Personality and Individual Differences 97 (2016) 289–299

Contents lists available at ScienceDirect

Personality and Individual Differences

journal homepage: www.elsevier.com/locate/paid

# Effects of Field Dependence-Independence and Frame of Reference on Navigation Performance Using Multi-dimensional Electronic Maps

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ARTICLE INFO

*Article history:*
Received 23 September 2015
Received in revised form 15 November 2015
Accepted 23 March 2016
Available online 7 April 2016

*Keywords:*
Field dependence-independence
Frame of reference
Electronic maps

ABSTRACT

Most prior studies regarding navigational efficiency of electronic maps mainly investigated map characteristics such as the frame of references of maps (track-up maps vs. north-up maps) and the map dimensionality (2D maps vs. 3D maps). However, relatively little research has been found regarding how user characteristics, especially a user's cognitive style, affect the effectiveness of navigational displays. The present study examined how individuals' field dependence-independence, as an essential dimension of cognitive styles, affects user performance in orienting and navigating tasks with 2D and 3D electronic maps. The results suggested field-independent individuals had higher mental rotation ability than field-dependent individuals. The results also indicated significant interactions between field dependence-independence and frame of reference on both orienting and navigating tasks. Field-independent (FI) individuals responded more quickly and with higher accuracy compared to field-dependent (FD) individuals when using north-up maps, but no such differences was revealed when track-up maps were used. This implication could be further utilized to improve user-centered designs of navigation displays by considering individual differences.



## 1. Introduction

Recent advances in information technology have led to the wide use of electronic maps in navigation tasks. An important question is how to present information about locations and directions in order to facilitate navigation tasks in various complex systems, such as driving navigation systems, air traffic control systems, and ship navigation planning and control systems (Hsu, Lin, & Chao, 2012). Previous research has provided recommendations on the design of electronic maps to achieve display effectiveness regarding the display characteristics (Aretz, 1991). However, relatively little research has been found regarding how user characteristics, especially a user's cognitive style, affect the effectiveness of navigational displays. A small number of research included cognitive ability rather than cognitive style when studying wayfinding, orienting, and navigation with virtual environments (Satalich, 1995; Waller, 1999; Waller, 2000; Waller, Beall, & Loomis, 2004; Waller, Hunt, & Knapp, 1998).

Cognitive style refers to the consistent and stable individual differences in their ways of organizing and processing information (Messick, 1984). Several cognitive styles have been identified and each of these cognitive styles is stable over time, resistant to training and changes, and is independent from general intellectual ability (Ausburn & Brown, 2006). Among these various dimensions of cognitive styles, the field dependence-independence dimension has been the most extensively and systematically studied (Evans, Richardson, & Waring, 2013; Evans & Waring, 2012). Witkin and his colleagues first proposed the concept of field dependence as one dimension of cognitive styles (Witkin, Moore, Goodenough, & Cox, 1977). The field dependence-independence (FDI) reflected the extent to which a person perceives and processes part of a field as discrete from the surrounding environment as a whole, rather than embedded in the field (Witkin et al., 1977). This construct determined how people look for information in the environment, and how they organize and interpret this information in an individual manner (Hayes & Allinson, 1998). Previous studies have indicated that field-dependent individuals are more likely to be influenced by external cues and are less likely to view information separate from the environment. Field-independent individuals are more likely to be influenced by internal cues and are able to separate essential information from its environment (Riding & Cheema, 1991; Zhang, 2004). Several studies have investigated the effects of cognitive style on navigational behaviors with web-based searching and navigations (Alomyan, 2004; Dong & Lee, 2008; Fiaola & MacDorman, 2008; Kim & Allen, 2002), and hypertext and hypermedia links (Chou & Lin, 1998; Korthauer & Koubek, 1994; Weller, Repman, & Rooze, 1994). Kroutter (2010) studied the effect of field dependence-independence on

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http://dx.doi.org/10.1016/j.paid.2016.03.078
0191-8869/

navigation behaviors and crime scene drawings of the virtual environment after their exploration along with the effects of other individual differences, such as gender and experience. They found cognitive style was associated with time spent in virtual environment learning but was not associated with learning outcomes. This work suggested that the dimension of field dependence-independence affected an individual's way of processing environmental information. However, this work focuses on the interactions of field dependence-independence with other individual differences rather than the interactions between field dependence-independence with display characteristics.

Among the display characteristics being studied, frame of reference (ego-centered vs. world-centered) and map dimensional (2D vs. 3D) are two important aspects of research on electronic maps (Wickens & Baker, 1995). In terms of the frame of reference, the orientation of the map in the display may potentially impact the workload of the driver and the time needed to process the presented information (Aretz & Wickens, 1992). Map display designs can be ego-centered, referred to as track-up (TU). The map display design can also be world-centered, referred to as north-up (NU) since north is always at the top of the map display (Aretz & Wickens, 1992). Extensive studies in literature have investigated the effect of frame of reference on navigation performance, finding disparate results, however, with regard to determining the best type of maps to optimize performance. Aretz and Wickens (1992) explains the benefit offered by either display is task-dependent. Studies found that the NU display supports route planning, route learning, communication, and cognitive map development, whereas the TU display benefits users in their decision making, navigation, tracking and relative judgment. Cuevas, Huthman, Knudsen, and Wei (2001) explored the effect of navigation display type (i.e. north-up vs. track-up) on the performance of computer-based navigation tasks. The results suggested that neither display lead to better performance, but there was a significant effect of a user's spatial orientation ability on navigation tasks. In particular, the track-up group had more difficulties in the tasks (higher workload) and rated the map display less helpful.

