A Software Tool for the Experimental Investigation of Cognitive Effects in Audiovisual Maps

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Abstract

The increasing importance of cognitively oriented visualization in cartography implies the use of modern approaches of experimental user studies. Such experiments are usually standardized, and researchers try to avoid confounding factors as much as possible. Therefore, modern experimental studies are based on digital, software-based methods and techniques to fulfil the demands. A set of established standard software exists which can partly be adopted to individual research questions in cartography and spatial cognition. However, these tools have not primarily been developed for the field of cartography and, thus, cartographic peculiarities are missing. For example, this can be related to the implementation of multimedia, incl. auditory (map) stimuli to investigate the impact of specific sound elements on cognitive processing in audiovisual cartography. This may also refer to the way (behavioural) user data measured during spatial tasks in maps are presented to the analyst. To make use of a more cartography-focused study software which can be used in map-based studies on spatial memory performance, an individual software tool was programmed. The tool is based on the object-oriented programming language ActionScript 3.0 and allows an easy customization due to its simplicity. The tool can be exported in the runtime system Adobe AIR and is highly suitable for lab studies. This paper presents some functionalities and peculiarities of this tool, including several examples of the written and commented scripting code.

Keywords Audiovisual cartography · Multimedia cartography · Empirical cartography · User studies · Sound · Study software

Zusammenfassung

Ein Software-Tool zur Untersuchung kognitiver Effekte audiovisueller Bildschirmkarten

Die zunehmende Bedeutung von kognitiv-gesteuerten Visualisierungen in der Kartographie impliziert die Verwendung moderner Ansätze experimenteller Nutzerstudien. Solche Experimente sind für gewöhnlich standardisiert und es wird versucht, Stör- und Verzerrungsfaktoren so gut wie möglich zu minimieren. Deswegen basieren moderne experimentelle Studien auf digitalen, Software-gestützten Methoden und Techniken, um diese Anforderungen zu erfüllen. Derzeit existiert eine Reihe etablierter Standardprogramme, die jedoch nur teilweise für individuelle Forschungsfragen zur Kartographie und Raumkognitionsforschung geeignet sind. Diese Tools wurden nicht primär für die kartographische Forschung konzipiert, weswegen manche kartographischen Spezifika unberücksichtigt bleiben. Dies bezieht sich bspw. auf die Implementierung multimedialer, und somit auch auditiver Elemente, um den Einfluss von Ton auf die kognitive Verarbeitung im räumlichen Gedächtnis untersuchen zu können. Zudem bezieht es sich auf die Präsentation der erfassten raumbezogenen Verhaltensdaten. Um ein etwas mehr auf Kartographie ausgerichtetes Tool nutzen zu können, wurde eine Spezialanwendung entwickelt. Dieses Tool basiert auf der objektorientierten Programmiersprache *ActionScript 3.0*. Es ermöglicht wegen seiner Einfachheit eine einfache Anpassung. Es kann als Adobe AIR-File exportiert werden. Diese Laufzeitumgebung ist unabhängig von einer Web-Verbindung und daher sehr geeignet für Laborstudien. In diesem Aufsatz werden einige Funktionalitäten und Besonderheiten dieses Tools vorgestellt, einschließlich mehrerer Beispiele des geschriebenen und kommentierten Skriptcodes.

Schlüsselwörter Audiovisuelle Kartographie · Multimediakartographie · Empirische Kartographie · Nutzerstudien · Ton · Testsoftware

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1 Introduction

In cartography and spatial cognition, researchers regularly stress the steadily increasing importance of understanding cognitive structures in map use (e.g. Andrienko et al. 2014; Dickmann 2018; Griffin 2017; Montello et al. 2018; Roth et al. 2017; Touya et al. 2018). If cartographers are familiar with cognitive structures during the user's processing (e.g. reading and learning) of map content, new cartographic design rules could be considered to improve the efficiency of cartographic communication in (multimedia) maps (Bestgen et al. 2013, Dickmann et al. 2015, 2013).

