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Field Dependence, Efficiency of Information Processing in Working Memory and Susceptibility to Orientation Illusions among Architects

***Abstract**: This study examined cognitive predictors of susceptibility to orientation illusions: Poggendorff, Ponzo, and Zöllner. It was assumed that lower efficiency of information processing in WM and higher field dependence are conducive to orientation illusions. 61 architects (30 women) aged M = 29, +/– 1.6, and 49 university students (29 women) aged M = 23.53, +/– 4.24, were tested with Witkin's EFT to assess their field dependence; the SWATT method was used as a measure of WM efficiency, and susceptibility to visual illusions was verified with a series of computer tasks. We obtained a small range of the explained variance in the regression models including FDI and WM indicators. On the basis of WM efficiency indicators, we managed to confirm the existence of memory predictors of susceptibility to illusions (they are rather weak, as they explain from 6% to 14% of the variance of the dependent variable). Among the architects, lower efficiency of WM processing (weaker inhibition, task-switching) and higher field dependence are responsible for greater susceptibility to orientation illusions.*

***Key words**: working memory, weaker inhibition, task-switching, orientation illusions, field dependence, architects*

The main aim of the study is to answer the question of whether the efficiency of visual information processing in working memory and field dependence affect susceptibility to the geometrical illusions (of shape, direction, and reference frame) that are based on orientation principles (Ninio, 2014).

Despite universality of the phenomenon of visual illusions in Western culture and a long tradition of studying it, the cognitive mechanisms that underlie resistance to these illusions have not yet been clearly specified. Researchers assume that illusions occur partly due to the sub-optimal cognitive functioning. Visual illusions are most often regarded as an incorrect perception that may have physical reasons (the stimulus features) or cognitive reasons (applying an inappropriate rule). They occur when a stimulus is unclear, data are incomplete, elements are linked together in an untypical way, or familiar patterns are invisible (Coren, Girgus, Erlichman, & Hakstian, 1976; Gregory, 2005). On this basis, sensory illusions and perceptual illusions are distinguished. There is also a view, represented by Króliczak (1999), that since all people are susceptible to visual illusions, illusions are a manifestation of standard functioning of the cognitive system. The perceptual system processes information suitably corrected both in the "normal" and "illusory" (i.e., distorted) perception. Illusions arise as a result of latent data correction (cf. Changizi & Widders, 2002) that is automatically made by the perceptual system during information processing. In this paper, we assumed that illusions arise when a tested hypothesis (mental model of a particular situation) is accepted by the person despite its inadequacy to reality (Gregory, 1997).

It is difficult to find a commonly accepted classification of illusions (Coren et al., 1976; Prinzmetal & Beck, 2001; Gregory, 2005; Day, 2010; Ninio, 2014) and of psychological mechanisms of their formation (according to Lester and Dassonville [2011], we may expect different mechanisms for different groups of illusions). Ninio (2014) expresses illusion formation metaphorically: the brain, using three instruments: a meter, a compass, and a protractor, makes errors that result in metric illusions (e.g., Ebbinghaus, Müller-Lyer) and orientation illusions (e.g., Zöllner, Poggendorff, Rod-and-Frame Illusion, Roelofs effect). Prinzmetal and Beck (2001) add the Ponzo

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illusion to the group of orientation illusions. According to Ninio, among the principles responsible for visual illusions, there are those relating to metric aspects (contrast, assimilation, shrinkage, expansion, attraction of parallels), and principles relating to orientations (regression to right angles, orthogonal expansion) or, more recently, to gestalt effects. Thus, orientation illusions arise at an early stage of perception, whereas metric illusions – at a later stage.

Since the publication of works by Witkin and Asch (1948a, 1948b), it has been known that the concept of field dependence-independence (FDI) is an important predictor of susceptibility to orientation illusions (Coren & Porac, 1987; Prinzmetal & Beck, 2001; Rock, 1992; Walter & Dassonville, 2011; Bednarek, 2011). Field-dependent (FD) people reveal a greater tendency to use contextual hints in a wide range of tasks. In contrast, the people who achieve shorter times in the Embedded Figures Test (EFT) (Witkin, Oltman, Raskin, & Karp, 1971), i.e., those who are more field-independent (FI), are less affected by contextual hints, and consequently less susceptible to orientation illusions such as the Roelofs effect (Dassonville, Walter, & Lunger, 2006).

Miyake, Witzki, and Emerson (2001) demonstrated that EFT performance primarily reflects the operation of the visuospatial and executive components of working memory (WM). The visuospatial sketchpad is the component of working memory that allows us to temporarily hold and manipulate information about places. The central executive includes functions that are responsible for the control and regulation of cognitive processes in general (Baddeley, 1999; Repovs & Baddeley, 2006). The model of working memory developed by Baddeley and his colleagues, and especially the role of the visuospatial sketchpad, storing and processing visual and spatial information, and of the central executive system, constitutes the theoretical basis for analysis of cognitive determinants of visual illusions in this study.

