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How Do People View Multi-Component Animated Maps?

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Quite a few examples in the cartographic and information visualisation literature suggest that multi-component animated maps may be appropriate for examining complex spatio-temporal phenomena. Such space–time visualisations typically consist of multiple dynamic map or data windows, linked by means of interactive tools. Little empirical evidence exists, however, providing support of the potential advantages of such complex visual space–time displays. This research aimed at filling this gap.

An empirical study was carried out to obtain insight on how multi-component animated maps are used to explore dynamic spatio-temporal phenomena. We examined which particular components attract users' attention and in what sequence, and whether display effectiveness can be characterized by users' viewing behaviours. Based on behavioural data collected with the eye-tracking method, we find that component size, and employed dynamic variables attracted users' attention most. We are also able to identify visual behaviour patterns that result in performance differences between participants, using multi-component animated map. Finally, we highlight component layout design issues that should be further examined empirically, in order to reduce potential split attention effects.

Keywords: multi-component animated map, multi-component dynamic cartographic display, cartographic animation, eye-tracking, map usability

INTRODUCTION

When investigating complex geographic phenomena and highly dynamic environmental processes such as Arctic shrinkage, or the impact of oil spills on the environment, various physical and human factors have to be examined to uncover latent associations, and to better understand analysed processes. For such studies, map-based tools are often employed, for inference making, knowledge discovery and knowledge communication. Multi-component animated maps or, to be more precise, multi-component dynamic cartographic displays (MCDCD), seem to be a suitable choice when examining complex multivariate, spatio-temporal data. MCDCDs typically consist of main map window, complemented by supplementary display components offering additional views on the same data, or additional datasets. One can imagine an animated interactive map in the main window, linked to additional static or dynamic maps, charts, diagrams, cross-sections, 3D views, etc. All windows are linked by means of interactive tools.

How many components should be included in a MCDCD will probably depend on the theme of the investigation, and the inference and decision-making tasks the MCDCD should support. However, the number of display components cannot be limitless, as user's limited perceptual and cognitive capabilities have to be taken into account (Opach, 2005). The question arises then how component quantity and display design might interact with cognitive load of the user (Harrower, 2007). It is not clear how multi-component visualisations might support spatio-temporal inference making, due to the potential additional perceptual and cognitive challenges like 'change blindness' (Simons and Levin, 1997), when having to track multiple items jointly in different parts of an interface.

For example, split attention is a common problem when a map reader needs to look at two or more display elements at once, in order to integrate and understand the information provided by different parts of the interface. Even if an animated map has only one component (i.e. a single-display animated map), split attention is still a problem, as information separated across time needs to be mentally integrated (Hegarty, 1992).

In the research reported in this paper, we address the question whether information acquired from different map components is perceptually and cognitively integrated when viewing MCDCDs. Thus, the empirical assessment of the

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Description:

In this scenario map user is provided with following components: the main animated map, geographic context, selectable cross-sections and diagrams presenting information about environmental conditions. Map user is able to analyse spatial changes simultaneously with analysis of changes of climatic conditions and geomorphologic processes as well.

Figure 1. The opening window of the Kampinos Forest animated map (A) allows users to choose the most appropriate map scenario, i.e. the set of components, static and dynamic. For instance, in the third scenario (B), map user is able to view simultaneously main animated map, small animated map, animated cross-section and timeline with information about climatic conditions (http://www.geomatikk.ntnu.no/prosjekt/KampinosForest/)

effectiveness of such MCDCDs, including the potential split attention challenge, is the main aim of our study. The analysis of users' eye-movement behaviour seems to be particularly relevant concerning effective and efficient multi-component layout design.

BACKGROUND AND RELATED WORK

Multi-component approach for presenting geographic phenomena

The single-static-map visualisation strategy (Bertin, 1967) is sometimes not enough to gain insights into highly complex, dynamic phenomena (Andrienko and Andrienko, 1999). In such circumstances, the multi-component visualisation approach seems to be a valuable solution (Roberts, 2005). Multi-component animated maps have been already identified in prior cartographic studies. Monmonier (1992) proposed the concept of dynamic cartographic sequences called 'graphic scripts'. These sequences were composed of maps juxtaposed with statistical diagrams and blocks of text for visual exploration of temporal patterns and geographic correlations. This idea is also apparent in the GeoVISTA Studio software encompassing several multi-component applications that support spatial data exploration (Takatsuka and Gahegan, 2002; Hardisty, 2009) and some modules contain animated displays (Hardisty *et al.*, 2001). The Atlas Information System (Jenny *et al.*, 2006) or the Multimedia Atlas Information System (Hurni, 2008) are other examples of the multi-component visualisation products with predefined map themes linked to other data displays that may include animations (Oberholzer and Hurni, 2000).

Besides mentioned projects broadly discussed in the literature, many other cartographic or semi-cartographic applications have been introduced, both academic and commercial. For instance, the Gruben Glacier (Switzerland) project (Isakowski, 2003) features the multi-component approach, including animation. This well-designed product comprises an animated map and interactive diagrams. The prototype of the multi-scenario and multi-component animated map of the Kampinos Forest genesis (Opach *et al.*, 2011) may serve as another example (Figure 1). In this project, various visualisation techniques have been employed in order to depict palaeogeographic changes of the Kampinos Forest landscape (a geographic region in the centre of Poland) between 20,000 and 10,000 years BP. From the private sector, the product called Panopticon (http://www.panopticon.com/) offers interesting functionality, similar to already mentioned GeoVISTA Studio.

Visual attention and multi-component cartographic displays

Multi-component dynamic cartographic displays offer both advantages and weaknesses. On the one hand, they allow map makers to visualize potentially very large time series datasets by means of one map interface. On the other hand, due to high level of conceptual and graphical complexity, they may be difficult to read. According to various authors (Harrower and Sheesley, 2005; Harrower, 2007), split attention is one of the most significant issues that should be addressed when animated maps are designed and used. It is a challenge to overcome for any user whenever information from disparate sources has to be processed simultaneously (Harrower, 2007).

Visual attention is guided by a bottom-up saliency map, and top-down task relevance of all locations in the viewed scene (Itti and Koch, 2001; Navalpakkam and Itti, 2005). The saliency map reflects conspicuity at every location in the visual input. Several visual features, known in cartography as Bertin's visual variables, influence a feature's saliency in the visual scene, such as colour, intensity, orientation (Itti and Koch, 2001) and movement (Andrade *et al.* 2002). The saliency of a location is determined in the context of other objects in the visual scene (Fectau and Munoz, 2006). A topographic attention guidance map is based on the interaction between the salience of stimuli in a visual field (i.e. saliency map) and task relevance, encoded in working memory. This map maintains information on spatial and visual aspects of conducted tasks (Findlay and Walker, 1999; Navalpakkam *et al.*, 2005; Factau and Munoz, 2006). According to the 'winner-takes-all' principle (Itti and Koch, 2001), the map reader selects one object with the highest visual priority which is then cognitively processed.

