21 Using Web-Based 3-D Visualization for Planning Hikes Virtually *An Evaluation*

Susanne Bleisch and Jason Dykes

CONTENTS

OVERVIEW

The use and usefulness of an interactive three-dimensional (3-D) desktop application is explored in the context of evidence that landform may be understood more intuitively through realistic 3-D visualization than in traditional maps. A Web-based digital environment that combines elevation models and photorealistic imagery with additional abstract information is tested for planning hikes in the foothills of the Swiss Alps. Participants' efforts in fulfilling standard hike planning tasks are recorded through questionnaires and interviews and subsequently analyzed. The 3-D visualization is preferred over the 2-D (two-dimensional) map for tasks associated

with getting an overview, but participants requested more abstract information or additional 2-D maps for tasks involving extracting exact information. The application is more useful to those who spend a longer time using it. Problematically, participants underestimated the scale of the relief depicted. Additionally, their confidence in solving the tasks involving extracting exact information from the 3-D visualization was low, even when tasks were solved correctly. We conclude that there is scope for using 3-D visualization for effective hike planning among tech-savvy hikers, especially in combination with additional information or 2-D maps, but that this may involve some risk of underestimating the scale of the topography involved.

21.1 INTRODUCTION

A range of recently developed technologies has made it increasingly straightforward to digitally visualize information in interactive three-dimensional (3-D) forms. Realistic 3-D visualizations may be understood more intuitively than traditional maps [1,2], and distributing them over the Internet makes them accessible to a wide audience [3]. They are also popular, as demonstrated by the rapid advances and widespread uptake associated with desktop virtual reality environments or geobrowsers such as Google Earth [4] or NASA's World Wind [5]. But are these forms of representation effective when used for particular activities to help support successful task completion? And does their use lead to any particular biases or behaviors?

Geovisualization applications are frequently technology driven, but while we continue to build exciting and impressive applications the need for evaluating them in supporting particular tasks is paramount [6]. Here we address a particular need and test a desktop 3-D visualization technology in a specific context and with a predetermined and real task set. Hiking is the most popular recreational activity among the Swiss [7], and the tourism organizations and other agencies are looking for ways to promote their region and support hiking [8]. We explore the usefulness of an interactive 3-D application that provides Web-based realistic visualization in the context of planning hikes in the foothills of the Swiss Alps. Our 3-D maps are photorealistic but enhanced with abstract information that is valid to the task at hand, such as a hiking route and spot heights. The assessment of usefulness includes aspects of both utility (the tool's performance regarding a specific task) and usability (the users efficiency and satisfaction with a tool), as defined in the field of human–computer interaction design [9]. Although many different sources may be consulted when planning hikes, we test the 3-D visualization as the sole tool used in this study. Doing so enables us to evaluate its usefulness in isolation, and make inferences about its potential contribution to hike planning and the possible effects of using it as part of this process.

21.1.1 Visual Realism in a 3-D Environment: Background, Data, and Visualization

Hiking tours in Switzerland are generally planned using the Swiss National Maps 1:25,000 (LK25) which are highly detailed and reliable. Several researchers suggest that people have difficulties interpreting the kind of 3-D information that is essential for planning hikes from 2-D maps, where the information is encoded with 2-D visual variables through contour lines or hill shading [10,11]. Thus, new types of maps and maplike representations have been developed that look more similar to the real world and may be easier to decode and to understand (e.g., [12,13]). Recent advances in computer processing capabilities, graphics hardware, and data availability have led to widespread digital 3-D terrain visualization as found in Google Earth [4] or Memory-Map [14]. Dickmann [15] compares the interpretation of spatial information from a Web-based 3-D visualization and a print-based traditional map, concluding that the 3-D visualization is generally more effective in communicating the information presented. However, studies also indicate that the acceptance and utilization of 3-D cartography is relatively low among certain groups, and the effort required to learn to use it effectively can be very high when compared with the increase in knowledge achieved [2].

