Individual Differences in Object/ Spatial Processing and Cognitive Style

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DEDICATION

This thesis is dedicated to Prelestinka.

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I would like to thank my friends, relatives, and supporters who have made this happen (and especially Prelestinka). My supervisor, Maria Kozhevnikov, supported and guided me in my research. Michael Motes also provided valuable advice and guidance in my research.

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ABSTRACT

INDIVIDUAL DIFFERENCES IN OBJECT/ SPATIAL IMAGERY AND COGNITIVE STYLE

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This current thesis focuses on visual cognitive style and individual differences in object and spatial visual processing, both from theoretical and applied perspectives. The research is based on a new approach to examining individual differences in mental imagery that relies on a key distinction regarding visual imagery, namely the distinction between object and spatial imagery (e.g., Farah, Hammond, Levine, & Calvanio, 1988; Kosslyn, Ganis, & Thompson, 2001; Kosslyn & Koenig, 1992; Kozhevnikov, Kosslyn, & Shephard, 2005; Mazard, Tzourio-Mazoyer, Crivello, Mazoyer, & Mellet, 2004; Ungerleider, & Mishkin, 1982). *Object imagery* refers to representations of the literal appearances of individual objects and scenes in terms of their shape, color, brightness, texture, and size, whereas *Spatial imagery* refers to relatively abstract representations of the spatial relations among objects, parts of objects, locations of objects in space, movements of objects and their parts, and other complex spatial transformations.

Furthermore, this distinction between object and spatial imagery has also been found in individual differences in imagery in the cognitive style model that distinguishes between these two visual, object and spatial, dimensions (Kozhevnikov, Hegarty & Mayer, 2002; Kozhevnikov et al., 2005; Motes & Kozhevnikov, 2007). *Object visualizers* consistently prefer to construct pictorial, colorful, high-resolution images of individual objects and scenes, and *spatial visualizers* consistently prefer to use imagery to schematically represent spatial relations among objects and can efficiently perform complex spatial transformations (Kozhevnikov et al., 2002; Kozhevnikov et al., 2005).

The current thesis focuses on the assessment and further theoretical justification of the object-spatial distinction in Visual-Verbal cognitive style. In particular, it focuses on the validation of the object imagery dimension and its relation to spatial and verbal dimensions in cognitive style, which has hitherto never been systematically studied. Furthermore, it focuses on the ecological validation of the object-spatial distinction in individual differences, and in particular on its relation to complex real-life tasks such as course or profession selection.

The first line of research focused on the design and validation of a new self-report instrument assessing individual differences in object imagery, spatial imagery, and verbal cognitive styles, the *Object-Spatial Imagery and Verbal Questionnaire,* OSIVQ (Blajenkova, Kozhevnikov & Motes, 2006; Blazhenkova & Kozhevnikov, submitted), based on the new Object-Spatial-Verbal cognitive style theoretical model (originally proposed by Kozhevnikov et al., 2005). The results of Principal factor analyses revealed a clear factor structure, with distinct object, spatial and verbal factors. Furthermore, the

Object, Spatial and Verbal scales were correlated with the criterion measures. Thus, across a series of studies, the OSIVQ demonstrated acceptable internal reliability as well as predictive validity. Further, research focused on validating this new cognitive style model that challenges traditional approaches to Visual-Verbal cognitive style as a unitary, bipolar dimension, and instead suggests a new three-dimensional cognitive style that distinguishes between Object Imagery, Spatial Imagery, and Verbal dimensions. The current research provides further validation of the new Object-Spatial-Verbal cognitive style model, and investigates the relationships between all three of its dimensions. The results of the confirmatory factor analysis demonstrated that the overall fit to the data of the new three-dimensional model of cognitive style was significantly better than that of the traditional, two-dimensional Visual-Verbal model. Thus, the current research supports the theoretical value of the new Object-Spatial-Verbal cognitive style model as well as the validity of the measurement approach based on this theory.

The second line of research focused ecological validation of the new cognitive style model and object-spatial distinction in visual imagery. In particular, it validated the new cognitive style assessment instrument, the OSIVQ, by establishing the relationship between the Object, Spatial and Verbal scales and learning and professional interests in the fields of visual art, science and humanities, correspondingly. Furthermore, this line of research investigates the object and spatial imagery preferences and abilities in members of different professions. The studies include behavioral paper-and-pencil and computerized testing. In the behavioral testing study (Blajenkova & Kozhevnikov, 2005), visual artists, scientists, architects, and humanities professionals completed spatial imagery tests, assessing the ability to process spatial relations and perform spatial transformations, and object imagery tests, assessing the ability to process literal appearances of objects in terms of colour and shape. A clear distinction was found: visual artists showed above average object imagery abilities but below average spatial imagery abilities. In contrast, scientists showed above average spatial imagery abilities but below average object imagery abilities. Thus, visual artists tended to be object imagers, and scientists tended to be spatial imagers. In addition, three groups of children (10-16 years old), those with interests and outstanding abilities in the fields of natural science, visual art, generally gifted children , as well as children without any specialized interests, were compared on a battery of spatial and object imagery tests. Overall, the results were consistent with those obtained from adult professionals, supporting the dissociation between object and spatial imagery abilities.

Furthermore, we explored the qualitative differences between visual artists and scientists in approaches to interpreting abstract visual information, i.e., kinematics graphs and abstract art. Overall, the results showed that object and spatial visualizers tended to interpret abstract visual information (i.e., abstract art and kinematics graphs) in qualitatively different ways. Visual artists tended to interpret the abstract art as abstract representations, but scientists tended to interpret abstract art literally, in a concrete way. In contrast, visual artists tended to interpret graphs literally (graphs-as-pictures), but scientists tended to interpret graphs schematically, in an abstract way. Thus, the results demonstrated that object visualizers (visual artists) were indeed able to form abstract representations in object visual thinking, contrary to the view that object imagery is a concrete type of imagery that cannot support abstract visual representations. Moreover, the results showed that spatial visualizers (scientists) failed to form abstract representations in non-spatial domain, which suggests that abstract reasoning ability can not be considered as an inseparable property of spatial imagery. Furthermore, these results suggest that, overall, abstract thinking is domain specific (i.e., object or spatial), and each mode of processing can support abstract representations.

Overall, the present research demonstrated quantitative and qualitative differences between object and spatial processing modes in individual differences, and provided validation of the Object-Spatial-Verbal cognitive style theoretical model. In particular, the significance of the current research is the validation of the Object imagery dimension as independent and having its own unique functional role and predictive validity. Moreover, the research suggests that object imagery may support unique abstract representations, and uniquely predict a range of abilities important for real-life, thus providing ecological validity for this dimension. Furthermore, the current research managed to develop a new, theoretically-guided measurement tool that will be useful in applied settings (e.g., education, vocational guidance), and for psychological research (e.g., for studying object and spatial visual and verbal processing).

INTRODUCTION

The focus of the present work is to investigate individual differences in object versus spatial visual processing and visual cognitive style. In particular, the current research focuses on theoretical and empirical verification of the new Object-Spatial-Verbal theoretical model of cognitive style (proposed by Kozhevnikov et al., 2005), that includes three relatively independent dimensions: Object Imagery, Spatial Imagery, and Verbal. This model re-examined the traditional Visual-Verbal cognitive style model, in accordance with current behavioral and neuroscience findings, and challenges commonly held assumptions: first, that imagery is a unitary and undifferentiated construct, and that a given individual can be characterized as having high- or low-imagery abilities in general; second, that Visual-Verbal cognitive style is a bipolar, unitary construct, with the preference to verbal or visual ways of information processing portrayed as two contrasting poles.

Specifically, this research focuses on the evaluation of the validity of the Object-Spatial-Verbal theoretical model versus traditional Visual-Verbal model. It also aims to develop a theoretically guided self-report measure of Object-Spatial-Verbal cognitive style, which does not currently exist. Lastly, the present research focuses on the ecological validation of the Object-Spatial distinction in visual processing, especially in establishing the predictive and ecological validity of Object imagery dimension. Previously, individual differences in the Object imagery dimension have not been systematically studied and assessed, unlike the Spatial or Verbal dimensions that are traditionally employed in IQ testing.

Our approach is based on recent cognitive and neuroscience research that distinguishes between Object and Spatial systems in mental visual imagery, perception and memory. *Object* processing refers to representations of the literal appearances of individual objects in terms of their precise form, size, shape, color and brightness. *Spatial* processing refers to relatively abstract representations of the spatial relations among objects, parts of objects, locations of objects in space, movements of objects and object parts, and other complex spatial transformations. As will be discussed in the review, evidence from the behavioral and neuroscience research has shown that these two visual systems encode and process visual information in different ways and they are anatomically and neurologically distinct (e.g., Farah et al., 1988; Kosslyn et al., 2001; Kosslyn & Koenig, 1992; Kozhevnikov et al., 2005; Mazard et al., 2004; Ungerleider, & Mishkin, 1982). Furthermore, this distinction between object and spatial imagery has been also found in individual differences in imagery in object versus spatial cognitive styles (Kozhevnikov, Hegarty & Mayer, 2002; Kozhevnikov et al., 2005; Motes & Kozhevnikov, 2007). Research by Kozhevnikov and colleagues proposed that visualizers could be divided into two groups: object visualizers and spatial visualizers. *Object visualizers* consistently prefer to construct pictorial, colorful, high-resolution images of individual objects and scenes, and *spatial visualizers* consistently prefer to use imagery to schematically represent spatial relations among objects and can efficiently perform complex spatial transformations (Kozhevnikov et al., 2002, 2005).

However, the traditional approaches to Visual-Verbal cognitive style investigating the individual preferences for processing visual versus verbal information has been based on the assumption that imagery is an undifferentiated, unitary construct and did not distinguish between object and spatial dimensions (e.g., Hollenberg, 1970; Paivio, 1983; Richardson, 1977). One of the most commonly acknowledged and popular cognitive styles, which will be the focus of the present work, is the Visual-Verbal cognitive style dimension (e.g. Paivio, 1971; Richardson, 1977) that describes consistencies and preferences in processing visual versus verbal information, and classifies individuals as either *visualizers*, who rely primarily on imagery when attempting to perform cognitive tasks, or *verbalizers*, who rely primarily on verbal-analytical strategies.

Despite the promising prospective applications of this approach, numerous research studies reported lack of construct and predictive validity as well as weak internal consistency of instruments assessing Visual-Verbal cognitive style that challenged the validity of Visual-Verbal cognitive style, and even cast doubt on the usefulness of this dimension (e.g., Boswell & Pickett, 1991; Green and Shroeder, 1990). Self-report instruments assessing imagery have failed to establish significant correlations with spatial imagery tests (see McKelvie, 1995). Therefore, the doubts have been raised regarding the validity of introspective assessments of imagery (e.g., J.T.E. Richardson, 1980), and moreover, about the functional role of subjectively experienced imagery (see Kosslyn, 1995 for a review). It was suggested that self-report questionnaires are “quite unreliable and can provide only little more than a rough index of imagery" (Lohman, 1979, pp. 149-150). However, we suggest that these problems arose because imagery was considered as a single, undifferentiated construct and that self-report instruments simply did not assess aspects of spatial imagery but rather assessed aspects of object imagery (Heuer, Fischman, & Reisberg, 1986; Kozhevnikov et al., 2005; Reisberg, Culver, Heuer, & Fischman, 1986). In this case, imagery self-reports, per se, should not be to be a problematic issue, but the correspondence between the type of imagery (i.e., Object or Spatial) assessed by the self-report instrument and the type of imagery required for a particular imagery task should matter. Furthermore, we suggest that Object imagery is an independent dimension, which has its unique predictive and ecological validity, is important for everyday and professional tasks (e.g. visual art or design), and cannot be reduced to concrete, underdeveloped case of general imagery ability. However, previous research frequently considered pictorial vivid imagery as a concrete imagery ability, and associated it with low intelligence or inability to form abstract imagery representations (for discussion see Lean & Clements, 1981).

Thus, the first goal of this thesis was the theoretical justification of object-spatial distinction in cognitive style, and in particular, the evaluation of the validity of the new Object-Spatial-Verbal cognitive model versus the traditional Visual-Verbal model. Furthermore, the purpose of the current work was to examine the relationships among all three cognitive style dimensions that have never been purposely studied before (especially, between Object and the other two cognitive style dimensions). Second, the goal of the present work was to develop a valid and reliable measurement of cognitive style based on recent cognitive psychology and neuroscience approaches that distinguishes between Object and Spatial processing: the Object-Spatial Imagery and Verbal Questionnaire (OSIVQ). Third, the research focused on the ecological validation of object-spatial distinction in cognitive style and individual differences. In particular the research focused on the relation between differences in cognitive style preference and complex real-life tasks such as course selection or a profession. Furthermore, the research investigated object-spatial imagery differences between members of different professions and gifted children by examining the differences in their performance on object-spatial measures, and also the qualitative differences in processing of complex visual information. In particular, this research focused on the ecological verification of the Object imagery dimension, and investigated whether Object mode of processing might support abstract representations.

In Studies 1a and 1b, the Object, Spatial and Verbal scales of OSIVQ questionnaire were designed and its factor structure and internal reliability were examined. In Studies 2a, 2b, and 2c, the predictive and discriminant validity of the Object and Spatial scales were examined. Next, in Study 2d, the predictive and discriminant validity of the full 3-dimentional cognitive style self-report instrument that included all three Object, Spatial, and Verbal scales, was investigated. Furthermore, in Study 2d, the predictive power of the three-dimensional (Object, Spatial, and Verbal) model of cognitive style was compared to that of the traditional two-dimensional (Visual-Verbal) bipolar model, and the relationships between Object, Spatial, and Verbal dimensions were further explored. In Studies 3a and 3b, the Object, Spatial, and Verbal scales were further ecologically validated, by examining the relationship between the OSIVQ scales and real-world activities (beyond the laboratory testing settings) that require object imagery, spatial imagery, or verbal abilities. The OSIVQ was administered to a sample of members of different professions known to use predominantly either object or spatial imagery or verbal ability in their training and work (i.e. professional visual artists, scientists and humanities professionals, respectively) as well as to college students who were asked about the amount of classes taken in visual art, science and writing . In Studies 4a and 4b, the differences in object and spatial imagery skills and cognitive styles were investigated between members of different professions (i.e., visual artists, scientists, architects and humanities professionals), and between children gifted in visual art, science and generally gifted children. Study 5 examined the qualitative aspects of imagery differences between members of different professions, and in particular, the differences in interpretation of abstract visual information (i.e., abstract kinematic graphs and abstract visual art).

LITERATURE REVIEW

Object-Spatial Distinction in Visual Processing

Until recently, most of the investigations of individual differences in mental imagery, as well as the investigations of individual preferences for processing visual versus verbal information, have been based on the assumption that imagery is an undifferentiated, unitary construct and therefore that individuals may be simply classified as good or poor imagers (e.g. Hollenberg, 1970; Paivio, 1983; Richardson, 1977). However, considerable cognitive and neuroscience research on visual processing (Farah et al., 1988; Kosslyn, 1994; Kosslyn & Koenig, 1992; Levine, Warach, & Farah, 1985) challenges the view that mental imagery is unitary, and instead this research suggests the existence of two distinct object and spatial systems that encode and process visual information in different ways.

Defining Object and Spatial Systems

One approach in defining these two visual systems (e.g., Ungerleider & Mishkin, 1982) emphasizes the difference between type and properties of information (e.g., shape, color or location) been processed by a visual system. For example, Farah et al. (1988) distinguishes between *Visual* “modality-specific representations that encode the literal appearance of objects, including perspective properties, color information, and aspects of form not available through touch or other modalities" and *Spatial*: "relatively abstract, amodal or multi-modal representations of the layout of objects in space with respect to the viewer and each other" (p.442-443). Other similar definitions contrast *Figurative* (e.g., color, shape, texture) versus *Spatial* (e.g., locations and spatial attributes) representations (e.g., Mazard et al., 2004; Mellet, Petit, Mazoyer, Denis, & Tzourio, 1998). Similarly, some other definitions describe functional properties of object and spatial systems; for example, Mazard et al. (2004) describes spatial imagery functions such as mental scanning or mental navigation, Milner & Goodale (1995) contrast the two systems: one is concerned with perceptual processing and the other with controlling actions.

The current research is based on the definition of spatial vs. object processing that elaborates and broadens previous descriptions accepted in cognitive neuroscience literature, and emphasizes different aspects of visual information, as well as their functional properties. In particular, *Object imagery* refers to representations of the literal appearances of individual objects and scenes in terms of their shape, color, brightness, texture, and size, whereas *Spatial imagery* refers to relatively abstract representations of the spatial relations among objects, parts of objects, locations of objects in space, movements of objects and object parts and other complex spatial transformations. Notably, although object imagery is related to the visual appearances of individual objects, it is not limited to individual objects, but could also refer to imagery of patterns and scenes, characterizing their color, vividness, shapes or details. Similarly, spatial imagery is not limited to spatial locations or relations between objects in spatial array, but could refer to spatial relations between parts of the object, and also it could refer to object's movement and dynamic spatial transformations of different elements of the object.

Object/Spatial Distinction in Imagery, Perception and Memory

Though, visual imagery has its unique functions and involves more top-down processing (Miyashita, 1995), it is tightly interconnected with perception and working memory. For example, many visual imagery tasks involve the activation of visual representations of previously viewed scenes or objects. In Kosslyn's model (1994), visual imagery is considered to be a part of the working memory buffer, and many other studies even use visual imagery and working memory interchangeably. Also, research shows much overlap in brain activation during *visual imagery* and *visual perception* (Ishai, Ungerleider, & Haxby, 2000; Kosslyn et al., 1999; O'Craven & Kanwisher, 2000), and as it will be discussed further, imagery deficits are associated with the same brain damage patterns as perceptual deficits (Farah et al., 1988; Levine et al., 1985). Similarly, cortical networks involved in visual *object-spatial working memory*, largely overlap with neural networks associated with visual-spatial imagery (Farah et al., 1988; Luzzatti, Vecchi, Agazzi, Cesa-Bianchi, & Vergani, 1998; Hecker & Mapperson, 1997).

The object-spatial distinction has been reported in studies on imagery, working memory and perception. For example, recent memory studies argue that there are object and spatial working-memory buffers and separate neural systems in the brain that are involved in storing spatial and object information. The classical model of working memory that consists of phonological loop, visuospatial sketchpad and a central executive (Baddeley & Hitch, 1974) has been recently revised, and it was suggested that the visual-spatial sketchpad needs to be further divided into visual and spatial components (Baddeley, 1992; Logie & Marchetti, 1991; Logie, Irwin, & Ross, 2003). This distinction between visual and spatial processing in working memory has been supported by behavioral and neuroimaging studies. For example, Baddeley and Lieberman (1980) found that spatial tasks (e.g., tracking a light while blindfolded with only auditory feedback) interfere with other spatial tasks more than with purely visual tasks (e.g., discriminating the brightness of two lights). Logie (1986) also showed that visual memory tasks are impaired by concurrently viewing irrelevant pictures but not by arm movements, whereas spatial memory tasks are impaired by arm movements but not by irrelevant pictures. Consistent with behavioral studies, the neuroimaging results argue for a separate dorsal-ventral functional organization for spatial and non-spatial visual information in working memory (e.g., Courtney, Petit, Maisog, Ungerleider, & Haxby, 1998; Darling, Sala, Logie, & Cantagallo, 2006; Darling, Sala, & Logie, 2007).

Furthermore, our review suggests that object and spatial imagery have unique relationships with other cognitive functions. In particular, though, overall, visual imagery relies on perception and memory, object and spatial imagery differ in their relation to memory and perception. For example, Kosslyn (1994) has argued that object imagery requires activating representations of object properties in visual working memory, whereas spatial imagery does not require activation of visual memories; spatial images are formed using spatial relations representations to arrange components, and attention is engaged at each location successively. Also, Goodale and Milner (2006) argued that the ventral stream supplies representations of the visual world, which can be stored for future reference and to help plan actions ‘offline’, whereas dorsal system acts in real time, guiding actions as they are needed. On the other hand, Milner, Dijkerman, McIntosh, Rossetti, and Pisella (2003) presented evidence that spatial system also involves memory processes for example, for memory-guided actions. Possibly, the object imagery system relies more on long-term memory, whereas spatial imagery relies more on the immediate working memory. It also likely that object imagery is more related to visual perceptual experience than spatial imagery, while spatial imagery has also non-visual motor, vestibular, and propriosensory components. For example, research evidence suggests that blind people are able to perform some spatial tasks such as mental rotation (Barolo, Masini, & Antonietti, 1990), and even more, some spatial tasks are performed better in the blindfolded condition (Baldy, Devichi, & Chatillon, 2004); nevertheless, visual experience is necessary for spatial processing (Loomis et al., 1993).

Overall, the distinction between object and spatial processing extends from visual imagery to other related visual cognitive processes such as perception and working memory. In the subsequent review, the spatial and object visual cognitive and neural systems that process object-spatial visual information will be discussed more broadly.

Neuropsychological Research on Object-Spatial Distinction in Visual Processing

Substantial neuropsychological and neuroimaging research has shown that object and spatial visual subsystems are anatomically and neurologically distinct and may function independently from one another (e.g. Cabeza & Nyberg, 2000; Farah et al., 1988; Kosslyn et al., 2001; Levine et al., 1985; Mazard et al., 2004; Milner & Goodale, 1995; Schneider, 1969; Ungerleider & Mishkin, 1982). The *ventral system* processes properties of objects and scenes, such as shape, contour, color, fine detail and other figurative aspects of visual properties of visual representations; it participates in object identification and recognition. The *dorsal system* processes locations and spatial attributes such as spatial relations among objects and complex spatial transformations; it is sensitive to motion and binocular depth information, linked to eye movement and selective attention and essential for guiding movements (Mellet et al., 1998; Zeki, 1993).

