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Controllability matters: The user experience of adaptive maps

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Abstract Adaptive map interfaces have the potential of increasing usability by providing more task dependent and personalized support. It is unclear, however, how map adaptation must be designed to avoid a loss of control, transparency, and predictability. This article investigates the user experience of adaptive map interfaces in the context of gaze-based activity recognition. In a Wizard of Oz experiment we study two adaptive map interfaces differing in the degree of controllability and compare them to a non-adaptive map interface. Adaptive interfaces were found to cause higher user experience and lower perceived cognitive workload than the non-adaptive interface. Among the adaptive interfaces, users clearly preferred the condition with higher controllability. Results from structured interviews reveal that participants dislike being interrupted in their spatial cognitive processes by a sudden adaptation of the map content. Our results suggest that adaptive map interfaces should provide their users with control at what time an adaptation will be performed.

Keywords Map adaptation · User experience · Activity recognition · Maps

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1 Motivation

Maps that adapt to the user's context have the potential of increasing usability by providing more intelligent and more personalized support, especially in mobile or cognitively demanding situations [41, 42, 47]. An adaptive map could, for instance, highlight all restaurants if it knows the user is looking for a place to eat, or the bicycle lanes if the user is planning a bicycle route.

Adaptive maps can be seen as a sub-class of general adaptive interfaces, which have for a long time attracted the interest of researchers in Human-Computer Interaction (HCI) (e.g., for office tools [13, 17] or mobile interfaces [57]). It has been argued that interface adaptation must be applied carefully to avoid a loss of control, transparency, and predictability [21], which would make the user feel patronized. A notorious example for an arguably ill-designed interface adaptation is the 'Clippy' agent of older Microsoft® Office versions which has anecdotally been reported to cause an experience of low controllability [56].[1]

Returning to the interaction with maps, there has not been much research devoted to user experience (UX) for map adaptation: do users experience a lack of control, transparency, or predictability when interacting with a highly adaptive map? Are adaptive map interfaces susceptible to the 'Clippy' trap? One reason why this issue has not sparked considerable interest in the Geographic HCI (GeoHCI) literature so far might be that most map adaptations in practice are rather simple ones, such as those using sensor readings directly for adaptation (e.g., moving the 'you-are-here' symbol on a mobile map). We argue here that more sophisticated adaptations, such as those based on the recognition of a user's cognitive state (tasks, plans or intentions), are more likely to lack control, transparency or predictability, thus requiring special attention of user experience.

Advances in sensing technology and activity recognition have lead to increasingly sophisticated user models (e.g., [2, 31]), facilitating more efficient and more accurate algorithms for the recognition of a user's cognitive states. An especially promising basis for the recognition of cognitive processes while interacting with maps are the visual search activities these processes involve. People's cognitive processes become apparent in their eye movements [5], and it has been shown that classifiers can be trained which recognize (search) activities from gaze, both on maps [25], and other interfaces [6]. A semantic gap still remains, however, between the visual search activities and the user's (high-level) intentions.

In this article, we assume gaze-based intention recognition to be solved and – following a Wizard of Oz approach [23] – investigate the user experience achieved by different map adaptation types of a system that pretends to recognize intentions. Our contributions are as follows:

1. Two types for map adaptation are explored – toggable and revertible adaptation – differing in the degree of control which is left to the user.
2. In a controlled experiment with 24 users we demonstrate that the user experience of both, toggable and revertible adaptation is significantly higher than that of a map interface with no adaptation. The overall perceived cognitive workload of revertible and toggable adaptation was significantly lower than for no adaptation. Asked for their

[1]Example user comment on 'Clippy': 'It's not very helpful. You've got to stop what you're doing and click on it.' [56].

preference, 75 % of the users preferred the toggable adaptation over revertible or no adaptation.

3. We report the results of an analysis of structured interviews on the adaptation types. As the most important finding we identify controllability as the critical characteristic of an intention-recognizing adaptive map interface.

The rest of this article is structured as follows: Section 2 provides an overview of relevant related work. Section 3 explores the design space of adaptation types w.r.t. controllability and motivates our choice of three adaptation types. We then describe the implementation of the system used in the experiment (Section 4) and the experiment design (Section 5). Results are reported and discussed in Sections 6 and 7. The article is concluded in Section 8.

2 Related work

This section introduces related work on user interface adaptation in general, mobile map adaptation in particular, as well as on gaze-based interaction and activity recognition.

2.1 User interface adaptation

Early work in HCI on adaptive systems ranges back several decades ago when Fischer first described them as *'systems [which] change themselves based on the user's behavior'* [11, 12]. They aim at increasing the usability by *'filter[ing] information in a user- and task-specific way [...] and [by] present[ing] to users information of which they are not aware of'* [11]. Examples for adaptive systems include moving and popout toolbars in Microsoft Office [13] or systems adapting to the learning curve of their users [29].

In this article, we focus on adaptive *map* interfaces. Based on the definition by Fischer, we consider a map adaptation a change of the visual appearance of a digital map triggered by the system. We particularly envision *intention-aware* map adaptation for which the trigger is based on an intention recognition algorithm, taking as an input the user's behavior, such as eye movements classified as a visual search activity.

Although adaptive interfaces can be helpful they often violate important usability principles [21]: controllability, transparency (user understands the inner workings of the system), and predictability (user can predict the output for a given input) [14]. Research on adaptive interfaces has addressed, and still is addressing, these challenges in several ways, such as by allowing the user to interrupt an animated adaptation [8]. In this article, we are specifically interested in the controllability of an adaptive map interface. We compare whether the map adaptation should be triggered by the system automatically, or whether the system should offer the user a means of triggering the adaptation herself.