Our own research shows that the FD cognitive style is based on a capacious, but passive memory mechanism (rather cautious strategy of information processing, resulting in a greater number of omissions than false alarms), while the FI cognitive style – on an efficient and active attentional mechanism (which means a preference towards an analytical perceptual strategy and a tendency towards false alarms errors). FI people are highly efficient both in the selection of information (efficiency of inhibition processes) and in the shifting of attentional resources, and are moreover characterized by more efficient information storage and processing that is adequate to changing circumstances (Orzechowski & Bednarek, 2004). Perhaps the reason why FI people are more resistant to illusions, compared with FD people, is because they have more efficient cognitive control mechanisms, as shown by Miyake, Friedman, Emerson, Witzki, Howerter, and Wager (2000).

Neuropsychological research by Walter and Dassonville (2008, 2011), using the fMRI technique, showed that the superior parietal cortex and precuneus play a crucial role in the processing of contextual information in a wide range of visuospatial tasks (EFT, the Rod-and-Frame Illusion [RFI], and the Roelofs effect), while the frontal regions coordinate these processes. In people who were faster performing the EFT test (i.e., the field-independent people), a greater activation of the parietal and frontal areas of the right hemisphere, particularly from the parietal-temporal region to precuneus, inferior frontal gyrus (IFG), and insula, was observed. The right inferior frontal gyrus (rIFG) plays an important role in inhibitory control (Aron, Robbins, & Poldrack, 2004, quoted in: Walter & Dassonville, 2011), whereas the right inferior and middle frontal gyri, inferior parietal regions, and insula are activated during tasks that require inhibition of interference (Bunge et al., 2002, quoted in: Walter & Dassonville, 2011). This means that the above-mentioned regions, which are active during the test assessing the FDI dimension and differentiating susceptibility to illusions, are also responsible for the main functions of the central executive in working memory. On this basis, we have assumed that the same brain regions that are responsible for higher field dependence and lower efficiency of executive functions in working memory (especially the shifting of attention and the inhibition of distractors) are also involved in visual illusions formation.

Searching for other relations between working memory and perception, scientists have demonstrated a number of important links between the working memory system and top-down mechanisms directing the eye movements (Navalpakkam & Itti, 2003; Mitchell et al., 2002). It can be assumed that at the stage of making original settings of perception, information contained in the working memory decide which features of physical stimulation will be recognized as essential. During the construction of objects, e.g., illusory figures, the working memory indicates the rules for distinguishing figures from the background, and then a task-importance map is created in the spatial memory buffer. Finally, on the basis of the comparison with the content of visual buffer, an object is recognized. These unconscious operations may result in normal or illusory perception.

Despite the ambiguity of the results of the research on illusions reviewed by Smeets and Brenner (2006) (various paradigms and tools were used), there are attempts to identify cognitive predictors of particular visual illusions. For example, in the context of the so-called metric illusions, it was reported that poor attentional selection is conducive to the Müller-Lyer illusion (Tsal, 1984), and affects the magnitude of the Ebbinghaus illusion (Shulman, 1992). De Fockert and Wu (2009) showed that the greater the working memory load, the stronger the interference from distractors, and consequently the higher susceptibility to the Ebbinghaus illusion; whereas, the so-called orientation (contextual) illusions vary in magnitude and direction in accordance with the cognitive strategies that are used (Daini & Wenderoth, 2008). Higher efficiency of attentional selection concerning physical features of stimuli (a top-down mechanism) can reduce the impact of contextual information on the perception of the Roelofs illusion (Lester & Dassonville, 2011). Vogel et al. (2005) suggest that the working memory capacity is responsible for individual differences in efficiency of selection of relevant visual stimuli from among distractors. People with high WM capacity encode essential elements more efficiently; people with low WM capacity often inefficiently encode and also store information about irrelevant elements. However, extensive research by Dassonville, Walter, and Lunger (2006) that aimed to answer the question of whether field dependence assessed by the Hidden Figures Test (HFT) (Ekstrom et al., 1979) and higher susceptibility to visual illusions, such as the RFI and the Roelofs effect are simply a manifestation of individual differences in WM efficiency (the capacity and efficiency of information processing in WM, including the speed of digit encoding and processing, was examined), did not give an affirmative answer to that question. On the basis of the factor analysis, three factors were identified, one of which indicates the impact of subjects' gender: the first was the speed of information processing in WM – which was loaded by HFT indicators, digit encoding and WM capacity; the second was related to the FDI dimension – which was co-created by the RFI and Roelofs illusion indicators and HFT; and the third factor was constituted by HFT performance indicators and WM capacity, when gender was considered. The quoted pattern of results does not allow us to explain individual differences in field dependence and susceptibility to illusions on the basis of efficiency of particular working memory functions. Therefore, when planning the research involving architects, i.e., a specific group of professionals who underwent several years of training of visuospatial functions during their studies, similarly as Dassonville and his team, we posed the question about the role of field dependence and working memory in inducing orientation illusions.

