The Influence of Personality Traits and Cognitive Load on the Use of Adaptive User Interfaces

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ABSTRACT
One of the problems adaptive interfaces must solve is the issue of stability—users must be able to complete a familiar task reliably. Split Adaptive Interfaces, where a limited part of the screen contains copies of the interface elements predicted to be of immediate use, are one technique for resolving this difficulty. While prior work demonstrated that Split Adaptive Interfaces improve performance on average, the results of our study demonstrate systematic individual differences in the utilization of the adaptive features, which correlate with the stable user traits of Need for Cognition and Extraversion. Specifically, higher Need for Cognition (a willingness to undertake difficult mental activities) is correlated with increased utilization rates, while higher Extraversion (a general orientation towards seeking gratification from the external world) is negatively correlated with utilization rates. Our results also demonstrate a significant negative correlation between cognitive load induced by a secondary task and the utilization of the adaptive features. This effect, however, is very small (less than two percentage points). Together, these results provide additional evidence of the usefulness of the split adaptive interface approach and a negligible effect of additional cognitive load, but also demonstrate that the approach does not benefit all users equally.

Author Keywords
Adaptive user interfaces, cognitive load, extraversion, need for cognition

ACM Classification Keywords
H.5.m. Information Interfaces and Presentation: Miscellaneous

INTRODUCTION
In Split Adaptive Interfaces, functionality that is predicted to be immediately relevant to the user is *copied* to a clearly designated adaptive part of the user interface (see Figure 1). Thus, if the system correctly predicts the user's needs, the user can access the functionality either at its original location or potentially save time by accessing it through the adaptive part of the interface. If the system's prediction is incorrect, the user is no worse off because the functionality they need remains at its usual location in the static part of the interface. Unlike several other adaptive strategies, Split Interfaces have been demonstrated to reliably improve both performance and satisfaction compared to static designs [12, 11, 16].

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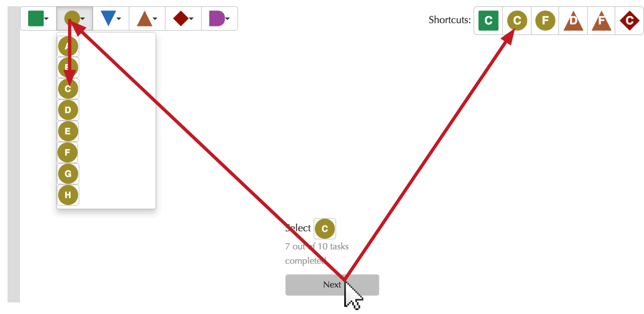

Figure 1. The design of a Split Adaptive Interface used in our study. In a Split Adaptive Interface, functionality predicted to be most relevant to the user is copied from the original location (hierarchical menu, top left) to the adaptive shortcut toolbar (top right). The user has the option to either access the functionality from its usual location or from the adaptive toolbar if the system correctly predicted the user's needs.

Split Interfaces trade off physical effort for cognitive effort: people can access user interface functionality with fewer movements (and therefore save time) by taking advantage of the adaptive part of a Split Interface, but they have to explicitly monitor the adaptive section to determine whether the functionality they need has been copied there [16, 17]. A cognitive perspective on this would suggest that the increased effort comes from the additional working memory load and need for impulse inhibition, since participants must monitor an additional space and prevent themselves from taking an action that was previously correct based on new information.

Although prior laboratory studies provide a strong evidence that participants are faster with and prefer Split Adaptive Interfaces to the non-adaptive baselines, we set out to explore how robust these findings are with respect to additional cognitive demands and two stable personality traits. Specifically, we investigated the following two questions:

First, would a person working on a cognitively-demanding primary task still benefit from the Split Adaptive Interface? We hypothesized that the utilization of the adaptive feature of the Split Interfaces would decline as additional working memory load increased. To that end, we asked users to perform rehearsal tasks of varying difficulty that taxed the phonological loop component of working memory while also using the Split Interface.

Second, are Split Adaptive Interfaces equally beneficial to all people? Behavioral tendencies that remain stable in individuals over the long term may mean that some users are better able to take advantage of the adaptive feature than others. Specifically, differences in Need for Cognition (a tendency to undertake challenging cognitive tasks) and Extraversion (an increased likelihood or speed of responding to external stimuli) may change the utilization rates of the adaptive feature.

The results of our study conducted with 16,373 participants demonstrated significant effects of all three factors (additional cognitive load, Need for Cognition, Extraversion) on the utilization of the adaptive feature of the Split Adaptive Interface. However, the effect size for additional cognitive load was so small as to be negligible in practice.