It is well-known that users adapt their visual search strategies to the expected information gain [54]. This implies that, for adaptive interfaces, the user might adapt to the adaptive system once she thinks having understood how the adaptation mechanism works [45]. Some users in our study reported similar strategies.

Adaptable interfaces – in contrast to adaptive ones – enable their users to explicitly change the user interface and the interaction with it according to their needs (e.g., through a settings dialogue), thus providing control to the user [11, 35, 53]. This, however, may be unattractive for mobile and spontaneous interactions in which it would be too time-consuming to open a settings dialogue.

2.2 Mobile map adaptation

Interface adaptation is particularly relevant for mobile interfaces because mobile users are often facing (potentially stressful) decision situations under frequently changing context [1], constrained by small screen size [10], limited interaction possibilities (e.g., carrying items in both hands), and limited cognitive resources [4].

Even though map-less interaction principles for spatial decision situations have been proposed (e.g., [16, 39, 46]), map interfaces are still one of the most frequently used mobile interface types, and novel approaches to map interaction are actively discussed in the HCI community (e.g., [28, 32, 34, 55, 58]).

Cartographic content is different to other content types because maps are content-dense, and because people use their individual spatial competences and concepts when interpreting maps [3]. Thus, map-based mobile services and interfaces have been studied at the intersection of Cartography and HCI [36]. Formal models for map adaptation have been developed which allow a system designer to specify how a mobile map will adapt if certain context changes are recognized [41, 42, 47], depending on geographic relevance [44], or based on the user's spatial knowledge [48]. Mobile You-Are-Here (YAH) Maps are probably one of the most commonly used type of mobile maps, and sophisticated models for adapting YAH maps based on the user's location context have been proposed [49]. YAH maps are also one type of map which will be used in our experiment.

The graphical parameters of the map adaptation, such as changing the size or color of cartographic elements, are typically based on cartographic design rules [51]. Advanced adaptations may go beyond the change of a single visual variable, e.g., by changing the visualization of a road network in a focus region based on geometry and topology [19].

Here, we are not focussing on the visual design aspects of the adaptation, but on the amount of control left to the user. Decision making under time pressure, as typical for mobile situations, is also not our focus. We did not limit the time participants had for solving the tasks in our study.

2.3 Gaze-based interaction and activity recognition

Eye trackers are devices that measure a person's eye movements [9]. They have found a number of applications as a research tool in Geographic Information Science, including the usability evaluation of interfaces [7], the study of cognitive processes in wayfinding [26], and the analysis of visual search processes of novice and expert map users [38]. At the same time, most eye tracking devices enable the real-time processing of the gaze data, thus facilitating using gaze as an input means for both, desktop [37, 40] and mobile systems [15, 27].

Gaze-based interaction can generally be distinguished in explicit and implicit interaction [50]. In explicit interaction, the user gazes at certain elements of the interface with the intention to trigger an interaction (e.g., gaze typing [33]), while in implicit interaction, the user's natural gaze behavior during the task at hand (e.g., route planning) is interpreted by the system and used for an adaptation. We here focus on implicit *map* interaction, based on the visual search activities naturally occurring when the user tries to solve the task through map reading. Next to the user's eye gaze, no further input modalities were involved in the interaction dialogue.

Activity recognition based on gaze data has been demonstrated for a number of domains, such as office activities [6]. These approaches describe gaze tracks by spatio-temporal features (e.g., average number of fixations) and use machine learning techniques on these features to recognize the activity.

This article is motivated by the authors' own previous work on gaze-based activity recognition on maps [25]. Based on a dataset of 587 eye movement recordings from 17 participants, we trained a Support Vector Machine (SVM) classifier that was able to distinguish between 6 different map activities (free exploration, search, route planning, focused search, line following, polygon comparison) with an accuracy of approx. 78 %. As mentioned in the introduction, these activities may possibly be used as an input to an intention recognition algorithm that interprets them on a higher semantic level (in terms of intentions or plans). Here, we treat activity and intention recognition as a black box and investigate only the adaptation of the map interface that may be triggered based on a recognized intention. Our study uses a Wizard of Oz experiment [23] in which users were told the system would recognize their intentions from gaze, while instead the system applied the adaptation based on a time threshold.

3 Adaptation types

We consider the design space of map adaptations w.r.t. the degree of automation the adaptation is appearing, and disappearing respectively. All possible combinations are illustrated in Table 1.[2]

An adaptation may appear or disappear *"not at all"*, *"automatically"* or *"manually"*. The first category is straight forward, the map is not adapting at all (*(1) no adaptation,* ***NoA***). The second category in which the adaptation appears automatically comprises three possible ways of how the adaptation can disappear. The adaptation might not disappear at all ((2) *"Persistent automatic adaptation"*), the adaptation might disappear after some threshold *t-diss* ((3)*"transient automatic adaptation"*), or provide an option (e.g., a button) to manually choose whether the adaptation should disappear and make the map return back to the initial state ((4) *"revertible adaptation",* ***RevA***). In the third category, the adaptation can be activated manually (e.g., when the intention has been recognized, a button appears). Similar to the previous category, the adaptation might not disappear at all ((5) *"persistent manual adaptation"*), it might disappear automatically after some threshold *t-diss* ((6)*"transient manual adaptation"*), or provide an option (e.g., a button) to manually choose whether the adaptation should disappear and force the map to return back to the initial state ((7) *"toggable adaptation",* ***TogA***).