Consequently, in the case of MCDCD, when a viewer's attention is attracted by many potential locations within the visual field, the hierarchical structure of visual salience within the scene is essential. Similarly, this hierarchy should match the thematically organized task relevance map (Tarnowski, 2009). For this reason, users' viewing behaviour analysis may reveal possible design problems in multi-component displays.

EMPIRICAL STUDY

We designed an empirical study to examine how multi-component animated maps are viewed. The following issues questions guided our research:

- How and where do users allocate their attention when viewing a multi-component animated map display?
- Which components attract users attention and when?
- Are there different viewing strategies identifiable across individuals?

The eye movement data collection technique was applied to answer these questions. According to the 'mind-eye hypothesis' (Nielsen and Pernice, 2010), people tend to look at things they are thinking about. Consequently, map users tend to attend to interface components they are thinking about. Peripheral vision does also play a role, for example, with respect to bottom-up saliency assessments of features in a visual scene. The acquisition of detailed information and object identification of selected locations in a visual field is carried out in foveal and parafoveal vision (Liversedge and Findlay, 2000). Eye fixations are thus located mainly on the objects with the highest priority, according to the bottom-up saliency map and top-down task relevance map.

The use of eye tracking as an empirical research approach, and the analysis of eye movement patterns captured during map reading process, have been already discussed in the context of cartographic visualisation (Steinke, 1987; Montello, 2002). The eye tracking technique has been already recognized in the cartographic community as a useful, and a relevant solution for examining usability aspects of both static maps (e.g. Jenks, 1973; Vanecek, 1980; Chang *et al.*, 1985; Brodersen *et al.*, 2002; Fabrikant *et al.*, 2010), and dynamic and/or interactive map displays (Heil, 2009; Opach and Nossum, 2011). As this empirical technique provides information about user's visual behaviour in an unobtrusive manner (Fabrikant *et al.*, 2008; Henderson and Hollingworth, 1998), a variety of human–map interaction issues have been investigated with this method. For instance, Garlandini and Fabrikant (2009) have been recording eye movements in order to investigate the efficiency of visual variables for geographic information visualisation. In other studies, Çöltekin *et al.* (2009) have employed eye-movement analyses while considering two informationally equivalent, but differently designed interactive map interfaces, whereas Ooms *et al.* (2010) have tackled map labelling issues with this approach.

Although methodological aspects of the eye tracking technique have been widely presented in literature (Rayner, 1998; Duchowski, 2007; Nielsen and Pernice, 2010), there is still a shortage of clear methodological guidelines for conducting eye movement research on cartographic displays (Opach, 2011).

Study design

We designed a MCDCD of a fictitious forest fire to investigate how participants manage their visual attention when viewing this spatio-temporal phenomenon. Millions of dollars are spent for fire prevention and rehabilitation every year. Especially damaging are uncontrolled burning fires in wild, which might cause damage not only to forestry but also agriculture, infrastructure and buildings lands (Guha-Sapir *et al.*, 2012). Different strategies targeted at wildfire prevention can be employed; however, getting knowledge about mechanisms of this extreme disaster should be perceived as a fundamental task. As map animations provides a useful analysis platform for hypothesis generation when analysing wildfires (Kim *et al.*, 2006), a multi-component map-based display system seems to be suitable for research on the perception of multi-component animated maps. We developed our test application using Adobe Flash technology and we called it the Forest Fire Visualisator.

Materials

A scheme of our MCDCD and its three frames are shown in Figures 2 and 3. respectively. The multi-component display is composed of three maps, two animated (Figure 2A and B) and one static (Figure 2C). The largest map component, covering 52.4% of the display area, presents the animated progression of a fictitious fire overlaid on a satellite image (Figure 2A). This window is supplemented by a second animated map display (18.4% of the display area), containing a synchronized animation of the direction and speed of the wind during the fire (Figure 2B). A third, static display (Figure 2C) presents the land cover of the fire area (18.4% of the display area). A timeline (10.8% of the display area) is located at the bottom of the largest map (Figure 2D).

Participants

Twenty-three participants (female=9, male=14, average age=28 years) recruited from the Department of Geography at the University of Zürich, (one participant declared other affiliation) took voluntarily part in the study. Participants were not given any financial recompensation. None of the participants indicated to be colour-blind. In terms of map use expertise, 8 participants (35%) stated to use maps sometimes and 15 participants (65%) use maps very frequently. All participants use printed paper maps in their leisure time, mainly when travelling, and during outdoor activities. Nine participants (39%) stated that they sometimes played video games. We also asked participants

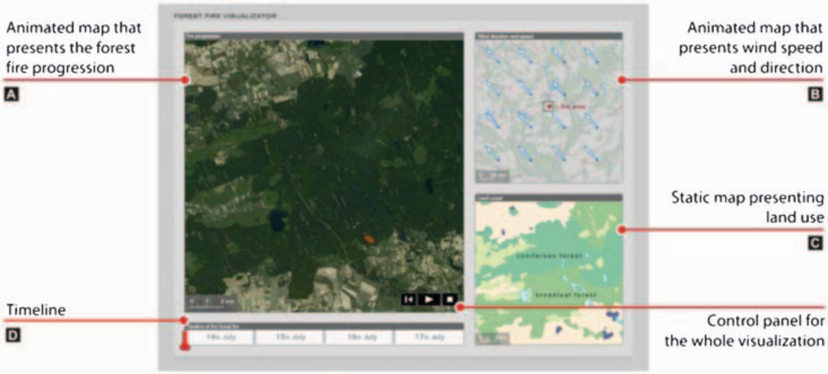

Figure 2. A screenshot demonstrating the Forest Fire Visualisator used in the research

to rate their level of training from 1 (no training) to 5 (proficient) in cartography, GIS and computer graphics. Participants, not surprisingly, showed a high level of training in these fields, with the average scores being 3.7 and 3.8 for cartography and GIS, respectively, and with 3.3 on average for training in graphic design and fine arts. Participants also reported high level of experience with the employed operating system (MS Windows 7), the Internet browser (Mozilla Firefox) and graphics use in general. The participants had a choice for running the test in either German or English. Only five participants (22%) are non-native speakers in either of these two languages, but all declared to be fluent in English.