This investigation focuses on a digital environment that combines digital elevation models and photorealistic imagery with additional abstract information to support hike planning. We use the virtual reality (VR) technologies from Geonova AG—software tools that allow highly interactive 3-D visualizations to be generated from digital terrain models and orthoimagery, and subsequently distributed over the Internet. The elevation data used for the 3-D visualization in this study is the DHM25, the most frequently used digital height model of Switzerland with a resolution of 25 m. Our study focuses on an area in the heart of Switzerland that permits moderate hiking between 430 and 2400 m above sea level. The area is established but far from notorious among hikers, and representative of many similar regions, enabling us to compare users who know the region with those who are new to it and to generalize our results to other areas of similar geography. To facilitate the comparison, the 3-D representation contains approximately the same information as the traditional Swiss National Maps (LK25). There are some key differences, however. When on the map, the third dimension is encoded using contour lines and spot heights; this information is represented by perspective views of the digital elevation model in the 3-D scene. Lange [16] shows that draping orthoimages over terrain is the most important element for generating virtual environments that are perceived as realistic. Following Lange, we drape orthoimagery with a resolution of 0.5 m over the elevation model (Figure 21.1). This approach is typical of many of the current wave of geobrowsers. Another key difference thus relates to the way that land cover is represented. On the map it is preinterpreted and represented through coded symbols, while the 3-D visualization employs the uninterpreted orthoimagery to show land cover. MacEachren et al. [18] recommend cartographic designs for virtual environments that combine abstract and realistic representations of geographic phenomena. For this study, abstract vector information showing a hiking route, spot heights, and place name labels were added to the 3-D visualization (Figure 21.1). Similar information is available in traditional panoramic representations of tourism regions (e.g., [19]). The addition of only one specific hiking route ensures that all participants in the study refer to the same route when attempting the tasks. One significant difference relating to information content is that place names and height labels are less dense in the 3-D representation than in the 2-D LK25 so that the 3-D scene is not overcrowded with labels.

FIGURE 21.1 Monochrome reproduction of 3-D visualization used in the experiments. This example view includes a marked hiking route, place names, and height labels.

21.1.2 Planning of Hikes

The Swiss Federal Office of Sports has a program called Youth & Sport (J&S) with guidelines describing the sequence of events involved in planning a hiking tour [20]. The J&S instructions are used as guidelines for measuring the utility of the 3-D visualization for planning hikes. The map-related parts of the guidelines can coarsely be divided into three categories: getting an overview of a hiking region, which means studying maps and getting a feeling for the region and its topography; selecting a suitable route; and planning the hike in detail, for example, by checking the heights, steepness of slope, and distances. This is often an iterative process.

21.2 DATA COLLECTION AND ANALYSIS

To capture information on the way in which the 3-D visualization is used in a virtual hike planning activity and to measure task performance, we developed an experimental framework based upon established methodologies for the evaluation of visualization techniques and of virtual environments [21,22]. This involves developing plausible user tasks (see Section 21.2.1) and performing a formative evaluation by asking a representative sample of likely users (hikers and mountaineers) to complete the tasks. Their efforts are recorded through questionnaires and interviews (see Section 21.2.2), and analyzed with a focus on overall patterns and trends within particular groups. These methods of evaluation have been employed in a number of user-centered geovisualization studies (e.g., [17,23]).

21.2.1 Tasks

A number of specific tasks were designed to represent hike-planning activities by converting the guidelines from each of the J&S categories into questions. Tasks that had been designed for paper-map hike planning [20,24] were analyzed according to their information content and translated into questions that required the same information to be acquired by interacting with the 3-D visualization. For example, a height profile is created during the paper-map planning stage because this information is regarded as being difficult to interpret from contour lines in the 2-D map. The contention that realistic 3-D visualizations are more intuitive than traditional maps [1,2] suggests that information about steep sections or the highest and lowest points of a route may be visually interpreted directly from the oblique views of the 3-D visualization by interacting with the model. To fulfill the tasks, the users were encouraged to navigate around the 3-D visualization. Use of the mouse to control viewing position and to fly across the landscape was explained to all participants.

21.2.2 Questionnaire and Interviews

A series of questions about the specific tasks were designed to record activities undertaken and levels of task completion (Figure 21.3 and Figure 21.4 show task titles that summarize the questions used here). Users were also asked to record their feelings about the ease of task completion and their confidence in the results. Details about prior map reading skills, knowledge of the region, prior contact with 3-D visualization applications, and demographic status were also recorded [25]. Multiple choice questions were employed in some cases with one or more answer possibilities. Where appropriate, a "Don't know" or "Other" category was added with opportunities to provide further explanation to allow for omitted answers [26]. Short answer (closed) questions that could also be quantitatively analyzed were used for some of the tasks, for example, finding the steepest part of the hike. Open-ended questions allowed the participants to express their thoughts and feelings about using the visualization. To generate more qualitative information and to follow up on written statements, interviews were conducted with a sample of respondents [27]. This allowed us to validate our interpretations of the responses from those participants and explore some of the reasons behind them.