The adaptation types (2) and (5) are not considered since there is no real scenario in which an adaptation never disappears again. The adaptation types (3) and (6) are also not considered since next to recognizing the user's intention, these adaptation types would also require a further step, recognizing when the user wants to continue with a subsequent task (i.e., recognition of completion). In this work we therefore focus on two adaptation types, **RevA** and **TogA**. The main difference between these two adaptation types is that in the case of **RevA**, the system helps the user (i.e., starts the map adaptation process) without an explicit request, while in case of **TogA**, the system only offers a trigger for the adaptation to the user. These two adaptation types are evaluated in the experiment section and also compared with a **NoA** condition in order to retrieve the users' preferences on the type of adaptation. To conclude, we test the following three adaptation types:

[2]Transitions between different adaptation types are also possible, but not considered further here. For instance, a system could employ a transient automatic adaptation and then, once the adaptation automatically disappears, switch to another adaptation type, such as the toggable adaptation, offering manual adaptation. This does not form a new type of adaptation, but rather possible transitions between adaptation types.

Table 1 Adaptation types and the degree of automation the adaptation is appearing/disappearing. We evaluate (1), (4), and (7)

	Adaptation Disappears		
Adaptation Appears	not at all	automatically	manually
not at all	1) no adaptation (NoA)	n/a	n/a
automatically	2) persistent automatic adaptation	3) transient automatic adaptation	4) revertible adaptation (RevA)
manually	5) persistent manual adaptation	6) transient manual adaptation	7) toggable adaptation (TogA)

1. **Revertible Adaptation (RevA):** Once the system recognizes the user's intention it adapts the map in order to facilitate the task at hand. The adaptation can be reverted by clicking a button.
2. **Toggable Adaptation (TogA):** Once the system recognizes the user's intention it provides a "help me" button that the user can press in order to start the adaptation. In the adapted state, the adaptation can be reverted with another button click. The button thus provides the user the ability to enable or disable the adaptation based on her needs.
3. **No Adaptation (NoA):** The system does not adapt.

Through the evaluation of these adaptation types we are aiming at finding an optimal means to provide assistance to the user, at the same time increasing the user experience and decreasing the workload during a task. Our hypotheses are as follows:

H1. Users prefer an adaptation type (**RevA**, **TogA**) over **NoA**.
H2. UX for each of **RevA** and **TogA** is higher than for **NoA**.
H3. The perceived workload for each of **RevA** and **TogA** is lower than for **NoA**.
H4. Users prefer **TogA** over **RevA**.

The rationale behind these hypotheses is as follows: for hypotheses H1, H2, and H3 we assumed that providing help (i.e., map adaptation) to the user, or at least providing the option to ask for help, will always be better (in terms of user experience and perceived workload) than having to solve the tested tasks completely alone. A patronizing effect might occur if the user is getting unwanted help by the system, which can be annoying for users that want to stay in control (refer to the 'Clippy' example, [56]). Since the toggable adaptation does not force an adaptation, we hypothesize that this would be the most preferred type (H4).

4 Implementation

The *Wizard of Oz* methodology [23] was utilized for the simulation of intention recognition and map adaptation. This allows us to study the UX of gaze-based adaptive maps without having engineered an intention recognition algorithm. The hardware and software necessary for the application of this technique are described in the following.

4.1 Hardware

The SMI (v1.8) eye tracking glasses[3] were used to simulate gaze-based intention recognition for the Wizard of Oz approach. Next to that, four 24” monitors were employed, two for the experimenter to control the study and two for the participant, one for the task and one for the instructions. A computer mouse was provided for user input in two of the conditions and a Galaxy Nexus phone (Android 4.2.2) was utilized for voice recordings during the structured interviews.

4.2 Software

The software was implemented from scratch in order to simulate gaze-based intention recognition and adapt the maps accordingly. All possible task sequences were hard-coded and the software was implemented to load and display a series of images. For every task, the software displayed one of the corresponding maps and based on a predefined time threshold (refer to Section 5), exchanged the map image with a sequence of several other images that were manually designed to simulate a map adaptation, e.g., slowly changing the opacity levels of the map and highlighting relevant features. This software was the control unit of the experiment and recorded a log file for all trials containing the user interaction and meta information on the task sequences.

5 Experiment

We performed a controlled user study in order to evaluate the adaptation types **RevA**, **TogA** and **NoA** (refer to Section 3) concerning the user preference as well as their impact on UX and perceived cognitive workload.

5.1 Participants

In total 24 participants (15 male) were recruited for the experiment with different cultural backgrounds. 17 were PhD or Master students, 3 were working for the university, 1 was a teacher, and 3 came from industry. They participated on a voluntary basis and were not compensated. The sample that was necessary for this experiment was estimated based on the number of combinations that resulted from counterbalancing the conditions. The participants had a mean age of 29 years *(SD = 3.9)* and rated their experience using digital maps, on a 7 point Likert scale with higher values indicating higher experience, with a mean of 5.75 *(SD = 1.32)*. The users’ estimated spatial abilities had a mean of 5.2 *(SD = 0.88, Min = 2.66, Max = 6.46)* (on a scale with minimum 1 and maximum 7).

5.2 Setup

Participants were placed in front of the two 24” desktop monitors, one displaying the current task instructions and one for the actual task (see Fig. 1). A computer mouse was provided for explicit input in the conditions **RevA** and **TogA**. Right before the experiment started,

[3] http://www.smivision.com/en.html

Fig. 1 Experiment setup. The monitor left of the participant was used to display the maps and the monitor on his right side for the instructions

the SMI eye tracker was mounted on the participant's head and calibrated. Note that the eye tracker was not actually used as an input device although participants thought so (Wizard of Oz study, [23]).