A review of studies involving architects show that their susceptibility to visual illusions is poorly examined, while cognitive predictors of these illusions in this professional group has not been studied at all. Jahoda and Stacey (1970) demonstrated that architects are generally less susceptible to visual illusions (including the Ebbinghaus and Poggendorff illusions) than people in the control group (with no architectural training), but no difference between the groups in susceptibility to the Müller-Lyer illusion was found. Morris and Bergum (1978) showed that architecture students are more field-independent than business students, whereas Barrett and Thornton (1967) demonstrated that engineers are more field-independent than the rest of population. Highly creative young architects tend to perceive details on the background of the whole and prefer analytical accuracy and precision, i.e., they are field-independent (Menelly & Porillo, 2005). McKenna (1984) linked architects' greater field-independence with their visuospatial abilities, which are the basis of the designing process. Similar conclusions were drawn by Strzałecki (1973), who in his longitudinal studies demonstrated that architects' abilities to manipulate spatial 3D configurations instead of making 2D transformations, and the role of their divergent thinking on figural material, increase during successive years of architectural studies.

This paper attempts to identify cognitive predictors of susceptibility/resistance to orientation visual illusions: Zöllner, Poggendorff, and Ponzo, in architects, i.e., people with visuospatial aptitudes who during their studies undergo systematic training of thinking on the spatial material, which should be conducive to higher resistance to visual illusions. For this study we chose a specific group of people who are known to be more field-independent (Morris & Bergum, 1978; Barrett & Thornton, 1967) and more resistant to visual illusions (Jahoda & Stacey, 1970) compared to the wider population. We put forward the following hypotheses: (H1) Architects, who during their studies undergo systematic training of visuospatial functions and thinking on graphic material, are more field-independent and more resistant to the orientation illusions: Zöllner, Poggendorff, and Ponzo, compared with the people who do not train their visuospatial functions in the course of their studies; (H2) The cognitive predictors of susceptibility to the orientation illusions include: (1) field dependence (FD), (2) lower WM capacity, and (3) lower efficiency of WM executive functions, and especially the shifting of attention and inhibition processes.

Method

Participants

The study involved 61 professional architects (30K, 31M), age: M = 29; +/–1.6, range: 25–31 years) and 49 students at the University of Social Sciences and Humanities in Poland (29F, 20M), the average age: 23.53; +/– 4.24, range: 19–31 years. All participants were volunteers and they got information about the study from the advertisement that was placed on the university website. The group of architects consisted of graduates of architecture from several Polish universities of technology who had undergone several years of training of visuospatial functions on geometric material in 2D and 3D during their studies. The comparison group consisted of university students who had not had any architectural training. All participants had normal or corrected-to-normal vision. The experiments were conducted according to the ethical standards of the 1964 Declaration of Helsinki.

Research tools

Visual Illusion Simulation (VIS)

A self-developed method – consists of 5 tasks that examine illusions from the following categories: (1) metric illusions: Ebbinghaus, Müller-Lyer; (2) orientations illusions: Zöllner, Poggendorff, Ponzo (see Figure 1).

Procedure

The VIS test was presented on a MacBook (late 2008) computer with 13,3-inch display, 1280 x 800 pixels at 16:10 aspect ratio (113,49 dpi). The 2D computer program, written in the Java language, displays illusions in a window size 9.7 x 13 cm. One graphical unit magnitude for the window of the above-mentioned size in metric units is 0.194 mm. Stimuli were presented statically as black figures on a white background. The size of the images with illusions was designed so that the entire illusory figure was in the area of accurate vision when the distance of the observer from the screen was 50 cm. The areas of vision for the illusions were as follows: Ebbinghaus 14°, Müller-Lyer 10°, Poggendorff 12°, Ponzo 10°, and Zöllner 10°. The areas of vision determined by extreme points of the compared elements in the illusions were as follows: Ebbinghaus 10°, Müller-Lyer 3°, Poggendorff 4°, Ponzo 6°, and Zöllner 4°.

Participants sat at comfortable viewing distance (approximately 50 cm) from the screen, with their heads free. Participants were instructed to keep their heads straight. Susceptibility to each illusion was assessed by the method of adjustment. Participants were required to press keys (←, →, ↓, ↑) on a keyboard to adjust a comparison stimulus to match a second stimulus presented in an illusion-causing context. Specifically they adjusted: (1) size – the Ebbinghaus illusion, (2) length – the Müller-Lyer and Ponzo illusions, (3) position – the Poggendorff illusion, and (4) orientation – the Zöllner illusion. Pressing an arrow key once adjusted the characteristics of the comparison stimulus in fine increments: 0.1° clockwise or counter-clockwise, respectively, when precisely adjusting orientation and 1 pixel left, right, up or down, respectively, when precisely adjusting size, length or position. Pressing an arrow key for a longer duration adjusted the characteristics of the stimulus in steady increments to quickly adjust the target towards its goal. An initial position of a comparison element appeared randomly on the screen. Participants adjusted: (1) the diameter of a comparison circle to match that of the target circle in the Ebbinghaus illusion (5 trials), (2) the length of a comparison line to match that of the target line in the Müller-Lyer and Ponzo illusions (5 trials each), (3) the position of an oblique line segment on the top right of the figure to lie collinear with the oblique line segment on the bottom left of the figure in the Poggendorff illusion (5 trials), and (4) the orientation of a comparison line so that it appeared to be parallel to the two target lines in the Zöllner illusion (5 trials). When participants decided that the object was located in a desired position, they confirmed and proceeded to another trial. Before each new illusion a new instruction was displayed. The test took approximately 7 minutes to complete, although there was no time limit for the test.