The dorsal/ventral division has been associated with a division earlier in the visual pathway, between the parallel parvocellular (ventral) and magnocellular (dorsal) systems. These two processing streams originate in retinal parvo and magno ganglion cells, proceed through the LGN in the thalamus, and then to the primary visual cortex V1, remaining mostly segregated, but partly interconnected. The object, or “what”, pathway (also called *ventral system*) runs from the occipital lobe down to the inferior temporal lobe through V1, V2, V3 (ventral), V4, and on to superior prefrontal cortex. The spatial, or “where”, pathway (also called *dorsal system)* runs from the occipital lobe to the posterior parietal lobe, through V1, V2, V3 (dorsal), V5/MT, and on to middle and inferior prefrontal cortices. The earlier visual areas are more associated with perception, and later prefrontal areas associated with memory and attention processes (Zeki, 1993).

Lesion studies in object-spatial visual processing

Research with brain lesioned monkeys as well as with brain-damaged humans demonstrated a double dissociation between object and spatial visual systems. Damage to temporal cortex impaired performance in visual tasks that relied on pictorial, visual images of objects and their properties, whereas such damages did not impair performance on perception and imagery tasks that required spatial processing. Lesions in parietal cortex, however, impaired performance on spatial processing tasks, whereas such damages did not disrupt performance on object processing tasks. Ungerleider and Mishkin (1982) found that monkeys with lesions in the parietal cortex were severely impaired in perceptual tasks that required assessing an object's spatial properties, but not in tasks that required visual discriminations between different forms, patterns, and objects. In contrast, monkeys with lesions in the inferior temporal cortex were impaired in learning to discriminate the visual appearance of objects, but not in spatial tasks. Similarly, in humans, it has been shown that that patients with lesions to the posterior parietal cortex (a part of a dorsal system) demonstrate visuomotor deficits such as optic ataxia, the distortion of goal-directed movements toward targets in visual periphery, but have relatively intact perceptual functions such as estimates of objects' shape, size, and orientation (e.g., Jeannerod, Decety, & Michel, 1994). Also, damage to the dorsal system resulted in impairments of memory-guided actions such as pointing after delay (Milner et al., 2003). In contrast, lesions in ventral stream lead to visual agnosia (object recognition deficits) and to cerebral achromatopsia (the type of color-blindness) but not to spatial deficits such as object-directed grasping (James, Culham, Humphrey, Milner, & Goodale, 2003; Zeki, 1990).

Furthermore, *imagery* deficits were found to be associated with the corresponding type of *perceptual* deficits, and therefore it has been argued that the dissociation between representations of visual appearance and spatial relations exists not only in perception but also in mental imagery. For example, it was revealed that after brain lesions to temporal cortex, patients become extremely impaired in tasks tapping the visual aspects of imagery; they have difficulty imagining how objects look and their colors. However, their spatial imagery abilities were intact, and they did not have difficulty scanning a mental map or imagining rotations. In contrast, parietal damage leads to impairments in spatial imagery skills, such as mental rotation or maze learning, but not to impairments in imagery for shapes (Farah et al., 1988; Levine et al., 1985).

Neuroimaging studies in object-spatial visual processing

Cognitive neuroscience research provided considerable evidence for the dissociation between the dorsal/parietal and ventral/temporal visual processing pathways that underlie object and spatial visual processing in perception, imagery, and memory (e.g., Cabeza & Nyberg, 2000; Courtney, Ungerleider, Keil, & Haxby, 1996; Mazard et al., 2004). Table 1 summarizes the research on cortical areas that were found to be involved in processing various aspects of object and spatial information.

Overall, neuroimaging studies found that object and spatial tasks activated a neural network composed of either occipitotemporal (ventral pathway) or occipitoparietal (dorsal pathway) regions, respectively, and a set of frontal regions related to memory. For example, Mazard et al. (2004) examined the neural basis of spatial versus object mental imagery tasks using PET, and revealed that superior parietal areas are more strongly activated during spatial imagery tasks, but the anterior part of the ventral pathway, including fusiform, parahippocampal, and hippocampal gyri, are more active during object imagery tasks. Wilson and Farah (2006) found that object recognition and mental rotation produced distinct patterns of brain activity, where object recognition resulted in greater overall activity within ventral stream visual areas, and mental rotation resulted in greater overall activity within dorsal stream visual areas.

Table 1

Dorsal and Ventral visual areas and their functions

Area	Function
	Ventral
primary visual cortex, V1, V2	activated by object imagery tasks (Mazard et al., 2004), sensitive to global organization of the scene (Lamme & Roelfsema, 2000)
V3 ventral	color-selectivity (Zeki., 1993)
V4	selective for complex patterns (Gallant et al., 1995), object parts (Pasupathy & Connor, 2001) and color (Zeki, 1990)
lateral-occipital complex (LOC)	object identification and object completion (Doniger et al., 2000); processing shapes and object recognition (Gilaie-Dotan, Ullman, Kushnir, & Malach, 2002; Grill-Spector, Kourtzi, & Kanwisher, 2001; Lerner, Hendler, Ben-Bashat, Harel, & Malach, 2001)
fusiform gyrus	object recognition (Gauthier et al. , 2002)
left fusiform, lingual gyri, and in the right lingual gyrus; left inferior parietal lobule (IPL)	color imagery tasks, e.g., imagining the color of objects from grayscale object drawings (Chao & Martin, 1999; Oliver & Thompson-Schill, 2003)
left fusiform gyrus	size imagery task (Oliver & Thompson-Schill, 2003)
fusiform face area (FFA)	faces (Kanwisher, McDermott, & Chun, 1997).
	Dorsal
primary visual cortex, V1, V2	*deactivated* by spatial imagery tasks (Mazard et al., 2004), sensitive to object orientation and object boundaries (Bakin, Nakayama, & Gilbert, 2000; Gallant et al. ,1995)
V3 dorsal/ DM	coherent motion of large patterns (Lui et al., 2006)
MT/V5	motion cues, stereoscopic disparity (Nguyenkim & DeAngelis, 2001; Doner, Lappin, & Perfetto, 1984; Bradley, Chang, & Andersen, 1998; Xiao, 1997)
parietal regions	mental transformation tasks (Alivisatos & Petrides, 1997; Carpenter, Just, Keller, Eddy, & Thulborn, 1999; Cohen et al., 1996; Tagaris et al., 1996, 1997; Richter et al., 1997; Desrocher, Smith, & Taylor, 1995; Peronnet & Farah, 1989; Wijers, Otten, Feenstra, Mulder, & Mulder, 1989; Just et al., 2001)
right inferior frontal and premotor cortices	spatial selective attention (Wilson et al., 1993; Courtney et al., 1998)
superior parietal lobule (SPL)	visuomotor processing (Jeannerod & Jacob, 2005)
right and left inferior parietal lobules	processing of spatial relationships and visually-guided goal-oriented actions (Jeannerod & Jacob, 2005)
caudal intraparietal sulcus	3D surface orientation defined by various depth cues (Tsutsui et al., 2001, 2002)

Furthermore, this neuroimaging research demonstrated evidence of further segregation between the neural systems responsible for processing spatial and object information in prefrontal areas, showing that object and spatial streams continue in cortices involved in visual working memory. Specifically, research demonstrated a consistent functional topography that shows superior prefrontal cortex producing the greatest response during spatial working memory tasks, and middle and inferior prefrontal cortices producing their greatest responses during object working memory tasks. In particular, the spatial working memory components include extrastriate regions that encode spatial information stored in right posterior parietal regions, and right inferior frontal and premotor cortices related to spatial selective attention (Courtney et al., 1998). The object working memory components include inferotemporal cortices that are important for object recognition processes (Haxby, Petit, Ungerleider, & Courtney, 2000; Ungerleider & Mishkin, 1982). For example, Wilson, O'Scalaidhe, & Goldman-Rakic (1993) found evidence of the distinction between spatial vs. object working memory from single single-cell recordings in non-human primates, revealing a ventral-dorsal segregation in prefrontal cortex, with ventral neurons demonstrating sustained activity during object working memory delays and dorsal neurons demonstrating sustained activity during spatial working memory delays. Courtney et al. (1996) performed a PET study demonstrating the dissociation between object working memory and location working memory tasks. Face working memory was associated with increased activation in the fusiform, parahippocampal, inferior frontal, and anterior cingulate cortices and also in the right thalamus and midline cerebellum, relative to location working memory.

Location working memory demonstrated increases in cerebral blood flow, relative to face working memory, in superior and inferior parietal cortices and in the superior frontal sulcus. Smith, Jonides, Koeppe, & Awh (1995) performed a PET study that revealed increased activation in right-hemisphere regions (occipital, parietal, and prefrontal) during spatial tasks (retaining position), whereas object tasks (retaining identity) activated primarily left-hemisphere regions (inferotemporal and parietal areas). Similarly, Owen Milner, Petrides, & Evans (1996) found dissociation in brain activations for tasks requiring memory for object features (ventral prestriate cortex and both anterior and posterior regions of the inferior temporal gyrus) versus memory for the locations (dorsal regions of prestriate cortex and posterior regions of the parietal lobe). Owen et al. suggested the two-stage stage model of working memory: while ventrolateral regions are responsible for the maintenance and evaluation of representations held in working memory, dorsolateral regions subserve monitoring and manipulation of these representations.

Object-Spatial Dissociation in Individual Differences in Imagery

Starting from 1920th, spatial ability became recognized as a separate (non-verbal) dimension of intelligence (Smith, 1964, Eliot & Smith, 1983). Individual differences in spatial ability have been extensively studied in the psychometric approach. These studies were motivated by significant relationship found between spatial ability and success in science, mechanical engineering, and technical drawing (Paterson, Elliott, Anderson, Toops & Heidbreder, 1930; Holliday, 1943; Smith, 1964; see McGee, 1979 for a review).

Thus, spatial ability was found to be an important predictor of real-life ecological tasks, distinct from those predicted by verbal ability. In contrast to spatial imagery, until recent, individual differences in *object imagery* have not been studied or even considered in individual differences research. Moreover, despite the existing research on object-spatial imagery in neurological and neuroscience approaches (e.g., Ungerleider & Mishkin, 1982; Farah et al., 1988) the dissociation between object and spatial imagery has not been considered in individual differences in imagery. Although, psychological studies accepted that visual-spatial imagery is not a single unidimensional construct (e.g., Kosslyn, 1980), they did not identify object imagery ability as a separate non-spatial component of imagery. The factor analytical studies on visual ability, in addition to spatial ability factors (e.g., spatial visualization, speeded rotation), revealed a number of other visual factors such as closure speed or flexibility of closure (e.g., Carroll, 1993), which relations to spatial ability seemed to be unclear.

Furthermore, such an object imagery component as the ability to generate vivid and colorful images of objects and scenes (usually measured by self-reports) was expected to measure spatial imagery, but not a separate object imagery skill (for review see McKelvie, 1995). However, self-report instruments assessing individual differences in imagery vividness, such as the Vividness of Visual Imagery Questionnaire (VVIQ; Marks, 1973) where people rate the vividness of their subjectively experienced visual images, have failed to establish significant correlations with spatial imagery tests (McKelvie, 1995). Several issues have been raised regarding the validity of introspective assessments of imagery (e.g. Richardson, 1980), and it was even suggested that introspective, self-report questionnaires are ‘quite unreliable and can provide only little more than a rough index of imagery’ (Lohman, 1979, pp. 149–150).

Poltrock and Agnoli (1986) examined the relationship between self-reported vividness of visual imagery and spatial abilities, and concluded that visual imagery was used to solve spatial problems, but that vividness self-report questionnaires measured some different qualities of imagery unrelated to the performance on spatial tests. In fact, introspective vividness assessments have been shown to correlate with some visual perception tasks (e.g. gestalt closure; Wallace 1990) and some visual memory tasks (e.g. RT for short-term recognition memory for picture details; see Marks, 1983), thereby providing some evidence of criterion validity for such questionnaires (see McKelvie, 1995; Poltrock & Agnoli, 1986). Furthermore, Dean and Morris (2003), found that ratings of vividness, ease of formation, ease of maintenance and ease of transformation of schematic ‘spatial’ stimuli similar to those used in standard mental rotation tests correlated with performance on the mental rotation tests. Unlike ratings of the vividness of schematic ‘spatial’ stimuli, ratings of the vividness of the VVIQ images (e.g. a friend or a relative, a familiar store, a country scene recalled or constructed from long-term memories) did not predict performance on spatial imagery tests. Thus, imagery self-reports, per se, do not appear to be a problem, but it appears that it is the correspondence between the type of imagery assessed by the self-report instrument and the type of imagery required for a particular imagery task that matters (for review see McAvinue & Robertson, 2007).

Only recently, it was suggested that imagery is not a single, undifferentiated construct and that self-report instruments like the VVIQ simply do not assess aspects of spatial imagery, but instead assess aspects of object imagery (Kozhevnikov et al., 2005; Reisberg et al., 1986). Kozhevnikov and colleagues first explicitly suggested that object-spatial dissociation found in perception and imagery, also exist in individual differences in imagery. Kozhevnikov, Hegarty, and Mayer (2002) showed that success in mathematical and scientific problem solving is positively correlated with spatial visualization ability and negatively correlated with the use of vivid pictorial (i.e., object) imagery (Hegarty & Kozhevnikov, 1999; Kozhevnikov et al., 2002). Further, Kozhevnikov et al (2005) designed a number of behavioral measures of object imagery (e.g., recognizing degraded pictures of objects) that were administered along with measures of spatial imagery (e.g., 3-dimensional mental rotation task) to psychology undergraduates. The researchers identified two distinct groups of individuals who reported high use of imagery in general: first, those individuals who excel in object imagery tasks but tend to score poorly on spatial imagery tasks, and second, those who excel in spatial imagery tasks tend score poorly on object imagery tasks. From these results, researchers concluded that that object and spatial imagery might not only be distinct abilities, but also that they might be mutually exclusive in individual differences.

Furthermore, Kozhevnikov et al. (2005) suggested that object imagery ability may relate to the performance in complex real-life tasks (e.g., visual art), such as spatial ability relates to performance in science and engineering. Indeed, they showed that visual artists excel in performance on object imagery task, while scientists excelled on spatial imagery task. Moreover, they showed that visual artists and scientists used different approaches in interpreting spatial abstract kinematic graph, i.e., visual artists used literal pictorial descriptions, while scientist used abstract\schematical descriptions.

Although research has shown that certain professional domains, particularly visual arts and science, require the extensive use of imagery, research also suggests that these professional domains require the use of qualitatively different types of imagery (e.g., Casey, Winner, Brabeck, & Sullivan, 1990; Hegarty & Kozhevnikov, 1999; Pellegrino, Mumaw, & Shute, 1985). In fact, examination of the training and research on the imagery skills of visual artists and scientists suggests that the object-spatial distinction should generalize to these groups. The training of visual artists emphasizes object visualization skills: for example, studying the details of real and depicted objects and scenes and developing strategies for identifying and depicting such details (Gombrich, 1977), whereas the training of scientists emphasizes spatial visualization skills: for example, visualizing and dynamically transforming abstract schematic images of figures and graphs (Ferguson, 1977; Hegarty & Kozhevnikov, 1999; Pellegrino et al., 1985). Additionally, research on mental imagery has revealed that visual artists preferred using object imagery over spatial imagery and that they characterize their typical mental images as pictorial, vivid and clear (Lindauer, 1983). Furthermore, research has shown that those who major in the sciences tend to have better spatial visualization skills than non-science majors (Casey et al., 1990; Lord & Nicely, 1997). In particular, they are better at spatial imagery than visual arts majors; conversely, visual arts majors have better visual memory abilities than non-visual arts majors (Casey et al., 1990; Rosenblatt &

Winner, 1988). Overall, there have only been a few studies that compared different imagery skills between members of different professions or college majors, and this difference not been systematically investigated. The current research will further examine this distinction, and specifically the role of object imagery in the professional success.

Cognitive Styles and Individual Differences in Imagery

The cognitive style approach is popular for studying individual differences in visual imagery. "Cognitive style" refers to psychological dimensions representing preferences and consistencies in an individual's particular manner of cognitive functioning, with respect to acquiring and processing information (Ausburn & Ausburn, 1978; Messick, 1976; Witkin, Moore, Goodenough, & Cox, 1977). One of the most commonly acknowledged measures of cognitive style is the Visual-Verbal cognitive style dimension (e.g. Paivio, 1971; Richardson, 1977), that describes consistencies and preferences in processing visual versus verbal information, and classifies individuals as either *visualizers* (also called *imagers*), who rely primarily on imagery when attempting to perform cognitive tasks, or *verbalizers,* who rely primarily on verbal-analytical strategies.

Most of the previous conceptualizations of Visual-Verbal cognitive style were based on a general idea about the existence of distinct visual and verbal processing systems; they were neither motivated by any particular theory that specified the characteristics of these two systems, nor did they attempt to apply stringent theoretical principles. As a consequence, a variety of ways to operationalize the Visual-Verbal cognitive style have been proposed (e.g., as self-reported experiences, learning preferences, problem solving strategies, memory for verbal vs. visual stimuli, preference for verbal vs. visual cues for recall, and accuracy or response times on verbal vs. visual aptitude tasks) that have resulted in the development of numerous instruments to assess this dimension. These instruments range from measures of individuals' responses to particular stimuli (e.g., perceptual speed or rate of word production) to cognitive tasks underlying more complex behaviors (e.g., conceptual thinking and problem-solving strategies).

Among the multiplicity of the proposed instruments, two distinct approaches to assess Visual-Verbal cognitive styles can be distinguished. The first approach has focused on the development of self-report questionnaires that asked the participants to rate a variety of statements with respect to their preferred use of imagery versus verbal modes of thinking (e.g., "*I often use mental pictures to solve the problem*" or "*I am really fluent in using words*"). Examples of these questionnaires include: *Individual Differences Questionnaire* (IDQ: Paivio, 1971), *Verbalizer-Visualizer Questionnaire* (VVQ: Richardson, 1977), and *Style of Processing* (SOP: Childers, Houston, & Heckler, 1985). The main problems of these questionnaires, identified in subsequent studies, were their relatively low internal reliability (Antonietti & Giorgetti, 1998; Boswell & Pickett, 1991; Sullivan & Macklin, 1986) and poor predictive validity (e.g., Alesandrini, 1981; Green & Schroeder, 1990). For instance, factor analyses of the IDQ items identified not only imagery and verbal factors, but also a number of other factors (Paivio & Harshman, 1983). Similarly, principal components analysis failed to show that the VVQ items formed a homogenous scale (e.g., Green & Schroeder, 1990); likewise, Boswell and Pickett's (1991) principle components analysis did not produce a clear factor structure that was acceptable, in the authors' opinion, for a test purportedly measuring a unitary construct. Thus, these analyses of the constructs underlying the IDQ and VVQ scores suggest that the imagery items from these scales assess more than one imagery preference. Furthermore, although several studies showed a moderate correlation between the verbal subscale of such self-report instruments and performance on verbal ability tests (Green & Schroeder, 1990; Kirby, Moore, & Shofield, 1988; Mayer & Massa, 2003), their visual subscale did not correlate with any visual-spatial aptitude measures (e.g., Alesandrini, 1981; Edwards & Wilkins, 1981; Green & Schroeder, 1990; Parrott, 1986; Mayer & Massa, 2003).

A second approach to measuring Visual-Verbal cognitive style has been proposed that has aimed at the development of the objective measures to assess Visual-Verbal cognitive style, such as response time in solving tasks that require either visual or verbal thinking (e.g., the *Verbal-Imagery Subtest of Cognitive Styles Analysis* [CSA; Riding & Cheema, 1991] and the *Verbal-Imagery Cognitive Style Test* [VICS: Peterson, Deary, Austin, 2005]). In CSA and VICS, for instance, statements that require imagery as well as verbal semantic processing were presented on a computer screen, and the subjects were classified into verbalizers and visualizers based on the ratio of means (in CSA) or ratio of medians (in VICS) between the time to respond to verbal and imagery questions. Another example of the objective measures to assess Visual-Verbal dimension is the *Mathematical Processing Instrument* (MPI: Lean & Clements, 1981; Presmeg, 1986a, 1986b). The MPI was developed in order to avoid noted problems associated with self-report measures like the IDQ and the VVQ. It was designed by mathematics education researchers to measure students' individual differences in imagery preferences to measure the tendency to use visual imagery versus verbal-analytical strategies when solving mathematical problems that could be solved by either visual or analytical methods (Lean & Clements, 1981). The MPI included a number of simple mathematics problems that could be solved by either visual or analytical methods. Depending on their preferences for solving problems, the individuals were positioned on a "degree of visuality" continuum, with the highest scores corresponding to the more often use of visual solutions, and the lowest scores corresponding to the more often use of verbal-logical strategies.

In contrast to most Visual-Verbal self-report questionnaires, the above objective instruments were based on more specific and constricted measures, and thus, not surprisingly, demonstrated relatively good internal reliability (e.g., Spearman rank-order correlation r >.72 for VISC in Peterson, Deary, & Austin, 2003, and between rankings r = 0.90 for MPI, Lean & Clements, 1981). However, their construct validity has been questioned. For example, Peterson, Deary, & Austin (2005) reported a high correlation between an individual's response time not only to visual but also to verbal items (r >.84), suggesting that response time might reflect an individual speed of processing in general rather than preference for a certain mode of processing. Furthermore, although the MPI has shown internal reliability (Cronbach's .0.87), its predictive validity has been questioned. The results did not show clear relationship between the degree of visuality and students' performance on either mathematical or spatial ability tests. Moreover, students who preferred to process information by verbal-logical means tended to outperform more visually inclined students on both spatial ability and mathematical tasks (Lean & Clements, 1981). Thus, the with the objective measurement approach, the problems with the predictive validity of the visual scale have not been resolved, that is, no clear relationship between the visual measures of cognitive style and the performance on visual-spatial tasks has been found (e.g., MPI; Lean & Clements, 1981; CSA; Massa & Mayer, 2005).