5.3 Design

A within-subject design was employed for the evaluation of the adaptation types. Each participant was exposed to all 3 tested adaptation types (**RevA**, **TogA**, **NoA**) and asked to solve simple map tasks of 4 different types (see below). Each combination of adaptation type and task type was presented to each participant, yielding in 12 trials in total. The order of both, adaptation type and task type was counterbalanced.

The selection of tasks was motivated by the gaze-based activity recognition study on cartographic maps (see Section 2.3, [25]) in which six types of activities were analyzed. We selected the following four of these activities:

1. (Global) Search: searching for a point with a given label
2. Focused Search: searching for the n closest point symbols with certain properties (e.g., of type t) w.r.t. a position marked blue on the map (like one would search for close restaurants on a YAH map, [49])
3. Route Planning: planning an optimal route on a network. In our case, searching for the route with the minimum number of stops on a subway map.
4. Polygon Comparison: deciding which of two polygons has the larger area

These activities were chosen as they seemed to be the most promising cases for map adaptation. They require some time and are sufficiently complex to require assistance, whereas the two omitted activities ("Free Exploration" and "Line Following") were considered as too simple for this study. We used different time thresholds based on average activity durations in the [25] dataset (20 seconds for activities 1 and 3, 10 seconds for activity 2 and 5 seconds for activity 4), pretending this would be the time our intention recognition algorithm would need before an adaptation can be activated (i.e., the time required for recognition).

For each of these activities we used three different (official) maps. Nine of the 12 maps depicted the center of a city, while the 3 maps for the route planning task depicted metro lines of a city. The maps were either from a European, an American or an Asian city. None of the maps was from a country where one of our participants came from, and no participant mentioned familiarity with any of the maps in the interview after the experiment. Refer to Figs. 2, 3 and 4 for examples.

The task descriptions were based on the type of activity tested. For the global search task, participants had to find a labeled point object on the map, e.g. *"Find the telephone*

Fig. 2 Example stimuli for a global search task: city map of Phuket town, Thailand (top) and its adapted state (bottom). The transition between the two was animated with a blurring out effect. The task was 'Find the telephone booth called Pacific'

booth called Pacific". For focused search, the instructions were of the form *"Find the three closest hotels to your location"* where an icon on the map indicated their location. For route planning the instructions were of the form *"Find the route from Palau Reial to Sant Andria de Besos with the smallest number of stops"* and finally, for the polygon comparison tasks the instructions were of the form *"Do the Flagstaff gardens or the Treasury gardens have a bigger area?"*.