As the Forest Fire Visualisator is intended to support decision-making processes, it is rather directed towards users skilled in map use and interpretation. We have found the participants attending our study to fulfil those expectations. The tested individuals were quite homogeneous regarding the background and featured a moderate variety of skills that might reflect diversity amongst potential users of MCDCD.

Set-up

The experiment was conducted in the Eye Movement Lab of the Geographic Information Visualization and Analysis unit of the Geography Department at the University of Zürich. The Tobii X120 eye-tracker running on a Windows 7 workstation was used for the eye movement data collection, running the Tobii Studio software. The stimuli were displayed on a 20-inch colour flat screen at a 1600 × 1200 screen resolution, and 24-bit colour depth (True colour). The survey instrument was delivered digitally in a web browser.

Procedure

After welcoming participants to the Eye Movement Lab, they were told about the general goal of the study by the first author leading the experiment. Before the test, participants signed a consent form, and filled in a paper and pencil background questionnaire. Then participants' eye movements were calibrated with the eye tracker. All other experiment instructions and stimuli were presented in a web browser.

At the beginning of the digital portion of the test, participants were informed schematically about the multi-component display, as shown in Figure 4. It enabled them to familiarize with the test environment. Following that, they were asked to view the entire animation without any particular purpose, which means without further instructions or interaction. We chose this so-called free examination task (Yarbus, 1967) as it enables to gain insights on how users intuitively direct their attention to the various displayed components, perhaps mostly driven by bottom-up, stimuli-driven processes (i.e. saliency, design, etc.). It was of great importance to recognize modules they focus on and to diagnose the order they perceive the presented information. Next, participants were asked to play the animation once again. This time, they were told specifically to 'look at all components of the display'; however, they were not told that they would have to answer the questions

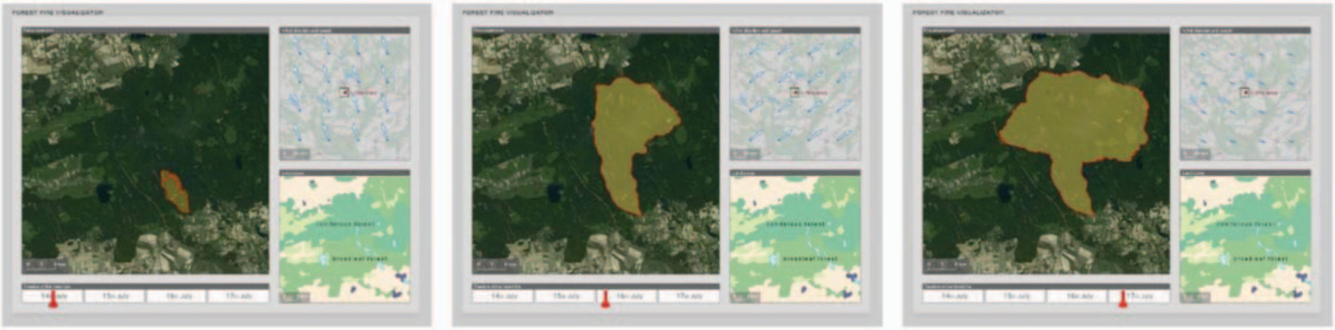

Figure 3. Three exemplary frames of the map stimulus used in the research

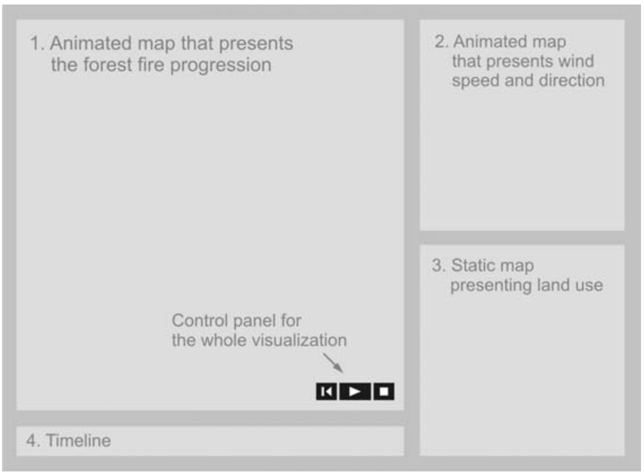

Figure 4. Scheme of the map stimulus

after the second viewing event. Owing to that procedure, a viewing behaviour of the second goal-directed viewing task could be later compared with the free-viewing task. The procedure was composed of two viewing sessions since the presented spatio-temporal data were quite complex, and thus, it would have been difficult to discover and memorize all the information presented in only one animation viewing session. The first viewing of the animation was thus also intended to be a 'practice session', to further assess the effectiveness of this kind of data visualisation for inference making.

At the end of the second animation, participants were asked to answer six closed questions (Q1–6), as shown in Table 1. These questions were designed such as to cover the information presented in specific components (Q1 linked with component B, Q2 with component A and Q3 with component C), as well as to investigate how participants could integrate the depicted information across two components (Q4 – component A and B, Q5 – component A and D, Q6 – component A and C). Participants' response accuracy could then be further used to compare the effectiveness of applied visual behaviour strategies. At the end of test sessions, we thanked every person for attending the research. Total completion times were approximately 20 min.

The questions posed after the second viewing were intended to be easy-to-understand and easy-to-link to the content of specific components. We were therefore trying to minimize possible doubts resulting from potentially misleading nature. We have done so by asking about the main features only which might be clearly recognized when viewing the Forest Fire Visualisator. For instance, in question Q3, we asked the individuals to answer which sentence described the land use most accurately. Since the possible answers were about the areas of the coniferous forest and the broadleaf forest, we assumed that the

Table 1. List of questions and their response options. Underlined responses are the correct answers

Q1	Which sentence describes the wind speed and wind direction most accurately?	a. very strong wind all the time, wind mainly from north b. changeable wind speed, wind mainly from south c. light breeze, almost always from east d. I don't remember/I don't know/I haven't noticed
Q2	Which sentence describes the forest fire progression most accurately?	a. at the beginning very slow, later fast b. the progression is more or less of constant speed c. at the beginning very fast, later slow and fast again at the end d. I don't remember/I don't know/I haven't noticed
Q3	Which sentence describes the land use most accurately?	a. the region is covered mainly by the coniferous forest b. the region is covered mainly by the broadleaf forest c. the area of the coniferous forest is similar to the area of the broadleaf forest d. I don't remember/I don't know/I haven't noticed
Q4	Which sentence describes the relation between forest fire progression and wind direction most accurately?	a. fire progression is strictly related to the wind speed and wind direction all the time b. wind influences fire progression but at the end of the animation that relationship is not so evident and not easy to notice c. although the fire progression is dependent on the wind speed and wind direction, there are moments when that relationship is not visible d. I don't remember/I don't know/I haven't noticed
Q5	When did the direction of the forest fire progression change?	a. 14 July b. 15 July c. 16 July d. I don't remember/I don't know/I haven't noticed
Q6	Which sentence describes the relation between the fire progression and the land use most accurately?	a. the progress of the fire is more intense in the coniferous forest b. the progress of the fire is more intense in the broadleaf forest c. in this case it is hard to say whether forest type affect the fire progression d. I don't remember/I don't know/I haven't noticed