Overall, a host of studies has challenged the validity of Visual-Verbal cognitive style and cast doubt on the usefulness of this dimension. Despite the promising prospective applications (e.g., predicting complex learning behavior, increasing the efficiency of learning by matching the individual cognitive style to appropriate instructional material), research on Visual -Verbal cognitive style has declined over the past decade due to the reported lack of construct and predictive validity as well as weak internal consistency. As noted in a number of reviews on cognitive styles (e.g., Kogan, Saarni & Saracho, 1990; Kozhevnikov, 2007; Sternberg & Grigorenko, 1997), one the main reason for the preceding problems was that many of the studies on cognitive style were rather descriptive and did not attempt to relate cognitive styles to contemporary cognitive science theories.

Kozhevnikov and colleagues first challenged the theoretical assumption underlying the classical two-dimensional Visual-Verbal model of cognitive style (Kozhevnikov et al., 2002, 2005). In particular, they challenged the common assumption of the previous Visual-Verbal cognitive style research that imagery presents a unitary and undifferentiated construct, and that a given individual can be characterized as high- or low-imagery in general. Instead they suggested that Visual dimension should be divided into object and spatial dimensions, in accordance with behavioral and neuropsychological evidence of the existence of object and spatial imagery subsystems. Kozhevnikov and colleagues (2002, 2005), revised the old model of cognitive style on the basis of contemporary neuroscience findings, and suggested that dissociation between object and spatial imagery might exist in individual differences in imagery and cognitive styles. Thus, instead of the previous conceptualization of Visual-Verbal style as a unitary bipolar construct, they proposed a new model of cognitive style, with three relatively independent dimensions: Object Imagery, Spatial Imagery, and Verbal (Kozhevnikov et al., 2002, 2005). Furthermore, Kozhevnikov et al. (2005), found that while *verbalizers* (i.e., those who prefer to use verbal-analytical coding versus imagery), typically performed at an 'intermediate' level on all imagery tasks, visualizers (i.e., those who reported strong and consistent preferences for processing information visually) can be reliably classified as *object and spatial visualizers*. They research showed that *object visualizers* tend to construct colorful, pictorial, and high-resolution images of individual objects, report having vivid pictorial memories, encode visual stimuli holistically, and they also tend to excel in object imagery tasks but score poorly on spatial imagery tasks. In contrast, *spatial imagers* tend to use imagery to schematically represent spatial relations among objects, prefer learning from abstract schematic diagrams rather than colorful pictorial illustrations, process figures analytically, and generally excel in tasks that require complex spatial transformations, but score poorly on object imagery tasks (Kozhevnikov et al. 2005). Thus research by Kozhevnikov and colleagues , showed, first, that there are two contrasting groups of visualizers that are quantitatively different with respect to their scores, second, that these groups of visualizers tend to employ radically different strategies and preferences in problem solving, tend to have different professional preferences, and moreover, these researches related the found differences in abilities and cognitive style to object-spatial dissociation shown in neurological research (e.g., Farah et al., 1988; Levine et al., 1985; Ungerleider & Mishkin, 1982).

The goal of the present work is to further examine theoretically and to evaluate empirically the Object-Spatial-Verbal cognitive model (Kozhevnikov et al., 2005), and specifically, its new Object dimension. Second, this thesis will investigate the relationships between all three dimensions of this model of cognitive style. Next, it will provide the ecological validation of all three dimensions of cognitive style.

Finally, besides the theoretical justification and validation of the Object-Spatial-Verbal cognitive model, the current research proposes the new theoretically guided approach to measurement of the Object-Spatial-Verbal cognitive style. In particular, current work challenges the previous approaches to measurement of Visual and Verbal cognitive styles. First, it challenges the common assumption held by most of the previous assessment approaches, that Visual-Verbal cognitive style is a bipolar unitary construct, with the preference to verbal or visual ways of information processing portrayed as two contrasting poles. Yet, the assumption about the existence of the bipolar Visual-Verbal dimension is inconsistent with current neuroscience research showing that visual and verbal systems are relatively anatomically and functionally independent (e.g., Mellet et al., 2002; Gazzaniga, 2004, Thierry & Price, 2006). Second, the current work challenges another common assumption held by previous measurement approaches that considered imagery as unitary and undifferentiated construct. Thus, the current work will focus on the development of a new theoretically guided instrument of cognitive style that will overcome the previous theoretical misconceptions as well as problems with establishing predictive validity of visual cognitive style (and especially its object imagery dimension).

EXPERIMENTAL DESIGN

Studies 1a and 1b

The goal of the Study 1 was to design and validate a new self-report instrument for assessment of the three cognitive style dimensions, *the Object-Spatial Imagery and Verbal Questionnaire (OSIVQ)*, which includes Object Visual, Spatial Visual, and Verbal scales. The above review suggests that a crucial problem with previous assessments of individual differences in imagery preferences and experiences has been the assumption that imagery ability is a single undifferentiated skill. The current research challenges previous attempts to develop such self-report measures of mental imagery. Instead, we focused on the construction of a new self-report instrument for imagery assessment, based on cognitive psychology and neuroscience approaches that have emphasized a key distinction in visual information processing, namely, that there is a distinction between processing object properties and processing spatial relations. Furthermore, the two visual measurement scales were combined with a verbal scale, making it the instrument that assesses all the dimensions of the revised Visual-Verbal cognitive style. Since most of the previous instruments (e.g., Richardson's VVQ, 1977) focused primarily on assessing verbal expression and fluency, the current instrument expanded the previous verbal assessment to other aspects of verbal cognitive style such as habitual, problem solving, learning, and professional preferences.

The design of this self-report measure of Object-Spatial-Verbal cognitive style was motivated by several reasons. First, no such measure currently exists, second, a self-report cognitive style measure would allow us to assess the important subjective aspects of imagery (e.g., colorfulness and brightness of mental images) and verbal thinking (e.g., awareness of sentence structure) which is impossible to assess by the existing objective measures; third, finding introspective-based evidence for a distinction between object and spatial imagery abilities would provide further validation of theory and research supporting such a distinction, and forth, in contrast to time-consuming objective measures of cognitive style, which might take up to an hour to assess the cognitive style of one subject (see Kozhevnikov et al., 2005), a single, brief questionnaire will be more efficient to use for large-scale testing and specifically, it will be useful in further research and applied (e.g. vocational decision making) settings (e.g. McKelvie's, 1995, meta-analysis included over 200 studies that used the VVIQ).

The study 1a focused on the development of Object and Spatial scales, and study 1b integrated the Verbal scale. The first goal of Study 1 was to design the self-report imagery questionnaire (*Object-Spatial Imagery Questionnaire*: OSIQ) consisting of two separate scales: an object imagery scale, with self-report items designed to assess object imagery preferences and experiences, and a spatial imagery scale, with self-report items designed to assess spatial imagery preferences and experiences. The second goal was to examine the factor structure and internal reliability of the OSIQ and to select the final items for the OSIQ. The goal of Study 1b was to develop a full measure of 3-dimentional Visual-Verbal cognitive style, the *Object-Spatial Imagery and Verbal Questionnaire* (OSIVQ) by designing a Verbal scale assessing individuals' preference to process information verbally, and integrating it with the two existing OSIQ Object and Spatial imagery scales. The second goal of Study 1b was to examine the factor structure and internal reliability of the full three-scale OSIVQ. In this, in order to examine the descriptive characteristics, factor structure, and internal reliability of the OSIVQ, the questionnaire was administered to an independent sample of the participants.

Method

Design of items and development of the OSIVQ scales

Sixty initial items assessing *object* and *spatial visual* style, and 23 initial items assessing *verbal* cognitive style were developed through a series of pilot studies where the questionnaire statements were formulated and selected based on content validity and internal reliability (these pilot studies were conducted by Kozhevnikov et al., 2005, as described in Blajenkova, Kozhevnikov, & Motes, 2006). In the current study, the final 44 visual and 19 verbal items were used. Some of the items were variations of statements from previously developed questionnaires for assessing the Visualizer-Verbalizer cognitive style (Richardson, 1977; Paivio & Harshman, 1983). Object-Spatial questions were developed based on previous research and theoretical frameworks concerning distinctions between object and spatial imagery (Farah et al., 1988; Kosslyn & Koenig, 1992; Levine et al., 1985) and distinctions in performance between object versus spatial visualizers (e.g., Hegarty & Kozhevnikov, 1999; Kozhevnikov et al., 2002, 2005).

For instance, object imagers prefer to construct colorful, high-resolution, picture-like images of individual objects and to encode and process images holistically, whereas spatial imagers prefer to construct schematic representations of objects and spatial relations among objects, generate and process images part by part, and are capable of performing complex spatial transformations. Thus, some items addressed qualitative characteristics (e.g., vividness, colorfulness, or abstractness) of images (e.g., object imagery items like *my mental pictures are very detailed precise representations of the real things* and spatial imagery items like *my images are more like schematic representations of things and events*); some items addressed image maintenance and transformation processes (e.g., object imagery items like *I can close my eyes and easily picture a scene that I have experienced* and spatial imagery items like *I can easily rotate three-dimensional geometric figures*); some items addressed preferences for certain types of visual representations, such as pictorial versus schematic representations, (e.g., object imagery items like *I enjoy pictures with bright colors and unusual shapes like the ones in modern art* and spatial imagery items like *I prefer schematic diagrams and sketches when reading a textbook*); and some items addressed self-estimates of abilities in performing tasks requiring the use of object or spatial imagery (e.g., object imagery items like *I have excellent visual memory; I can recount what people wore for a dinner, the way they sat and looked* and spatial imagery items like *I am good at playing spatial games involving constructing from blocks and papers*).

The verbal items extended previous measures of people's preferences for verbal thinking that focused primarily on items assessing verbal expression and fluency ("*I have better than average fluency in using words"; IDQ*), to include more questions about such aspects of verbal cognitive style as habitual and learning preferences (e.g., *"When explaining something, I would rather give verbal explanation than make drawings or sketches"*), professional preferences (e.g., *"My verbal abilities make a career in language arts relatively easy for me"*), and self-estimates of one's verbal abilities (e.g., *"My verbal skills are excellent"*). The verbal statements in the new verbal scale were formulated in a format similar to visual-object and spatial-object items included in the OSIQ (that is, it consisted of a similar type of questions targeted to assess a variety of aspects of cognitive style) in order to design a full self-report instrument assessing all three dimensions of the cognitive style in a comparable way.

Participants

In the Study 1a, 214 undergraduates (106 females and 108 males), ranging from 17 to 44 years of age (*M* = 20.33), were recruited from the participant pool at Rutgers University-Newark and the New Jersey Institute of Technology.

In the Study 1b, 625 (374 females, *M* age = 24) were recruited from student participant pools at Rutgers University-Newark for credit reimbursement, and other participants were students from New Jersey Institute of Technology (NJ), George Mason University (VA), New York Institute of Fashion and Design (NY), and Stevens University (NJ) as well as professionals from various fields, who were given monetary compensations for their participation. The data were collected from a relatively large sample to satisfy sample size suggestions for principle components analyses (see Stevens, 1996).

Procedure

In the current studies 1a and 1b, the participants were tested in groups of up to 30. The participants were asked to read all of the questionnaire items and rate each of them on a 5-point scale with 1 = *totally disagree* and 5 = *totally agree, and ratings "2" through "4" to* indicate intermediate degrees of agreement/disagreement. The items on the questionnaire were intermixed in the random fixed order. No time limit was specified for the completion of the questionnaire.

Results

Principal components analysis

In the study 1a, Principal components analysis was performed on the responses to the 44 *object* and *spatial* items. Six items were negatively formulated (4 object items and 2 spatial items) and thus were reverse scored (e.g., *totally agree* = 1). The initial analysis revealed 13 factors with eigenvalues above 1. Two factors, however, had markedly higher eigenvalues (6.87 and 5.00) than the others (ranging from 2.09 to 1.05), and these first two factors explained 26.98% of the variance. Together, the other 11 factors explained an additional 35.12% of the variance. All of the items designed to assess object imagery experiences were positively loaded on the first factor, whereas all of the items designed to assess spatial imagery preferences either did not load or loaded negatively on this factor. Additionally, all of the items designed to assess spatial imagery preferences loaded positively on the second factor, whereas none of the items designed to assess object imagery preferences loaded on this factor. Thus, the first factor appeared to capture object imagery preferences, and the second factor appeared to capture spatial imagery preferences.

None of the other 11 factors met recommendations regarding component saturation (see Guadagnoli & Velicer, 1988; e.g., four or more loadings above +/- .60). For example, none of the 11 factors had loadings above .60 (the loadings ranged from -.499 to .467), only one of factor had three loadings with absolute values above .40, four only had two loadings with absolute values above .40, four only had one loading with an absolute value above .40, and two did not have any loadings with absolute values above .40. Thus, these factors were not considered further. Based on the first results from the initial principal components analysis, a second principal components analysis with Varimax rotation was performed, and for this analysis, the factor structure was limited to two factors. This second analysis also yielded a predominantly object imagery factor and predominantly spatial imagery factor. From these two factors, object imagery items having low loadings on the predominantly object factor and spatial items having low loadings on the predominantly spatial factor, and items for which loadings on both scales were both positive or were both negative (i.e., those that were not discriminating between spatial and object imagery constructs) were excluded from further analysis. Fifteen items from the object imagery factor and 15 items from the spatial imagery factor (one of which was reverse coded) were retained. The loadings of object imagery items on Object factor ranged from .368 to .768 with average loading .537, and the loadings of spatial imagery items on Spatial factor ranged from .138 (this item was negatively loaded on object factor -.365) to .730 with average loading .493[1].

Next, the 19 *verbal* items were administered along with object and spatial items of the OSIQ to a sub-sample of participants in study 1a that consisted of 166 undergraduates. The results of principal factor analysis revealed a verbal factor distinct from Object and Spatial factors. Based on these results, the final 15 items out of 19 with the highest loadings (.411 to .607) on the verbal factor were kept.

In the study 1b, the 15 final Verbal items were intermixed with the 15 OSIQ Object and 15 OSIQ Spatial items to construct a new three scale OSIVQ instrument (the items were presented in random fixed order, see Table 2). The data was analyzed using Principal Components analysis with Varimax rotation. One spatial and three verbal items were negatively formulated and therefore reversed for the analysis. The initial Principal Components analysis revealed 18 factors with eigenvalues above 1. Only three factors, however, had eigenvalues markedly higher (5.76, 5.54, and 3.08) than the others (ranging from 1.06 to 1.85), and these first three factors explained 31.95% of the variance (12.80%, 12.31%, and 6.84%). None of the other factors met the recommendations for component saturation (see Guadagnoli & Velicer, 1988); the highest loading was .44, and most of the items very weakly loaded on the remaining factors, and therefore were not considered further. Based on the results from the initial Principal Components analysis, a second Principal Components analysis with Varimax rotation was performed.

The 45 OSIVQ items and their loadings on the object, spatial imagery, and verbal factors are presented in Table 2. The first factor was identified as *Object imagery factor*, since all of the items designed to assess object imagery experiences were positively loaded on this factor, whereas most of the items designed to assess spatial imagery or verbal preferences either did not load or loaded negatively. The second factor was identified as *Spatial imagery factor,* since all of the items designed to assess spatial imagery preferences loaded positively on the second factor, whereas most of the other items did not load or loaded negatively on this factor. Finally, the third factor was identified as *Verbal factor*, since all of the items designed to assess verbal preferences loaded positively on the third factor, whereas most of the other items were not loaded or loaded negatively on this factor.

Table 2

Principal component loadings, after Varimax rotation, for the OSIVQ items

OSIQ Items[a]		Object Factor 1	Spatial Factor 2	Verbal Factor 3
1	Spatial Item	.05	.67	-.01
2	Verbal Item	.16	-.17	.55
3	Spatial Item	-.39	.45	-.06
4	Verbal Item	.04	-.39	.45
5	Spatial Item	-.18	.56	-.02
6	Object Item	.55	.12	.05
7	Spatial Item	-.27	.48	.010
8	Verbal Item	.04	.09	.42
9	Verbal Item	.07	-.15	.53
10	Spatial Item	-.41	.13	.07
11	Object Item	.54	.09	.05
12	Object Item	.38	-.49	.14
13	Object Item	.37	.11	.28
14	Spatial Item	.18	.70	.01

15	Object Item	.21	-.15	.03
16	Verbal Item	.15	-.08	.66
17	Spatial Item	.00	.40	.01
18	Object Item	.40	.21	.21
19	Verbal Item	-.12	-.20	.19
20	Object Item	.65	.14	.24
21	Verbal Item	-.19	-.38	.46
22	Verbal Item	-.15	.28	.12
23	Object Item	.43	.23	.10
24	Verbal Item	-.39	.00	.24
25	Spatial Item	-.49	.19	.11
26	Object Item	.45	.03	.16
27	Spatial Item	.12	.73	-.01
28	Verbal Item	-.28	-.17	.39
29	Object Item	.56	-.04	.10
30	Spatial Item	.16	.60	-.06
31	Spatial Item	-.24	.44	-.02
32	Spatial Item	.07	.35	-.04
33	Object Item	.51	.22	.05
34	Object Item	.56	.13	.10
35	Verbal Item	.16	.05	.66
36	Verbal Item	-.11	.00	.38
37	Verbal Item	.09	.13	.44
38	Spatial Item	-.46	.26	.07
39	Verbal Item	.22	-.06	.58
40	Object Item	.50	.01	.05

41	Verbal Item	.04	-.12	.45
42	Spatial Item	.10	.46	-.07
43	Object Item	.53	.21	-.01
44	Spatial Item	.15	.70	-.15
45	Object Item	.46	-.12	.02

Note: Underlined loadings within the Object Factor 1 column identify items that were designed to measure object imagery. Underlined loadings within the Spatial Factor 2 column identify items that were designed to measure spatial imagery. Underlined loadings within the Verbal Factor 3 column identify items that were designed to measure verbal preferences and abilities.

[a] The OSIVQ questionnaire is copyrighted by Rutgers University. No part of this questionnaire may be reproduced without prior written permission.

Internal reliability of the scales

For each participant, the fifteen items from each factor were averaged to create Object, Spatial scale and Verbal scores. In the Study 1a, the internal reliability for the object scale, Cronbach's α was .83, and for the spatial scale, Cronbach's α was .79. Additionally, in Study 1a, these two scales were negatively correlated (r = -.155, p = .023), and this correlation was consistent with previously reported findings that many people prefer to use one type of imagery over the other (e.g., Kozhevnikov et al., 2002; Kozhevnikov et al., 2005). In the Study 1b, for the internal reliability of Verbal scale, Cronbach's α was .74.

Descriptive statistics

In the Study 1a, the resulting object scale descriptive statistics were M = 3.59, SD = 0.57; and the resulting spatial scale descriptive statistics were M = 2.93, SD = 0.60. In Study 1b, the resulting descriptive statistics were M = 3.63, SD = 0.62 for the Object scale, M = 2.83, SD = 0.66 for the Spatial scale, and M = 2.99, SD = .57 for the Verbal scale. The one-sample Kolmogorov-Smirnov test of goodness-of-fit provided no evidence against the null hypothesis that the sample has been drawn from a normal population for Spatial (D =.040; *p* =.277) and Verbal scales (D =.039; *p*=.297). However, Object scale was not normally distributed (D =.060; *p* =.021); the distribution of object scores appeared to be negatively skewed (Skewness = -.392; *SE* = .098). Figure 1 represents the correspondence of raw OSIVQ scores to percentiles to make it easier to interpret and compare the scores on the three scales. As seen in the figure, the participants tended to rate themselves higher on Object imagery than on Spatial imagery or Verbal dimensions. This trend is consistent with the findings of Blajenkova et al. (2006) and Chabris et al. (2006) that people rate themselves higher on the Object scale than on either Spatial or Verbal scales. Figure 1 also presents the suggested cut-offs for interpretation of individual scores as high- or low- Object, Spatial, and Verbal[2].

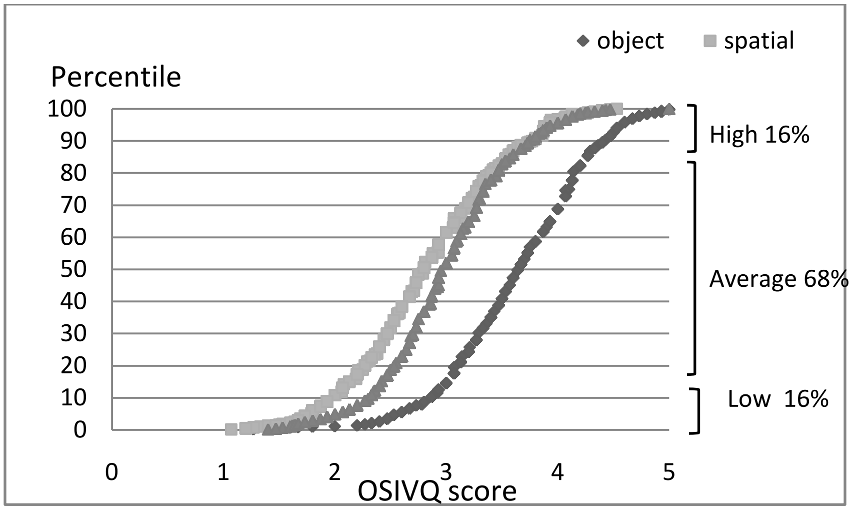


Figure 1. The correspondence of raw OSIVQ scores to percentiles. The distribution of the raw scores on the three scales of OSIVQ in terms of percentiles. For example, a raw score of 3 on the Object scale means that 10% of participants scored below, but the same raw score of 3 on the Spatial scale is higher since it means that 50 % of participants scored below.

Gender differences

Although the examination of gender differences was not the primary goal of the present studies, gender differences have been reported in the visual-spatial cognition literature, with males typically performing better on mental rotation, spatial perception, and spatial relations tasks and females typically giving higher vividness ratings. For example, previous studies on gender differences in spatial ability reported that males perform better than females on spatial tasks (Linn & Petersen, 1985; Voyer, Voyer, & Bryden, 1995) and also they report higher spatial imagery ratings (Blajenkova et al., 2006). Conversely, females tend to report higher object imagery and imagery vividness ratings (Blajenkova et al., 2006; Richardson, 1995; McKelvie, 1995). The gender differences in verbal ability indicated a female advantage (reviewed in Halpern, 2000; Hyde & Linn, 1988); however, according to Hyde & Linn's meta-analysis, this difference appears to be negligible.