RELATED WORK

Adaptive User Interfaces. In this project, we use the term "adaptive user interfaces" to mean user interfaces that automatically adapt the organization or presentation of user interface *functionality* in response to some characteristic of the user or context. The design space of such adaptive user interfaces is large [2] and designing an effective adaptive user interface is challenging: past research documented both successes (designs that improved participants' performance and satisfaction) [23, 13, 3, 16, 18, 30, 33] and failures (designs that cause confusion and got in the way of users' tasks) [10, 31, 16]. Split Adaptive Interfaces are a particularly effective approach in that they reliably help participants be more efficient and participants generally report preferring them to conventional static designs [12, 11, 16]. The success of Split Adaptive Interfaces is likely attributable to the fact that this approach does not hinder the learnability of the original interface [7]. Split Adaptive Interfaces are based on the concept of Split Menus [35] with one key difference: in the original Split Menus functionality was *moved* from its initial location to the adaptive location, which hurt participants' performance in situations where adaptation occurred frequently [10]. In Split Adaptive Interfaces, functionality is *copied* to the adaptive portion of the interface, which allows the user to still access the functionality at the original location. Prior work has characterized the impact of screen size, the accuracy of the adaptive algorithms at predicting a person's need and the predictability of the behavior of the adaptive algorithm on users' performance and satisfaction with Split Adaptive Interfaces [11, 17].

Individual Differences. The area of individual differences in psychology has a long track record of validated measures of stable individual traits over time (for a review, see [32]). When operating Split Adaptive Interfaces, participants trade off physical effort (using the static part of the interface, where they can rely on habit, but need to perform a larger number of clicks) and cognitive effort (monitoring the contents of the adaptive part of the interface to see if a helpful adaptation took place and task can be performed with fewer clicks). For this reason, we selected two personality traits that have strongest links to performance on cognitively-demanding tasks: Need for Cognition (NFC) reflects one's willingness to undertake difficult mental activities and has a demonstrated relevance to exploratory behavior and deep learning activities [6]. Extraversion trait is relevant to performance on tasks requiring sensory processing and directed attention [22] (such as monitoring the state of the adaptive part of the interface). However, results are highly inconsistent: some show introverts performing better, and others the reverse [36]—there is strong agreement about the relevance of the Extraversion trait, but there is neither a consensus on the mechanism responsible for the effect nor even on the direction of the effect [27].

Both constructs have validated measurement instruments going back decades [4, 9]. However, applying this body of knowledge to behavior in the human-computer interaction context is an understudied area. Some work has shown that extraverts and introverts use differing types of computer services [24], and that extraverts perform better under noisy conditions than introverts [15]. People with higher Need for Cognition indices are more likely to be curious and in a focused attentive state while using a computer [29] and have higher performance at complex skill acquisition in the context of computer task performance [8]. Individual differences in specific cognitive abilities (particularly spatial abilities) have been shown to predict different levels of success with different user interface design paradigms (command line, menu-based, etc) [1]. These findings suggest that some aspects of human performance in a static-interface computing context may be shaped by user traits. Given that adaptive user interfaces may require additional cognitive effort to operate, it is logical—but untested—that these user traits may also lead to differing behavior with adaptive interfaces.

STUDY

Informed by the prior research, we formulated the following hypotheses and a research question:

H1: Increasing additional memory load will result in lower utilization of the adaptive toolbar.
H2: People with higher need for cognition scores will utilize the adaptive toolbar more than those with low NFC scores.
RQ1: Will extraversion have an impact on the utilization of the adaptive toolbar and if so, what will this impact be?

Tasks. Participants were asked to perform menu selection tasks using a Split Adaptive Interface illustrated in Figure 1 (similar to the design used in prior research [16, 17]). The interface comprised of a hierarchical menu (Figure 1, top left), which stayed unchanged throughout the study. The interface also included an adaptive shortcut toolbar (Figure 1, top right), whose content changed frequently: the most recently selected item was copied onto the shortcut toolbar unless that item was already there. The least recently added item was removed from the toolbar if space was needed. The shortcut toolbar held up to six items.

Participants initiated a trial by clicking the "Next" button. At that point, the next target was revealed. With 50% probability, the system chose a target that was present on the shortcut toolbar. If the target was present on the shortcut toolbar, the participant had the choice of either selecting the target from the shortcut toolbar or selecting it from the static hierarchical menu. Selecting the item from the shortcut toolbar was faster, but required the participant to check if the item was there.

Cognitive load is defined as the load on the working memory. Therefore, we manipulated cognitive load by asking participants to memorize between zero and six randomly selected symbols (letters and numbers) at the beginning of each experimental block. Participants were asked to keep the numbers in memory for the duration of the experimental block and were asked to recall them at the end of the block. A different memory load was imposed for each block to enable for within-subject comparisons.