New proposals of cartographic design rules for 'better communicating' maps go back to the outcomes of user studies (e.g. Çöltekin et al. 2017, 2018; Edler et al. 2018a, b; Keil et al. 2018, 2019; Kuchinke et al. 2016). Such user studies are based on study designs that try to minimize interfering factors as much as possible. Following the standards of experimental psychology, the behavioural data of the study participants should only be influenced by the factors and conditions declared and examined (e.g. Myers and Hansen 2014).

To collect-usually quantitative-behavioural data, such as distance estimations or the distance error of recalled or recognized object locations (Bestgen et al. 2017a, b; Okabayashi and Glynn 1984) in cartographic user studies, research groups either use existing 'standard software', for e.g. Tobii Studio or OGAMA for eye-tracking analyses (Voßkühler et al. 2008), or develop their own customized software solutions (Edler et al. 2014, 2015a; Popelka et al. 2016; Sasinka et al. 2017). These customized solutions are adjusted to the individual study purpose. However, the inclusion of diversified multimedia elements in such lab software is still rare. Although the relevance of investigating auditory stimuli is regularly emphasized in user-oriented cartography (e.g. Ballatore et al. 2018; Bearman and Lovett 2010; Dodt et al. 2017; Edler et al. 2012, 2018c; Lammert-Siepmann et al. 2011, 2014, 2017; Papadimitriou et al. 2009; Schiewe 2015; Schito and Fabrikant 2018; Reagan and Baldwin 2006), it is no common standard to include auditory stimuli as data elements in study software.

To gather behavioural data on quantitative measures of the performance in memory of object-locations, a software tool for lab studies was developed in the Geography Department at the Ruhr-University Bochum (RUB). The tool is based on ActionScript 3.0, and updated versions of the tool are exported in the cross-platform runtime system (Adobe AIR, formerly Adobe Integrated Runtime). The scripted tool was recently extended to measure the impact of acoustic map elements on spatial memory performance (Lammert-Siepmann et al. 2017).

Related versions of this audio-featured *ActionScript*-based tool have been used in several studies dealing with cognitive structures in map use. Identified effects, such as the grid effect on map-based object-location memory performance (Edler et al. 2014), have repeatedly been confirmed based on a related recall memory paradigm and a similar (*ActionScript*-based) software tool (Edler et al. 2015b, 2018b; Dickmann et al. 2017).

This paper is intended to present and discuss some main functionalities of this tool which supports the automatized execution of a recall memory paradigm. The presentation of the tool is based on case examples of written and 'commented' scripting code (in the object-oriented programming language *ActionScript 3.0*). These code-based examples are focussed on important aspects of experimental design. Before these code-examples are presented, the procedure of study design which represents the conceptional background of the tool is briefly introduced.

2 A Recall Memory Paradigm Including Audio Elements

The methodological paradigm used in this study is based on a standard paradigm of experimental and cognitive psychology. It is used to investigate recall performance in memory (Baddeley 1997; Mandler et al. 1969). The method presented in the following is an adaptation of the recall memory paradigm to measure the performance in memory of object locations (see also Postma and De Haan 1996). It includes visual and auditory stimuli linked with topographic maps. The audio files are recordings of spoken place names. They were recorded with a music studio equipment.

The (visual) study materials include digital topographic base maps-an adjustable number, but six in this case. These maps are based on open (ATKIS) data (.shp-files) provided by "Geobasis NRW" (https://open.nrw/). These open data allow to (re-)build topographic maps of North Rhine-Westphalia (NRW), Germany, in the currently defined graphical style. The size (30 cm × 20 cm; in pixels: 1065 × 710), format (landscape) and scale of all maps (1/10,000) were identical in this example. The digital maps are designed for being displayed on a TFT-LCD 24″ screen. They are created and exported with *ESRI ArcGIS* (v. 10.5). The screen was calibrated to mirror the official colours.

Another graphical layer included six circular (point) symbols which are added to each topographic base map. These points (size: $d = 0.5$ cm, fill color: #e100c8) marked fictional locations within the represented topography. Each point is given a fictional (German) place name consisting of two syllables and eight characters. Both, location (spatial information) and name (attribute information), are randomly selected for each map. The selection is based on a pool of

40 possible locational options, combined with 48 possible place names. Each place name can only appear in one map.