Consistent with these reports, males had significantly higher OSIQ spatial imagery scores than females, in Study 1a, $F(1, 213) = 79.80$, $p < .001$, *M males* = 3.24, *SD* = 0.51, *M females* = 2.62, *SD* = 0.51. However, although our results showed that females tend to report themselves as object visualizers and males as spatial visualizers, the differences between spatial and object visualizers, however, cannot be reduced to gender differences (see also Blajenkova et al., 2006; Kozhevnikov et al., 2005). For instance, 33 % of all the females from Study 1a reported above average spatial imagery preferences and abilities, while 40% of males reported above average object imagery preferences. Further, in study 1b, we examined the effect of gender on object-spatial-verbal preferences for information processing, using repeated measures ANOVA, with gender as a between-subject variable, and three OSIVQ scales as within-subjects variables. The repeated measures ANOVA demonstrated a significant effect of gender but small effect size, $F(1, 622) = 6.505$, $p =.011$, partial $\eta^2=.010$, the significant and moderate effect of OSIVQ scale, $F(2, 1244) = 243.977$, $p <.001$, partial $\eta^2=.282$, and the significant Gender X OSIVQ interaction, $F(2, 1244) = 61.057$, $p <.001$, with partial $\eta^2=.089$ representing a small effect. Males were higher than females on OSIVQ Spatial scores, $F(1, 622) = 105.57$, $p < .001$, *M males* = 3.13, *SD* = 0.59, *M females* = 2.62, *SD* = 0.61, but females had higher OSIVQ Object imagery scores than males, $F(1, 622) = 23.118$; $p <.001$, *M females* = 3.72, *SD* =0.57, *M males* = 3.48, *SD* = 0.66, and we found no significant differences on OSIVQ Verbal scores. Thus, consistent with previous studies, the gender differences were found only on imagery dimensions. Moreover, it can be concluded that the OSIVQ scales assess more than gender differences in imagery or verbal preferences and experiences.

Discussion

In summary, the new OSIVQ self-report instrument that assess Object, Spatial and Verbal cognitive styles, was developed based on the theoretical framework that postulates dissociation between object and spatial imagery, and consider the verbal style as a separate but not opposite dimension. Principle components analysis of the items tested revealed that the items designed to address object and spatial imagery or verbal style primarily loaded on three different factors. These results suggest that the two visual scales of the OSIQ assess the two distinct types of mental imagery, and this dissociation is consistent with previous cognitive and neuroscience research that has provided evidence for different object and spatial imagery subsystems (Levine et al., 1985; Farah et al., 1988; Kosslyn et al., 2001) and consistent with individual differences research that has provided evidence for two types, object and spatial, of imagers (Kozhevnikov & Kosslyn, 2000; Kozhevnikov et al., 2002; Kozhevnikov et al., 2005). Also, consistent with the individual differences research (e.g., Kozhevnikov et al., in press), a negative correlation between the object and spatial scales was found. Those who gave high ratings on one scale tended to give lower ratings on the other scale. Further, one of the important findings of Study 1b is that the distribution of self-assessments on Object, Spatial and Verbal dimensions may differ, that is, people might rate themselves higher on one scale than on the others. This finding questions the previous scoring procedures which inferred the dominant cognitive style by subtracting or creating ratios of raw visual and verbal scores before normalizing them.

Another important finding of Study 1 is that the OSIVQ demonstrated acceptable internal consistency and reliability for all three scales, hence additionally supporting the value of separately assessing object and spatial mental imagery and verbal preferences and experiences. Unlike many previous self-report cognitive style instruments which have been criticized for unclear factor structure (Boswell & Pickett, 1991; Edwards & Wilkins, 1981; Kirby, Moore, & Schofield 1988), in the current study, principal components analyses revealed three distinct major factors (object, spatial and verbal). Overall, these findings challenge the idea of a single bipolar dimension of Visual-Verbal cognitive style and support the existence of its three different dimensions: object, spatial and verbal.

Studies 2a, 2b, 2c, and 2d

The main goal the series of studies 2a-2d was to examine the validity of the OSIVQ questionnaire. In particular, the goals of Studies 2a and 2b were to assess the predictive validity of the OSIQ (only for Object and Spatial scales of a questionnaire), whereas the main goal of study 2c was to evaluate the discriminant validity of OSIQ. The study 2d included all 3 scales of OSIVQ, and examined predictive, discriminant as well as test-retest validity of OSIVQ. Furthermore, study 2d evaluated the new 3-dimentional Object-Spatial-Verbal model of cognitive style to the traditional 2-dimentional Visual-Verbal model. In order to evaluate the criterion and discriminant validity of the OSIVQ, across the studies 2a-2d, the OSIVQ scales scores were correlated with other criterion measures of spatial and object imagery, and verbal cognitive style as well as measures of intelligence. In order to evaluate and compare the two cognitive style models, in the study 2d, the Confirmatory Factor Analysis was conducted.

For Study 2a, a large number of participants were administered the OSIQ and a battery of paper-and-pencil object and spatial imagery measures. For Study 2b, a smaller number of students were individually administered the OSIQ and a battery of computerized and paper-and-pencil object and spatial imagery measures. Study 2c was designed to assess the discriminant validity of the OSIQ by ruling out the possibility that differences in OSIQ spatial imagery scores reflect differences in general intelligence rather than spatial imagery preferences. Previous research has shown that spatial imagery ability is associated with successful performance on a number of analytical tasks (e.g., Hegarty & Kozhevnikov, 1999). Thus, people with higher intelligence might tend to report themselves as spatial imagers. Therefore, in this study, the OSIQ scale scores were correlated with measures of verbal and non-verbal intelligence. Additionally, tests of spatial and object imagery were included to provide further predictive validity of the OSIQ. Thus, the participants were individually administered the OSIQ, a verbal intelligence test, a non-verbal intelligence test, a verbal ability test, a spatial imagery test, and an object imagery test. The Study 2d had two goals. The first goal was to assess the predictive and discriminant validity of the OSIVQ Verbal, Object, and Spatial scales as well as to examine its test-retest reliability. The second goal of Study 2d was to compare the predictive power of the three-dimensional model of cognitive style to that of the traditional Visual-Verbal bipolar model and further explore the relationships between object, spatial, and verbal dimensions.

Method

Participants

For Study 2a, 146 undergraduates (83 females and 63 males) were recruited from the participant pool at Rutgers University-Newark. For Study 2b, 49 undergraduates (30 females and 19 males) were recruited from the participant pool at Rutgers University-Newark. For the study 2c, 45 undergraduate and graduate students (27 females and 18 males) were recruited from the participant pool at Rutgers University-Newark and through advertisements posted around the Rutgers and New Jersey Institute of Technology campuses. For the study 2d, 128 students (93 females, *M* age = 24) were recruited from the student participant pool at Rutgers University-Newark, and from George Mason University for credit reimbursement.

Materials and Procedure

The participants were administered various assessments of visual imagery, verbal ability and intelligence (for the descriptions and examples of all the tests, see the appendix). For some tests the time was strictly limited, and no time limit was specified for the other tasks, but the participants were instructed to respond as accurately and quickly as possible.

In Study 2a, participants were tested in groups of up to 25 during their recitations for an introductory psychology class. They were administered the OSIQ, a demographic questionnaire, two spatial imagery tests, and two object imagery tests. The spatial tests used were commonly used paper-and-pencil tests assessing spatial visualization skills: the Paper Folding test (Ekstrom, French, & Harsman, 1976) and the Vandenberg-Kuse Mental Rotation test (Vandenberg & Kuse, 1978). The object imagery tests used were the VVIQ (Marks, 1973) and the Degraded Pictures Test, which was a modification of the Degraded Pictures Test designed by Kozhevnikov et al. (2005).

In Study 2b, participants were tested individually and were administered the OSIQ, a demographic questionnaire, the Spatial Imagery Test from the Imagery Testing Battery (Version 1.0), and a computerized version of the Degraded Pictures Test from the Imagery Testing Battery (Version 1.0). Participants Study 2b were also administered the Paper Folding (Ekstrom et al., 1976) and Vandenberg-Kuse Mental Rotation (Vandenberg & Kuse, 1978) tests.

In the study 2c, all participants were tested individually, and the order of the tests was randomized. Participants were administered the OSIQ, the Advanced Progressive Matrices non-verbal intelligence test (APM; Raven, Raven, & Court, 1998), the Similarities verbal intelligence test from the WAIS-III (Wechsler, 1997), and the Advanced Vocabulary Test (Ekstrom et al., 1976). Additionally, they completed the VVIQ (Marks, 1973) and the Paper Folding Test (Ekstrom et al).

In the study 2d, participants were tested in groups of 6 to 30. They were administered a background questionnaire that included questions about demographics and their self-reported SAT verbal scores and the following paper-and-pencil assessments: the OSIVQ, two spatial imagery tests (Paper Folding Test: Ekstrom et al., 1976 and Mental Rotation Test: Vandenberg & Kuse, 1978), an object imagery assessment (Vividness of Visual Imagery Questionnaire: Marks, 1973), and two verbal tests (Advanced Vocabulary Test: Ekstrom et al and the verbal ability Arranging Words test: Ekstrom et al) described below.

Results

For all Studies 2a-2c, participants' Object, Spatial and Verbal scale scores scale scores were created by averaging their ratings on object, spatial, and verbal items, respectively. The descriptive statistics for the OSIVQ scales in all these studies are presented in Table 3.

Table 3

Descriptive statistics for the Object, Spatial and Verbal scales used in Study 2a-2d

	Study 2a Mean (SD)	Study 2b Mean (SD)	Study 2c Mean (SD)	Study 2d Mean (SD)
OSIVQ object scale	3.55 (0.56)	3.60 (0.49)	3.72 (0.45)	3.65 (0.62)
OSIVQ spatial scale	2.80 (0.58)	2.70 (0.56)	2.87 (0.66)	2.62 (0.62)
OSIVQ verbal scale	N/A	N/A	N/A	3.07 (0.53)

Study 2a

The correlations among the OSIQ scales, the Paper Folding Test, the Vandenberg-Kuse Mental Rotation Test, the Degraded Pictures Test, and the VVIQ are presented in Table 4. The OSIQ spatial scale was significantly correlated with the Paper Folding Test and with the Vandenberg-Kuse Mental Rotation Test, and the correlation coefficients, respectively. Additionally, the OSIQ spatial scale was not correlated with the Degraded Pictures Test, but the OSIQ spatial scale was weakly correlated (r = .18, p =.031) with the VVIQ. This correlation latter, however, was not replicated in Study 2c reported below. In contrast to the OSIQ spatial scale, the OSIQ object scale was significantly correlated with the Degraded Pictures Test and the VVIQ. Finally, the OSIQ object scale was not significantly correlated with either the Paper Folding Test or the Vandenberg-Kuse Mental Rotation Test.

Table 4

The Pearson product-moment correlations among the OSIQ Spatial and Object scores and the criterion measures administered in Study 2a

	1.	2.	3.	4.	5.	6.
1. OSIQ object scale	-	.085	-.104	.107	.190*	.484**
2. OSIQ spatial scale		-	.217**	.255**	.047	.179*
3. Paper Folding			-	.505**	.258**	.078
4. Mental Rotation				-	.169*	.144
5. Degraded Pictures					-	.256*
6. VVIQ						-

* $p < .05$ ** $p < .01$

Study 2b

The correlations among the OSIQ scales, the Paper Folding Test, the Vandenberg-Kuse Mental Rotation Test, the Spatial Imagery Test, and the computerized Degraded Pictures Test are presented in Table 5. The correlations are consistent with those found in Study 2a. The OSIQ spatial scale was significantly correlated with the Paper Folding Test, the Vandenberg-Kuse Mental Rotation Test, and accuracy on the Spatial Imagery Test (but not RT; however, RT was highly variable across participants[3]). The OSIQ spatial scale was not significantly correlated with either accuracy or RT for the Degraded Pictures Test. In contrast, the OSIQ object scale was significantly correlated with accuracy on the Degraded Pictures Test (but not RT; but RT was highly variable across participants). Finally, the OSIQ object scale was negatively correlated with the Paper Folding Test and also negatively, although non-significantly, correlated with the Vandenberg-Kuse Mental Rotation and Spatial Imagery tests, thus further supporting the divergent validity of the object scale.

Table 5

The Pearson product-moment correlations among the OSIQ Spatial and Object scores and the criterion measures used in Study 2b

	1.	2.	3.	4.	5.	6.	7.	8.
1. OSIQ object scale	-	-.245	-.328*	-.189	-.242	-.124	.312*	.050
2. OSIQ spatial scale		-	.507**	.494**	.470**	.254	-.047	.174
3.Paper Folding			-	.626**	.640**	.086	-.025	-.137
4. Mental Rotation				-	.559**	.049	.070	-.015
5. Spatial Imagery Test					-	.338*	.204	.077
6. Spatial Imagery Test RT						-	.392**	.438**
7. Degraded Pictures							-	.026
8. Degraded Pictures RT								-

* $p < .05$ ** $p < .01$

Study 2c

Again, as in the previous studies, 2a and 2b, the OSIQ object and spatial scale scores were created by averaging participants' ratings on the object and spatial imagery items, respectively. The correlations among the variables are presented in Table 6.

Table 6

The Pearson product-moment correlations among the OSIQ Spatial and Object scores and the criterion measures used in Study 2c

	1.	2.	3.	4.	5.	6.	7.
1. OSIQ object scale	-	-.171	-.235	-.004	-.123	-.129	.334*
2. OSIQ spatial scale		-	.199	-.204	-.245	.370*	-.021
3. APM			-	-.062	.099	.598**	-.081
4. WAIS: Similarities				-	.349*	-.197	-.023
5. Advanced Vocabulary					-	-.180	-.238
6. Paper Folding						-	.016
7. VVIQ							-

* $p < .05$

** $p < .01$

Neither the OSIQ spatial scale nor the OSIQ object scale was significantly correlated with the APM, the similarities test from the WAIS-III, nor the Advanced Vocabulary scores. There were weak, though non-significant, trends between the APM and the OSIQ scales (spatial imagery scale, $r = .20$, $p = .189$, object imagery scale, $r = -.24$, $p = .120$), and these trends were consistent with results reported by Kozhevnikov et al. (2005). Kozhevnikov et al. reported that spatial imagers were significantly better than object imagers on AMP items that required a more "analytical" approach, that is, on items that required identifying the correct spatial relations among the objects. However, Kozhevnikov et al. also reported that both spatial and object imagers performed equally well on "figural" type APM items, that is, items that required primarily visual-spatial analysis and that were based on perceptual operations such as continuation or superimposition. The authors suggested that the poor performance of object imagers on the APM analytical problems might have occurred because object imagers tend to process visual information globally, which sets limitations on their ability to solve tasks requiring analytical-sequential processing of spatial relations. Finally, the correlations between the OSIQ scales and the VVIQ and Paper Folding Test supported the results from Study 2a and 2b. The object scale was significantly correlated with VVIQ, but the spatial scale was not. In contrast, OSIQ spatial scale was significantly correlated with Paper Folding Test, but the object scale was not.

Study 2d

The correlations among the measures of verbal, spatial and object ability are presented in Table 7. The OSIVQ Verbal scale scores were positively correlated with verbal measures: the AW scores (p =.02) and the SAT verbal scores (p = .05). The OSIVQ spatial scores were positively correlated with measures of spatial imagery: PFT (p <.001) and MRT (p <.001). Finally, the OSIVQ object scores were positively correlated with the VVIQ, an object imagery measure (p <.001).

The partial correlation analyses among the measures of verbal, spatial, and object ability controlling for gender demonstrated that significant correlations between the scales and the corresponding criterion measures remain significant also after gender effect was partialled out: The OSIVQ Verbal scale scores were positively correlated with the AW scores (p =.025) and the SAT verbal scores (p = .05). The OSIVQ Spatial scale scores were positively correlated PFT (p <.001) and MRT (p = .043). Finally, the OSIVQ Object scale scores were positively correlated with the VVIQ (p <.001). Thus, consistently with previous studies (e.g., Blajenkova et al., 2006; Kozhevnikov et al, 2005), the self-report cognitive style preferences cannot be reduced to gender differences.

As for the discriminant validity of the three scales, although none of the OSIVQ scales correlated positively with any criterion task corresponding to the other scales, there were several significant negative correlations. In particular, there were significant negative correlations between the OSIVQ Object scale and both spatial imagery measures: PFT (p = .001) and MRT (p = .001); between the OSIVQ Verbal scale and PFT (p < .01), as well as between the OSIVQ Spatial scale and SAT verbal (p < .001). These negative correlations suggest that there might be some interference between spatial and object information processing as well as between spatial and verbal information processing.

Table 7

The Pearson product-moment correlations among the OSIVQ spatial, object and verbal scores and the criterion measures used in Study 2d

Measure		1	2	3	4	5	6	7	8	9
1.	OSIVQ object	_	-.03	.12	.41**	-.27*	-.18*	-.04	-.02	-.12
2.	OSIVQ spatial		_	-.18*	-.02	.47**	.31**	.07	-.05	-.12
3.	OSIVQ verbal			_	.04	-.27*	-.10	.17	.20*	.10
4.	VVIQ				_	-.12	-.03	-.01	.01	-.12
5.	PFT					_	.55**	-.07	-.06	.06
6.	MRT						_	-.01	-.10	.05
7.	SAT verbal							_	.17	.27*
8.	AW								_	.09
9	AV									_

** $p < .01$ * $p < .05$

Confirmatory factor analysis

According to the traditional model of Visual-Verbal style, Verbal and Visual styles constitute two opposite dimensions, whereas according to our new revised model of cognitive style, there should be three separate dimensions (Object, Spatial, and Verbal). In this study, we tested both models against each other using confirmatory factor analysis.

The traditional two-factor model of Visual-Verbal cognitive styles assumes all visual measures (OSIVQ Spatial, OSIVQ Object, PFT, MRT and VVIQ) to load on the visual factor, and all verbal measures (OSIVQ Verbal, AV, AW and verbal SAT) to load on the verbal factor. Since verbal and visual dimensions in such a model are considered to be bipolar, the model also assumes a significant negative correlation between visual and verbal factors. Figure 2 shows the results of the estimated two-factor model, and the values of fit are reported in Table 8.

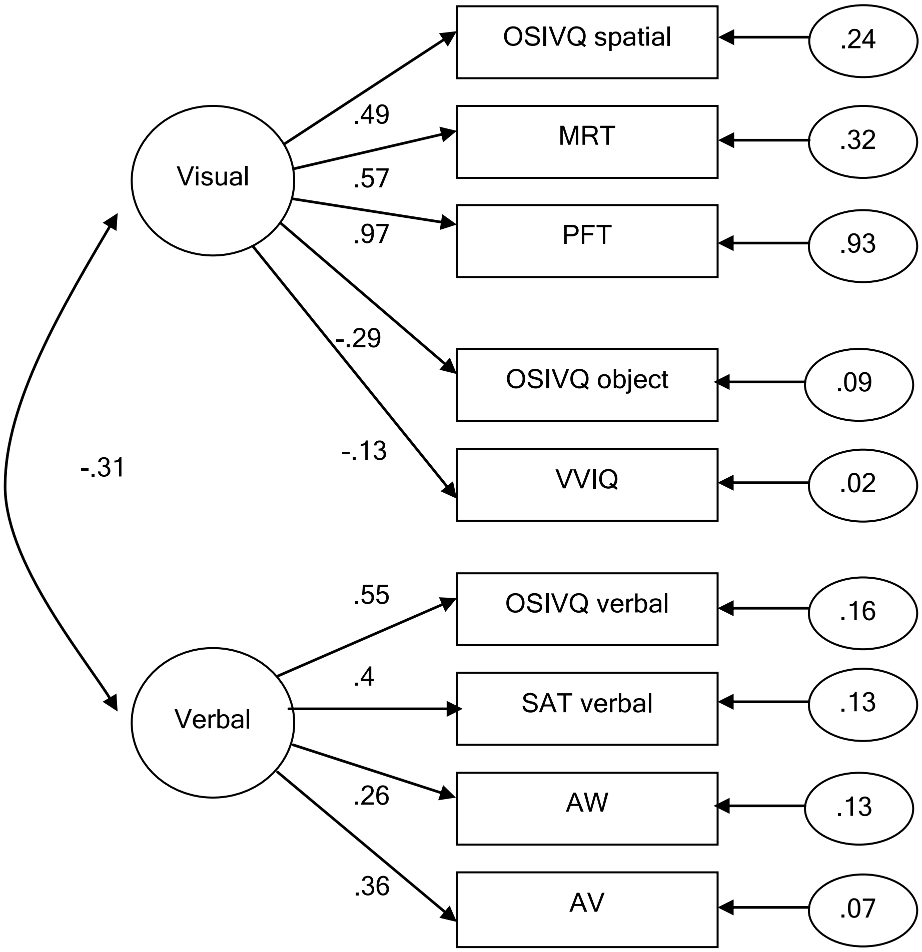


Figure 2. The estimated two-factor model of cognitive style.
The numbers accompanying the arrows on the left indicate the standardized factor loadings, the numbers accompanying the shorter arrows on the right indicate the error terms.

As seen in Figure 2, verbal measures according to the model are in fact loaded on the verbal factor and spatial imagery measures loaded on the visual factor, and the correlation between these two factors are negative (*p* = -0.31). However, the object imagery assessments (OSIVQ-Object and VVIQ) loaded negatively on the visual factor. The chi-square for the two-factor model is significant [χ^2 (26) = 49.322, *p*=.004] suggesting that the model significantly deviated from the data. Moreover, the values of CFI (.813) and RMRSEA (.084) indicate that this model does not have a good fit, and therefore does not describe the data.