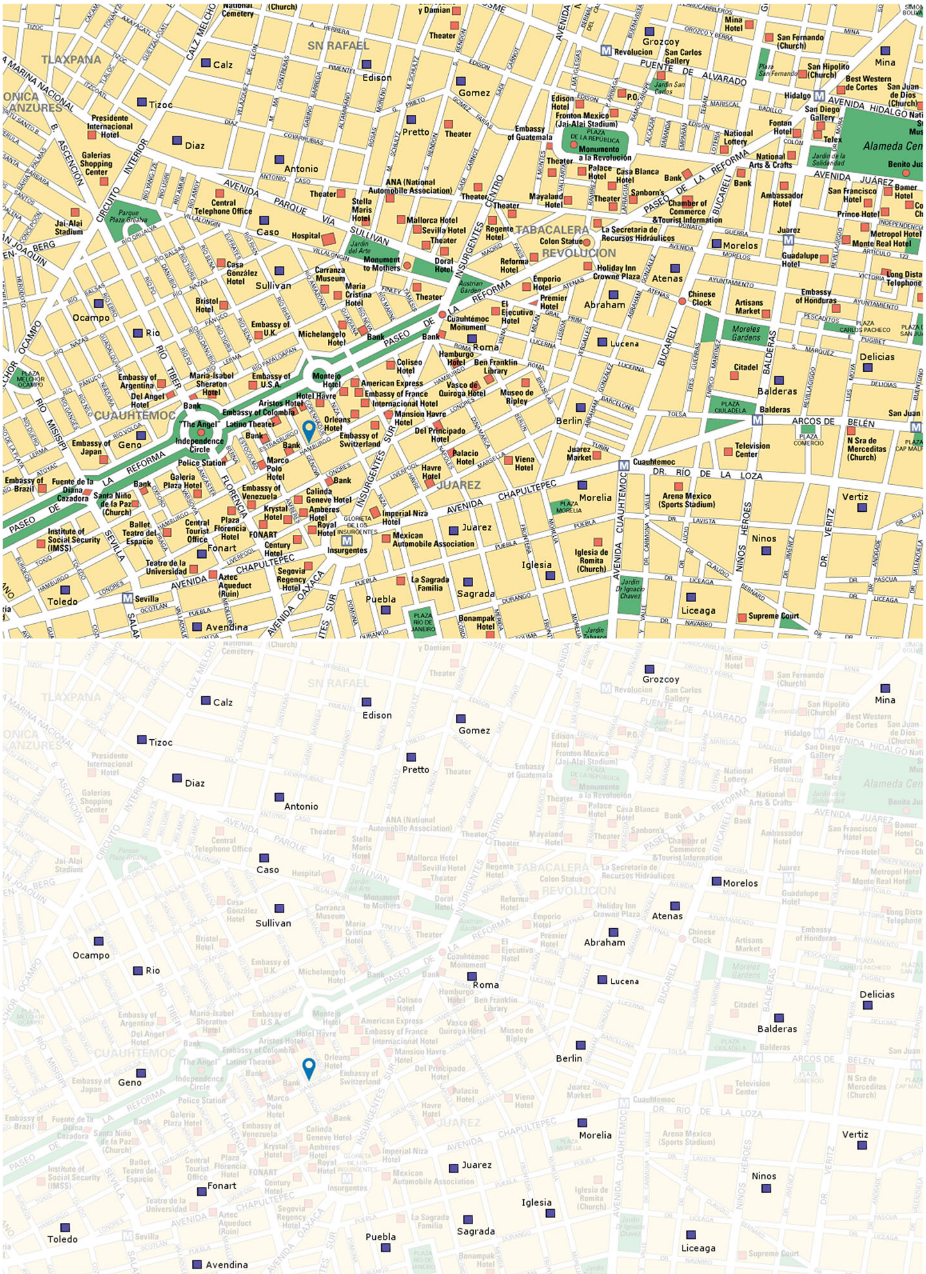

Fig. 3 Example stimuli for a focused search task: city map of Mexico City, Mexico (top) and its adapted state (bottom). The transition between the two was animated with a blurring out effect. The task was 'Find the three closest blue squares to your position' (icon examples for blue square and position were included in the instruction)

Fig. 4 Example stimuli for a route planning task: metro map of New York City, USA (top) and its adapted state (bottom). The transition between the two was animated with a blurring out effect. The task was 'Find the route from Broad St. to Queensboro Plaza with the smallest number of stops'

Each of the 12 maps was pre-processed in order to have also an adaptation state that would provide help to the participants. We utilized adaptation techniques based on standards in cartography [43]. The adaptation of every map was based on *information density reduction* and *emphasizing the object of regard* [43], i.e., blurring out irrelevant information and highlighting the relevant pieces (see Figs. 2, 3 and 4 for examples). The adaptation process was controlled by the software introduced in the implementation section.

5.4 Procedure

The procedure of the experiment was explained to the participants, and they were asked to fill in a questionnaire on demographic information and experience level (i.e., digital map experience), as well as to fill in the "Santa Barbara Sense of Direction Scale" [20], a self-estimation questionnaire assessing the spatial abilities of the participants.

Next, the participants were equipped and familiarized with the eye tracking device and seated in front of a desk. The participants received the first instruction and had to solve the first task. After they presented their solution, they also had to state their confidence on a 5 point Likert scale. They solved four tasks, one for each activity type, but all for the same adaptation type. Once the four tasks had been solved, the participants were asked to fill in a standardized questionnaire assessing their user experience (UEQ; [30]) with this adaptation type as well as the "Raw" Nasa TLX questionnaire [18] for the assessment of the perceived cognitive workload. This procedure was repeated for each of the three conditions (adaptation types). The activities and adaptation types were counterbalanced in order to avoid confounding among variables. Each possible combination of the adaptation types (6 in total) was repeated 4 times, also counterbalancing the order of the tested activities.

After all 12 trials had been performed, the participant was asked to fill in another questionnaire assessing their preferences on the tested adaptation types. Finally, the experimenter performed a structured interview with each participant in order to retrieve more qualitative information regarding the choices made.

6 Results

The data collected through the experiment were analyzed for the evaluation of the adaptation types tested in order to investigate the stated hypotheses. We were interested in assessing the users' preferences towards an adaptation type as well as the resulting UX and perceived cognitive workload.

6.1 User experience

Concerning the results from the UEQ questionnaire (see Fig. 5), a Friedman test revealed significant differences between the three adaptation types at all scales except for *Stimulation*. A Wilcoxon signed rank test was pairwise applied in order to retrieve these significant differences (Bonferroni adjustment, $\alpha = .017$). The revertible adaptation performed significantly better than the no adaptation for the scales *Attractiveness* $(p < .01, Z = -2.809)$, *Perspicuity* $(p < .01, Z = -2.971)$, *Efficiency* $(p < .001, Z = -3.636)$ and *Novelty* $(p < .001, Z = -3.618)$. There was no significant difference for the scales *Dependability* and *Stimulation* (see Table 2). The toggable adaptation performed significantly better than the no adaptation for the scales *Efficiency* $(p < .01, Z = -2.637)$, *Dependability* $(p < .01, Z = -2.738)$ and *Novelty* $(p < .01, Z = -2.875)$. There was no significant difference

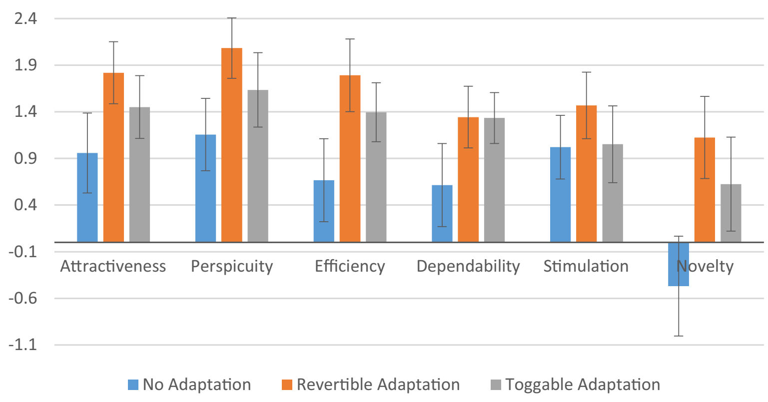

Fig. 5 UX evaluation. Mean and standard deviation for each of the UEQ scales are depicted for each condition

concerning the scales *Attractiveness*, *Perspicuity* and *Stimulation* (see Table 2). There was no significant difference between the revertible and toggable adaptation (see Table 2).