21.2.3 The Sample

The population sampled for the purpose of this study consisted of all people interested in hiking in the foothills of the Swiss Alps. The application and questionnaire were publicized through the Internet, through hiking Web sites, and communicated to hiking contacts via e-mail. All hikers informed about the study were asked to further distribute the information to acquaintances interested in hiking. As both the 3-D visualization and the questionnaire were made accessible over the Internet, only hikers with some IT knowledge were able to participate in the study. A subset of those who completed the questionnaire was interviewed. Producing an unbiased sample of this diverse population is an extremely difficult task [25]. The sample of the hikers reached through the methods described in this study may not be wholly representative of the background population. The findings are thus applicable only to this sample, but due to the similarities between the characteristics of those used in the sample and a section of the background population, they may be more widely relevant to hikers who are digitally aware and empowered by the Internet. These are likely to be those who use geobrowsers and to whom tourism agencies may want to promote hiking through interactive 3-D cartography.

21.2.4 Data Analysis

Quantitative data were analyzed graphically and, where appropriate, with statistical comparison techniques to investigate possible differences in successful task completion among gender, occupation, age, prior technical experience with 3-D visualizations, self-reported levels of map reading ability, previous knowledge of the study area, and time spent on the tasks. The data from personal feedback, open-ended questions and the interviews were analyzed in part through quantitative techniques, but predominantly through qualitative methods including content analysis [28]. The qualitative data was used to contextualize and interpret the quantitative findings.

21.3 RESULTS AND FINDINGS

Approximately 600 people were informed about the study and 99 participants completed the questionnaire. A further 68 people did not fill in the questionnaire completely or provided other forms of feedback, such as not being able to access the 3-D visualization or feeling motion sickness when navigating. The questionnaire reached people from a full range of ages and about a quarter of the participants were women. Notably, most participants claimed to have very good or good map reading skills. More than two-thirds of the participants stated that they had come into contact with 3-D visualizations prior to the study, perhaps suggesting a bias in the sample that may be associated with the Internet-based nature of both the software used and the dissemination techniques employed. More than half of the participants (58%) did not know the region. Qualitative statements from the open-ended questions in the questionnaire and interviews were used to triangulate the quantitative data obtained through the questionnaire.

21.3.1 Getting an Overview of a Region

Responses to tasks associated with the first of the J&S hike-planning categories are summarized in Figure 21.2. They show that 56% of the participants preferred the realistic 3-D visualization over the map for the task of getting an overview or an

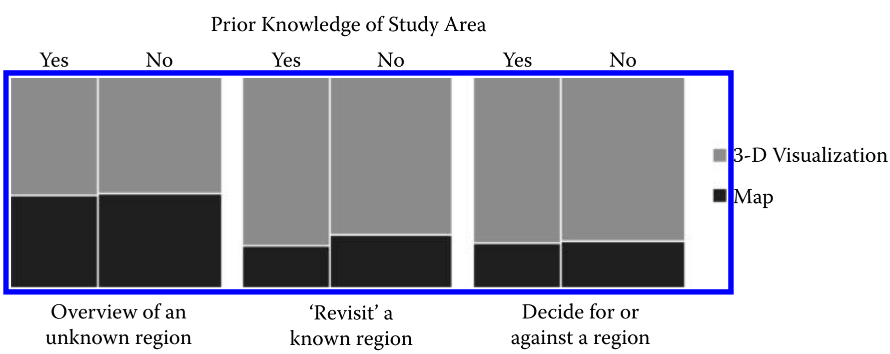

FIGURE 21.2 Three-dimensional visualization or map preferences subdivided by prior knowledge of the study region (graphic area per task = 100%).

impression of an unknown region (41% of these with and 59% without prior knowledge of the region). For virtually "revisiting" a known region, 76% of the participants preferred the 3-D visualization (43% of these with and 57% without prior knowledge of the region). Also, 78% preferred the 3-D visualization for helping with the decision as to whether to visit the region for hiking (41% with and 59% without prior knowledge of the region). These results suggest that users without prior knowledge of the study area have a stronger preference of using the 3-D visualization for any of the three tasks. However, employing a chi-square test reveals that these differences are not significant at the 0.05 level. The possible advantages of the 3-D visualization over the 2-D map for this stage of hike planning are evidenced through the content analysis, which highlighted a sizable number of positive statements about hike planning using 3-D: "It is faster to get an overview of a hike (where does it lead through) or region with the 3-D visualization"; "It is possible to know what the views from a specific point on the hike will be"; "It is more intuitive to comprehend the topography of the region."