In the study maps, the place names are presented either purely graphically (written text) or audiovisually (written text, plus played voice recording). The six maps are randomly subdivided into two groups comprising three maps each. The two groups refer to the different conditions of communicating the place names (visual vs. audiovisual). The theoretical background to the study leading to these two study conditions is documented in Lammert-Siepmann et al. (2017).

The procedure of the recall memory study consists of three major phases: (1) memory encoding, (2) filler task, (3) memory recall/retrieval. Memory encoding (60 s) refers to learning the locations of map objects and their semantic identities (place names). The names can be-depending on the study condition: visual vs. audiovisual-(dis-)played by clicking on the point symbols representing the locations. The filler task (45 s) is a visual search task which was independent from the memory-related tasks in the encoding and retrieval phases. Memory retrieval (60 s) involves the recall of encoded object locations and their corresponding semantic object identities (place names). The time values are based on a pre-test that was focused on the definition of suitable time parameters.

The dependent measures to be collected and statistically analysed firstly comprise the Euclidian distance between the original location of the map object and the location of the recalled object. It is quantified in the unit pixels (px) and refers to each recalled object in each map. The second dependent measure is the rate of correctly recalled place names bound to object locations. Based on a threshold of 1 cm, the data were further automatically processed and classified into correct recalls (within 0–1 cm range) and incorrect recalls (outside of the range). The data export (in. txt-files) is structured and exported in labelled columns for each participant. It is demanded to get export files that are easily compatible with standard software for advanced statistics, such as SPSS or R. Figure 1 sums up the sequence of the study trial which leads to the concept of the study software.

3 A Scripted Tool for Experimental Testing of Audiovisual Maps

The study software is based on the object-oriented language *ActionScript 3.0* and has been created to run the trial sequences of the user-study automatically and in a standardized way. Using an automatized (digital) approach supports a high comparability of the test results and a minimization of individual confounding factors, such as inaccuracies that might occur if test results are gathered manually or
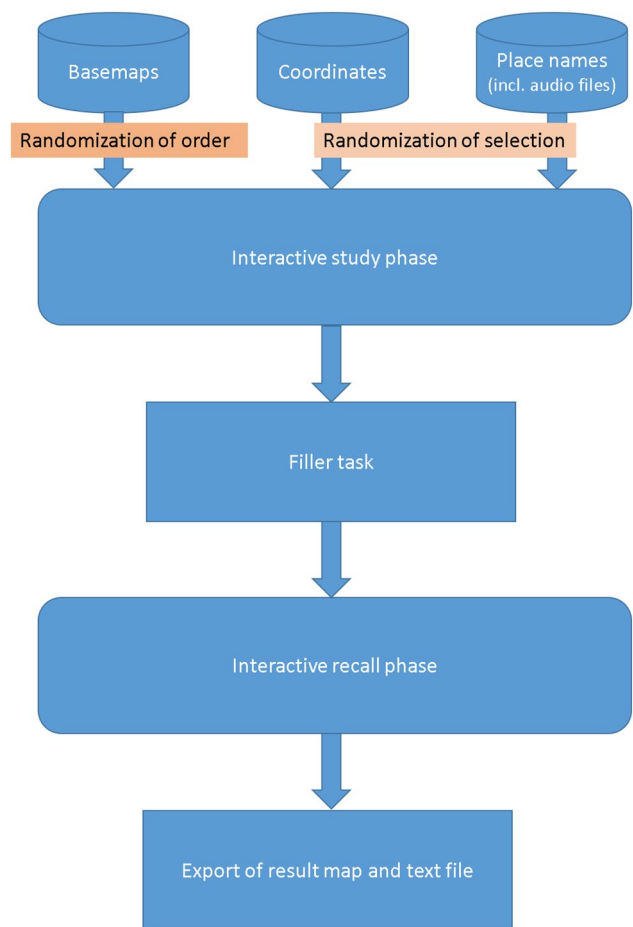

Fig. 1 Structure of the study trial as the basis for the study software

semi-automatized. The created software consists of several modules that could be easily adapted to the requirements of different studies. In other words, its structure was planned to be adaptable without investing too much additional programming/scripting work. In the following, several code-based examples are given to highlight relevant aspects of experimental design. The code blocks are commented so that the functional ideas behind the lines of scripting code are indicated.