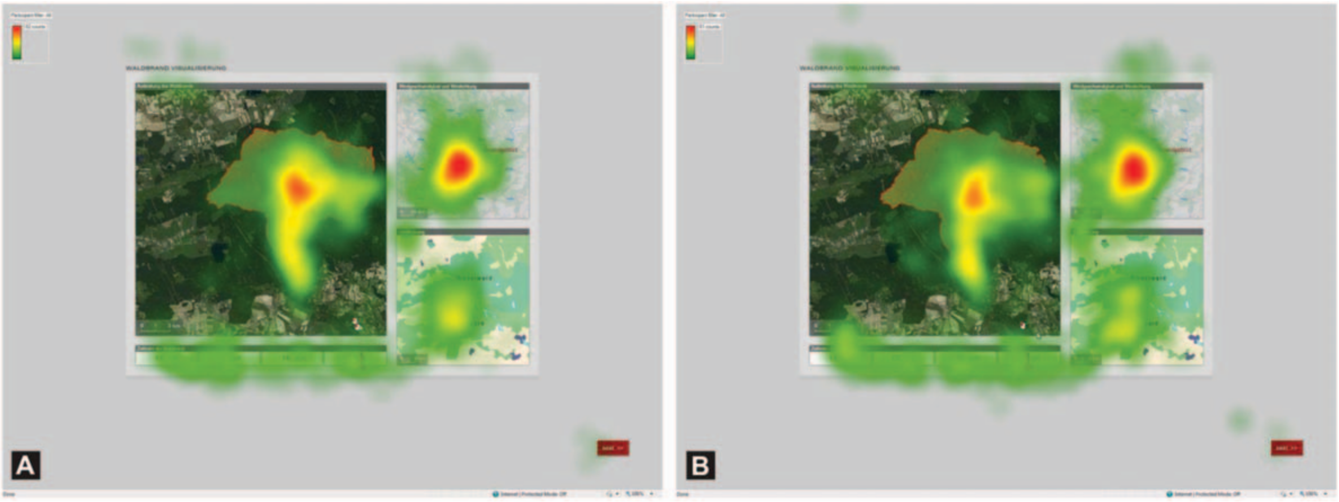

Figure 5. Kernel density surfaces showing the aggregated gaze patterns during (A) the first, free viewing task and (B) the task-oriented second viewing

participants would find it to be easy to answer. In other words, we were not asking about details or relationships that might be latent or not clear for the individuals.

RESULTS

Areas of interest (AOI) analysis

Owing to the technical problems, three participants had to be excluded from the analysis. That decision resulted from the quality issues of the eye movement recordings that we encountered twice since the sensor could not find the position of the eyes. Moreover, once we had to restart the web browser during the user testing. Hence, the results presented are based on the data of twenty participants, who completed all stages of the research (female=6, male=14).

In order to systematically analyse participants' viewing behaviour, we delineated AOI zones for each of the components in the multi-component display, as listed in Table 2. The table shows percentage of the map interface, overall mean fixation durations and percentage of the total fixation duration for each component and viewing event.

Figure 5 demonstrates participants' aggregated fixation locations for the first (Figure 5A) and the second (Figure 5B) viewing event of the animated map display, using a kernel density surface overlaid onto the map stimulus. The fixation filter threshold was set to a radius of 35 pixels, and minimum fixation duration was set to a period of 100 ms (TobiiStudio User Manual, 2010). The elongated yellow area following the fire path in Figure 5A suggests that participants visually followed the fire progression over time, although there has been no instruction given. It seems that, indeed, participants divide their attention across multiple components, as Table 2 and Figure 5 suggests.

When viewing the multi-component animated map for the first time, individuals intuitively divided their attention onto each component (Figure 5A) but with varying lengths. Participants spent 57.1% of their total fixation duration on the component 'Fire progression' (covering 52.4% of the map interface), 24.0% looking at the 'Wind speed and direction' component (18.4% of the map interface), 9.2% looking at the 'Land cover' component (18.4% of the map interface) and finally, 9.7% of their total fixation duration on the 'Timeline', covering only 10.8% of the multi-component interface. During the free-viewing portion of the experiment, visual importance based on surface area might explain participants' attention patterns. Additionally, the fact that the static map 'Land cover' yielded half the fixation duration, than the equally-sized animated map presenting the wind characteristics, suggests that motion, as predicted in the literature (Wolfe and Horowitz, 2004), indeed attracted viewers' attention.

Table 2. Total fixation duration for the individual display components

		First viewing event: total fixation duration			Second viewing event: total fixation duration		
Component	% of the map interface	Mean (ms)	Standard deviation (ms)	% of total fixation duration	Mean (ms)	Standard deviation (ms)	% of total fixation duration
Fire progression	52.4	18,557.5	4842.3	57.1	13,907.8	3917.1	43.8
Wind speed and direction	18.4	7784.3	2358.8	24.0	8995.7	3237.3	28.3
Land cover	18.4	3003.2	2071.7	9.2	5062.2	5094.0	16.0
Timeline	10.8	3158.9	1918.6	9.7	3776.6	1947.3	11.9

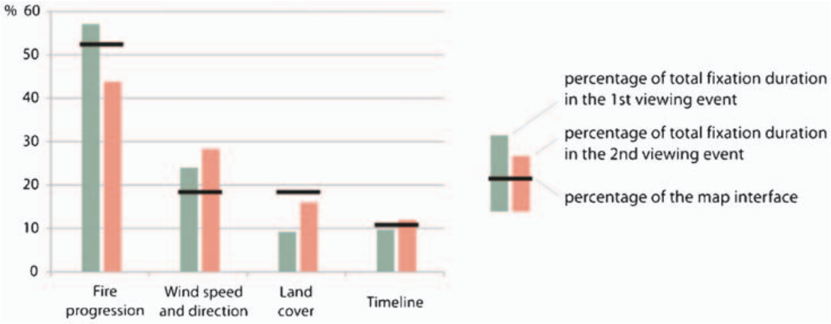

Figure 6. Percentages of the map interface and the total fixation duration per map component

The second viewing event also resulted in divided attention across display components (Figure 5B), as specifically required by the experimental task (to look at all components of the display), and similar in a visual behaviour to the first free-viewing task (Figure 5A). Again, the largest component 'Fire progression' yielded the longest fixation duration as shown in Table 2 (43.8% participants' total fixation duration). Furthermore, participants spent 28.3% of their total fixation duration looking at the 'Wind speed and direction' component, 16.0% looking at the 'Land cover' component and finally, 11.9% on the 'Timeline'. Although overall similarities between two viewing events are apparent, the gaze pattern in the 'Fire progression' module (Figure 5B) is not so coherent with the progress of the fire, compared to the first viewing (Figure 5A), since the 'gaps' appear within the core of the gaze pattern.