21.3.2 Selecting a Suitable Route

The second stage of hike planning involves selecting a suitable hiking route by detecting possible tracks on the orthophoto draped over the digital elevation model (DEM). About 56% of the participants were able to locate routes along streets and clearly visible paths. Another 15% located concealed or less visible paths such as those across pastures or through woodland. For selecting routes, 68% of the participants prefer to use the traditional map. However, 12 participants mentioned that this would change in favor of the 3-D visualization if more than one hiking route was included in the visualization. This coincides with participants' statements indicating that the orthoimagery is difficult to interpret by itself for exact information extraction tasks as, in contrast with most traditional 2-D maps, the realistic content is not preinterpreted and highlighted by cartographers. This supports the contention of MacEachren et al. [18].

21.3.3 Extraction of Exact Information

The participants were asked to gather exact information, such as heights, lengths, steepness of slope, and information about the nature of particular features from the 3-D visualization. These tasks are representative of the third stage of the J&S guidelines. Figure 21.3 shows that tasks that are completed using additional abstract information are solved most successfully. For example, the highest or lowest points can be extracted directly from height labels in the 3-D visualization. This corresponds with qualitative feedback on the importance of the height labels in the 3-D scene.

Tasks like estimating the length of a hike section or finding the steepest section of the hike were rarely solved satisfactorily in the 3-D visualization. Only 22% of the participants estimated the length of a 3 km section of the hike to within ±500 m.[1] On

[1] This is not a level of error that is generally regarded as being acceptable. We were unable to find a source that provided a standard distance. We derived this figure by calculating hiking time (based on the formula of 4 LKm/h [25], 1 LKm is either 1 Km distance or 100m height difference upwards) and deciding that spending 7.5 minutes (equivalent to 500m) more or less time to hike the section was acceptable. Some sensitivity analysis of the effects of this assumption would be appropriate.

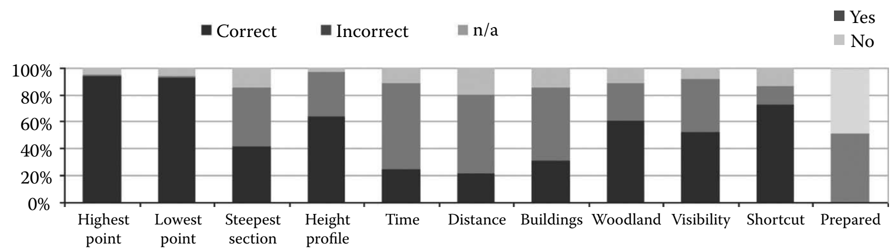

FIGURE 21.3 Extraction of information. Spot heights were labeled in the 3-D visualization; the questionnaire contained four graphical height profiles that could be compared with the visualization.

average they overestimated the length of the section by 700 m (23%) with a high standard deviation of 1.5 km. One or both of the two steepest sections of the hike were identified by 41% of the participants. These findings further support the suggestion that ancillary information, such as distance or height information or measuring tools, is needed when using realistic environments to help the successful completion of some tasks that are deemed essential in planning hikes. One clear trend was identified: 58% of the incorrect answers to the question about the steepest section selected the longest steep section, but this did not contain the steepest slope as measured between adjacent cells at a scale equivalent to the resolution of the DEM. The finding that a minority of participants was able to identify the steepest section at this scale may be surprising as 3-D maps are believed to be understood more intuitively. Such judgments may relate to the fact that slope is a scale-dependent property. This suggests that although the form of the landscape might be understood, the nature and scale of its variation may not be interpreted accurately or effectively from the 3-D visualization. Alternatively, participants may have used their experience of longer shallower sections being harder to hike than the short steeper sections in completing this task. The content analysis of our qualitative data identified three statements in support of this interpretation, noting that it is difficult to estimate the steepness of slopes in the 3-D visualization. Our data also show that those who solved the different tasks of extracting exact information from the 3-D visualization correctly were not confident that this was the case, associating considerable uncertainty with this task.

The conflicting overestimation of distance and likely misinterpretation of slope and the associated uncertainty suggest some difficulties in effectively planning hikes using the 3-D visualization software evaluated here. It is important in this context that even though almost all participants were unable to use the 3-D visualization to extract exact information with confidence, 51% of them felt sufficiently prepared to go hiking having used the 3-D representation. These possible misinterpretations could have serious consequences. More than half of those 51% who stated that they felt sufficiently prepared also indicated that they did not have prior knowledge of the hiking area.