3.1 Randomization: Assigning Study Materials to Different Study Conditions

Randomization is a core concept used in many modern experimental studies. When repeating a study sequence several times, the sequence should be changed between the participants. This helps to avoid effects that are linked to a standardized sequence order (e.g. Barker and Milivojevich 2016). The programmed tool supports randomization at different stages. The base maps are selected in a random order and they are also randomly assigned to the two different

study conditions (visual vs. audiovisual). A random-based procedure is also used for the selection of (*x*- and *y*-) coordinates of the object locations and to the allocation of the corresponding place names.

The code block in Fig. 2 gives an example how randomization can be programmed in *ActionScript 3.0* to divide the base maps (imported as image files from Adobe Animate's library) into two groups that correspond to the visual and audiovisual study conditions. In this step, the method *Math. random()* is employed. It generates a randomized number between 0 and 1. This random value can be used to assign the maps to the groups. The number of the (in total: six) maps assigned to each group is reduced to three. Using the same randomization method, the order of the maps presented to the individual participants is specified.

Approaches of randomization are further used for the allocation of object locations and place names to the (topographic) base maps. Technically, suitable place names for all base maps are stored in a single array, an *Action-Script* class designed for listing, holding and accessing data. In the initialization of the study software, each map is assigned a specified number of names from this array via the *Math.random()* method. Similarly, locations on the base map for these place names are chosen from an array that contains multiple previously chosen suitable pairs of coordinates for each map. This selection of locations also takes place during the initialization, managed by a function *init ()*.

```actionscript
//declare an array object containing map names
var allMapsArray = new Array("e_01", "e_02", "e_03", "e_04", "e_05", "e_06");

//loop 0 to length of previously defined array allMapsArray
for (var i = 0; i < allMapsArray.length; i++){
    //randomly assign either 0 or 1 to a variable
    randomNumber = Math.floor(Math.random());
    //check if the randomization yielded a 0:
    if(randomNumber == 0){
        //check if the array for audiovisually presented maps contains_
        //less than half of all maps:
        if (audiovisualMapsArray.length < allMapsArray.length/2){
            //if yes, add the item from allMapsArray at position i to array
            //audiovisualMapsArray
            audiovisualMapsArray.push(allMapsArray[i]);
        }
        else {
            //if no, add it to the array for visually presented maps
            visualMapsArray.push(allMapsArray[i]);
        }
    //if randomization yielded a 1:
    } else {
        //check if the array for visually presented maps contains_
        ////less than half of all maps
        if (visualMapsArray.length < allMapsArray.length/2){
            //if yes, add the item from allMapsArray at position i to array
            //visualMapsArray
            visualMapsArray.push(allMapsArray[i]);
        }
        else {
            //if no, add it to the array for audiovisually presented maps
            audiovisualMapsArray.push(allMapsArray[i]);
        }
    }
}
```

Fig. 2 Randomization as important concept to vary the study sequence between participants