We can identify significant differences when comparing the fixation durations for each component across viewing events, as shown in Table 2. The fixation durations per component were subjected to a dependent t-test for paired samples. Participants viewed the 'Fire progression' component significantly shorter during the second task-based viewing event, $t(19)=4.20$; $P<0.001$; Cohen's $d=0.93$, compared to the first, free-viewing event. The other apparent viewing differences in fixation duration were not statistically significant.

In general, the percentages of total fixation duration per map component follow the size distribution of the display area they cover. However, some interesting remarks can be revealed when comparing the percentage of the total fixation duration with the percentage of the display area per one component. As shown in Table 3, during the first viewing event, participants focused their attention the most on the 'Wind speed and direction' component compared to the percentage of the display area it covers (score 1.30). On the other hand, they spent relatively small amounts of their fixation durations looking at the 'Land cover' component (score 0.50). In turn, during the second viewing event, individuals not surprisingly sacrificed more time for looking at the 'Land cover' component (score 0.87); however, the proportion between the percentage of the total fixation duration and the percentage of the map interface of that component still reminded below a score 1. Again, the highest score, equal to 1.54, was observed for the 'Wind speed and direction' component. All mentioned observations are apparent in Figure 6 where the percentages of the total fixation duration might be straightforwardly compared with the percentages of the display area.

Table 3. Relation between the percentage of the total fixation duration and the percentage of the display area

Component	First viewing event	Second viewing event
Fire progression	1.09	0.84
Wind speed and direction	1.30	1.54
Land cover	0.50	0.87
Timeline	0.90	1.10

While our finding about the lower attention on the static 'Land cover' component is convergent with the finding that animations grab user's attention more compared to static images (Wolfe and Horowitz, 2004), there is no clear explanation why users spent more of their attention on looking at the 'Wind speed and direction' component. That issue will be considered in the further part of the paper while discussing other aspects of collected data.

Figure 5 suggests more fixations on components titles and maps, scale bars and map scale bars during the second animation viewing compared to the first, free-viewing event. One can notice a general increase of attention, in terms of number of participants (Figure 7A) and mean fixation duration (Figure 7B) for each component title and scale bar in the second viewing event (red bars in Figure 7).

The only interface component with shorter fixation duration in the second viewing event is the title of the 'Fire progression' component. In contrast, the fixation duration of its scale bar is more than twice longer compared to the first, free examination viewing event. Despite the fact that the total fixation duration of the 'Fire progression' component is significantly shorter for the second viewing event compared to the first event, the title and the scale bar of that component were viewed by more participants, and the scale bar was viewed longer in the second viewing event. Surprisingly, the title and the scale bar of the only static component, 'Land cover', were viewed by the largest number of participants (Figure 7A). It is also the component that was viewed much shorter than the dynamic 'Wind speed and direction' component.

Accuracy of response per question type

The accuracy of response, as shown in Figure 8, suggests that participants did not perceive all information presented

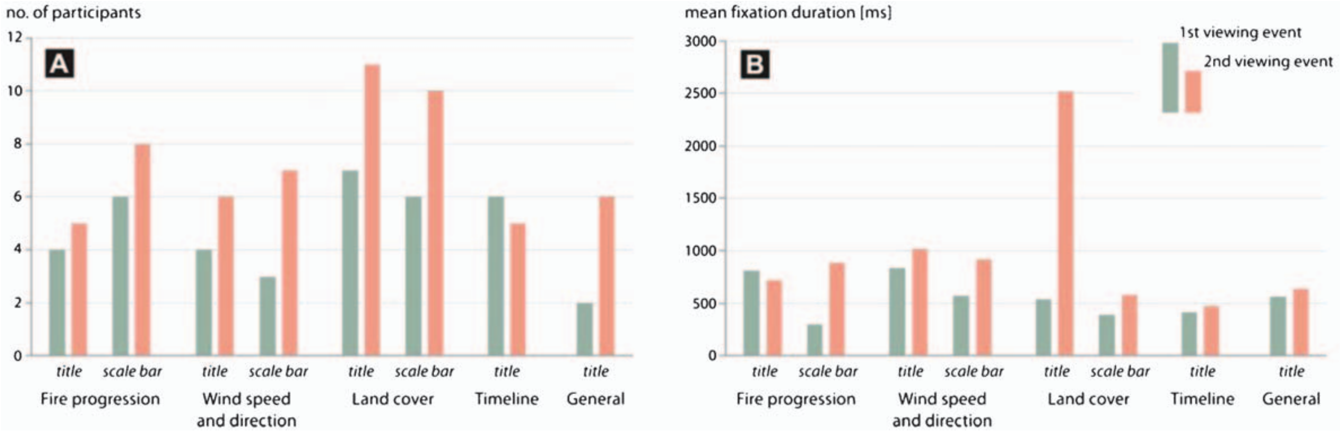

Figure 7. Attention toward titles and scale bars of the components described with (A) number of participants that looked at them and (B) mean fixation durations

in each component, and did not perceive all spatio-temporal relations across different components.

None of the questions were answered correctly by all participants. The first question related to wind characteristics (Table 1) was answered correctly by 90% of the participants. The second question linked to the information presented in the 'Fire progression' component which yielded indeed the highest fixation durations. This question appeared to be far more challenging for the participants, than the first one, as it resulted in a low response accuracy (35% of answers are correct). Furthermore, question 3 concerning the land cover information, presented in the only static component in the display, was the only component that resulted in 'I don't know' responses among questions linked to specific components (Q1–3). The first of the components integration questions (Q4), relating to fire and wind information (both dynamic components), was correctly answered by more than half of the participants, and resulted in no 'I don't know' responses. The last two information integration questions (Q5–6), one on the relations between the fire progression and the timeline, and one relating the fire progression to land cover, resulted in a low response accuracy (30% and 35% of the participants, respectively).