Indicators

An error magnitude is counted for each illusion separately as a sum of errors (pixels in the Ebbinghaus, Müller-Lyer, Ponzo, and Poggendorff illusions, and in degrees in the Zöllner illusion) made in 5 trials during estimation of the size or orientation of a comparison stimulus. Additionally, an error magnitude is counted for overestimated and underestimated adjustments of a comparison stimulus for each illusion separately. The higher the error obtained, the higher the susceptibility to perceptual illusions. Only the orientation illusions (Poggendorff, Ponzo, and Zöllner) were further analysed.

Embedded Figures Test (EFT)

EFT (standard version) is used to examine field dependence-independence as a manifestation of psychological differentiation (Witkin et al., 1971). It measures the extent to which an individual can overcome the effects of irrelevant background elements when consciously focusing on a task or activity.

Procedure

The task is to differentiate as quickly as possible a simple geometric figure hidden in an obtrusive complex figure. The contour of the simple figure is also the contour of the figure constituting the geometric pattern (Figure 2). EFT comprises 8 simple and 24 complex figures.

Indicator

An indicator serving as means to identify preference on the FDI dimension is the accumulated time needed to solve 24 tasks (the time limit for each task in the test is 3 minutes). People who take a longer time to solve the tasks are considered to be "field-dependent" (Witkin et al., 1971).

SWATT (Switching of Attention Task)

The computer task SWATT was used as a measure of efficiency of working memory functioning (switching of attention and inhibition efficiency) (Chuderski and Nęcka, 2004).

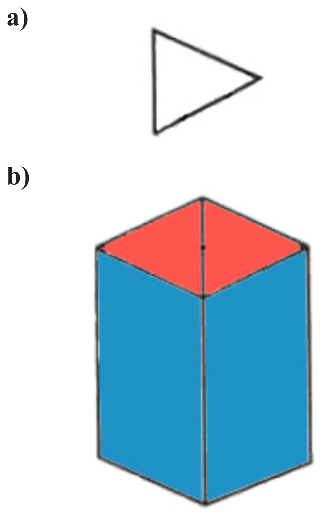
Task description

The centre of the screen showed two digits with two letters underneath (see Figure 3). All the stimuli

Figure 1. Computer simulation of visual illusions (VIS)
a) Poggendorff; b) Ponzo; c) Zöllner
Elements for setting are marked by a dotted line (for illustrative purposes). The arrow indicates a possible direction of the object manipulation. In the computer simulation, the Zöllner figure is rotated 45° to the right

a) b) c)

Figure 2. Embedded Figures Test (EFT)
a) simple geometric figure; b) complex figure



were displayed as black digits and letters on a light blue background, at regular intervals of 800 ms. Presented sequences included 100 pairs of numbers (above) plus 100 pairs of letters (below) with 12 pairs of numerical patterns (odd numbers) and 12 pairs of alphabetical patterns (two identical letters) among them. Numerical and alphabetical patterns could not appear simultaneously and were separated by at least one non-pattern. No more than 3 patterns (letters or digits) were presented in a row. There was a practice trial followed by 4 test trials presented one after another with 3-second breaks. The test took around 5–6 minutes to complete.

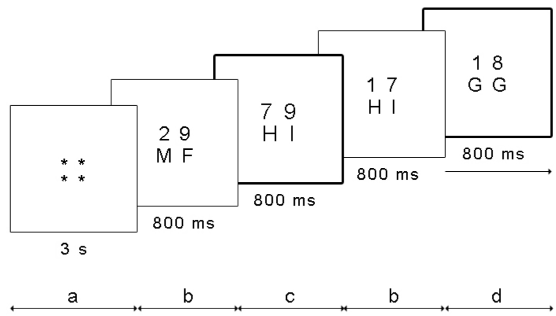
Procedure

Participants were asked to press a spacebar every time they saw two identical letters or two odd digits on the screen. In case of no reaction, the next stimuli came up on the screen after 800 ms. The overall efficiency of working memory is estimated on the basis of the total number of errors (omissions of letters and digits, and false alarms).

Indicators – see Table 1.

Figure 3. Switching of Attention Task (SWATT)

a) the point of visual fixation; b) a set of distractors; c) a set containing a correct arrangement of odd digits; d) a set containing a correct arrangement of letters



Procedure

The participants were tested individually using computer tests as follows: VIS, EFT, SWATT. The study lasted between 50 and 70 minutes.