3.2 Time Management in the Trial Sequence

The trial sequence itself is controlled by an ActionScript Timer object. This object ensures that each step of the trial is executed with the desired duration. The time management of the software especially refers to the correct durations of the three study phases (see chapter 2). In the tool (Fig. 3), an initial white screen of 3 s (used as beginning slide) is followed by the study phase (60 s), a filler task (45 s), another white screen (3 s) and, finally, the recall phase (60 s). The timer class offers the study leaders the complete control over the time spans defined for the individual phases of the trial sequence. It only refers to time management and does not restrict any other interaction of the participants.

```
//define variables containing length of the sections of the trial
//measure: 1/10 of a second
//very brief white screen at the beginning (3 s)
var firstWhiteScreenLength:Number = new Number(30);
//study phase (60 s)
var studyPhaseLength:Number = new Number (600);
//filler task between study and recall phase
var fillerBreakLength:Number = new Number (450);
//very brief intermediary white screen
var secondWhiteScreenLength:Number = new Number (30);
//recall phase
var recallPhaseDauer:Number = new Number (600);

//initialize Timer object
mapTimer = new Timer(100,0);
//stop and reset Timer object
mapTimer.stop();
mapTimer.reset();

//check if the first 3 seconds of the trial have elapsed
if (mapTimer.currentCount >= firstWhiteScreenLength){
    //check which map has been randomly chosen
    if (mapNumber == "e_01"){
        //set chosen map to visible
        map_e_01.visible = true;
        //clear container for point symbols
        while(pointContainer.numChildren){
            pointContainer.removeChildAt(0);
        };
        //set container for point symbols to visible
        pointContainer.visible = true;
        //initialize function that draws symbols and _
        //assigns names
        drawCities(violetSymbol, map_e_01, labelArray, _
        xCoordinateArray, yCoordinateArray, false);
    }
    //[...]
```

Fig. 3 Time management used to control the durations of the trial sequences

3.3 Tracking Behavioural Data of Study Participants

ActionScript 3.0 offers several options for the recording of user input, which is vital for gaining behavioural data in experimental user studies. For example, this refers to the tracking of recalled object locations and object identities (place names). The tracking of user data can also be related to the counting of specific interactions, such as the amount of activating the sound files to learn (encode) the located place names. This automatized analysis may allow conclusions on the comparability of place names used. If there were specific names which have been activated more often, the analyst would have a strong indication for a different level of difficulty, which would be a base for the detection of outliers and, thus, improve the quality of the statistical analysis. If no outliers are identified, the analyst would generate an additional quantity to back up the robustness of the study design and method. Tracking the amount of clicks also allows to check if each participant has played each audio files at least once throughout the encoding phase.

The study software includes such a counter (Fig. 4) used to track the number of clicks on the point symbols (in the audiovisual condition linked with activating the audio file). In technical terms, an Event Listener is attached to the point symbols contained in the map. The listener tracks how often participants click on a symbol. Every time, a counter variable is incremented by one. The final value can be exported in the end.

3.4 Visual Map-Based Summary of the Behavioural Data

Supporting the evaluation of the study, the software exports screenshots for a user-friendly visual examination of the study results. These screenshots are an additional output to the txt.-files containing the data for statistical analyses. The screenshots are nothing but individual maps which visually summarize the behavioural data of each participant. These map-based information collages give a first visual impression of the data and the spatial measures (Fig. 5).

They include the original (violet) and recalled (yellow) locations and identities of objects. The order of recall (red number above yellow points) and the deviations (black numbers) between original and recalled locations (representing the distortion error in spatial memory) are also included. In addition to a first visual analysis, these screenshots also serve as a tool to give a feedback to the (interested) participants after the test [see a similar approach of visually and spatially summarizing behavioural user data in Edler (2015)].

The screenshots are created and exported based on a custom function (Fig. 6). From the scripting perspective, the software

```actionscript
//add Event Listener to container for point symbols:
//a mouse click on a symbol calls the function trackClick
pointContainer.addEventListener(MouseEvent.CLICK, trackClick);

//define the function trackClick
function trackClick(evt:MouseEvent):void {
    //transfer target of the click to a variable
    var selectedLabel = evt.target;
    //transfer text of the click to a variable
    var pointName = selectedLabel.text;
    //loop from 0 to length of all labels of a map
    for (var i = 0; i < labelArray.length; i++){
        //find clicked point by name
        if (pointName == labelArray[i]){
            //increase counter for this point by 1
            clickArrayActiveMap[i]++;
        }
    }
}
```