The three-factor model, based on the new theoretical approach that distinguishes between two types of imagery, assumes that all spatial imagery measures (OSIVQ-Spatial, PFT, and MRT) load on one factor, all object imagery measures (OSIVQ-Object and VVIQ) load on a second factor, and all verbal measures (OSIVQ-Verbal, AW, AV, and SAT verbal) load on a third factor. Figure 3 shows the estimated three-factor model, and values of fit are reported in Table 9. The indices suggest that the three-factor model fits the data well. The chi-square for this model was not significant (χ^2(24) = 27.607, *p* = 0.27). Moreover, the value of CFI (.97) is above the criterion of .90 for a good fit, the value of RMRSEA (.034) is below .05 that indicates a close fit of the model in relation to the degrees of freedom, which, overall, indicate that this model does explain the data.

Interestingly, consistent with the correlational patterns reported in the previous section, the results of the confirmatory factor analysis indicated a negative correlation between spatial and object constructs (*r* =-.30) as well as between spatial and verbal constructs (*r* =-.23), however, they indicated no relation between object and verbal constructs (r = -.02).

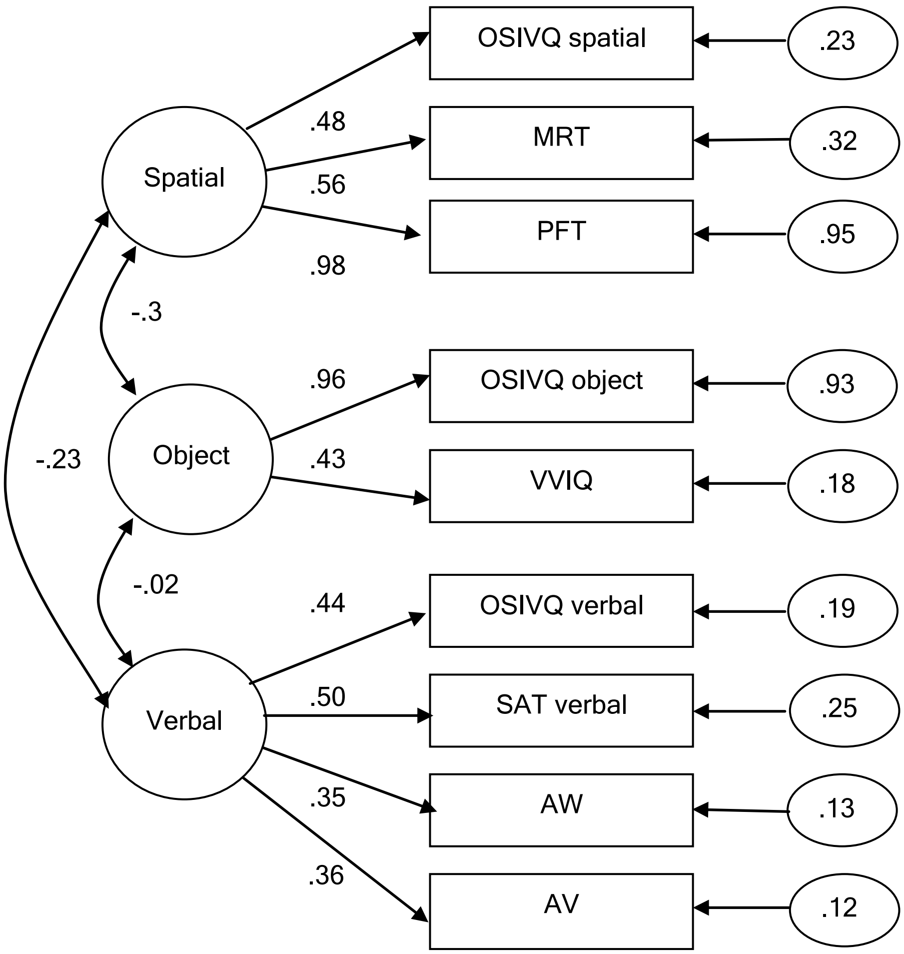


*Figure 3.*The estimated three-factor model of cognitive style.
The numbers accompanying the arrows indicate the standardized factor loadings, the numbers on the left accompanying the shorter arrows on the right indicate the error terms.

Furthermore, the traditional two-factor model was compared with the three-factor model. The chi-square difference comparing the fit of two models indicates that the overall fit of the three-factor model is significantly greater than that of the two-factor model (χ^2 (2) =21.72, $p < 0.001$).

Table 8

The values of fit for the two-factor and three-factor models

Model	χ^2	*df*	*p*	χ^2/df	$\chi2_{\text{diff}}$	df_{diff}	CFI	PCFI	PNFI	RMSEA
Three-factor	27.61	24.00	.28	1.15	-	-	.97	.65	.55	.03
Two-factor	49.32	26.00	.00	1.90	21.72	2.00	.81	.59	.50	.08

Note: CFI = comparative fit index; PNFI = parsimony normed fit index; PCFI = parsimony comparative fit index; RMSEA = root mean square error of approximation.

Test-retest reliability

To assess test-retest reliability, the OSIVQ was administered to a subsample of the participants who completed the measures for Study 2d (N=41), on a second occasion, separated from the first occasion by three weeks. The scores were computed by averaging across the 15 items for each scale, and correlations between the testing sessions were computed. For the Verbal scale, $r = .73$, $p < .001$, for the Object scale, $r = .75$, $p < .001$, and for the Spatial scale, $r = .84$, $p < .001$.

Conclusions

Overall, the data from Studies 2a-2d provided further validation of the OSIVQ as a measure of spatial and object imagery and verbal preferences and thus provided further support for the new Object-Spatial-Verbal model of cognitive style, that considers imagery as not a unified, undifferentiated construct, but as consisting from Object and Spatial imagery dimensions. Across series of studies, the Spatial scale was positively correlated with measures of spatial imagery and overall not correlated with measures of object imagery, with the exception of a weak correlation with the VVIQ in Study 2a. In contrast, the Object scale was positively correlated with measures of object imagery, but not correlated or inversely correlated with measures of spatial imagery.

These results have important implications because they provide a clear explanation for previous failures to find significant correlations between imagery self-report questionnaires and spatial imagery tests. The items on most of the previous imagery questionnaires were targeted to measure aspects of object but not spatial imagery (e.g., items on the VVIQ assessed the colorfulness, brightness, and vividness of the images constructed from long-term memory), yet most of the standard psychometric imagery tests assess aspects of spatial imagery (e.g., the transformations of elements of mental images). The pattern of correlations between the OSIVQ spatial scale and spatial imagery tasks, however, indicates that it is possible to use subjective ratings of imagery to predict performance on spatial imagery tasks, but the ratings must be of spatial imagery processes (e.g., asking people to rate whether their images are schematic, to rate their ability to manipulate and transform their images spatially, and to rate their ability to perform everyday spatial imagery tasks) and not object imagery processes (e.g., colorfulness or vividness).

The data from Study 2c provide discriminant validation of the OSIQ Object and Spatial scales. The scales were not significantly correlated with measures of verbal and non-verbal intelligence, and therefore, these results suggest that OSIQ scales assess constructs that are different from general intelligence. The data from Study 2c also confirmed the predictive validity findings from Study 2a and 2b in that the OSIVQ spatial scale was correlated with the Paper Folding Test but not with the VVIQ and in that the OSIVQ object scale was correlated with the VVIQ but not with the Paper Folding Test.

The results from Study 2d provide further validation of the OSIVQ. First, unlike many previous self-report questionnaires, all three scales of the OSIVQ demonstrated acceptable criterion validity: the participant's ratings on the object, spatial verbal correlated positively with only the corresponding criterion tasks. Second, the OSIVQ demonstrated acceptable test-retest reliability. Third, the traditional two-factor model that describes Visual-Verbal cognitive style as a bipolar dimension was compared to the three-factor model that comprises three independent dimensions, Verbal, Object, and Spatial. The results of the confirmatory factor analysis indicated that the overall fit of the three-factor model was significantly greater than that of the two-factor model and that only the three-factor model can provide a fit to the empirical data. Finally, the negative correlations found between spatial and object factors as well as between spatial and verbal factors obtained from the confirmatory factor analysis suggest that spatial imagery style might not be entirely independent, but exhibits some degree of interference with both object and verbal cognitive styles.

Overall, the findings of Study 2 demonstrate the validity of the OSIVQ instrument, provide support for the 3-dimensional model of cognitive style, and help to explain inconsistencies in previous findings regarding the relations between visual and verbal measures as well as help to explain problems with establishing the predictive validity of previous cognitive style instruments.

Studies 3a and 3b

Studies 3a and 3b were designed to examine the ecological validity of the OSIVQ by examining the relationship between the OSIVQ scales and peoples preferences regarding their real-world activities (beyond the laboratory testing settings) that require object imagery, spatial imagery or verbal abilities. Spatial imagery skills, such as spatial visualization of abstract schematic representations and spatial transformation of complex three-dimensional forms are important in physics, chemistry, engineering and other fields of natural sciences (e.g., Casey et al., 1990; Ferguson, 1977; Kozhevnikov et al., 2002; Pellegrino et al., 1985). On the other hand, such object imagery skills as the construction of clear and bright visual images, and depicting real objects and scenes in detail and color, have been shown to be crucial for creative processes in visual arts (e.g., Lindauer, 1983; Roe, 1975; Rosenberg, 1987). The work of humanities professionals, in contrast, requires more extensive reading, comprehension and production of verbal materials rather than the use of either object or spatial imagery. Thus, the different professional areas require different types of abilities. Indeed, the examination of GRE scores for different majors indicates that Humanities majors (Philosophy, History and English Literature) had the highest Verbal scores and Analytical writing scores of students in all majors, whereas Mathematics, Physics and Mechanical Engineering majors had the highest quantitative scores (ETS, 2006-2007). Furthermore, Kozhevnikov et al. (2005) demonstrated that visual artists scored higher than scientists on an object imagery task, whereas scientists scored higher than visual artists on a spatial imagery task, and the scientists prefer spatial strategies, whereas visual artists prefer object-based strategies in interoperation of complex abstract information (e.g., kinematics graph).

In Study 3a, we examined the correlations between each of the OSIVQ scales and the number of college-level courses taken in visual arts and physics and writing. In Study 3b, the OSIVQ was administered to visual arts, science, and humanities professionals. We expected that both professional membership and educational choices are related to the participants' cognitive style.

Method

Participants

For Study 3a, we recruited 186 participants (130 females) enrolled in undergraduate and graduate courses at Rutgers University, New Jersey Institute of Technology, George Mason University, New York Institute of Fashion and Design, and Stevens University.

In Study 3b, based on the convenience sample, we recruited 193 professionals with majors in visual arts, sciences, or humanities, and with at least two years working experience in their respective professions. The group of visual artists consisted of 79 (42 females) designers and visual artists. The group of scientists consisted of 67 (20 females) computer scientists, physicists, biologists, engineers, biochemists, chemists, and mathematicians. Finally, the group of humanities professionals consisted of 47 (30 females) historians, philosophers, English teachers, literature professors, and journalists.

Procedure

All of the participants in Studies 3a and 3b were administered the OSIVQ. The participants from Study 3a were asked about the number of classes taken in visual arts, physics or writing.

Results

Study 3a

We examined the correlations between the OSIVQ scales and the number of classes in visual art, physics or writing taken in college (see Table 9).

Table 9

The Pearson product-moment correlations among the OSIVQ Spatial, Object and Verbal scales and the number of classes taken in visual art, physics, and writing

Measure		1	2	3	4	5	6
1.	OSIVQ object	_	-.08	.05	.22*	-.12	-.07
2.	OSIVQ spatial		_	-.19**	-.09	.34**	-.23**
3.	OSIVQ verbal			_	-.11	-.19*	.28**
4.	Visual art classes				_	-.01	.34*
5.	Physics classes					_	.80
6.	Writing classes						-

** $p < .01$ * $p < .05$

The analyses revealed that the OSIVQ Verbal scores were positively correlated with the number of writing classes ($p <.001$), but negatively correlated with the number of physics classes ($p =.008$). The OSIVQ Spatial scores were positively correlated with the number of physics classes ($p <.001$), but negatively correlated with the amount of writing classes ($p =.002$). Finally, the OSIVQ Object scores were positively correlated with the amount of visual art classes ($p =.003$). Furthermore, the number of writing classes taken in college correlated positively with the amount of visual art classes ($p <.001$). Thus, the OSIVQ scale scores predicted the interests in the fields that require object or spatial imagery or verbal skills.

Study 3b

Figure 4 illustrates the distribution of the raw OSVIQ scores on the three scales for visual artists, scientists, and humanities professionals. As can be seen from the figure, three groups of the professionals form three separate clusters, and in fact, all three professional groups differ significantly on their OSIVQ scores. A MANOVA (Pillai's Trace) with professional group as a predictor and OSIVQ scales as criterion variables revealed a significant multivariate effect, $F(6,378) = 28.929$, $p < .001$, partial $\eta^2= .315$. The follow-up Univariate ANOVAs were performed on the individual OSIVQ scales to investigate differences between the professional groups. The analysis of the verbal scores revealed significant differences between the professional groups, $F\ (2, 192) = 40.026$, $p < .001$, partial $\eta^2= .296$. Tukey's HSD revealed that the humanities professionals' OSIVQ Verbal scores ($M = 3.53$; $SD =.47$) were significantly higher than the scientists' ($M =$

2.71; *SD* = 0.53) and visual artists' (*M* = 2.72; *SD* = 0.58) scores (*p* < .001). However, OSIVQ verbal scores did not significantly differ between the scientists and visual artists. Thus, the results showed that humanities professionals scored the highest on the verbal imagery scale.

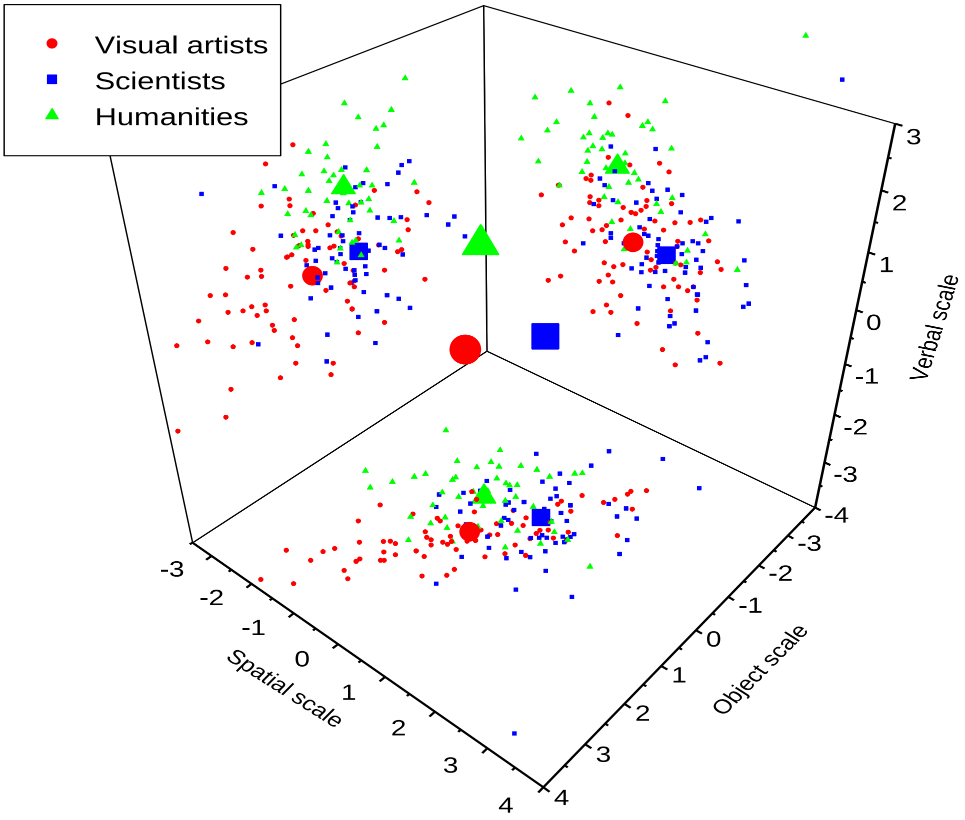


Figure 4. The OSVIQ scores of visual artists, scientists, and humanities professionals. The large points represent the group mean scores for visual artists (in circles), scientists (in squares) and humanities professionals (in triangles). The other points represent the projections of the group means (medium points) and individual scores (smallest points) onto different axes.

Given that visual art, science and humanities professionals known to be experts in use of object, spatial or verbal skills also highly rate their object, spatial or verbal abilities and preferences on OSIVQ, these findings further confirm the validity of the OSIVQ as an instrument assessing Object-Spatial-Verbal cognitive style. Furthermore, the follow-up Univariate ANOVA revealed significant differences in Object, F (2, 192) = 34.366, $p < .001$, partial $\eta^2 = .266$, and Spatial, F (2, 192) = 22.741, $p < .001$, partial $\eta^2 = .193$, OSIVQ scales among members of different professions. Tukey's HSD demonstrated that visual artists had significantly higher Object imagery scores (M = 4.01; SD = 0.52) than scientists (M = 3.23; SD = 0.68, $p < .001$) and humanities professionals (M = 3.39; SD = 0.57, $p < .001$), but scientists had significantly higher Spatial imagery scores (M = 3.40; SD =.56) than visual artists (M = 2.92; SD = 0.65, $p < .001$) and humanities professionals (M = 2.63; SD = 0.66, $p < .001$).

Conclusions

The results from Study 3 support the ecological validity of the three OSIVQ scales, and suggest that cognitive styles might be an important predictor in course choices, and thus, could be also helpful for vocational guidance. Overall, the findings of Study 3 demonstrated that professionals known to use either object imagery or spatial imagery, or verbal skills assess themselves differently on the three scales. Therefore, the OSIVQ three dimensions are related to the interests and activities in corresponding complex tasks beyond the laboratory testing settings. Furthermore, these findings support the idea that there is a close relation between an individual cognitive style and the area of specialization. Previous studies have shown the relation between such styles as holistic-analytical, divergent-convergent, concrete-abstract and professional specialization (e.g., Hayes & Allinson, 1993; Kolb, 1984). Thus, our results extend previous findings to the Object-Spatial-Verbal cognitive style.

Studies 4a and 4b

Study 4 was conducted to further investigate differences in visual imagery ability and their relation to the areas of specialization. Consistent with the approach that distinguishes between object and spatial processing, the current research hypothesizes that members of different professional groups would differ in their scores on spatial and object imagery tests and self-report imagery assessments. In particular, visual arts professionals are expected to excel in object imagery, and science professionals are expected to excel in spatial imagery. The humanities professionals predominantly deal with verbal materials rather than visual representations in their work, and thus, humanities professionals are expected to have less developed object and spatial imagery skills. Such a finding would provide ecological validation for the object-spatial visualizer distinction by showing that the distinction generalizes beyond the research lab.

In Study 4a, the three professional groups whose work extensively relies on visual processing (i.e., visual artists, scientists, and architects) completed a series of object and spatial imagery measures, and performance differences between the groups of professionals were examined. The tests were also administered to a group of humanities professionals that served as a comparison professional group, whose work did not require extensive use of visual imagery but instead required verbal processing. Furthermore, Study 4b was conducted to examine developmental aspects of individual differences and imagery, and their relation to learning interests and abilities (that might lead to future professional choices). Children gifted in visual art, science and generally gifted children, as well as children without special interests completed the battery of visual, spatial and verbal tests similar to the one used for professionals in Study 4a.

Method

Participants

In Study 4a, the participants were 26 visual artists (10 females), 24 scientists (6 females), and 23 humanities professionals (14 females). All of the participants held college degrees and had at least two years of professional experience in the field. The group of visual artists included professional painters, interior designers, and architects (8 males and 2 females). The group of scientists included computer scientists, physicists, biologists, engineers, biochemists, and mathematicians. Finally, the group of humanities professionals consisted of historians, philosophers, linguists, English professors, and journalists.

In Study 4b, the participants were 199 children (10 to 17 years old; 122 females) selected from 4 schools for gifted children 2 secondary schools in Russia, Moscow and one extra-curriculum weekend school in USA, City, NJ. The study was primarily conducted in Russia because of the specialized school system for gifted children. Generally, these children were selected based on the results of competitive exams and contests that honor creativity, original ideas, curiosity, and learning potential of a child such as capacity to develop proficiency in a particular areas (i.e., physics, visual art, humanities), rather than they test some specific knowledge in a particular field or consider previous school grades. In these schools, besides the traditional school program, students extensively learn additional materials in order to develop their future professional habits, and get prepared for admission in the best universities in Russia. Some of these schools (usually more science-oriented) start their program from 14-15 y.o., but some (usually more art oriented) can start specialized education from 7-8 y.o.

Based on their school membership as well as self-reported interests in different areas and vocational preferences, all children were classified into 4 groups: 1) "gifted in science", those with strong interest and ability in physics, math, and possibly but not necessarily in biology (*N*=43, 12 females) ; 2) "gifted in visual art", those with strong interest and ability in visual art (*N*=40, 35 females); 3) "gifted in other/many fields" , those with strong interests and abilities in several fields of knowledge with at least one in visual field, without a particular preference(*N*=73, 49 females); 4) general population from general public schools without extracurricular program (*N*=43, 26 females)[5].

Typically, during the last 2-3 school years (from 14 y.o.), children extensively prepare for university admission exams and get more area-specific training. Therefore, we split children into the two age groups: "younger" 10-13 y.o. (*N*=76) and "older" 14-17 y.o. (*N*=123) to analyze these groups separately, and further, to get a perspective about the development of imagery skills, to compare the object and imagery and their relationships in younger and older group. Additionally, this separation into age groups was motivated by the research that suggest that spatial ability is underdeveloped until the adolescence (e.g., Van Leijenhorst, Crone, & Van der Molen, 2007).