Table 1. SWATT (Switching of Attention Task) Indicators

Variable	Variable's characteristic	Indicator
OE OEL OED	omission errors omission errors – letters omission errors – odd digits	The efficiency of selective attention: The more omissions, the slower information selection
FA	false alarms	The efficiency of inhibition processes: The more false alarms, the weaker inhibition (weak executive control)
TE	total errors: TE = OE + FA	The efficiency of switching of attention: The more errors (omissions and false alarms) the weaker switching of attention
RT RTL RTD	mean correct reaction time mean correct reaction time – letters mean correct reaction time – odd digits	The efficiency of switching of attention: The longer RTs, the weaker switching of attention
B BL BD	strategy to respond – the ratio of the number of false alarms to the sum of errors: B = FA/TE – the greater B, the more active strategy strategy to respond to letters: BL = FA / (OEL + FA) strategy to respond to odd digits: BD = FA / (OED + FA)	The efficiency of inhibition processes: (1) The more FAs out of the whole number of errors, the more active (impulsive) strategy of performing a task/weaker executive control (2) The less FAs, the more passive strategy (cautious)/ too slow data selection

Results

Comparative analyses were carried out for EFT and SWATT indicators in both groups: architects (people who trained their visuospatial functions during their studies) and the control group (people who had no architectural training) (descriptive statistics in Table 2, Appendix). As expected (H1), the architects were found to be generally more field-independent (M = 227.92, SD = 135.77) than people in the control group (M = 944.42, SD = 482.70), $t(54.12) = -10.075$, $p < .001$. The architects also had significantly higher WM efficiency (at the level of $p < .05$) in the case of indicators of correctness of information processing in WM, i.e., TE – total errors; OE – omission errors; OED – omission errors – odd digits. The architects revealed also a strong tendency ($p = .057$) to make less FA (false alarms) errors than people in the control group. The architects needed more time to correctly accomplish the SWATT task than the control group. It was revealed in.: RT – correct reaction time; RTL – correct reaction time – letters; RTD – correct reaction time – odd digits ($p < .05$). We did not observe differences between the groups in the case of two indicators of WM functioning, namely: OEL – omission errors – letters; and B – strategy to respond ($p > .05$) The compared groups did not differ in their strategy of completing the SWATT task.

In accordance with our hypothesis, the architects were found to be more resistant to visual illusions than people in the control group (Table 2, Appendix). Poggendorff: $t(91.25) = -7.18$, $p < .001$, $d_{Cohen} = 1.41$ (architects M = 45.78 vs. control group M = 83.47); Ponzo: $t(85.81) = -2.52$, $p < .05$, $d_{Cohen} = 0.50$ (architects M = 23.90 vs. control group M = 29.38); Zöllner: $t(79.21) = -5.47$, $p < .001$, $d_{Cohen} = 1.09$ (architects M = 1.58 vs. control group M = 3.52).

The results confirm that architects constitute a professional group that is more field-independent and less susceptible to visual illusions than in the wider population. These results are consistent with earlier studies described in the literature (Menelly & Porillo, 2005; McKenna, 1984). The architects have more efficient WM mechanisms: inhibition and switching of attention, as compared to the control group. Therefore, in the second part of our analysis, when we tested the H2 hypothesis about predictors of susceptibility, we considered only the specific group of architects who had systematically trained their visuospatial functions during their studies and professional career that could have had an influence on their resistance to visual illusions.

Taking into account all the indicators of information processing efficiency in working memory in the SWATT task as well as the time of the EFT task completion (descriptive statistics in Table 2, Appendix), we exploratively built models and carried out successive multiple regression analyses by a stepwise method for particular orientation illusions: Poggendorff, Ponzo, and Zöllner – only among the architects (Table 3). We also attempted to find out what percentage of variance is separately explained by indicators of WM functioning (Table 4) and field dependence-independence (FDI Table 5).

Results show that for the dependent variable (the error size in pixels) in the Poggendorff illusion (Table 3), the best fit to data was obtained with a model containing two variables: FDI and the strategy of detecting letter patterns (BL) (detecting similar letters is a task requiring information processing on the physical level). The model is significant, $F(2, 58) = 6.80$, $p < .01$, and explains 16% of the total variance. The unique contributions of each predictor are shown in tables 3, 4, and 5. The model shows that higher susceptibility to the Poggendorff illusion is influenced by field dependence (on the FDI dimension) and a more cautious strategy of information processing in working memory (the propensity for omission errors rather than false alarms during information processing at the sensory level – detection of two identical letters). However, the correlation of both predictors with the dependent variable is low.

Table 3. Results of multiple regression analysis (the enter method) with both EFT and SWATT included in the predictors (among architects)

pred.	*b*	*se b*	*β*	*t*	*p*
		Poggendorff: $F(2, 58) = 6.80$, $p < .01$, $R^2 = .16$			
constant	264.46	55.88		4.73	< .001
FDI	.304	.105	.344	2.911	< .01
BL	-173.38	79.23	-.259	-2.188	< .05
		Ponzo: $F(3, 57) = 12.67$, $p < .001$, $R^2 = .37$			
constant	244.68	65.87		3.714	< .001
FDI	.179	.036	.520	4.928	< .001
RTD	-.275	.076	-.371	-3.605	< .01
BD	51.99	27.05	.242	2.291	< .05
		Zöllner: $F(2, 58) = 18.81$, $p < .001$, $R^2 = .37$			
constant	24.66	8.61		2.863	< .01
FDI	.030	.005	.574	5.606	< .001
RTD	-.031	.011	-.281	-2.745	< .01

Note. R^2 – corrected; FDI: Embedded Figures Test; SWATT: BL – strategy to respond – letters (the lower result, the more cautious strategy); RTD – correct reaction time – odd digits; BD – strategy to respond – odd digits (the lower result, the more cautious strategy); TE – total errors

Next, we attempted to find out what percentage of variance was explained by WM functioning indicators. The best fit to the data was obtained with a model containing one variable related to WM functioning, i.e., the strategy of detecting letter patterns (BL). This predictor in the significant model ($F(1, 59) = 4.56$, $p < .05$) allows us to predict susceptibility to the Poggendorff illusion, although its correlation with the dependent variable is low, as it explains only around 6% of the total variance (Table 4).