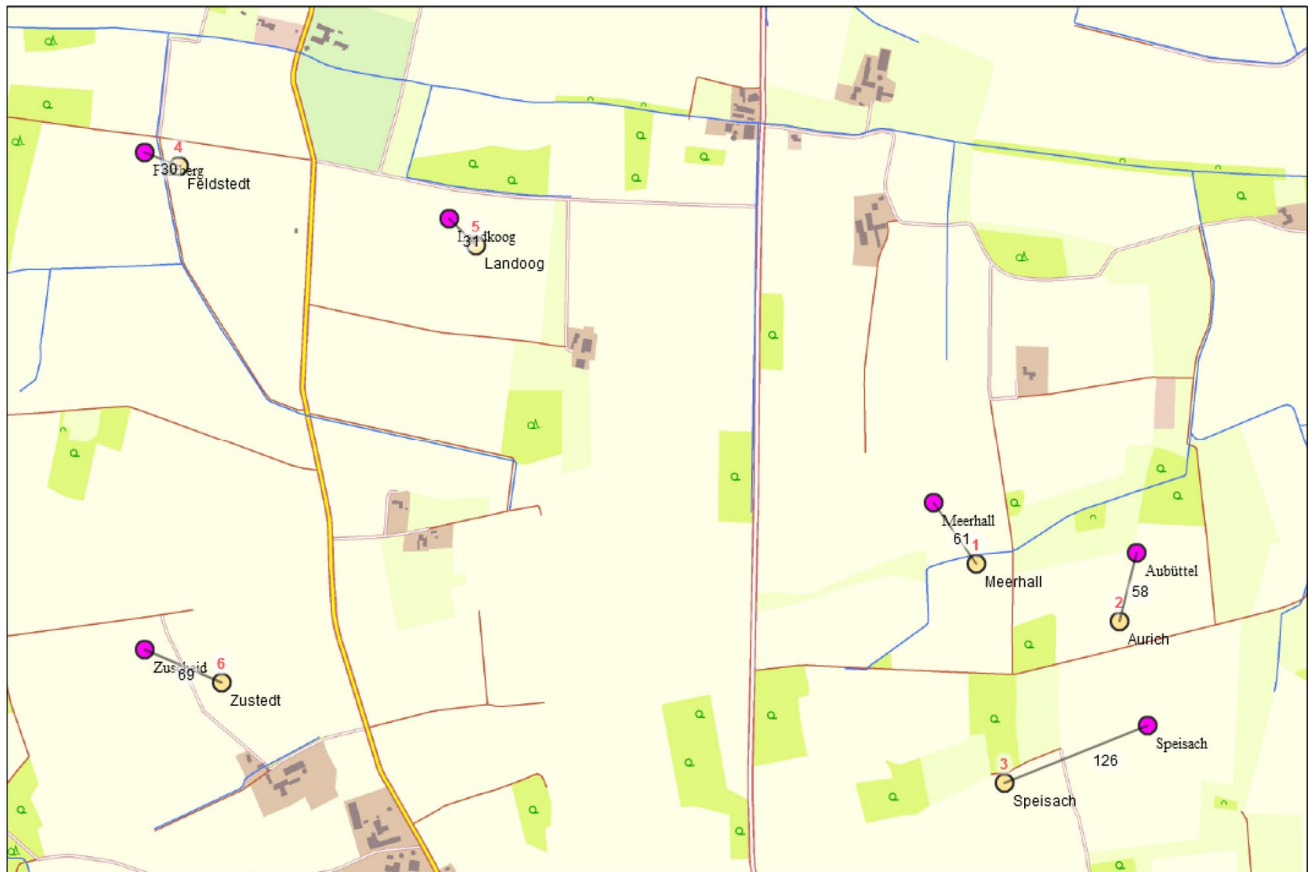**Fig. 4** Tracking user interaction to monitor the encoding phase and to reflect the method

Fig. 5 Tracking user interaction to monitor the encoding phase and to reflect the method (Base map data: State of North Rhine-Westphalia-Data Licence Germany-attribution-Version 2.0)

places the screen content into a variable and puts this variable into an array. If the trial has been entirely completed by the user, each item in this array, i.e. screenshot, is saved as an image (in the JPEG format) with a dynamic file name depending on the user ID assigned at the beginning of the trial and the map name (01–06). A separate function is used to add the content mentioned above (Fig. 6).