Procedure and Materials

In Study 4a, the participants were individually administered three object imagery and two spatial imagery assessments. The spatial tests were the Paper Folding Test (Ekstrom et al., 1976) and the computerized Mental Rotation Test (Shepard & Metzler, 1971). The object imagery measures were the VVIQ (Marks, 1973), the computerized Degraded Pictures Test (Kozhevnikov et al., 2005)[4] and the Grain Resolution Test (Kozhevnikov et al., 2005). In addition, participants completed the OSIQ (Blajenkova et al., 2006) to assess their preferences for object versus spatial imagery. All participants were tested individually.

In Study 4b, the participants were administered object imagery and spatial imagery tests, all paper-and-pencil. The spatial tests were the Paper Folding Test (Ekstrom et al., 1976) and the Mental Rotation Test (Vandenberg & Kuse, 1978), the object imagery measures were the VVIQ (Marks, 1973), the Degraded Pictures Test (Kozhevnikov et al., 2005)[4]. In addition, participants completed a modified version of the OSIQ version that adapted for children (Blajenkova & Kozhevnikov, 2007)[5]. All participants were tested in groups of up to 30 individuals.

Results

For Study 4a, the data were initially analyzed with the architects, painters, photographers, and interior designers considered as a single group of visual artists; however, closer examination of the data for architects versus the other visual artists revealed significant differences (reported below). Thus, for the subsequent analyses, the professionals were divided into four groups: visual artists, architects, scientists, and humanities professionals. Table 10 shows descriptive statistics and the ANOVA results for all assessments for each group.

Table 10

Descriptive statistics and ANOVA results for all assessments used in the Study 4a

	Science	Visual Art	Architecture	Humanities	ANOVA
	M (SD)	*M (SD)*	*M (SD)*	*M (SD)*	F (3,69), *p*
		Spatial imagery assessments			
PFT	6.68 (1.35)	4.43(2.48)	6.80 (2.46)	5.25 (2.26)	4.960, *p* = .004
MRT	88.88 (9.01)	73.75 (14.82)	83.20 (9.80)	79.73 (10.46)	6.423, *p* =. 001
MRT RT	6817 (3525)	5915 (2945)	5248 (1863)	6005 (2905)	0.535, *p* = . 535
OSIQ spatial scale	3.26 (.48)	2.90 (.49)	3.54 (.58)	2.81 (.72)	4.972, *p* = .004
		Object imagery assessments			
VVIQ	59.63 (11.65)	70.19 (7.96)	56.80 (7.27)	55.91 (9.71)	7.426, *p* < .001
GRT	10.25 (1.96)	11.75 (1.53)	11.60 (2.10)	10.70 (1.69)	2.835, *p* = .044
GRT RT	6557 (3104)	5405 (1538)	4026 (1058)	5135 (1610)	3.671, *p* = .016
DPT	5.28 (1.61)	6.96 (1.64)	6.10 (2.44)	5.48 (1.96)	3.002, *p* = .036
DPT RT	10724 (6060)	9238 (3492)	10576 (7755)	6605 (2906)	2.996, *p* = .037
OSIQ object scale	3.23 (.69)	4.18 (.45)	3.44 (.46)	3.28 (.57)	10.218, *p<.00)*

Following recommendations for analyzing multiple dependent measures (Bray & Maxwell, 1982), a MANOVA was conducted, and then follow-up univariate ANOVAs were performed on the individual dependent measures to investigate differences between the professional groups. A MANOVA (Pillai's Trace) with professional group as a predictor and all of the spatial and object imagery assessments as criterion variables revealed a significant multivariate effect, $F(30,186) = 4.255$, $p < .001$. A follow-up MANOVA with only the spatial assessments as criterion variables revealed a significant multivariate effect, $F(12,204) = 3.011$, $p = .001$, and a follow-up MANOVA with only the object assessments as criterion variables also revealed a significant multivariate effect, $F(18,198) = 4.371$, $p < .001$.

Univariate ANOVAs revealed that the professional groups significantly differed in their performance on the VVIQ, DPT accuracy and RT, GRT accuracy and RT and OSIQ object scale. However, unlike the trends observed for the spatial imagery assessments, Tukey's HSD revealed that visual artists tended to score higher on the object imagery assessments than scientists (VVIQ: $p = .007$; DPT: $p = .033$; GRT: $p = .056$; OSIQ: $p < .001$), architects (VVIQ: $p = .006$; OSIQ object scale: $p = .012$), and humanities professionals (VVIQ: $p < .001$; DPT: $p = .078$; OSIQ object scale: $p < .001$). Scientists also tended to respond more slowly than humanities professionals on the DPT ($p = .033$) and than the architects on the GRT ($p = .014$).

Univariate ANOVAs also revealed that the professional groups significantly differed in their performance on the PFT, MRT accuracy and OSIQ spatial scale, but not on MRT RT. Tukey's HSD revealed that scientists tended to score higher than visual artists (PFT: $p = .008$; MRT: $p < .001$; OSIQ spatial scale: $p = .222$) and humanities professionals (PFT: $p =.$

099; MRT: *p* = .030; OSIQ spatial scale: *p* = .048) but not architects. Additionally, architects scored higher than visual artists on the PFT (*p* = .032) and higher than visual artists and humanities professionals on the OSIQ spatial scale (*p* = .040, and *p* = .009, respectively).

For clearer visualization and comparison of the patterns across assessments and professional groups, z-scores were calculated for each assessment, and Figure 5 shows the mean z-scores for the combined spatial and object imagery assessments for each group. Furthermore, to specifically examine whether professional groups showed above or below average imagery skills, the combined z-scores were computed separately for all spatial and object imagery accuracy measures, and they were compared with the average (z=0).

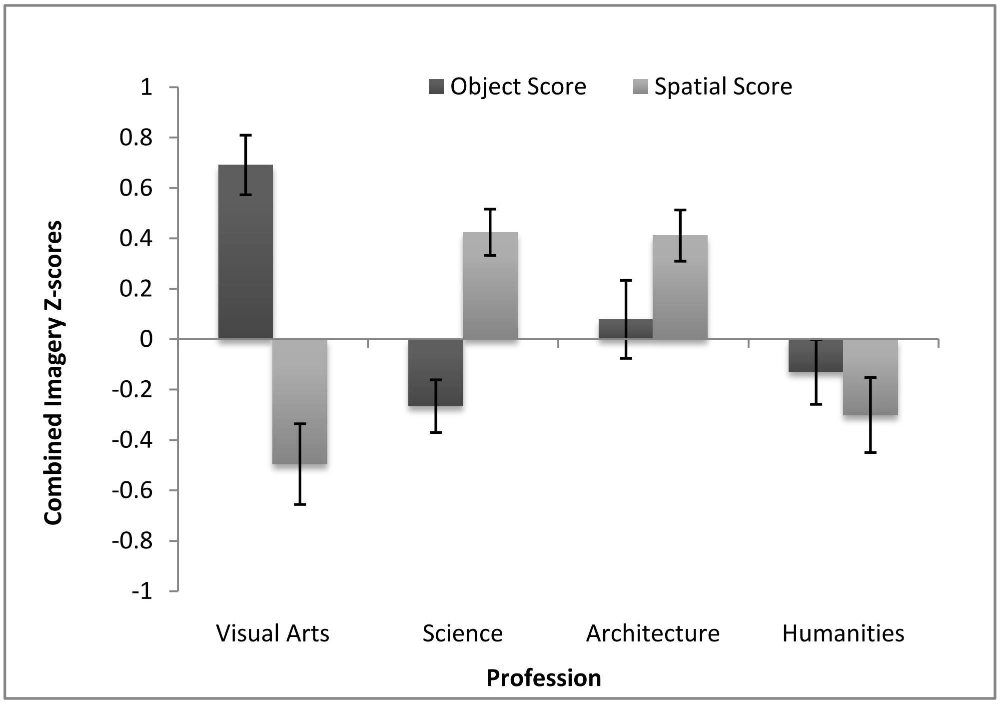


Figure 5. Normalized object imagery assessment scores for the different groups of professionals. The bars represents +/-1 SEM.

Overall, scientists' combined spatial imagery z-scores were significantly above average (t=4.613, p<.001), but their object imagery scores were significantly below average (t =-2.544, p=.018). Visual artists' object imagery scores, on the other hand, were significantly above average (t=8.474, p <.001), but their spatial imagery scores were significantly below average (t=-3.858, p=.02). Architects' spatial imagery scores were significantly above average (t=4.737, p=.001), but their object imagery scores were not significantly different from average (t=.214, p=.835). Finally, humanities' professionals object imagery scores (t=-2.008, p=.057) and their spatial imagery scores (t=-.658, p=.112) were not significantly different from the respective averages, although they tended to be slightly below average. None of the groups showed both high object and spatial imagery abilities. The above results support the existence of trade-off between object and spatial imagery ability.

In the Study 4b, the similar analyses were conducted separately for "younger" and "older" groups, and in addition, the difference between older younger groups was tested. A MANOVA (Pillai's Trace) with groups of children based on their areas of interest as a predictor and all of the spatial and object imagery assessments as criterion variables revealed a significant multivariate effect in both "younger" group, $F(18,207) = 3.426$, $p < .001$ and "older" group, $F(18,348) = 5.828$, $p < .001$. A follow-up MANOVA with only the spatial assessments as criterion variables revealed a significant multivariate effect, in both "younger" group, $F(9,216) = 3.550$, $p < .001$, and "older" group, $F(9,357) = 7.966$, $p < .001$. A follow-up MANOVA with only the object assessments as criterion variables also revealed a significant multivariate effect in both "younger" group, $F(9,216) = 3.071$, $p =.002$ and “older” group, *F(*9,357) = 3.150, *p* =.001. Table 11 presents the results of Univariate ANOVAs for children.

Table 11

Descriptive statistics and ANOVA results for all assessments used in the study 4b

	gifted in visual art	gifted in science	other gifted	general school	ANOVA
			Spatial imagery assessments		
	younger *M (SD)* older *M (SD)* *F* (1, 38), *p*	younger *M (SD)* older *M (SD)* *F* (1, 41), *p*	younger *M (SD)* older *M (SD)* *F* (1, 71), *p*	younger *M (SD)* older *M (SD)* *F* (1, 41), *p*	*F* (3,72), *p* *F*(3, 119), *p*
PFT	3.32 (2.48) 4.97 (2.71) 4.067, *p*= .05	7.38 (2.12) 8.61 (1.77) 4.045, *p*=.051	4.42 (2.16) 7.46 (2.10) 28.932, *p*<.001	3.47 (2.30) 4.47 (3.12) 1.410, *p*=.242	11.231 (*p*<.001) 18.034 (*p*<.001)
MRT	2.85 (1.65) 3.95 (2.44) 2.804, *p*=.10	4.60 (2.29) 6.14 (1.65) 6.484, *p*=.015	3.37 (2.45) 4.44 (2.16) 3.248, *p*=.076	2.47 (1.83) 3.45 (2.04) 2.742, *p*=.105	3.437 (*p* =.021) 8.073 (*p*<.001)
OSIQ spatial scale	2.96(.57) 2.83 (.70) 0.406, *p*=.528	3.50 (.72) 3.93 (.57) 4.628, *p*=.037	3.12 (.72) 3.09 (.74) 0.027, *p*=.869	2.98 (.76) 2.97 (.65) 0.002, *p*=.966	2.151 (*p*=.101) 13.704 (*p*<.001)
			Object imagery assessments		
VVIQ	4.35 (.40) 4.11 (.42) 3.419, *p*=.072	3.71 (.54) 3.87 (.67) 0.660, *p*=.421	4.17 (.44) 4.04 (.47) 1.011, *p*=.318	3.96 (.56) 4.10 (.40) 0.799, *p*=.377	5.592 (*p*=.002) 1.158 (*p*=.329)
DPT	4.71(2.31) 6.61 (3.07) 4.910, *p*=.033	2.97 (1.31) 4.47 (1.96) 7.184, *p*=.011	4.21 (2.80) 5.66 (2.39) 4.704, *p*=.033	4.30 (2.35) 4.21 (1.75) 0.021, *p*=.887	1.755 (*p*=.164) 5.201(*p*=.002)
OSIQ object scale	4.36 (.29) 4.27 (.54) 0.436, *p*=.513	3.45 (.75) 3.66 (.75) 0.699, *p*=.408	4.16 (.60) 4.12 (.55) 0.096, *p*=.757	3.89 (.49) 4.03 (.66) 0.555, *p*=.461	9.185 (*p*<.001) 4.742 (*p*=.004)

Overall, the results show the same trends as in the adult professional sample. Children gifted in science tend to outperform other groups in spatial ability assessments, but children gifted in visual art tend to outperform other groups on object imagery ability assessments. Furthermore, overall, both spatial and object imagery scores tended to increase with age for all groups of gifted children, but not for children from general school. Notably, self-report measures show less increase than performance ability measures; Interestingly, the only two groups that show the age-related differences in self-reports are children gifted in science (they showed the increase in OSIVQ spatial scores)., and gifted in visual art (unexpectedly, they show the decrease in VVIQ scores).

Consistent with Study 4a, the z-scores were calculated for each assessment, and Figures 6a and 6b show the mean z-scores for the combined spatial and object imagery assessments for each group (separately for younger and older children) . Also, similarly to Study 4a, the combined z-scores for all spatial and object imagery measures were compared with the sample average. Overall, the results were consistent with the professional study. The combined spatial imagery z-scores for the group of children gifted in science were significantly above average ("younger" group, $t\ (14)$=4.834, p<.001; "older" group, $t(27)$=9.436, p <.001), but their object imagery scores were significantly below average ("younger" group, $t\ (14)$=-3.533, p=.003; "older" group, $t(27)$=-2.511, p =.018). The object imagery scores for the children gifted in visual art, on the other hand, were significantly above average ("younger" group, $t\ (20)$=3.969, p=.001; "older" group, $t(18)$=3.422, p =.003), but their spatial imagery scores were below average ("younger" group, $t\ (20)$=-2.725, p=.013; "older" group, $t(18)$=-3.058, p =.007). Finally, children who have no specific interests, overall, tended to score significantly below average in spatial measures ("younger" group, *t (20)*=-2.369, *p* =28; "older" group, *t(21)*=-4.458, *p* =.002). No other significant differences were found.

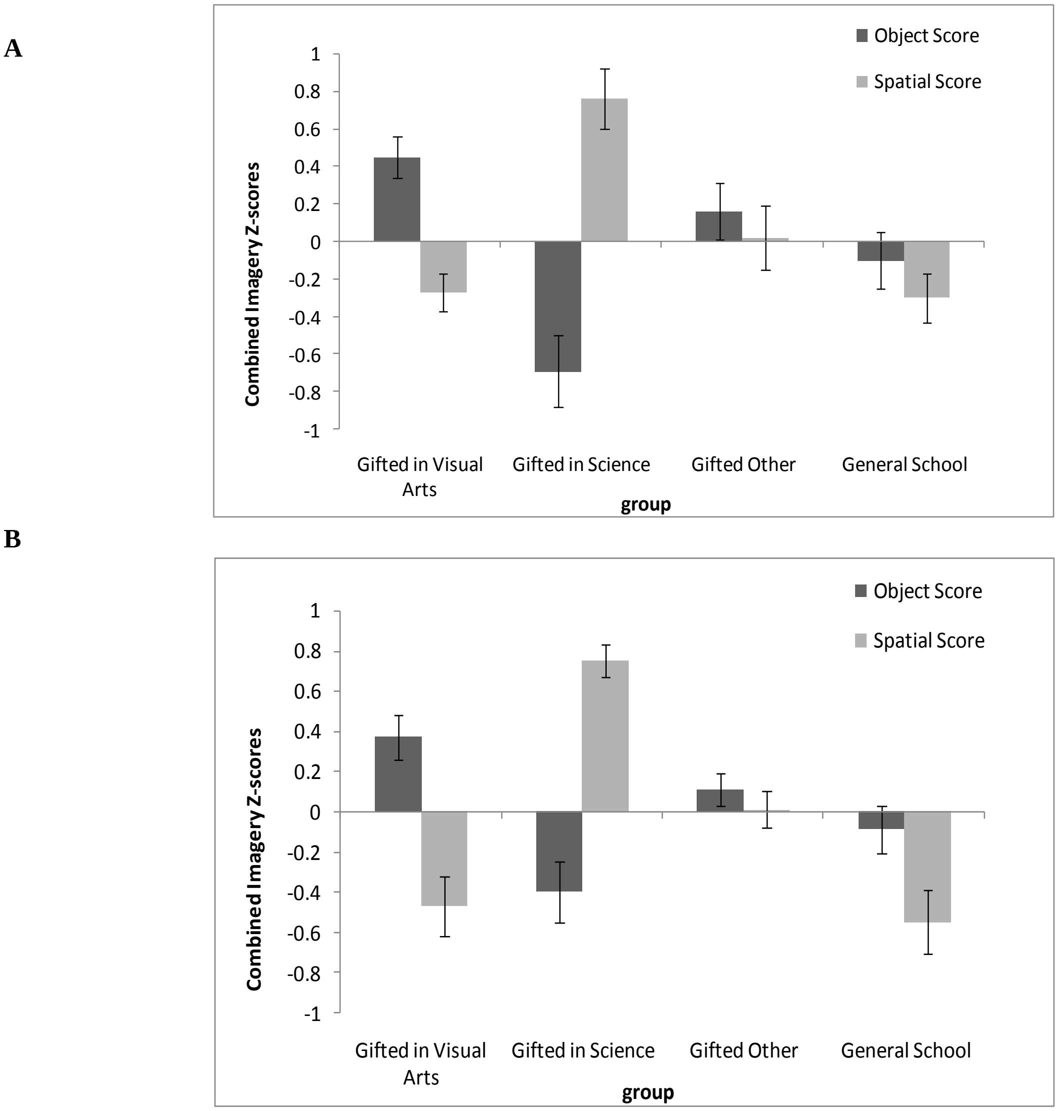


Figure 6. Normalized imagery assessment scores for the different groups of children. Figures A and B represent the data for younger and older groups, correspondently. The bars represents +/-1 SEM.

Conclusions

The results of Studies 4a and 4b further supported the distinction between object and spatial imagery. The distinction was most evident when comparing scientists and visual artists: visual artists tended to have higher object imagery scores than scientists humanities professionals, but scientists tended to have higher spatial imagery scores than visual artists and than humanities professionals. Moreover, while visual artists showed above average object imagery abilities and below average spatial imagery abilities, scientists showed above average spatial imagery abilities and below average object imagery abilities. The humanities professionals' spatial and object imagery scores generally were not significantly different from average. The humanities professionals did not score above average on any of the object and spatial imagery tests; in fact, they scored below average on both the VVIQ and the OSIVQ spatial scale, thus showing below average ratings of their abilities and preferences for using both types of imagery. The architects had higher PFT scores than the visual artists and higher OSIVQ spatial scores than both the visual artists and humanities professionals, but only their OSIVQ spatial scores were above average. Thus, the OSIVQ data suggest that the architects might view themselves as spatial imagers, but the PFT and MRT data, although showing above average trends, did not support this view. Overall, these findings suggest that even though both visual artists and scientists use visual imagery extensively in their work and training, they tend to excel in only one type of imagery, object or spatial.

The children's results were consistent with those obtained from adult professionals: 'young visual artists' scored the highest on object imagery tasks, but below average on spatial imagery tasks; whereas, 'young scientists' scored the highest on spatial imagery tasks but below average on object imagery tasks. In fact, none of the groups in the professional or children's sample excelled in both imagery tasks. This finding further supports conclusions made by Kozhevnikov et al. (2005), who suggested a trade-off between object and spatial imagery abilities, based on the finding that those people who excel on object imagery tasks showed below average performance on spatial imagery tasks, and vice versa. Moreover, notably, both younger and older groups of children showed very similar patterns of performance on imagery tasks, suggesting that dissociation between object and spatial imagery in individual differences might develop early in age and appear before visual imagery skills are fully developed, as well as before any comprehensive professional training.

Study 5

The goal of Study 5 was to investigate the qualitative differences between object and spatial visualizers in their approaches to interpreting visual abstract information, such as abstract kinematic graphs and abstract visual art. In particular, this research focused on the ecological validation of the object imagery dimension, and investigated whether the object mode of processing might support abstract visual representations.

Previous research extensively investigated spatial (but not object) ability from the psychometric, cognitive, and neuroscience perceptive, and showed that spatial ability is important in fields such as physics, geometry, chemistry, mechanical engineering etc. (Ferguson, 1977; Hegarty & Kozhevnikov, 1999; Pellegrino, Mumaw, & Shute, 1985; Ghiselin, 1952). While spatial and verbal abilities were traditionally considered to be main components of intelligence (Smith, 1964), object imagery ability was neither considered important for abstract reasoning, nor regarded as part of intelligence. Moreover, previous research considered pictorial vivid imagery as concrete imagery, and associated it with low intelligence or an inability to form abstract imagery representations (for discussion see Lean & Clements, 1981).

However, our findings from the current work demonstrated that object imagery is an independent dimension (Study 1), which has its own unique predictive and ecological validity (Studies 2 & 3), and is important for everyday and professional tasks such as visual art or design (Study 4). Also, historical analysis (Miller, 1984) demonstrated that not only science, but also art, develops from concrete to an increasingly abstract format, i.e., from realistic representational paintings in Renaissance art (e.g., landscapes or portraits) to abstract representations of pure emotions and concepts, starting in the late nineteenth and early twentieth centuries, such as Cubism (Pablo Picasso) and Abstract Expressionism (Mark Rothko). Thus, we suggest that object imagery can not be considered as concrete underdeveloped spatial imagery, but it can support its own unique forms of abstract representations, irreducible and unrelated to spatial imagery.