6.2 Perceived cognitive workload

A Friedman test revealed also significant differences concerning the perceived cognitive workload (see Fig. 6). Again, the Wilcoxon signed rank test and the Bonferroni adjustment ($\alpha = .017$) were applied in order to retrieve these significant differences. The revertible adaptation performed significantly better against the no adaptation type for the components *Mental Demand* $(p < .001, Z = -3.514)$, for *Physical Demand* $(p < .01, Z = -2.746)$, for *Performance* $(p < .001, Z = -3.668)$ as well as for *Effort* $(p < .01, Z = -3.188)$. There were no significant differences for the components *Temporal Demand* and *Frustration* (see Table 3). There was no significant difference between the toggable adaptation and the no adaptation type as well as between the revertible and toggable adaptation for any component of the Nasa TLX (see Table 3). The overall workload was significantly higher for the no adaptation type than for the revertible $(p < .01, Z = -3.401)$ or toggable adaptation $(p < .01, Z = -2.701)$.

Table 2 Inferential statistics for the UX scales comparison between the two evaluated adaptation types (**RevA**, **TogA**) and the no adaptation (**NoA**) condition (Bonferroni adjustment, $\alpha = .017$)

	Wilcoxon Signed Rank Test					
	RevA vs. TogA		RevA vs. NoA		TogA vs. NoA	
	p	Z	p	Z	p	Z
Attractiveness	.42	-2.033	<.01	-2.809	.47	-1.986
Perspicuity	.078	-1.761	<.01	-2.971	.71	-1.804
Efficiency	.032	-2.139	<.001	-3.636	<.01	-2.637
Dependability	.920	-.101	.24	-2.251	< .01	-2.738
Stimulation	.110	-1.597	.088	-1.707	.820	-.227
Novelty	.125	-1.533	< .001	-3.618	<.01	-2.875

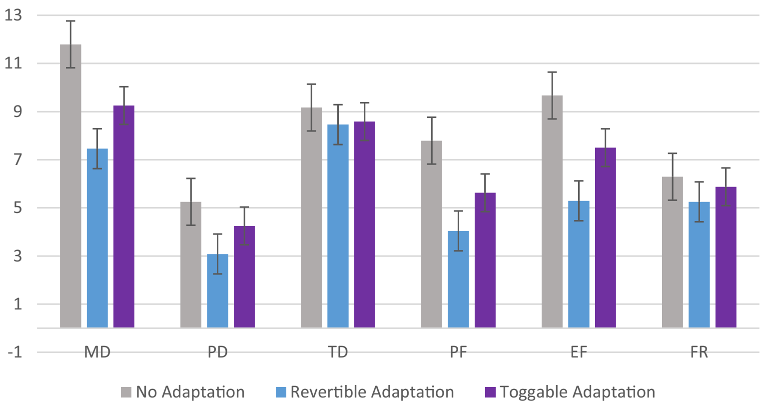

Fig. 6 Mean and standard deviation for the "Raw" Nasa TLX questionnaire depicting each component separately for every adaptation type (MD: Mental Demand, PD: Physical Demand, TD: Temporal Demand, PF: Performance, EF: Effort, FR: Frustration)

6.3 User confidence

A Friedman test revealed significant differences concerning the users' confidence about the provided answers. A Wilcoxon signed rank test and a Bonferroni adjustment ($\alpha = .017$) were applied for the pairwise comparison of the adaptation types. The participants were significantly more confident about their answers when the revertible adaptation was provided than the no adaptation ($p < .01$, $Z = -2.839$) as well as when the toggable adaptation was provided than the no adaptation ($p < .05$, $Z = -2.481$). There was no significant difference between the revertible and toggable adaptation ($p = .436$, $Z = -.778$).

6.4 Correlations

Further analysis was performed in order to reveal potential correlations between the users' preferences and other factors such as spatial abilities. A Pearson product-moment correlation coefficient between the users' spatial abilities and preferences did not reveal any

Table 3 Inferential statistics for the Nasa TLX components comparison between the two evaluated adaptation types (**RevA**, **TogA**) and the no adaptation (**NoA**) condition (Bonferroni adjustment, $\alpha = .017$)

	Wilcoxon Signed Rank Test					
	RevA vs. TogA		RevA vs. NoA		TogA vs. NoA	
	p	Z	p	Z	p	Z
Mental Demand	.139	-1.478	<.001	-3.514	.018	-2.359
Physical Demand	.026	-2.222	< .01	-2.746	.127	-1.524
Temporal Demand	.667	-.431	.455	-.746	.326	-.983
Performance	.110	-1.600	< .001	-3.668	.05	-2.543
Effort	.06	-1.868	< .01	-3.188	.06	-1.831
Frustration	.513	-.654	.314	-1.007	.599	-.525

significant correlation *(r = .098, n = 24, p = .648)* nor between the users' spatial abilities and the number of button clicks in the revertible *(r = .193, n = 24, p = .367)* or toggable adaptation type *(r = .135, n = 24, p = .531)*. There was also no significant correlation between the perceived cognitive workload and the number of button clicks in the revertible *(r = -.101, n = 24, p = .639)* or the toggable adaptation type *(r = -.272, n = 24, p = .199)*. There was a significant negative correlation between the adaptation type preference and the attractiveness scale *(r = -.468, n = 24,* $p < .05$ *)* of the UX questionnaire for the revertible adaptation as well as for the efficiency scale *(r = -.420, n = 24,* $p < .05$*)*.