Whereas, the FDI variable explains approximately 10% of the variance of the dependent variable (as shown in Table 5). The correlation between this predictor and the dependent variable is average. More field-dependent people (on the FDI dimension) are more susceptible to the Poggendorff illusion.

Table 4. Results of multiple regression analysis (the enter method), with SWATT (but not EFT) included in the predictors (among architects)

Variable	*B*	*SE B*	*β*	*t*	*p*
Poggendorff: $F(1, 59) = 4.56$, $p < .05$, $R^2 = .06$					
constant	337.55	53.00		6.40	< .001
BL	-179.57	84.07	-.268	-2.136	**< .05**
Ponzo: $F(1, 59) = 8.77$, $p < .01$, $R^2 = .11$					
constant	320.08	67.94		4.711	< .001
RTD	-.267	.090	-.360	-2.962	**< .01**
BD			.123	1.012	> .05
Zöllner: $F(1, 59) = 5.38$, $p < .05$, $R^2 = .07$					
constant	34.51	11.48		3.004	< .01
RT	-.035	.015	-.289	-2.320	**< .05**
RTD			.074	.578	> .05

Note. R^2 – corrected; SWATT: BL – strategy to respond – letters; RTD – correct reaction time – odd digits; BD – strategy to respond – odd digits; RT – correct reaction time; TE – total errors

Table 5. Results of multiple regression analysis (the enter method), with EFT (but not SWATT) included in the predictors (among architects).

Variable	*B*	*SE B*	*β*	*t*	*p*
Poggendorff: $F(1, 59) = 8.29$, $p < .01$, $R^2 = .10$					
constant	158.19	28.53		5.54	< .001
FDI	.304	.105	.344	2.911	< .01
Ponzo: $F(1, 59) = 14.73$, $p < .001$, $R^2 = .19$					
constant	84.44	10.62		7.95	< .001
FDI	.154	.040	.447	3.838	< .001
Zöllner: $F(1, 59) = 27.08$, $p < .001$, $R^2 = .30$					
constant	1.33	1.47		0.905	> .05
FDI	.030	.005	.574	5.606	< .001

Note. R^2 – corrected; FDI: Embedded Figures Test

In the case of the Ponzo illusion, for the dependent variable (the error size in pixels), the best fit to the data was obtained with a model containing three predictors. The strongest predictor of susceptibility to the Ponzo illusion was field dependence, followed by the mean time of correct detection of two odd digits (RTD), and the strategy of detecting odd digit patterns (BD). The model is significant ($F(3, 57) = 12.67$, $p < .001$) and explains approximately 37% of the total variance. Susceptibility to the Ponzo illusion is facilitated by higher field-dependence (on the FDI dimension), fast and correct execution of the more difficult task of detecting two odd digit patterns, and a more active (impulsive) strategy of completing this task, revealing a greater propensity for making false alarms (FA) than omissions (OED).

When we took into account only WM indicators, the best fit to the data was obtained with a model containing one significant predictor, namely the mean time of correct detection of two odd digit patterns (RTD). This factor predicts susceptibility to the Ponzo illusion in approximately 11.5% of the total variance. Its correlation with the dependent variable is moderately high (Table 4). Results show that the FDI variable itself explains approximately 19% of the variance of the dependent variable. There is a high correlation between susceptibility to the Ponzo illusion and FDI (Table 5).

In the case of the Zöllner illusion (the dependent variable was the error size in degrees), the best fit to the data was obtained with a model containing two predictors: FDI and the mean time of correct responses during detection of two odd digit patterns (RTD). The model is significant ($F(2, 58) = 18.81$, $p < .001$) and explains approximately 37% of the total variance. In this model, FDI proved to be the stronger predictor of susceptibility to the Zöllner illusion, whereas the second predictor, i.e., the mean time of correct responses during detection of odd digits (RTD) is moderately correlated with the dependent variable (Table 3).

In the case of models consisting only of WM efficiency indicators, the best fit to the data was obtained with a model containing only one significant predictor – RT. This factor predicts susceptibility to the Zöllner illusion in approximately 7% of the total variance of the dependent variable ($F(1, 59) = 5.38$, $p < .05$). Its correlation with the dependent variable is low (Table 4).

The results show, however, that the FDI variable explains approximately 30% of the variance of the dependent variable. We found a high correlation between susceptibility to the Zöllner illusion and field dependence (Table 5).