The participants were asked what they thought was missing from the 3-D visualization. About 71% suggested additional abstract height, time, and/or distance information in forms such as labels, contour lines, reference grids, or measuring tools, highlighting the need for additional abstract information and functionality to support specific tasks. Others desired additional functionality such as hotel or travel information or the automatic generation of height profiles. As neither of these features can be found in the traditional map it seems that the new technology has resulted in demands for new functionality and possibilities in general. But as shown by the rather poor task performance (see Figure 21.4), it also seems that the participants were not able to satisfy their information needs for hike planning from a 3-D visualization environment consisting solely of a DEM with draped orthoimagery and limited abstract ancillary information. The widely accessed geobrowsers discussed in Section 21.1 consist predominantly of precisely this combination, and our findings therefore suggest that solely using such tools for hike planning may be problematic.

21.3.4 Differences between User Groups

The tasks were evaluated in the light of differences between subgroups of participants using chi-square tests at a 0.05 significance level. Tests for differences between gender, occupation, age, and prior technical experience with 3-D visualizations suggested some trends but revealed no significant differences in relation to any of the findings reported above. Significant differences were found for some tasks when users were categorized according to completion time. Figure 21.4 shows that participants who spent more time with the 3-D visualization solved many tasks more successfully. The group with prior technical experience of 3-D visualizations also

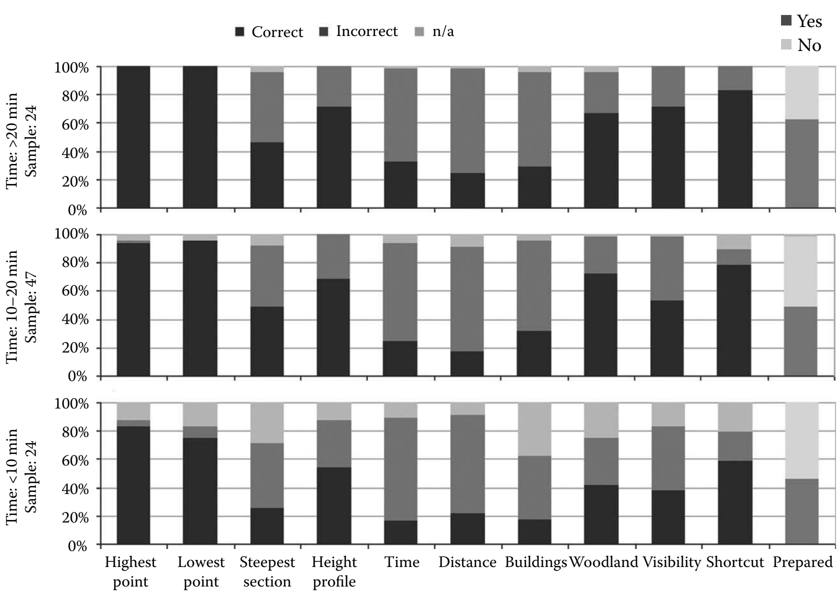

FIGURE 21.4 Hike-planning tasks by the time spent answering the questions. A trend toward higher proportions of correct answers among participants spending more time with the 3-D visualization is shown. This trend is significant for finding the lowest point, the steepest section, the number of buildings, the woodland, and the intervisilibity. Participants who spent more time with the 3-D visualization also feel better prepared for the hike.

solved some of the tasks with more success than the group without, though this was not a statistically significant difference. These results at least suggest that those who are more familiar or spend more time with 3-D visualizations (which may indicate a greater willingness to become familiar with the application) may find them more useful. Another trend relates to those who regarded themselves as having less accomplished map reading skills. This group of nine participants is a small sample of users, but their poor performance in the tasks warrants further investigation. Despite their inability to successfully complete the preparation tasks, this group felt best prepared for going hiking after completing the tasks in comparison to all other groups (e.g., in comparison with the group with more advanced map reading skills and also those groups relating to gender, age, completion time, etc.). It is interesting that the questionnaire data contained 13 statements from participants who mostly consider themselves as being proficient map readers suggesting that realistic 3-D visualizations might be most useful for moderate or poor map readers.

Evaluating the task performance of those with previous knowledge of the study area and those without yields almost no differences between these two groups. Only the task involving identifying the location of the steepest section seems to benefit slightly from prior knowledge of the area.