6.5 Help button, final questionnaire, and structured interview

During the toggable adaptation condition, the users asked the system for help (by pressing the "Help Me" button) 43.7 % of the trials. This means, although they could ask for help, in 56.3 % of the trials they preferred to solve the task without help (i.e., without an adaptation). During the revertible adaptation condition, in 11.45 % of the trials a user decided to cancel the adaptation and return back to the initial state of the map, but for 63 % of the canceled adaptations, the user asked at a later point for help (by pressing the "Help Me" button).

The user preference towards an adaptation type was analyzed based on the self reported ranking of the evaluated types. The users had to rank the three adaptation types. In total, 75.0 % of the users preferred the toggable adaptation type over the other two types. 20.8 % of the users preferred the revertible adaptation type over the other types, and only 4.2 % of the users preferred the no adaptation type.

The questions in the interviews at the end of the experiment were designed to help identify and explain the reasons for a user preference. The audio recordings of the users' answers were transcribed as text to an electronic file. In a next step, two raters independently rated each of the statements regarding whether they were referring to controllability (c), transparency (t), predictability (p), or none of them. Statements referring to at least one of the three properties were further classified regarding their sentiment (positive, negative), leading to 7 categories (c+, c-, t+, t-, p+, p-, other). Afterwards, the two raters discussed their ratings until they reached an agreement.

For the revertible adaptation type, 17 participants stated negative arguments concerning the control of the adaptation and not a single positive one. The arguments were of the form *"It did not help me when I wanted"* or *"If the system tells you what to do, this is something I hate"*. For the transparency of the adaptation only one argument could be extracted and it was negative (*"I did not trust the answer"*). Finally, concerning predictability, 7 positive and 1 negative argument (*"it was unpredictable"*) could be extracted.

On the other hand, for the toggable adaptation type, 19 participants stated positive arguments concerning the control. The majority of these arguments were of the form *"I liked to have the choice"* or *"I liked to be in control of things"*. For transparency, there was only one negative argument (*"it was difficult to understand"*). Concerning predictability, 3 participants argued positively and only 2 negatively (both stating that it was not clear what the button would do).

7 Discussion

Our first hypothesis was that users would prefer adaptation over no adaptation (**H1**). The results of the user-based ranking strongly support this hypothesis: 95.8 % of the users named either revertible (20.8 %) or toggable (75.0 %) as their preferred adaptation type. **H1** is further supported by the findings on user confidence: users felt significantly more confident about their answers in each of the two adaptation types than in no adaptation. Overall, this shows that map adaptation is generally liked by users.

We were further interested in the UX of the two adaptation types. The results of the UEQ questionnaire support **H2**: the revertible adaptation performed significantly better than no adaptation at every scale except for Dependability and Stimulation. The toggable adaptation performed significantly better than no adaptation for the scales Efficiency, Dependability and Novelty.

H3 hypothesizes a lower perceived cognitive load for each of the adaptation types, compared to no adaptation. This hypothesis is supported by the results. The overall perceived cognitive workload was significantly higher for the no adaptation condition than for the revertible or toggable adaptation type.

A central goal of the experiment consisted in comparing revertible and toggable adaptation. Due to the higher degree of control offered by toggable adaptation we hypothesized that users would prefer it over revertible adaptation (**H4**). As for **H1**, the results of the user-based ranking provide strong support for this preference (75.0 % preference for toggable, 20.8 % for revertible adaptation). It may seem surprising that, although toggable is the preferred adaptation type, the button was used in only 43.7 % of the trials with toggable adaptation. In other words: participants liked that the button was there, but they used it in less than half of the times.

The structured interviews provide an explanation: asked to list pros and cons of the two adaptation types, a large majority of participants (17 out of 24) made negative statements concerning the controllability of revertible adaptation, while also a large majority (19 our of 24) stated controllability as a positive feature for the toggable adaptation. It seems that the presence of the button conveyed a feeling of being in control, and that this was perceived as an important feature of the toggable adaptation type. Examples from the interviews underline this assumption: one participant stated that *'if you fail with your task you can switch to the helping system'*, while another participant simply called the button a *'safety net'*. This finding is also in accordance with the findings of the UX analysis. There was a significant difference between the toggable adaptation and the no adaptation condition for the dependability scale of the UX analysis but not between the revertible adaptation type and the no adaptation condition. The Dependability scale is capturing controllability, *"Does the user feel in control of the interaction?"* [30].

Although the no adaptation interface (the static map) was generally disliked, we asked participants about potential positive aspects of it. 11 out of 25 participants responded that you can '*enjoy the challenge*' of solving the task without assistance, you can *'stress your mind and spatial cognition abilities'* or learn the map better. A very philosophical comment was added by one user stating that *'we loose the purpose of life, if we don't even have to try something'*. These examples show that people do see positive aspects in using their own brain when reading a map, which contributes further explanation why they did not always click the button in the toggable adaptation. Or as one participant stated: toggable adaptation '*gives me the opportunity to solve the problem myself*'. Note that this may be influenced by the fact that we did not set a time limit for the tasks since we were focussing on user experience, not on efficiency. Therefore, it is unclear whether these findings generalize to decision making under time pressure. Even people who enjoy reading maps and solving tasks on their own are likely to prefer an efficient interface over self-determination when under time pressure. This would require further experiments.