Indeed, Kozhevnikov et al. (2005) found that object and spatial visuazliers tend to use qualitatively different strategies, which can not be considered as two opposite poles of single one-dimensional imagery construct. On a number of tasks, Kozhevnikov et al. showed that object visualizers use more global, holistic strategies, and encode visual information as a single perceptual unit, while spatial visualizers use more sequential, part- by-part, analytical approach. In particular, they showed that object visualizers performed better in identifying global properties of shapes, whereas spatial visualizers were more successful in identifying local properties. Furthermore, they demonstrated significant differences between types of interpretations of kinematic graphs between visual artists and scientists. Visual artists consistently described graphs in terms of their literal appearance, and referred to the global shape of graphs, whereas scientists tended to interpret the motion depicted on the graph successively, part-by-part, at different intervals. The scientists consistently used schematic descriptions of the graphs and referred to the abstract meaning rather than literal shape. Although research by Kozhevnikov and colleges suggests that spatial and object visualizers use qualitatively different strategies in interpreting visual information, and that spatial imagery does support abstract graphical interpretation, no studies were conducted to test whether object imagery might also support abstract object representation.

Thus, to address this question, in the current study both object and spatial types of abstract visual representation (i.e., abstract art and kinematic graphs) were administered to two groups of visual experts: visual artists and scientists. The abstract art was used as an abstract visual representation comparable to the abstract graphs that were used in the previous studies. We suggest that, while scientists should be able to form abstract representation in the visual-spatial domain (consistent with previous findings), they could fail to form abstract representations in the visual-object domain. Moreover, while visual artists may tend to from pictorial but not abstract representations in the visual-spatial domain, they could still be able to form abstract representations in the visual-object domain. In addition, for comparison, the same tasks were administered to a control group of humanities professionals. The previous conceptualizations of the traditional Visual-

Verbal cognitive style dimension tended to characterize verbalizers as individuals inclined to think in an abstract manner (see Jonassen & Grabowski, 1993; Kirby et al., 1988). The current study investigated whether humanities professionals are able to form abstract representations not in the domain of verbal-analytical conceptual thinking, but in visual thinking.

Method

Participants

The members of different professions, 24 scientists, 16 visual artists, 10 architects, and 23 humanities professionals who participated in the Study 4a, were also asked to complete the graph and picture interpretation task. From these professionals, 72 participants completed the Kinematics Graph Interpretation Task, 70 participants completed the Abstract Art Interpretation Task, and 68 participants completed the Art Estimation task.

Procedure and Materials

Kinematics Graph interpretation task

The Kinematics Graph interpretation tasks (see Figure 7) were designed to examine how object and spatial visualizers interpret abstract visual information. In the kinematics *graphs interpretation task* (Kozhevnikov et al., 2002), participants saw a kinematics graph that described changes in an object's position over time. They were asked to visualize a real situation depicted by the graph, and to write a story describing what happened to the object, leading to this particular graph of its motion. Finally, they were asked to draw the graph of velocity vs. time for this object's motion.

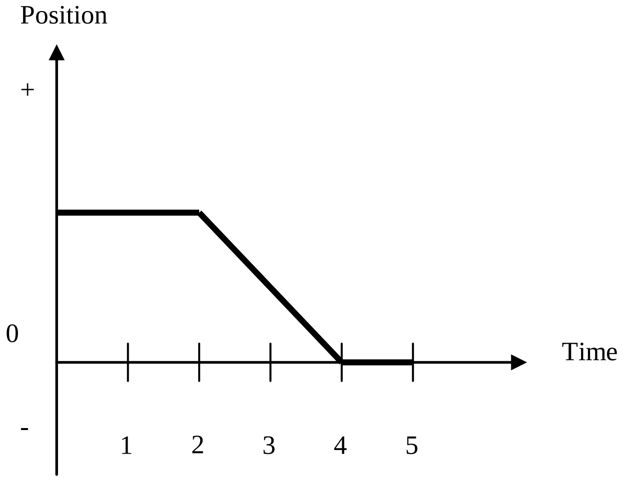


Figure 7. Kinematics Graph interpretation task

Art interpretation task

The Abstract Art interpretation task (see Figure 8) was designed to examine how object and spatial visualizers interpret visual information from abstract art. In the abstract *art interpretation task,* participants were asked to describe the meanings and feelings expressed by the abstract visual art painting (L. Berryhill "Breakthrough").

Figure 8. Abstract art interpretation task

Art estimation task

In the *Art estimation task ,* participants judged 8 pictures (Figure 9) on 7-step bipolar scales (i.e., good – bad, beautiful – ugly, abstract – realistic, interesting – boring, like – dislike, tense – relaxed, enigmatic – apparent, illusory – matter-of-fact, complex – simple, emotional – rational).

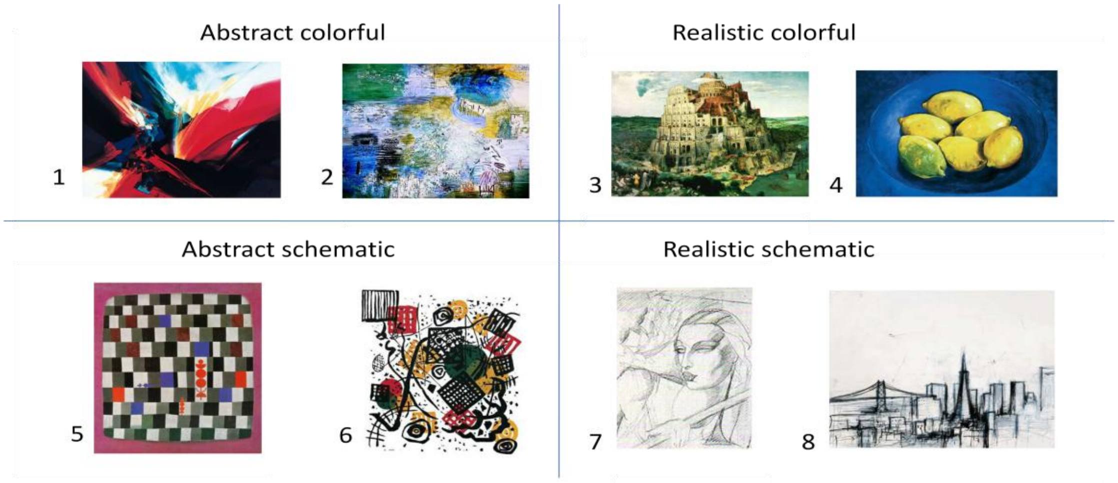


Figure 9. Different types of pictures used in the Art Estimation Task

Results

Graph interpretation task

For the graph interpretation task, consistent with the classification by Kozhevnikov et al. (2002), the graphical and verbal responses were classified by two coders (the agreement was 97%) in the three categories (see Figure 10): abstract\schematic, pictorial\ literal, and irrelevant. The abstract\schematic interpretations represented the abstract\conceptual meaning of the graph, considered it part-by-part, and described the object movement in three steps (i.e., "*1. object at rest, 2. it suddenly starts motion with constant V, 3. it suddenly stops and no motion again"*). The pictorial\ literal interpretations reflected the global pictorial downward shape of the graph (e.g., "*a plane landing at airport", "a squirrel climbing down a tree"*), and in some cases, the shape of the graph was interpreted literally, but in the horizontal plane (e.g., "*car is changing lanes*)". In the pictorial/literal interpretations, the velocity vs. time graph drawing, usually replicated this descending trend, or provided a pictorial illustration of the verbal descriptions (e.g., a drawing of ocean waves where the boat was lowered, or a drawing of an airplane and its descending trajectory) . The interpretations were considered irrelevant if they avoided the answer, or consisted only of vague and general descriptions unrelated to the graph (e.g., *"the weather is quiet and calm, the wind is 3-5 m/s, the wind is favorable"*), as well as of descriptions of a metaphorical sense ("*someone died", "the end of the wash cycle")*, but not in a sense of a real object movement as it was asked in the task. Interestingly, most of such metaphorical, irrelevant responses were given by humanities professionals. Participants who gave irrelevant types of interpretations tended to be totally confused by the task and refused to answer, or they drew a straight line as a symbol of continuous movement, or to draw various lines without making sense of them.

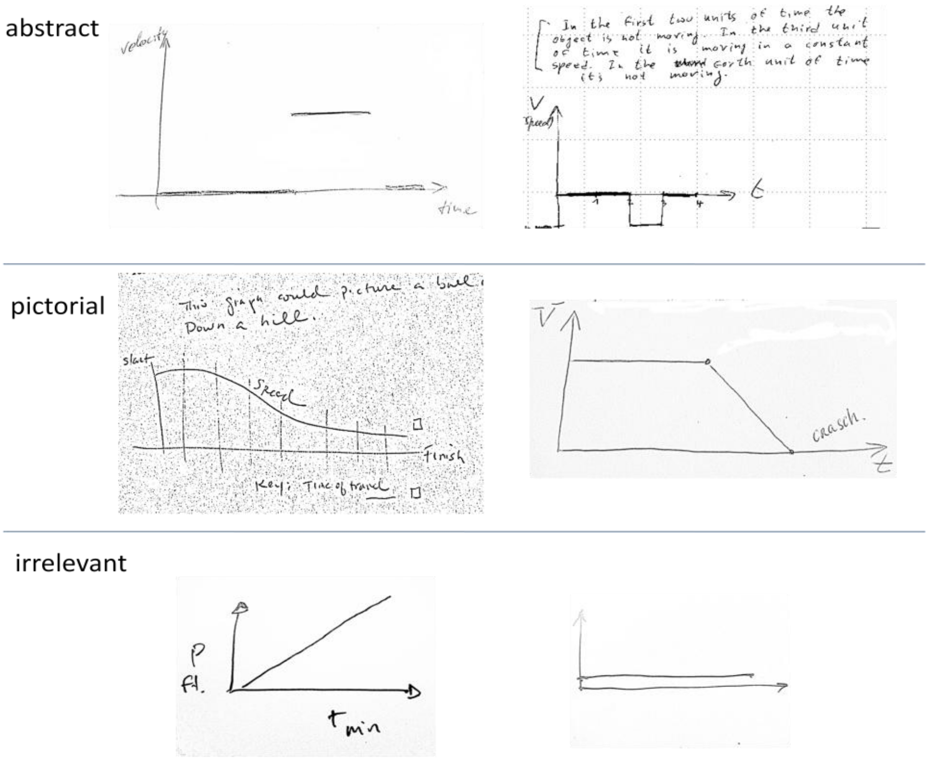


Figure 10. Examples of different types of interpretations of the Kinematics Graph

The results revealed the significant differences in graph interpretations between professional groups (see Figure 11); most scientists (70.8 %) provided abstract\schematic graphical solutions, whereas most of visual artists (93.8 %) and architects (77.8%) provided pictorial solutions ($\chi2(6) = 39.600$, $p < 0.001$).

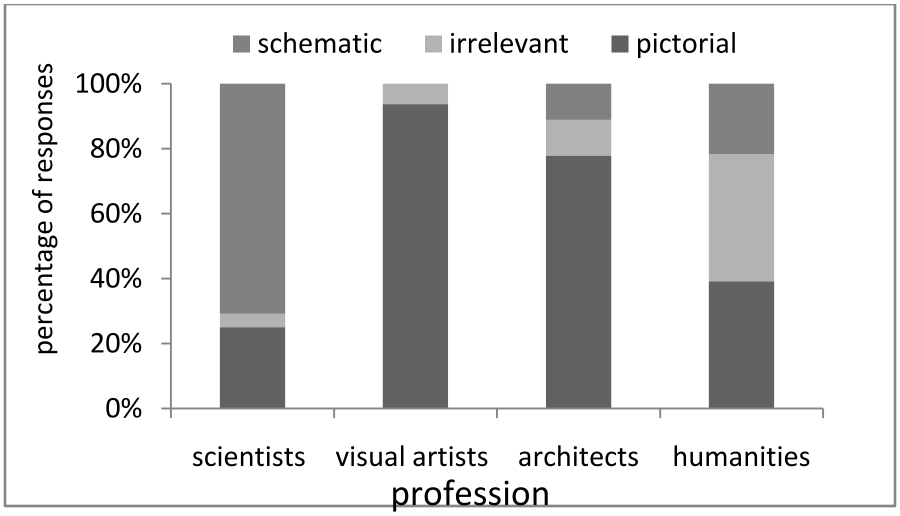


Figure 11. Interpretations of the graph by different professionals

The analysis of variance revealed significant differences in spatial (*F* (2, 69) = 11.592, *p* < .001) and object (*F* (2, 69) = 3.174, *p* =.048) imagery scores (z-scores for object and spatial assessments used in the Study 4a) between groups of participants who gave different types of interpretations. Those who gave abstract\schematic interpretations had higher spatial (*M* =.50; *SD* =.47) and lower object imagery scores (*M* = -.25; *SD* =.59), but those who gave literal\pictorial interpretations had higher object (*M* =.17; *SD* =.70) and lower spatial imagery scores (*M* = -.18; SD =.63). These results suggest that differences in approaches to the interpretation of abstract visual information are related to visual-spatial ability (i.e., scores on object and spatial imagery tasks), however, these can be an effect of expertise (see also Kozhevnikov et al., 2002).

Overall, the results of the *Graph interpretation task* are consistent with those of Kozhevnikov et al. (2005), and in particular, they replicated the findings that scientists tend to interpret graphs in an abstract way, while visual artists tend to interpret graphs literally, as pictures. Moreover, these results showed that humanities professionals (who are thought to be experts in abstract verbal-analytical reasoning) do not necessarily form abstract representations in the visual-spatial domain. Therefore, abstract verbal thinking may not be beneficial for visual tasks. Moreover, humanities professional gave the largest number of irrelevant interpretations, which indicates that they might have been confused by the task.

Art interpretation task

Similarly to those in the graph interpretation task, the responses for the *art interpretation task* were classified in the three categories: abstract\conceptual, pictorial\literal, and irrelevant (i.e., no answer or refusal to answer, descriptions irrelevant to the picture's properties) by two coders (the agreement was 94%). The interpretations were classified as abstract\conceptual if they represented ideas or feelings that were not directly depicted, but represented conceptual\emotional content related to the idea of breakthrough expressed by the painter (e.g., "*crash and liberation", "breakthrough", "eruption", "war", "catastrophe"," extreme tension").* The pictorial\literal interpretations were the descriptions given in terms of apparent visual features such as colors or concrete objects resembling the shapes in the picture (e.g., "*different colors: blue, black, red, yellow, white; sharp edges in red", "pieces of cloths thrown together", "crystals of ice; pieces of ice, glass",* "*mountains").* Finally, the irrelevant interpretations were vague and confused descriptions, avoiding answering, or descriptions irrelevant to the picture's content or appearance, e.g., "*don't see anything", "this is abstract painting", "complicated, don't want to figure out".* All participants indicated that they had never seen this picture before.

The comparison between the professional groups versus types of descriptions revealed significant differences between professional groups (see Figure 12); visual artists provided mostly abstract\schematic interpretations, whereas scientists provided mostly pictorial solutions ($\chi^2(6) = 26.188, p = .001$). Furthermore, the analysis of variance revealed significant differences in object (*F* (2, 67) =4.682, p =.012), but not spatial (*p* =.746), imagery scores (z-scores for object and spatial assessments used in the Study 4a) between groups of participants who gave types of interpretations. Those who gave abstract\schematic interpretations of of the abstract art had higher object (*M* =.37; *SD* =.63), but those who gave literal\pictorial interpretations had lower object imagery scores (*M* =-.12; *SD* =.60).

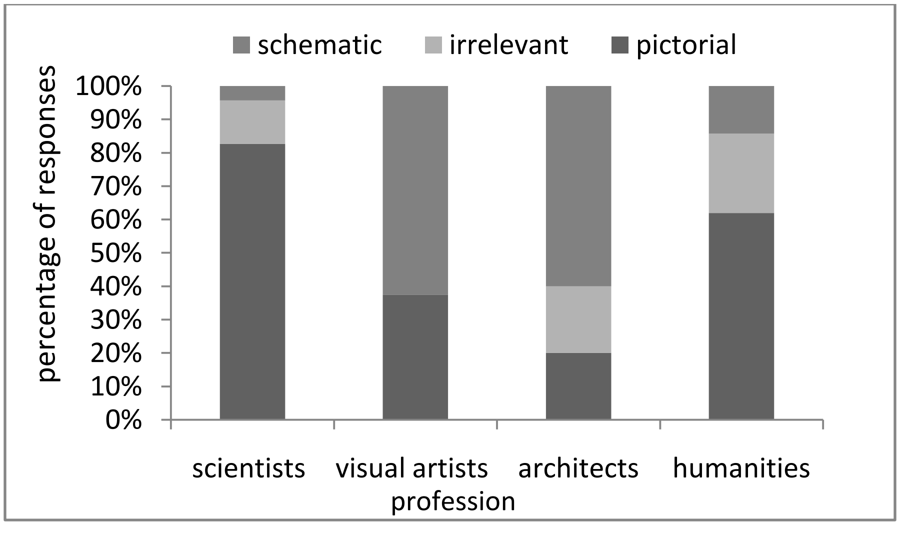


Figure 12. Interpretations of the abstract art by different professionals.

Interestingly, visual artists and architects expressed not only more feelings but also different kinds of feelings than scientists. Visual artists tended to give more complex and multimodal emotional descriptions, both in terms of intensity and meaning, (e.g., "*warm, intense, fear, longing, obstacles, uncertainty*"), they expressed mixed, ambivalent feelings, and also they tended to assign multiple meanings to the picture (e.g., "*1) heat and danger 2) a journey from home*"). Overall, they expressed more negative and intense emotions, which in fact correspond to the concept of "breakthrough" in the picture (e.g., *"explosion of emotions", "fear", "anxiety", "horror", "bursting", "alarm", "disturbance", "extreme tension"*); all of visual artists expressed feelings . Scientists expressed fewer feelings overall; 54% of scientists did not use any emotional expressions: they either expressed no feelings at all (e.g., *"nothing", "no feelings"),* gave estimates/descriptions of the picture itself (e.g., "*beautiful scenery", "nature"),* or made responses irrelevant to emotional descriptions (e.g., "*hunger*", "*everything happens together*"). Even if they had used emotional expressions, they expressed more simple, descriptive, depersonalized, superficial and positive emotions. Typically, in the picture, scientists recognized crystals or pieces of colored glass, which were not usually accompanied by any emotional descriptions, or they recognized mountains, which were usually associated with a positive and relaxed state and mood, as if they were walking on a nature trail. Interestingly, humanities professionals tended to come up with broad digressive metaphors, instead of emotional descriptions (e.g., "*Excitement & diversity. A clash of order & chaos", "ecstasy of mind").*

Overall, the results from both *Art interpretation task* and *Graph interpretation task* showed that object and spatial visualizers tended to interpret abstract visual information (i.e., abstract art and kinematics graphs) in qualitatively different manners. Visual artists tended to interpret the abstract art as an abstract representation, but scientists tended to interpret abstract art literally, in a concrete way. In contrast, visual artists tended to interpret graphs literally (graphs-as-pictures), but scientists tended to interpret graphs schematically, in abstract way. Interestingly, architects, despite their high spatial scores, tended to provide interpretations similar to visual artists: abstract of visual art, and literal for kinematics graphs. Notably, unlike humanities professionals, both spatial and object visualizers tended to give either literal or abstract interpretations of visual information, but not be confused with the task and thus provide irrelevant responses.

Thus, the results demonstrated that object visualizers (visual artists) were indeed able to form abstract representations in object visual thinking, contrary to the view that object imagery is a concrete type of imagery that cannot support abstract visual representations. Moreover, the results showed that spatial visualizers (scientists) failed to form abstract representations in the non-spatial domain, which suggests that abstract reasoning ability cannot be considered as an inseparable property of spatial imagery. Furthermore, the current results these results suggest that, overall, abstract thinking is domain specific (i.e., object or spatial), and either mode of visual processing might support abstract representations.

Art estimation task

Principal Component Analysis on all pictures' estimates revealed 3 main factors that explained 71 % of total variance. Attitude estimates (such as "good", "beautiful", "interesting", "like it") loaded positively on the first factor (loadings ranged from .819 - .850); this factor explained 29% of variance. Emotional estimates (such as "emotional", "enigmatic", "complex"), loaded positively on the second factor (loadings ranged from .786 - .843); this factor explained 25% of variance. The "abstract" and "illusory" estimates loaded positively (loadings: .829 and .657) and "tense" loaded negatively (loading: -.700) on the third factor, which seems to measure remoteness, abstractness, non-emotionality; this factor explained 17% of variance.

The regressed factor scores were correlated with standardized measures of object and spatial imagery ability, and the results revealed that only Factor 2 (emotional estimates) was significantly correlated with imagery scores: positively with Z-object (r =.257, p =.040), but negatively with Z-spatial (r = -.306, p =.014). Furthermore, the correlation analysis between each estimate and standardized measures of imagery abilities showed that spatial imagery ability tended to negatively correlate with emotional estimates (including "tense" estimate), whereas object imagery ability tended to positively correlate with emotional estimates (see Table 12). The results suggest that neither spatial nor object imagery ability predicted attitude estimates of art works.

Table 12

The Pearson correlations among estimates of art works and imagery standardized scores

	Z spatial	Z object
Attitude estimates		
Good	-.015	.144
Beautiful	.106	.064
Interesting	.008	.165
Like	-.036	-.128
Emotional estimates		
Emotional	-.211^{+}	.147
Enigmatic	-.291*	.247
Complex	-.355*	.124
Tense	-.050	.360**
Remoteness estimates		
Abstract	-.162	-.030
Illusory	-.044	.052

** $p < .01$ * $p < .05$ $^{+}$ $p < .10$

These results suggest that object imagery is positively related to attributing emotions. Moreover, these results suggest that spatial imagery ability tends to be negatively related to emotional attribution. Consistent with these results, the qualitative data from *Art interpretation task* showed that scientists, unlike visual artists, do not tend to give profound, complex, and intense emotional descriptions; they seem to be less aware about emotional meanings, and instead use simple, rational and positive descriptions. Consistent with our results, Downey, Mountstephen, Lloyd, Hansen, & Stough (2008) found that the Understanding Emotions measure significantly predicted scores for scholastic achievement in art, whereas that Emotional Management and Control measures were found to significantly predict scholastic achievement in math and science.