With advancements in graphic display technology, researchers in the field of navigation have focused on 3D maps. The 3D view is defined as a perspectival view of an object or scene displayed on a 2D image (St. John, Cowen, Smallman, & Oonk, 2001). The naturalistic look of a 3D map has leaded it to be preferable to users (Gould et al., 2009; Smith & Wilson, 1993). However, researchers warned system designers that 3D displays might not always enhance user performance (Andre and Wickens, 1995). St. John et al. (2001) reviewed empirical evidence of map dimensionality on user performance and found mixed results (Hickox & Wickens, 1999; Van Breda & Veltman, 1998; Wickens, Liang, Prevett, & Olmos, 1996; Wickens & Prevett, 1995). The inconsistency of results illustrated that there was an interaction between the task type and the type of display employed for that specific task. Haskell and Wickens (1993) argued that when there was a strong resemblance between a real world task and the display, the 3D display was best suited. Also, when 3D displays were implemented the user forgoes the mentally demanding process of combining two 2D displays to synthesize a mental representation of a 3D space. St. John et al. (2001) found that 3D displays facilitated shape understanding such as mental rotations, and 2D displays led to better performance for tasks that required judgments on positions in terms of both response time and response accuracy.

Although research has been conducted to study the effects of map characteristics and individual differences on navigational behaviors, the interaction between individual's field dependence-independence cognitive style and map characteristics (i.e. Frame of reference and map dimension) has not been studied. The present study investigated how an individual's field dependence-independence and its interaction with a map's frame of reference influenced performance in orienting and navigation tasks with 2D and 3D navigation maps. The first experiment focused on the effect of field dependence-independence on mental rotation task performance with 2D and 3D maps. The second and third experiments studied the interaction between field dependence-independence and frame of reference on orienting tasks with 2D and 3D maps, respectively. The forth experiment studied the same interaction effect on navigation tasks in a simulated virtual environment. Field dependence was used to refer to the dimension of field dependence-independence in the following sections. By studying the effects of map characteristics and individual differences on navigational behaviors, the results from the present study could be applied to improve the design of navigation maps in different systems, such as driving navigation systems, air traffic control systems, and ship navigation planning and control systems.

## 2. The Classification of Field Dependence Using Embedded Figure Test

An Embedded Figure Test was used to measure the field dependence of the participants (Witkin, Oltman, Raskin, & Karp, 1971). The experimenter presented instructions and an example of the test to participants first. The test included three sessions, a practice session and two formal test sessions. In the practice session, participants had four minutes to answer nine questions. Each of the formal test sessions had ten questions, and participants were given four minutes to complete all questions.

Each correct answer in the test session counted one score. Any misses or mistake answers were not counted in the final score. The full mark of the Embedded Figure Test was twenty.

The Embedded Figure Test was conducted 11 times with each test having 20 to 70 participants. There were 553 valid participants (215 males and 338 females). The valid scores were distributed normally between 0 and 20. Participants with scores ranging from 0 to 11 were classified as field-dependent, and participants with scores ranging from 17 to 20 were classified as field-independent. The classified sample included 126 field-dependent subjects (22.8%) and 106 field-independent subjects (19.2%). The subjects in the second phase of the experiments were randomly selected from this sample.

## 3. Experiment 1. Effects of Field Dependence on 2D and 3D Map Mental Rotation

Previous studies have indicated that there are significant effects of field dependence on performance in Mental Rotation Tests (Guillot, Champely, Batier, Thiriet, & Collet, 2007). The present study examined this effect on mental rotation with 2D and 3D maps.

### 3.1. Method

#### 3.1.1. Participants

Thirty-nine undergraduate students (22 females and 17 males) participated in the experiment. All had normal or corrected-to-normal vision with ages ranging from 18-23. Nineteen of them were classified as field-dependent subjects, while twenty of them were classified as field-independent subjects based on their performance on the Embedded Figures Test.

#### 3.1.2. Stimuli and Apparatus

The stimuli were 2D and 3D rotation maps. The spinning images for 2D maps were created with the normal image for 0° 90°, 180° or 270° of clockwise rotation, illustrated in Fig. 1 (a). The mirror-image versions of the 2D maps were produced for each of the orientations as spinning images, illustrated in Fig. 1(b).

The spinning and flipping versions of the 3D maps were produced in the same way as were 2D maps, illustrated in Fig. 2.

The 2D and 3D maps were presented on a 17-inch LCD with $1024 \times 768$ pixel resolution. The same-different judgment tasks were completed using E-Prime software 2.0. Standard keyboards were used to record subject responses.