In addition, a text file containing the results of all trials for each participant is generated by a specific function (Fig. 7). In the function, the results for each map are added to an array ("pushed"). After a unique file name has been assigned, the results are written into the text file. This text file can now be loaded into software for statistical analysis. If the software (*Adobe AIR file*) is installed on a Windows PC, all exports (screenshots and txt-files) are automatically stored on the desktop.

4 Summary and 'Flash'

This paper was intended to give a compact overview of a self-scripted study tool that was created to run experimental trials including auditory map stimuli in spatial memory tasks. This tool is characterized by features that help to increase the quality of automatized user testing and the subsequent analysis of collected behavioural data. In addition to the integration of audio files as map elements, this tool includes randomization, time management and a data export based on formatted text files and visual cartographic interpretations of the data. To allow an easy customization of the software to related studies focused on spatial memory tasks, the code was commented and structured into separate units. As *ActionScript 3.0* is known

```
function printScreenshot():void {
    //initialize BitmapData object
    var bd:BitmapData = new BitmapData(stage.stageWidth,stage.stageHeight);
    //add everything visible on the stage to the BitmapData object
    bd.draw(stage);
    //add to array containing all screenshots
    screenshot = new Bitmap(bd);
    screenshotArray.push(screenshot);
    //check if all maps have been finished
    if (trialEnded ==true){
        //loop from 0 to array length
        for (var i = 0; i < screenshotArray.length; i++){
            //initialize BitmapData object
            var myBitmapData:BitmapData = new BitmapData(screenshotArray[i].width,_
            screenshotArray[i].height);
            //assign BitmapData object from array
            myBitmapData.draw(screenshotArray[i]);
            //convert to JPEG
            var jpgEncoder:JPGEncoder = new JPGEncoder(100);
            var imgByteData:ByteArray = jpgEncoder.encode(myBitmapData);
            //assign dynamic file name
            var file:File = File.desktopDirectory.resolvePath(probandenID + "_" +_
            screenshotNamenArray[i] + "_ergebniskarte.jpg");
            //open and close file stream
            var fileStream:FileStream = new FileStream();
            fileStream.open(file, FileMode.WRITE);
            fileStream.writeBytes(imgByteData);
            fileStream.close();
        }
    }
}
```

Fig. 6 Exporting map-based information collages to support visual analysis of the behavioural data

(e.g. Huddleston 2009; Muehlenhaus 2013; Richardson and Milbourne 2014) for its simplicity, modifications of the code can be made in relatively easy steps.

In the present literature and online contributions, *ActionScript 3.0*, which is linked with Adobe Flash, is sometimes no longer considered as a modern, but rather outdated (object-oriented) scripting language (e.g. Fish and Calvert 2016). Such opinions often refer to the forthcoming 'expiry date' of the *Flash Player* at the end of 2020 (Hurtig and Scharlach 2018). The worldwide distribution of interactive and creative contents is more and more associated with open standards, such *HTML 5*, *WebAssembly* and *WebGL*, which has also found its way into cartography (e.g. Crickard III 2014; Derrough 2013; Dickmann 2018). These new standards support modern options of interactivity and visualization and are highly transparent in terms of contents and the programming job.

However, advantages of *ActionScript*-based air-files are still obvious. A 'closed system', like a locally installed air-file, runs without a browser and a connection to the internet. It is not influenced by web-related factors and is easy to script and set up. Therefore, there is still great value of *ActionScript*-based

```
function writeTestResults():void {
    //gather the recorded results for the individual maps into a single array
    resultsArray.push(resultsMap01,resultsMap02,resultsMap03,resultsMap04,_
    resultsMap05,resultsMap06);
    //insert new line
    resultsArray.push("\n");
    //create dynamic file name for text file
    var newFileText:File = File.desktopDirectory.resolvePath("x_" +_
    probandenID + ".txt");
    //open file stream
    var fileStreamText:FileStream = new FileStream();
    fileStreamText.open(newFileText, FileMode.APPEND);
    //write array content into text file
    fileStreamText.writeUTFBytes(resultsArray.toString());
    //close file stream, save file
    fileStreamText.close();
}
```

Fig. 7 Exporting (quantitative) behavioural data for further statistical analyses

software for lab studies, which are highly focused on standardization and a reduction of interfering factors.

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