21.4 CONCLUSIONS AND OUTLOOK

Some sections of the public seem extremely interested in the new possibilities associated with planning hikes virtually. The findings reported here suggest that Web-based 3-D visualizations that combine realistic and abstract information may be helpful additions to the paper map for some when planning hikes, but as implemented for our tests in the Geonova AG software are not suitable replacements. We also identify some possible risks associated with hike planning using 3-D visualization software. Although use of the visualization software was not directly compared to use of the LK25 in this study, the experienced hiker seems to base their judgments of the usefulness of the 3-D visualization for planning hikes according to this comparison. This argument is supported by a number of related statements such as "Nothing will ever be able to replace the LK25" or "I would never plan a hike without the LK25." We note that the methods employed here, whereby participants were asked to self-report their task performance, may lead to statements that do not reflect the true value or usefulness of the 3-D visualization [25].

The 3-D visualization supported overview tasks more successfully than those involving route detection and planning, whereas the extraction of exact information relied upon abstract symbols and labels rather than realism. However, it appears that the usefulness of 3-D visualization may improve when users spend longer with the application (Figure 21.4). In combination, these findings also suggest that more intuitive understanding may conceal some important misinterpretations and false impressions and support the suggestions of MacEachren et al. [18] that realistic and abstract information should be combined. The qualitative information collected also indicates that the technologies employed can result in some frustrating impediments, such as not being able to install the software or experiencing computer crashes; the cited advantages are of course dependent upon being able to access the 3-D application and getting it to work (see Section 21.3).

Three-dimensional visualizations are likely to become more available, more realistic, and more important in the near future, and perhaps the obstacles will be reduced. However, to be usable by the public, careful design is required that is appropriate for specific tasks and the combination of realistic and abstract information is key. Effective interaction design, supported by usability evaluation, should be considered an equally important factor as traditional cartographic design [30]. The suggestion that participants in this experiment underestimated the scale of the relief depicted in the 3-D visualization, which appeared small and controllable, needs further research due to the potential dangers involved in underestimating hazards when planning hikes. Gradient is scale dependent and the question about steep slope made no assumptions about measurement scale. The selection of a less steep, larger-scale feature by many participants, rather than a steeper, smaller-scale slope adds weight to the argument that users of desktop VR may underestimate the scale of the features with which they are interacting. In this sense, photorealistic 3-D environments may be virtually unrealistic. We also identify some inconsistencies between the ways in which users think that tasks have been completed when using 3-D visualizations and actual successful task completion. This may be related to the trend noted by Appleton and Lovett [17] who found that people self-report being better able to imagine the landscape and relate to the 3-D visualization with increased levels of detail. These issues are important in applications of visualization that are associated with significant safety issues and should be of particular concern to those promoting hiking using the kind of 3-D landscape interfaces evaluated here.

The findings draw attention to a number of opportunities for further research. We may be able to identify groups of tasks or users for which/whom 3-D visualizations may be a better choice than 2-D representations, or usefully enhance 2-D displays in combination. The result that participants predominantly prefer the 3-D visualization over the 2-D map for tasks concerning getting an overview, but request more abstract information or the use of the 2-D map for extracting exact information, indicates that a combination of 2-D and 3-D representations may be sensible. Thus, each visualization type may be used for the tasks for which it is most useful. Our continuing research examines how abstract information can best be combined with and represented in 3-D environments that are designed to look realistic. Preliminary results show that users are not significantly influenced by topographic information such as distance or elevation differences when comparing the heights of abstract symbols in virtual environments. Further research may include the exploration of scale in 3-D desktop-based landscape visualizations. Using larger surveys with more varied terrain may allow exploring whether responses and task completion success varies not only with the familiarity or the time spent with the application, but rather with the environment (e.g., terrain variability, route length, height discrepancy).

The participant's requests for more abstract information and functionality could be taken into account (for example, by using more abstract or preinterpreted draped imagery instead of the orthoimagery). Related to this, other researchers are investigating the use of (photo)realism as a visual variable [31]. A different study [32] has shown that draping a digital terrain model with a 2-D map or leaving it undraped does not influence the estimation of walking times or of gradients. Employing more abstract information or combining 2-D and 3-D visualizations may result in users who are more confident in their findings. Research undertaken on the technical and human aspects of using 3-D visualizations with additional abstract information in the field (e.g., [33,34]) may also help in making 3-D visualizations more useful as a hike-planning tool. The assessment of the risks resulting from overestimating distances, underestimating the size or steepness of landscape features, or poor map readers feeling prepared for going hiking is an important area for additional research.

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