Conclusions and discussion

On the basis of this study, we can draw the following conclusions:

(1) Despite several years' training of visuospatial functions, architects are susceptible to the orientation illusions: Zöllner, Poggendorff, and Ponzo. (2) In the group of architects, we find the following predictors of

susceptibility to the orientation illusions: field dependence (Poggendorff, Ponzo, and Zöllner), efficiency of visual information processing in WM, including lower efficiency of the inhibition of distractors (Ponzo), less efficient selection of sensory information (Poggendorff), and generally high speed/efficiency of visual information (letters and digits) processing in WM (Zöllner).

For orientation illusions the following predictors were obtained:

The Ponzo illusion. Higher susceptibility was found in people who were more field-dependent, efficiently processed semantic information in working memory (i.e., efficiently operating the "odd digits" rule), and preferred an active strategy of detecting digit patterns. The active strategy consists in responding both to the cues and distracters, which manifests itself in a large number of false alarms in relation to all the errors made. The preponderance of false alarms shows poor cognitive inhibition that manifests itself in difficulties with selecting correct information (Schachar & Logan, 1990). These three predictors explain approximately 37% of the dependent variable.

The Zöllner illusion. Higher susceptibility was found in people who were field-dependent, efficiently processed material that required engagement of the articulatory loop (operating the "odd digits" rule). On the basis of these two factors, we can predict higher susceptibility to the Zöllner illusion with approximately 37% probability. When only indicators of WM functioning are taken into account, higher susceptibility to the Zöllner illusion is related to generally higher efficiency of information (letters and digits) processing in WM (which manifests itself in shorter times of correct responses).

The Poggendorff illusion. Higher susceptibility can be expected with 16% probability on the basis of field dependence and a more cautious (passive) strategy of detecting letter patterns (physical similarity) that manifests itself by a propensity for omitting cues. People more susceptible to the Poggendorff illusion are characterized by poor selection of information at a shallow, sensory level of processing.

In our research, we confirmed the hypothesis that architects are more field-independent and more resistant to the orientation illusions (Zöllner, Poggendorff, and Ponzo), compared with the control group of students at the University of Social Sciences and Humanities. Similar results were obtained by Morris and Bergum (1978), and by Barrett and Thornton (1967). Previously published studies showed that FD people differ from FI people in their WM functioning (Miyake et al., 2001; Orzechowski & Bednarek, 2004). According to Miyake, completing the EFT test that identifies preferences towards the FDI dimension, requires efficient visuospatial and executive functions of working memory. In view of Repovs and Baddeley (2006), the visuospatial sketchpad is the component of memory that allows for temporary storage and processing of information about the location of visual stimuli in space, whereas the central executive is responsible for control and regulation of cognitive processes. Our research shows that the field dependence (FD) is based on a capacious, but passive mechanism of memory, while the field independence (FI) – on an efficient and active attentional mechanism. FD people have a more capacious visuospatial sketchpad (Bednarek, 2011). The above-mentioned components, derived from Baddeley's model of working memory, seem to be crucial for the formation of visual illusions.

Our results show that architects who are susceptible to the Ponzo illusion are field-dependent and use an active strategy of information processing, resulting in a tendency to make more false alarms than omissions. Because of poor inhibition of distractors, these people have problems with differentiating stimuli and confuse cues with distractors already at the sensory stage of receiving physical stimulation. As a result of these problems with proper selection of information, the attention filter is letting in unnecessary – for the task being completed – information, and this probably results in inclusion of erroneous visual cues into the mental model of the situation (and a misperception arises). Poor selection of information at the sensory level is also responsible for higher susceptibility to the Poggendorff illusion. People who are susceptible to this illusion are field-dependent and use a rather cautious strategy of information processing, resulting in greater number of omissions than false alarms. Thus, it turned out that both false alarms and omissions are conducive to misperception. If already at the physical level, a too large portion of visual stimulation is rejected, then the information accessible to the cognitive system may not be sufficient for its proper interpretation. As a result of incomplete stimulation, the perceptual system automatically makes a correction complementing the data. Correction of what is on the retina of the eye is a constant feature of perception. Latency correction (Changizy & Widders, 2002; Króliczak, 1999) occurs both in the natural and illusory perception. The process of data complementing is unconscious and essential for further information processing and building a mental model of the situation (often contributing to a "distorted perception"). According to Gregory (1997), illusions arise when a tested hypothesis (mental model of a particular situation), despite its inadequacy to reality, is accepted by a person.

The finding that FD subjects with more efficient working memory are more susceptible to the Zöllner illusion, although it does not confirm the hypothesis H2, can be analysed also in the context of the research results cited above (Miyake et al., 2001; Orzechowski & Bednarek, 2004). The Zöllner illusion to a large extent depends on the specific nature of the perceived material. In the Zöllner figure, the perspective is imitated by short diagonal "strokes" crossing long vertical or horizontal lines at an angle from 0 to 90 degrees. The greatest effect is achieved by an angle of 10 to 30 degrees (Maheux, Townsend, & Gresock, 1960). And the illusion is stronger when the image is rotated at around 45 degrees, compared to the situation where the long lines are horizontal or vertical. Because the origin of orientation illusions is peripheral (selection of sensory material is made automatically, largely unconsciously), people who prefer a global strategy of capturing data in the visual field, defined by Huteau (1983) as being rather inflexible or even rigid, are particularly vulnerable to misperception. One can conclude that in the group of field-dependent architects their high efficiency/speed of information processing in WM does not protect them against susceptibility to the Zöllner illusion, because their speed of processing is probably less important than their global perceptual strategy that determines how much and what information is selected and encoded already at the sensory level of processing. The global strategy implies a broad capture of information in the visual field, temporarily stored in VWM. The amount of information encoded by the cognitive system is restricted by the limited capacity of VWM. This is consistent with Cowan's (1995) activation concept of working memory, and with the concept proposed by Feldman-Barrett, Tugade, and Engle (2004), who suggest that global processing involves parallel and automatic registering of multiple data perceived as part of a larger structure and depends on WM capacity. Therefore, the primary predictor of susceptibility to all the orientation illusions tested in this study proved to be field dependence (FD), which means preference for a global perceptual strategy.

