile environment, as Stavrinos et al. [25] implied.

The performed ANOVA detected a slightly significant influence of the process time on ‘perceived usefulness’ ($p = 0.085$), whereas the mean values for the long process time were higher than the values for the short process time. This implies that vibration feedback is useful in the context of long process times. Nevertheless, the performed t-Tests did not support the results of the ANOVA as the differences between the mean values of ‘perceived usefulness’ for each ‘vibration type’ were not significant ($p = 0.891$ for ‘continuous vibration’, $p = 0.106$ for ‘end vibration’ and $p = 0.144$ for ‘no vibration’). Therefore, it is correct to deny an influence of process time on all vibration types in terms of the examined process times. However, what this experiment proved in this context is that the annoyance factor of process times, which was described by Roto and Kaikkonen [19], could be superimposed by a more annoying factor. In this case the ‘continuous vibration’ signal. It was identified by the participants to be really annoying, especially in the case of the longer process time. This circumstance is supported by the mean values of ‘perceived usefulness’, which are nearly equal (5.10 for the ‘short’ process time and 5.08 for the ‘long’ process time). Furthermore, the experiment supported the assumption of Roto and Oulasvirta [18] that vibration feedback for processes lasting longer than 4 s would be appreciated by users.

The performed experiment proved further that vibration feedback during mobile browsing improves user experience on smartphones. Through the usage of a vibration-loading interface with a short vibration signal at the end of a process, it was possible to improve ‘perceived enjoyment’ and ‘perceived usefulness’ during a search task. In addition this vibration-loading interface supports users’ performance in dual tasking situations as the interface decreased the ‘mental workload’ of participants. Conclusively, it should be emphasized that a vibration-loading interface is able to increase the safety of smartphone users in a mobile environment, which was one of the motivations for this research.

6 Outlook

Future research should evaluate if the user experience of a vibration-loading interface is truly independent from process time. In this experiment, two exemplary times were used (5 s and 12.5 s). A further experiment with a higher number of different process times and even a sequence of different process times during a search task might lead to a different conclusion than the ANOVA for ‘perceived usefulness’ indicated in this experiment.

In this research two simple vibration signals were investigated. Even between these two signals, a significant difference in terms of experienced enjoyment was discovered. Further research should explore this effect to optimize the vibration signal and thereby the user experience of smartphone users.

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