Procedures. We launched our study on LabintheWild.org [34], a platform for conducting behavioral research with unsupervised and unpaid online volunteers. Unlike participants in traditional laboratory studies or those recruited via online labor markets (such as Amazon Mechanical Turk), participants on LabintheWild are incentivised to participate by the promise that at the end of the study they will receive feedback about how they did and the will be able to compare their performance to that of other participants. Despite the lack of monetary incentive or direct supervision, several validation studies demonstrated that the data collected on LabintheWild and other volunteer-based platforms match those collected in conventional laboratory settings [19, 21, 34] as long as best practices are followed.

The landing page for the study advertised it as a Multitasking Test, it briefly explained the purpose of the test and informed participants that at the end of the test they would receive their results and be able to compare them to the results of others. The landing page was followed by a statement of informed consent and a brief demographics survey (all questions there were optional). Next, participants were presented with instructions explaining the basic task and the behavior of the shortcut toolbar. They were then asked to complete a brief (10 trials) practice block. Following recommendations for studies that involve a novel user interface element [28], a prominent message was dynamically displayed on the screen encouraging participants to make use of the shortcut toolbar at least once if they didn't try it on their own. The second set of instructions explained the procedure for memorizing and reporting back the symbols and was followed by another practice block, during which participants had to memorize several symbols. Next, participants completed three or four (depending on study variant) experimental blocks of 20 trials each. Before seeing their results, they were given a chance to report cheating, distraction or technical difficulties and to provide open-ended comments. The results page reported their speed and accuracy overall, as well as how their speed was impacted by the additional cognitive load.

In the later versions of the study, a four-item Need for Cognition questionnaire (comprised of the four items from [5] with the highest factor loadings) was presented during the break after the first block, and an extraversion questionnaire made up of the four items with the highest loadings from the International Personality Item Pool measuring the Extraversion domain [20] was presented after the second block.

Throughout the lifetime of the study, 5 variants were available differing in the number of experimental blocks (3 or 4) and the levels of the additional memory load (i.e., the number of symbols to memorize) assigned in each block. These variants (described in terms of the memory load levels) were: {0,3,6}, {1,3,6}, {0,1,3,6}, {0,2,4,6} and {1,2,4,6}. Upon arrival on the landing page for the study, participants were randomized into one of the study variants available at the time of their arrival. We initially varied the number of blocks to determine the maximum length of the study that participants would be willing to complete. We varied the memory load levels across variants to more completely cover the full range of additional memory loads (from 0 to 6 symbols). The ordering of memory load levels was randomized for each participant.

Participants. Data from 16,373 participants were included in the analysis of the impact of cognitive load on the utilization of the adaptive interface. The questionnaires measuring need for cognition and extraversion were added later in the study and their completion was optional. Data from 4,866 participants (who answered at least three out of four questions for both traits) were used in the analyses related to the personality traits.

As is recommended practice for conducting studies with unpaid online volunteers [34], we excluded all participants who reported having taken the study before, cheated, getting distracted or having encountered technical difficulties.

Design and Analysis. The study was a mixed within/between subjects design: the memory load was varied both within participants (three of four levels depending on study variant) and between participants (different study variants explored different sets of cognitive load levels).

We included only one measure as a dependent variable in the analysis: the *utilization* of the adaptive toolbar, which is defined as "the number of times that the participant selected the requested UI element from the adaptive toolbar divided by the number of times that the requested element was present on the adaptive toolbar" [17].

We used analysis of variance to analyze our data. The data were averaged by block prior to analysis. Practice blocks were excluded as were the first four trials in each block (we assumed participants would need a few trials to "warm up").

In our first analysis, we characterized the impact of additional memory load on the utilization of the adaptive toolbar. Memory load was modeled as an ordinal variable (the number of symbols the person was asked to memorize). To account for the within-subjects effects, we included participant identifier as a random effect. We included study variant as a covariate.