Not surprisingly, the highest response accuracy was observed for questions related to and/or integrating the animated maps on fire progression and wind characteristics. However, low value was noted for question 2. Since we were asking about the fire speed changes, the participants might have recognized it as not so distinct and thus, not easy to follow. Moreover, the 'I don't know' answers were observed for the land cover map and the timeline only. For these components, the participants sometimes have not been even trying to give an answer. It may suggest that perception of these components and information integration was most challenging.

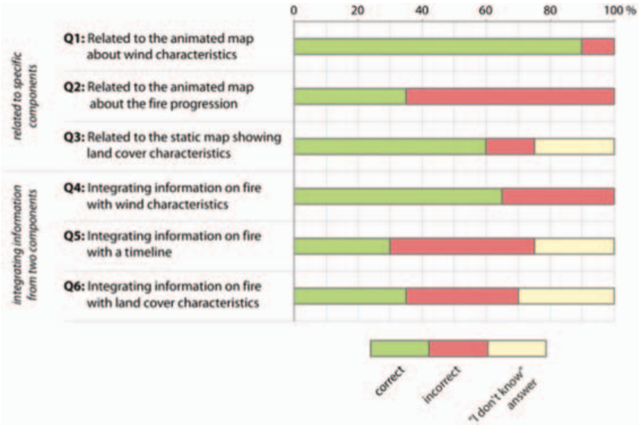

Figure 8. Participant response accuracy for each question

Accuracy based on viewing strategy

None of the participants were able to answer correctly all six questions (Figure 9). Response accuracy varied widely across participants: from one to five correct answers. We distinguish more effective participants, with five or four correct answers (*N*=9), depicted on the left hand side of Figure 9 with a grey background, compared to less effective users, who gave one or two correct answers (*N*=7) on the right hand side with a grey background in Figure 9. The third, middle group of participants in Figure 9 gave 50% correct responses.

The differences amongst participants in the effectiveness of response could imply that users might have perceived the presented information in different ways. We calculated AOI statistics for each user group to shed further light on this issue, and carried out viewing sequence analyses to systematically analyse potential viewing strategy differences.

Figure 10 depicts average viewing times for each component and the number of viewing transitions between components across groups. During the first free-examination viewing, less effective participants focused mainly on the three dynamic components, of which the 'Fire progression' component yielded the longest average fixation duration (M=19.4 s). Furthermore, most fixation transitions link the 'Fire progression' component with the two other animated components, 'Timeline' and 'Wind speed and direction'. The only static 'Land cover' component features the shortest mean fixation duration. When comparing these results with the more accurate (i.e. effective) participants, one notices that the mean fixation duration for the 'Land cover' component (M=4.1 s) was twice longer, compared to the

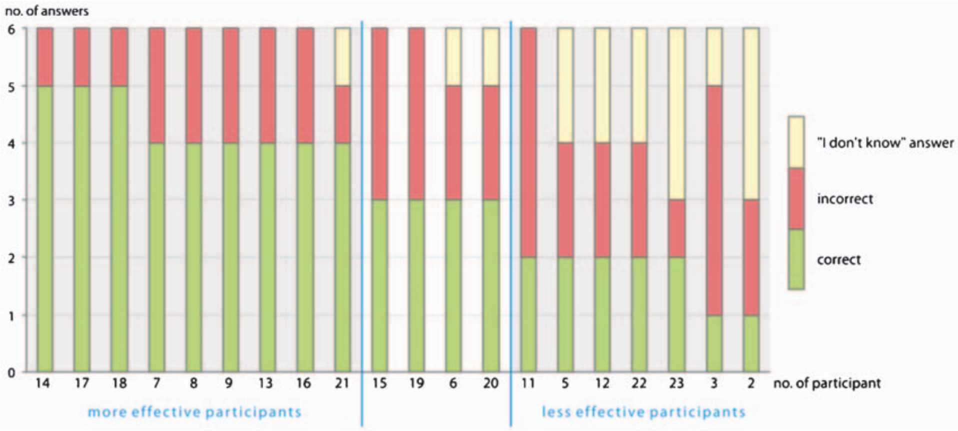

Figure 9. Response accuracy for each participant

less effective users (M=2.0 s). Furthermore, on average, the timeline was viewed not as long by the more effective users (M=2.8 s), compared to the less effective participants (M=4.1 s). Overall, transitions between map modules are more frequent in the case of more accurate participants, compared to the less accurate participants, especially between the only static component, 'Land cover', and the rest of the interface components.

During the second, task-based viewing event, both more and less effective participants fixated the animated 'Fire progression' component shorter, whereas the 'Land cover' and 'Wind direction' components were fixated longer. More effective participants, on average, fixated the 'Land cover' components almost twice longer (M=6.5 s), than less effective users (M=3.8 s). Also, fixation transitions between components featured a similar pattern in each group, when comparing the first and second viewing trial. Although less effective users' behaviour resulted in more transitions between the 'Land cover' and the 'Fire progression' components, the most frequent transitions still link the main 'Fire progression' component with the two other animated modules. The number of transitions ('Fire progression'↔'Timeline' and 'Fire progression'↔'Wind speed and direction') even increased in the second viewing event. The timeline component was linked with a smaller number of transitions with the two smaller map components. In contrast, the more effective participants did not alter considerably transition behaviour across the first and second viewing event.

We employed the sequence alignment analysis to further analyse viewing patterns across more and less effective participants. SSA algorithms measure similarity between character sequences (Wilson *et al.*, 1999). This sequence analysis technique has been applied and discussed in previous cartographic research (e.g. Fabrikant *et al.*, 2008; Griffin, 2009), proving to be helpful in identifying groups of similar viewing behaviour in cartographic displays. We employed the ClustalTXY software (Wilson, 2008) to systematically summarize and compare individual viewing sequences of AOI (i.e. display components) collected through eye-tracking.