A particularly interesting finding is based on interview comments by several participants who described in a very detailed way how the revertible adaptation interrupted their cognitive processes. Examples: *'if I was about to find, and then something changed, and then I had to reassess the whole situation, then it's like I have to go through the whole situation twice'*, *'you're following a line and then something happens and you are distracted'*, *'If you're focused on something and it then pops up it is a bit annoying. Even though I was expecting, but still'*. One participant explicitly stated that this interruption made her *'feel stressed because [she] wanted to find the answer faster than the system'*. This feeling of competing with the system was not reported for the toggable adaptation. An interesting question for future work is how much users would feel interrupted for shorter recognition time thresholds.

The last-mentioned finding is related to the learning effects our adaptation types might need to deal with. Even if users do not feel they are competing with the system they might adapt their behavior once they note how the system works. For example, one participant mentioned in the interviews that *'you eventually will only look around and do nothing, waiting for the adaptation'*, another participant said that in one trial she *'pretended searching for an answer'*. A change in visual behavior, however, may lead to problems with the underlying activity classifier.

Errors in activity recognition are generally a challenge for the UX and acceptance of gaze-based adaptive map interfaces. While in this article, we used a Wizard of Oz experiment with simulated 100 % recognition accuracy, the accuracy in (potentially mobile) real-world scenarios is obviously an issue critically influencing the predictability and UX of the system. Or as one of our participants stated in the free comments section: the system *'could be very annoying if it does unpredictable stuff'*. Dealing with problems in activity recognition was out of scope of this article. However, we would argue that (mobile) eye tracking systems and gaze-based activity recognition in the wild have made tremendous progresses in the last years [52], and it is likely that even higher accuracies can be achieved in the future.

Still, a real system will need to be able to deal with recognition errors. Our results can serve as a guideline for this: if the recognition algorithm has two or more intention candidates with equally high likelihood several options to trigger an adaptation could be offered (e.g., several buttons). The likelihood and type of each underlying intention could be visualized. This would be in line with a general indication we found in the structured interviews: 5 participants suggested to make the button in the toggable adaptation more self-explanatory, i.e., it should not just be labeled 'Help me' but indicate what kind of help it would offer.

In the study design we decided to keep the button as simple as possible to be able to use the exact same button for each activity and each stimulus, thus excluding button design as a potential confounding variable. It can be assumed that, with a better (i.e., more informative) button design, the user experience of **TogA** would be even better, and that the usage rate of the button in **TogA** would increase.

As often in studies on map interaction, it is difficult to exclude the influence of the type of map and map design on our results. Would we find the same results, say, for topographic maps, or for ski maps? We cannot claim this at this point. However, based on the structured interviews, we can say that none of our 12 maps was mentioned as being particularly outstanding in terms of difficulty or visual design, which was our aim when selecting real city maps as stimuli.

Although the adaptation types were evaluated in the context of maps and gaze-based activity recognition, the findings might also be generalizable to a variety of application contexts, using also other interaction modalities for activity recognition. This generalization might not be possible for situations where other factors are crucial for decision making, e.g., wayfinding under time pressure. In that case, efficiency and effectiveness will often be more important than user experience, and trade-offs between these three measures will exist. Here, we were not interested in performance measures. Participants could take as much time as they wanted to find the solution and were not told whether the solution was correct.

8 Conclusions and outlook

Our goal was to investigate different adaptation types for map interfaces that adapt to the user's intentions, in our case based on gaze-based intention recognition. The adaptation types we analyzed were 'revertible adaptation', in which the adaptation appears automatically and can be manually reverted, and the 'toggable adaptation' in which the adaptation is offered without interfering with the user's task and can be toggled (show/hide) by an explicit user interaction. A user study with 24 participants demonstrated that the users prefer an adaptation over no adaptation at all. Between the two adaptation types tested, the findings of the UX questionnaire, the Nasa TLX questionnaire and the structured interviews, clearly suggest that the toggable adaptation type is more in line and not interfering with the user' cognitive processes while they solve a task, thus being the preferred one by a large majority of the study participants.

We derive the following design guidelines for map interface adaptation in intention recognizing interfaces:

1. Let the user be in control of the adaptation.
2. Provide more details concerning the adaptation (e.g., 'you are looking for a restaurant, would you like help?').
3. In case the recognition cannot clearly identify one activity, provide more than only one help option.

In future work the impact of time pressure and other factors that might influence decision making will be in focus. The presented findings are based on a study simulating a static situation in which users were sitting in an office environment in front of a large monitor. This should be transfered to mobile situations, e.g., when a user, while walking, is looking up information using a mobile map.

The gaze-based activity and intention recognition, which we treated as a black box here, is another field that requires further investigation. A low accuracy in the recognition component will naturally lead to a low user experience. One potential direction here is the prediction of how much disruption a certain adaptation will cause (e.g., refer to [22] for a probabilistic model of disruption). If we could predict from eye movements whether the user is going to end a task soon [24], or in which part of a particular cognitive process she is, this could be identified as the optimal moment for an automated adaptation.

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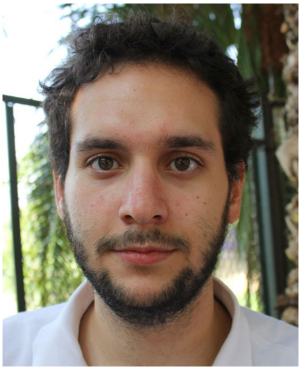

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