In our second analysis, we focused on the between-subjects effects of the need for cognition (NFC) and extraversion (both

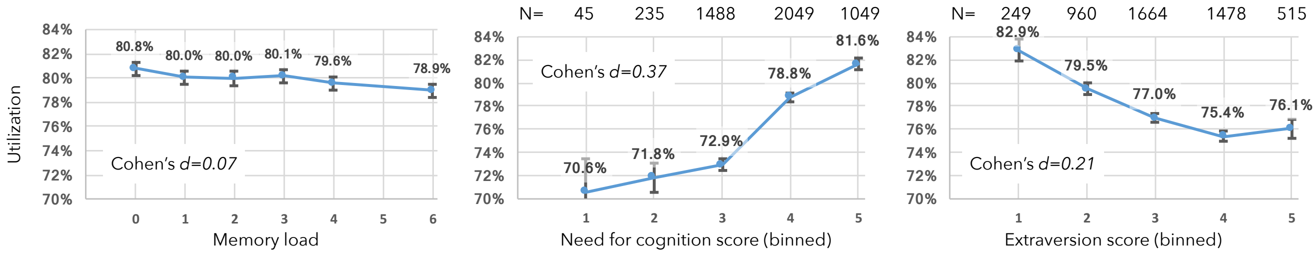

Figure 2. Summary of the results. The results for Memory load manipulation show marginal means. The other results show raw means. NFC and Extraversion were modeled as continuous variables in analysis, but they are discretized here to improve the clarity of the illustration. The numbers above the NFC and Extraversion graphs show the number of participants with scores in each bin. Error bars show standard errors. Effect size estimates are between lowest and highest values of memory load or trait.

of which were modeled as continuous variables). We therefore no longer included participant as a factor. Instead, we included memory load and study variant as covariates. We also included all pairwise interactions among NFC, extraversion and memory load in the analysis.

Results. Controlling for study variant, we observed a significant main effect of memory load on utilization of the adaptive shortcut toolbar ($F_{5,43225} = 14.90, p < .0001$). However this effect was very small: participants with no additional memory load used the adaptive shortcut toolbar 80.8% of the times when a helpful shortcut was available, while participants who had to memorize six symbols utilized it 78.9% of the time (Cohen's $d = 0.07$). Figure 2 (left) illustrates this result.

Controlling for study variant and additional working memory load, we also found significant main effects of both need for cognition ($F_{1,19323} = 34.10, p < .0001$) and extraversion ($F_{1,19323} = 12.94, p = .0003$). These effects were substantial: As shown in Figure 2 (center), participants with mean NFC scores equal or greater than 4.5 (on a scale of 1–5) utilized the shortcut toolbar 81.6% of the time while participants with scores lower than 1.5 utilized it only 70.6% of the time (Cohen's $d = 0.37$). As shown in Figure 2 (right), the most introverted participants (those with extraversion scores lower than 1.5) utilized the adaptive toolbar 82.9% of the time, while the most extraverted participants (scores 4.5 or higher) utilized it only 76.1% of the time (Cohen's $d = 0.21$). These between subjects effects persist after controlling for age, gender, education and frequency of computer usage.

None of the pairwise interaction effects was significant. There was also only negligible correlation between NFC and extraversion scores among our participants ($r(1868) = .05$, $p = .0006$) indicating that the two effects were independent of each other.

DISCUSSION, FUTURE WORK AND CONCLUSION

Our results supported both initial hypotheses. The utilization of the adaptive feature of the interface did decrease as working memory load increased, but that effect—while significant—was very small. A statistically significant (that is, not due to noise) but negligibly small effect in this case is a positive indicator for Split Adaptive Interfaces overall, as it firmly demonstrates that the additional cognitive burden is not a significant reason to avoid this interface design technique and that Split Adaptive Interfaces should continue to provide performance benefits even when the user is working on a cognitively demanding primary task.

As hypothesized, Need for Cognition was positively correlated with utilization. The Need for Cognition effect in this study is consistent with the general understanding of the construct—it measures willingness to undertake effortful mental activity.

Extraversion was negatively correlated with utilization. Previous work has found that introverts perform better on "mundane" or unarousing tasks than extraverts, but extraverts perform better if the task is made more arousing [36]. This suggests that the effect observed here may be related to the specific task and adaptation design.

Regardless, both of the trait-related effects strongly suggest that adaptive interfaces are not equally useful to all participants, indicating that adaptive strategies may themselves need to be adapted to the individual traits of their users.

These results raise a number of questions for future work in both the engineering of useful adaptive interfaces and the science of individual differences in cognition. Relevant to the engineering of useful adaptive interfaces, it is still an open question whether these effects of NFC and extraversion generalize to other kinds of adaptive interfaces. In the area of the science of cognition and individual differences, the NFC effects could be due to disposition alone or a mix of disposition and working memory span or general intelligence; the literature is divided on if or which aspects of intelligence or memory NFC correlates with [14, 26, 25]. Assessing working memory span, general intelligence (g), or attention allocation in addition to NFC could clarify what construct is driving the increased utilization rate here. In addition, the challenge of this task may lie more in the related areas of attentional allocation or impulse inhibition; as there is no data directly linking these constructs, it is difficult to say how differences might impact behavior.

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Online Appendix. The data used in this work can be found at `http://iis.seas.harvard.edu/resources/`

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