We focused on the order of fixations, but not fixation counts. Therefore, we analysed collapsed sequences, similar to Fabrikant *et al.* (2008) and Çöltekin *et al.* (2010), and

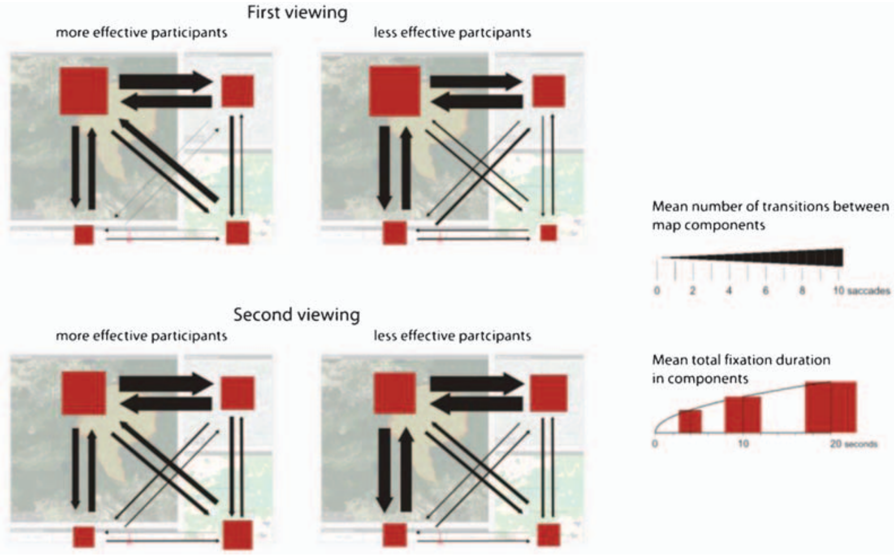

Figure 10. AOI statistics across user groups distinguished on response accuracy

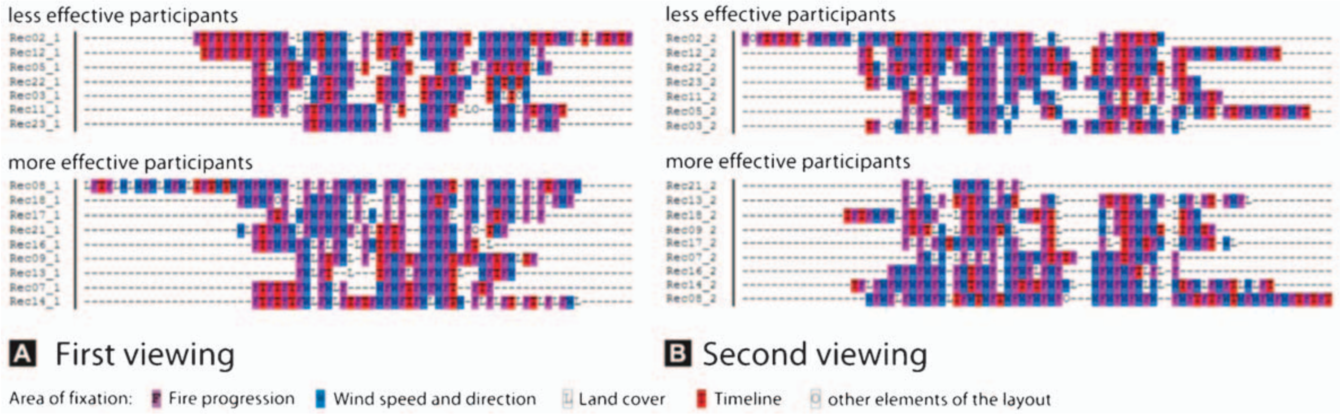

Figure 11. Aligned sequences for the first (A) and the second viewing event (B)

we excluded repeated fixations on the same module. In other words, if a participant fixates on the component 'Fire progression' (F) three times (thus F–F–F), we record one code F in the collapsed sequence. Figure 11 demonstrates aligned viewing sequences, colour-coded based on the animated map components of the tested display. One row represents a viewing sequence for one participant, and it begins on the left hand side of the window. A multiple alignment process was carried out, based on recommended input values by the Clustal software developers (Wilson *et al.*, 1999).

In Figure 11, the aligned sequences for two viewing events are shown separately for more and less effective participants. One might notice that two user groups exhibit similar aligned sequence patterns, both during the first and second viewing event. In general, at the beginning of the first viewing event, most of participants try to identify the fire in the timeline, as there are a series of 'Fire progression'–'Timeline' successions. In many cases, more effective participants seemed to look at the 'Timeline' more often at the beginning and at the end of the viewing event, whereas less effective users referred to this component several times during the entire viewing event.

DISCUSSION

In our study, a major focus was to recognize whether information received from different components of dynamic cartographic displays is perceptually and cognitively integrated by users. Hence, in the map stimulus, we applied several dynamic modules as well as static one. Moreover, we intended to investigate more deeply how and where users allocate their attention when viewing MCDCDs and whether there are different viewing strategies identifiable across individuals.

Indeed, *a priori*, there have been some reasons presented in the literature (Harrower, 2007) to assume that while using complex animated maps, people do struggle to acquire the information. Overall, we have shown that when viewing MCDCDs users seem to intuitively split their attention across all components, even if there is no a specific task given and a map display is complex. The participants divided their attention in uneven ways, based on the visual characteristics of the display components. In our case, attention is based on motion characteristics of the component, and its surface area.

We recorded participants' viewing behaviour with the eye-movement data collection method to investigate how users view MCDCDs. Not surprisingly, the largest animated component in the interface attracted participants' attention the most in terms of fixation duration. Participants also looked at the other layout components, but not as long as at the main animated map component. For the bottom-up, salience-driven free examination task trial, fixation duration appeared to be approximately proportional to the surface area the components cover. The static 'Land cover' component seems to stand out from this general pattern. Motion turned out to be indeed attention grabbing and a perceptually salient feature in a map display as Wolfe and Horowitz (2004) suggest. The animated components attracted users' attention most, and thus, might have limited the ability to perceive additional thematically relevant information from static component. However, as the information shown in the animated components changes over time, it is rather logical that users tend to spend more time looking at them, compared to the static component where the information is fixed. Thus, it is not necessary to look at the static component as long as at the animated parts of the interface.

Furthermore, when comparing the percentage of total fixation duration with the percentage of the map interface per map component, we noticed that the 'Wind speed and direction' component received higher attention comparing to the 'Fire progression' component. The possible explanation of that effect might be an unpredictable nature of the presented phenomenon, since wind may change considerably in a minute whereas fire changes slower and through extending the already covered area (so it is predictable to some extend). We argue therefore that it is likely that due to the unpredictable change, the participants were fixing more on the 'Wind' module than on the 'Fire' component. Moreover, the way of presentation might also play an important role in attention differentiation. The areal presentation of fire progression makes visible the area that has been covered just before, whereas arrows indicating wind speed and direction do not show what has happened before.

Besides the rationale presented above, this interesting finding needs further investigations.