Field-dependent people, relying on a capacious, but passive memory mechanism, maintain both relevant and irrelevant elements activated, which can interfere during their storage in outline form in VWM, or during comparison of the information with a memory pattern or incoming pieces of information. Taking in from the environment both relevant elements and distractors is related to the poor operation of selective attention, i.e., the inability to inhibit distractors. As a result of their global perceptual strategy, FD people are more exposed to the impact of peripheral cues in the form of oblique lines inducing the orientation illusion. Such peripheral cues stimulate the exogenous system of visual attention that is automatically controlled, and the person is not aware of the processes taking place in that system (Wright & Ward, 2008).

The present study is complementary and constitutes to some extent a continuation of the research done by Dassonville et al. (2006), in which the researchers did not manage to confirm unambiguously the links between the capacity/efficiency of information processing in WM and susceptibility to visual illusions. Our findings, on the one hand, confirm the regularities that are well described in the literature and concern the influence of field dependence on susceptibility to visual illusions, and, on the other hand, are a part of research aiming to find memory mechanisms of illusions. On the basis of WM efficiency indicators, we managed to confirm the existence of memory predictors of susceptibility to illusions (they are rather weak, as they explain from 6% to 14% of the variance of the dependent variable). The presented results show that not all WM mechanisms have a direct relation to susceptibility to orientation illusions in the group of architects. A crucial role is played by the perceived material (the graphic structure of illusory figures) and the mechanism of inhibiting distractors that underlies selectivity of attention at an early stage of perception.

Due to the small range of the explained variance in the regression models including FDI and WM functioning indicators, the question arises: what other cognitive variables should be considered in further studies? In our view, we should take into account FDI internal differentiation, e.g., flexibility vs. rigidity (Kholodnaya, 2002), and global vs. local strategy of information processing as presented by Navon (1977).

This problem seems to be important both theoretically and practically, because in Western culture we are all susceptible to illusions, including architects who undergo many years of training of visuospatial functions on graphical material in 2D and 3D.

The results based on the group of architects, whose spatial-perceptual skills were trained during their studies, do not allow to state whether their training increased their field independence and improved their WM performance. It is possible that the architects were more field-independent and less resistant to illusions than the rest of population prior to their studies (occupational skills). To evaluate this precisely, one should compare architects at the beginning of their studies and after their graduation.

Future studies, with architects as an experimental group, should contain modified graphic material that evokes illusions, e.g. differently placed illusory figures (vertical, horizontal, rotated) since such 2D and 3D material is frequently used by architects.

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Appendix

Table 2. Results of Student's t-test for all predictors WM and EFT (architects vs. control group)

Variable	*M* *architects*	*SD* *architects*	*M* *control*	*SD* *control*	*t*	*df*	*p*
EFT	227.91	135.77	944.42	482.70	-10.07	54.12	.000
TE	36.48	14.93	47.51	17.16	-3.60	108	.001
OE	22.13	10.27	29.10	13.57	-2.97	87.54	.004
FA	14.03	8.40	18.41	13.97	-1.92	74.89	.057
RT	752.38	57.37	710.18	58.90	3.79	108	.001
OEL	9.33	6.40	9.88	6.55	-.44	108	n. s.
OED	12.43	7.27	19.22	11.91	-3.66	108	.001
RTL	755.62	70.39	700.86	68.45	3.66	108	.001
RTD	752.46	63.12	710.04	128.34	2.26	108	.026
B	.39	.15	.38	.19	.26	86.55	n. s.
BL	.60	.18	.62	.19	-.56	108	n.s.
BD	.53	.18	.49	.22	1.13	108	n.s.
Poggendorff	45.78	24.00	83.47	29.79	-7.18	91.25	.001
Ponzo	23.90	9.35	29.38	12.71	-2.52	85.81	.014
Zöllner	1.58	1.40	3.52	2.14	-5.47	79.21	.001

Note. EFT (Embedded Figures Test) – RT; SWATT: TE – total errors; OE – omission errors; FA – false alarms; RT – correct reaction time; OEL – omission errors – letters; OED – omission errors – odd digits; RTL – correct reaction time – letters; RTD – correct reaction time – odd digits; B – strategy to respond; BL – strategy to respond to letters; BD – strategy to respond to digits; Illusions: POG – Poggendorff; PON – Ponzo; ZOL – Zöllner.
N = 61 architects; N = 49 control group.