The empirical study was designed as such to study the split attention effect in two different contexts: when viewing a multi-component animated map spontaneously and when viewing it with a given task to follow all components. We aimed therefore to compare users' visual behaviours in order to reveal how people split their attention depending on their purposes. The outcomes revealed that when viewing the animation the first time, with a visual attention guided mainly by a bottom-up saliency map (Itti and Koch, 2001; Navalpakkam and Itti, 2005), participants tended to focus their attention on the largest animated component, but also on other display's modules. Therefore, even though participants were not given a task to follow all components, they were trying to split their attention. As an attention guidance map is based on the interaction between the saliency map and task relevance (Findlay and Walker, 1999; Navalpakkam *et al.*, 2005; Factau and Munoz, 2006), we expected to observe the participants' visual behaviours altered when viewing the animation the second time. Indeed, during the second viewing event with a given task to follow all components, the participants were trying to reduce their attention on the 'Fire progression' component which was fixed the longest during the first viewing. The fixation duration on that component was significantly shorter then. We assume that it was caused partly by the task effect and partly by the learning effect, which is convergent with findings reported in other papers where eye-tracking has been employed (e.g. Opach and Nossum, 2011). But still, it was the longest watched component. Other modules did not yield significant differences in terms of fixation duration across viewing events.

Based on the accuracy of user response, the information extracted from a multi-component layout seems to be difficult to integrate into a clear cognitive image. This finding can be explained by a cognitive overload (Harrower, 2007) or by the issues of mental integration of information (Hegarty, 1992). As none of the questions were answered correctly by all participants, none of the participants answered all questions correctly. Surprisingly, the questions with the lowest number of correct answers related to the longest studied component. This raises the question about the quality and depth of the perceived information. This could be the subject of further studies, with more detailed questionnaires, and by applying think aloud protocols, for instance, to further examine the quality of users' information acquisition from this kind of layouts.

Based on the accuracy of response, we were able to identify different user groups. Further analysis shows that participants' effectiveness seems to be related to varying viewing strategies. Less effective participants focused mainly on the largest, animated map window, and to some extent, on the smaller animated map and the animated timeline component. Even with a given task to view all map components in the display, one can still notice a considerable dominance of the number of transitions between the largest window, and other two smaller animated components. More effective participants, on the other hand, from the very beginning of the viewing session, were intuitively dividing their attention more evenly across modules, compared to the less effective users. During the second viewing event, with a given task to view all components, the number of transitions between two smaller animated windows increased. Even though all participants tried to divide their attention across all windows, there is a group of participants who got attracted mainly by large, and/or animated components. Thus, their visual attention was guided more by a bottom-up saliency map, than by a top-down task relevance (Itti and Koch, 2001; Navalpakkam and Itti, 2005). Hence, while designing multi-component cartographic visualisation, the silent variables that attract attention the most, should be carefully employed in each module. Otherwise, it may result in hiding important information through covering it by more attractive modules (e.g. dynamic).

The performed sequence alignment analysis allowed us to find that less effective participants repeatedly inspect the timeline component during the entire viewing sessions. In turn, more effective participants referred to the timeline components mainly at the beginning, and at the end of both viewing sessions. It seems that this viewing pattern enables more effective users to focus on the thematically relevant content, without being distracted by shifting attention to perceptually salient, but less important display components. These results show that the design of the temporal legend is an important factor to consider when studying the split attention effect, as suggested by Harrower (2007). Similarly, studying the legend at the beginning of the viewing event resulted in a more efficient pattern for problem solving (Gołębiowska, in press). Repeated legend inspection during the viewing event, especially for animated map components, may considerably distract map users, potentially resulting in ineffective information acquisition. In order to avoid such effects, the design of the legend for animated multi-component displays should be the subject of thorough further analysis. The ideas of embedding legends in map window (e.g. Kraak *et al.*, 1997; Mitbø, 2001; Clarke *et al.*, 2010) should be further tested, to offer effective dynamic layout design solutions. As Mitbø (2001) suggests, sound to enhance map animation, should be carefully considered, and empirically verified. Psychological research offers evidence that visual and sonic systems interact in complex stimuli environment (e.g. Noeslett *et al.*, 2008; Talsma *et al.*, 2008). Furthermore, the sense of touch has been employed in the latest research (Steinmetz *et al.*, 2005). It may provide an important input while testing multi-component visualisations.

Basic layout design issues, such as the location and/or size of an interface component, should be the matter of special care, as our results reveal. The larger a component the more perceptually salient, the longer it is studied in terms of fixation duration, compared to smaller display components. The number of transitions between closely located components is higher than between components that are further away, even though they might be logically connected.

Finally, a tutorial session (Opach and Nossum, 2011) might increase an overall efficiency of the application either, since individuals can be trained how to use a MCDCD in a proper way. It can be especially relevant for those whose visual behaviour tends to be driven more by a bottom-up saliency map.

CONCLUSIONS

Multi-component dynamic cartographic displays could be a useful approach to depict spatio-temporal phenomena, but they need to be carefully designed. Our research revealed that although users tend to integrate perceptively information given in various components (since they indeed split their attention), the cognitive shortages may occur when using MCDCDs. If a MCDCD is composed of static and animated map components, the latter ones may attract users' attention most, according to the metaphor that motion is interpreted as vehicle for important information (e.g. Fuhrmann and Kuhn, 1999). On the one hand, it might result in a higher efficiency of cognitive processes based on information acquired from animated components. On the other hand, users might neglect information shown in other components or interface elements like static maps, scale bars or temporal legend, even if it is animated too. These weaknesses can reduce users' capabilities to integrate cognitively information given in auxiliary components with information acquired from leading components. That reason in turn can cause misunderstandings when viewing and interpreting multi-component dynamic cartographic displays.

It is our belief that multi-component dynamic cartographic displays work. However, we claim that when making use of them more efficient are users who keep control over their visual behaviour, it means who can split their visual attention onto all components, dynamic and static as well, even if animated components attract the attention more. Therefore, thematically relevant static and animated map components should be carefully designed in a perceptually salient manner, and logically organized in the display, by minimizing the distance between thematically connected components. This includes well-designed and carefully placed animated and static map legends like timelines or scale bars. These design issues should be further examined experimentally, to reduce the potentially negative effect of split attention and respective cognitive burden when viewing multi-component dynamic cartographic displays.

BIOGRAPHICAL NOTES

Dr Tomasz Opach is a post-doctoral researcher at the Department of Geography at the Norwegian University of Science and Technology in Trondheim. He earned a PhD in 2007 at the University of Warsaw. His PhD thesis concerned the efficiency aspects of cartographic animations. His current research interests include cartographic interactive visualisations (static and dynamic), GI Science and graphic design as well as problems of cartographic representation of natural and cultural heritage.

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