Conclusions

Overall, the research findings from study 5 suggest that object imagery can support abstract representations, and therefore it is irreducible to a low-spatial, concrete type of imagery. At the same time, spatial imagery can not be considered as purely abstract, and, thus both visual dimensions are independent from the abstract-concrete dimension (see Figure 13). These results confirms the qualitative differences between object and spatial imagery dimensions, and show that the distinction between object and spatial imagery does not simply reflect a difference between concrete and abstract representations. This study further provides ecological validity for the Object imagery dimension, and shows that is has unique characteristics, as well as a special relationship with emotion.

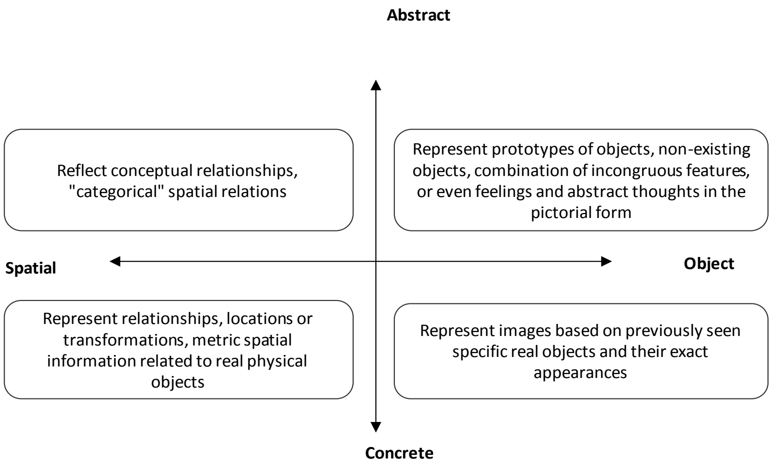


Figure 13. Object vs. Spatial and Abstract vs. Concrete dimensions

GENERAL DISCUSSION

The current research examined the theoretical and applied aspects of individual differences in object and spatial imagery. Throughout all studies in this thesis, the Object-Spatial-Verbal model of cognitive style (Kozhevnikov et al., 2005) was empirically and theoretically examined and validated. In particular, innovatively, the current research established the ecological validity of object imagery dimension and its relation to other dimensions, which has hitherto never been systematically studied. Furthermore, this work was first to develop the theoretically-guided assessment of Object-Spatial-Verbal cognitive style, and to resolve the previously reported issues with predictive validity of visual imagery assessments.

First, this research *further examined Object-Spatial-Verbal theoretical model of cognitive style* that distinguishes between three separate dimensions: Object Visual, Spatial Visual, and Verbal, as opposed to the traditional bipolar Visual-Verbal cognitive style model that distinguishes between two dimensions. Furthermore, current research *investigated the relationship between Object, Spatial and Verbal dimensions in cognitive style.* The results from a Principal Component Analysis (Study 1) demonstrated that Object Visual, Spatial Visual, and Verbal measures loaded onto separate factors, and, thus, constituted unique dimensions. Furthermore, the results of the confirmatory factor analysis (Study 2) demonstrated that the overall fit of the new three-factor model is significantly greater than that of the traditional Visual-Verbal two-factor model. The new important finding revealed by confirmatory factor analysis, was the negative relationship between object and spatial factors as well as between verbal and spatial factors.

Furthermore, *a new theoretically-guided self-report instrument assessing individual differences in object and spatial imagery, the OSIVQ, was designed,* based on the above three-dimensional model and validated in Studies 1 and 2. Overall, the results of these studies supported the construct validity of the OSIVQ, demonstrating that the new instrument measures the Object, Spatial, and Verbal theoretical constructs that it purports to measure. According to the findings of Study 1, all three scales of the OSIVQ showed acceptable internal reliability, and principal component analysis performed on the OSIVQ items demonstrated that items constructed to measure Object, Spatial or Verbal constructs indeed loaded onto distinct and coherent factors, supporting the legitimacy of the operationalization of our theoretical constructs. The results from Study 2 showed that the patterns of correlations between the measures known to be related or unrelated to Object, Spatial, and Verbal constructs were consistent with the theoretical expectations, thus supporting the convergent and discriminant validity of OSIVQ. The OSIVQ reliably assesses three different dimensions of cognitive style, unlike most of the previous instruments such as IDQ or VVQ, which failed to significantly predict scores on the criterion tasks, particularly on visual imagery measures.

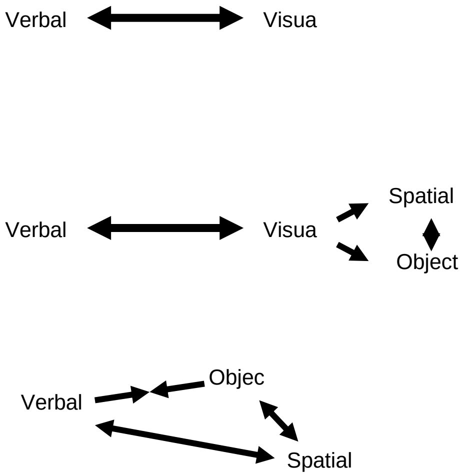
Thus, the current research has supported the validity of the cognitive style measurement, developed on the basis of the new cognitive style model that distinguishes between Object, Spatial, and Verbal modes of processing. Our results demonstrate that the OSIVQ Object and Spatial scales appear to reliably assess two different types of imagery, and the data further confirm that imagery self-report instruments can be used to successfully predict individuals' performances on objective imagery tests. Therefore, these data suggest that a crucial problem with the criterion validity of previous imagery self-report instruments (i.e., their failure to predict performance on spatial imagery test) was a lack of theory and an incongruity between theory and measurement. In particular, these instruments frequently required participants to imagine objects, people, and scenes recalled from long-term memory when such imagining requires object rather than spatial imagery processes. The current research suggests that the problem of predictive validity of self-report cognitive style instruments can be resolved when imagery is considered as a multidimensional rather than unitary construct, and when imagery self-report measures and the corresponding criterion tasks assess the same type of imagery (see also Blajenkova et al., 2006; Dean & Morris, 2003; McAvinue & Robertson, 2007).

Next, this *research investigated the object-spatial distinction in individual differences in relation to complex real-life tasks such as course or profession selection, and provided ecological validation of the object-spatial distinction* in individual differences. The results from Study 3 provided ecological validation of the object, spatial imagery and verbal measures. In particular, Study 3 demonstrated a significant relationship between the Object, Spatial, and Verbal scales of the OSIVQ and the number of college courses taken by the participants in visual arts, physics, and writing respectively. In addition it showed a significant relationship between an individual cognitive style and area of specialization. These findings demonstrate the generalizability of the new cognitive style model to real-life activities that extend beyond laboratory testing settings.

Furthermore, the research *found object-spatial imagery differences between members of different professions*, as well as *children gifted in visual-spatial fields, and thus, it further provided empirical justification* of the object-spatial imagery dissociation in individual differences. The results from Study 4a revealed clear distinctions between visual artists' and scientists' visual imagery skills; visual artists had higher object imagery scores than scientists, but scientists had higher spatial imagery scores than visual artists. Furthermore, visual artists' object imagery scores tended to be above average when compared with the rest of the professional groups, yet their spatial imagery scores tended to be below average. Scientists' spatial imagery scores, on the other hand, tended to be above average, but their object imagery scores tended to be below average. Thus, visual artists tended to be object imagers, and scientists tended to be spatial imagers. The humanities professionals and architects did not show the contrasting patterns found for the visual artists and scientists. The results from Study 4b demonstrated that children as of 10 years old, gifted in visual art and science (but not yet extensively trained in these fields) already exhibit individual differences in object and spatial imagery similar to adult professionals, suggesting that cognitive styles might start to develop prior to formal training and career selection. The finding that professional domain, where work or even interest in the certain professional field involves extensive use of object imagery or spatial imagery, differentially predicted scores on object and spatial imagery measures provides ecological validation of the distinction between object and spatial imagers.

Finally, the research *revealed qualitative differences between object and spatial visualizers in their interpretations of abstract visual information*. The results from Study 5 showed that object and spatial visualizers tended to interpret abstract visual information in qualitatively different manners. Visual artists tended to interpret abstract art as an abstract representation, but scientists tended to interpret abstract art literally, in a concrete way. In contrast, visual artists tended to interpret graphs literally, following their literal appearances, but scientists tended to interpret graphs schematically, in abstract way. Thus, the research *showed that object imagery can support abstract visual interpretations, and thus, is irreducible to concrete, low-spatial type of imagery*.

The main theoretical goal of the current research was further examine and empirically validate the new theoretical model of Object-Spatial-Verbal cognitive style, and to further examine the *interrelationships between the three dimensions*. Specifically the current research innovatively investigated the validity of the Object imagery dimension and its relationships with other dimensions. Previous research had focused on the relationship between visual and verbal constructs; however, there were no systematic examination of the relationships between the object, spatial and verbal constructs. Figure 14 illustrates the different approaches to understanding the relation between Verbal and Visual systems.



1. Classical cognitive style model (Paivio, 1971; Richardson, 1977): A single bipolar construct. Negative relation between verbal and visual poles; undifferentiated visual pole.

2. Revised cognitive style model (Kozhevnikov et al., 2005): Dissociation (and negative relation) between Object and Spatial visual dimensions. The relations between all 3 dimensions are not fully investigated.

3. Updated new cognitive style model: Three distinct dimensions: object, spatial and verbal. The negative trends between object-spatial and verbal-spatial dimensions, positive trend between verbal-object dimensions.

Figure 14. Different approaches to understanding the relation between Verbal and Visual systems

Our results analysis showed a negative trend between object and spatial factors as well as between verbal and spatial constructs. Although relatively independent on structural and functional levels, in many real-life tasks these three systems collaborate (e.g., Mazoyer, Tzourio-Mazoyer, Mazard, Denis, & Mellet, 2002; Paivio, 1991), and also, there is evidence of interferences and trade-offs between them (e.g., Kirby, 1993; Morey & Cowan, 2004), for instance, argued that the arising interference between the processing systems in complex tasks is due to competition for limited executive resources. Kozhevnikov et al. (2005) provides evidence regarding the trade-off between object and spatial imagery abilities. It is possible that in a complex spatial task, keeping all the pictorial details of an image while manipulating the image spatially may overload visual working memory. Thus, it is possible that spatial visualizers might tend not to maintain many pictorial details in their images in order to develop efficient spatial transformation abilities. Object visualizers, in contrast, might tend to develop an ability to maintain a large amount of pictorial details in their images which hampers effective spatial transformations. Similarly, there might be cases when spatial and verbal processing interferes. In natural science fields such as physics or mathematics, spatial and verbal processing modes might serve as alternative strategies to approach the same problem. Thus, in order to not overload limited cognitive resources, if one is effective in spatial imagery, one may use this skill more frequently than verbal-analytical strategies in one's work and vice versa. Indeed, the accounts of many scientific discoveries contrasted scientists who developed only one prevalent mode of thinking, either spatial or verbal-analytical, at the expense of the other (see, Miller, 1996). For example, the workbooks of the famous mathematician Poincare demonstrated an abundance of clearly written sequential text and formulas, without any lines being crossed out or any diagrams drawn. In contrast, Einstein was known for his difficulties in learning language, but in his creative thinking, he relied on primarily spatial visualization. As for the *relationship between object imagery and verbal systems*, overall, they do not seem to compete for shared cognitive resources (Paivio, 1971, 1991), but rather support each other to permit dual coding of information. There is evidence showing that concrete nouns are better recalled due to dual information coding than less imaginable abstract concepts (Paivio & Yuille, 1969), and that verbal information automatically activates visual-object imagery (Sadoski, 1985; Wharton, 1980). For example, research suggests that processing of the global shape of objects automatically leads to accessing semantic information and object identification (Boucart & Humphreys, 1992). Moreover, recent neuroimaging studies suggest that mental images generated from verbal descriptions elicit activations in both visual and language areas of the brain, share common structural properties (Mazoyer et al., 2002), and that retrieval of visual features is associated with neural activity in processing natural semantic categories (Sim & Kiefer, 2005).

Although we did find negative correlations between the object and spatial scales as well as between verbal and spatial scales, there was a notable proportion of the participants (e.g., about 11% of all the participants from Study 1) who scored above average on all three OSIVQ scales as well as a notable proportion of the participants (e.g., 10% of all the participants from Study 1) who scored below average on all three OSIVQ scales. This indicates that although there may be some tendencies in the development of different dimensions of cognitive style (i.e., a person who is especially good in spatial processing might tend not to develop object imagery or verbal cognitive style), an individual's scores on these three dimensions should not be combined (e.g., as ratio or subtraction), but assessed independently, since a given person could score high or low on all three scales. One interesting direction for future research could be the investigation of factors (e.g., age, gender, differences in experience and training, inborn abilities, and cultural differences) that affect the development of a preferred style of information processing (object, spatial, or verbal), and the relationship between these styles.

An interesting question raised by the data from the present study is *how such differences in object and spatial imagery between professional domains arise,* whether through training or self-selection. Kozhevnikov et al. (2005) proposed that the mutual exclusivity between object and spatial imagery might result from a person being more effective at using one type of imagery and then tending to use this type of imagery more frequently than or instead of the other type of imagery, thus exercising the use of one type of imagery over the other. Of course, for educators and practitioners, it would be appealing if the visualization skills needed for success in a given class or profession could be trained, but even if training specific visualization skills is not possible, or is limited, conflicts between a student or worker's imagery abilities and the imagery requirements of the task might be bridged by teaching the use alternative strategies or by the use of compensatory technologies. The results of study 4b demonstrated that children exhibit the differences in imagery abilities and cognitive styles, thus suggesting that object-spatial dissociation might start to develop early in life and prior to formal professional training. Although the present research does not address how the differentiation in imagery skills arises, the data are consistent with previous research showing that imagery is not a unified construct and, therefore, that both the object and spatial imagery task requirements need to be considered when developing training methods or compensatory technologies. The data also support the notion of object and spatial visualizers, thus suggesting that the visual imagery strengths and weaknesses of the student or worker need to be considered; and the data confirm that these object-spatial differences in visual imagery generalize to meaningful experiences and real-life applications outside of the research lab.

Another important question arising from the current research is the relation between *each of the three dimensions of Object-Spatial-Verbal cognitive style and abstract-concrete dimensions.* The previous conceptualizations of the traditional Visual-Verbal cognitive style dimension tended to describe visualizers as individuals inclined to think concretely, holistically, and subjectively. In contrast, verbalizers have been characterized as individuals inclined to think abstractly, successively, and objectively (see Jonassen & Grabowski, 1993 for review; Kirby et al., 1988). However, the results of the present research suggest that the preceding description might not be accurate (see also Kozhevnikov & Thornton, 2006). All three models of processing might support abstract representations. According to the results of Study 3, most scientists (who are known to think in an abstract way) reported themselves as spatial visualizers. Indeed, a spatial imagery system could rely on schematic representations such as graphs or diagrams depicting abstract structural relations. Furthermore, an object imagery system could also rely on abstract object images, not based on previously seen real objects, but represent an abstract mixture of feelings and emotions (e.g., Miller, 1996). Similarly, a verbal system might support abstract verbal-analytical thinking. Thus, the differences and similarities between the processing of information by the three systems cannot be simply explained by the differences in abstract-concrete dimensions. Furthermore, the results from Study 5 confirmed that object visualizers were able to form abstract representations of abstract art, while spatial visualizers failed to from abstract representations in a non-spatial domain.

In addition, the results from Study 5 suggest that Object imagery has a special relationship with emotion, e.g., the ability to distinguish emotional expressions (see Holmes & Mathews, 2005). Our finding is also consistent with Lang's (1979) bio-informational theory of emotional imagery where he emphasized the link between affective images and emotion, and specifically the role of affective images in the fear response. The found relationship further establishes the validity of Object imagery dimension, and suggests that object imagery might be closely connected to other emotionally moderated cognitive processes. For example, object imagery can be advantageous for fast intuitive decisions based on the limited information, for making immediate manifold connections, for empathy, self-awareness and social behavior. In addition, our results from interviewing visual artists and scientists about the use of imagery in their work (Blajenkova & Kozhevnikov, 2005), support the link between language, self-awareness, emotion and object-spatial imagery. During these interviews, scientists, overall, tended to experience problems with expressing their feelings, and moreover, with consciously accessing their internal states and verbalizing their introspective experiences. Overall, these findings and discussions suggest that suggest that object imagery has its own unique relationship with other cognitive functions, and demonstrate the ecological validity of this dimension. Thus, the current research pioneers the ecological validation of object imagery dimension in individual differences and cognitive styles.

Furthermore, current research further provides evidence of qualitative differences between Object and Spatial modes of processing and approaches to perceiving and producing visual information that can have different applications in real-life. Table 13 summarizes the differences and similarities, between Object, Spatial and Verbal systems in terms of their organization, processing, unique functions, related cognitive systems, and real-life ecological applications, and outlines a wide range of possibilities for future theoretical and applied research that were opened by the current research.

Table 13

The Comparison between Verbal and two Visual processing systems

Systems	Verbal	Visual	
		Object	Spatial
Brain areas involved in processing (Cabeza & Nyberg, 2000; Gazzaniga, 2004).	Primary Auditory Cortex, Broca's area, Wernicke's area, Supramarginal gyrus, Angular gyrus.	The ventral stream runs through V1, V2, V4, and to the inferior temporal lobe.	The dorsal stream runs through V1, V2, V3, V5/MT and to the inferior parietal lobe.
Functions (Farah et al., 1988; Paivio, 1991)	Representation of verbal information, comprehension and production of spoken and written language.	Representation of individual objects and scenes in color, detail, and shape; object recognition.	Representation of object locations, motion, spatial relationships, manipulations and transformations.
Units and organization (Paivio, 1991; Richardson, 1977)	Discrete linguistic units; Symbolic representations, systematically organized semantically and grammatically.	Integer visual scenes and discrete objects Pictorial, analogous, representations.	Schematic representations of discrete objects and patterns, and their transformations.
Processing (Kozhevnikov et al., 2005; Paivio, 1991)	Sequential	Holistic	Sequential
	Units have to be integrated in order to be comprehended	Units have to be identified and separated in the continuous visual field	
	Phonetically processed before assessing semantic representation	Meaningfully identified before it can be verbally named	Not necessarily identified and verbally named
Related cognitive systems (Baddeley, 1992; Grelotti et al. 2002; Richter et al., 2000; Sim & Kiefer, 2005; Vygotsky, 1978).	Verbal working memory, Social behavior, Self-Awareness, Consciousness.	Visual-Object Working memory, Visual Perception, Emotion, Language, Social behavior, Self-Awareness, Consciousness	Visual-Spatial Working memory, Motor system
Large-scale, real-life applications	Communication, reading, writing, learning languages, memorizing verbal material, achievement in humanities professions: history, philosophy, philology, verbal creativity, verbal reasoning.	Visual pictorial memory, attention to visual details, color fine discrimination , recognition of objects in limited visibility, achievement in visual art and designing, aesthetic perception, artistic creativity, abstract object reasoning.	Achievement in mathematics, physics, chemistry and a wide range of technical and engineering subjects; fixing and assembling mechanical devises, reading maps, scientific creativity, abstract spatial reasoning.

As a final point, it is important to emphasize that the current research established that Object imagery dimension has ecological validity, and uniquely predicts a range of real-life skills and preferences. Therefore, this finding suggests the importance of further development Object imagery assessments for predictions of performance on these large-scale, real-life tasks. In fact, several researches noted that visual ability was a neglected dimension in talent searches (Webb, Lubinski, & Benbow, 2007), and criticized the existing system of identification of giftedness (e.g., based on Scholastic Aptitude Test) that is currently mainly restricted to verbal and mathematical ability, despite the claimed ideological approach to develop talents across multiple dimensions. In fact, the longitudinal research showed that talent searches based on SAT miss more than a half of spatially gifted students (Lohman & Korb, 2006). Moreover, Shea, Lubinski and Benbow (2001) found that non-verbal spatial ability provides greater discriminative power than quantitative and verbal ability, and provides unique information for predicting educational-vocational life choices. Thus, the current psychometric and talent search approach appear to provide an incomplete picture of an intellectual talent, and limit the possibilities for optimal educational opportunities and later career development for gifted students. Moreover, though, some talent search programs include assessments of Spatial visual ability, there is no currently existing assessment procedures for Object visual abilities, which implies that many professional areas might be potentially loosing talented persons. Thus, in the long run perceptive, our research proposes the idea of including the Object imagery dimension in the talent search identification procedures, as well to educational curriculum. Currently, the newly developed OSIVQ can be such a unique tool that includes all three dimensions of cognitive styles, and that should be valuable in applied settings. In particular, it can serve as a useful tool for career selection, or for educators in the development of efficiently targeted teaching methods and choice of instructional materials. An understanding of the particular combinations of imagery and verbal skills that underlie successful performance in different professional domains should lead to efficiently conceptualized teaching and training methods, and vocational guidance.

Footnotes

[1] For the table with all items and their loadings, see Blajenkova et al., 2006.

[2] Though, the cut-offs for selection high and low extreme groups are arbitrary, the research usually use cut-offs ranging between 15 and 25 percentiles (Richardson, 1977). We recommend the 16% high and low cut-offs based on 1 Standard Deviation criterion, since it is the standard estimate of the average deviation from the expected value, and it includes the majority of the distribution scores (68% of all scores). The slope of the destitution changes at the points of +-1 SD, and these points segregate scores, below and above 1 SD.

[3] For the computerized tests, RTs for correct responses were analyzed, and RTs with z-scores that exceeded 2.5, where z-scores were computed based on the distributions of each participant's responses, were excluded. Overall, five data points from the Spatial Imagery Test and two data points from the Degraded Pictures Test were excluded.

[4] The Study 4a used the earlier version of the Degraded Pictures test that consisted of only 10 test trials.

[5] All of the assessments in Study 4b were translated in Russian.

APPENDIX

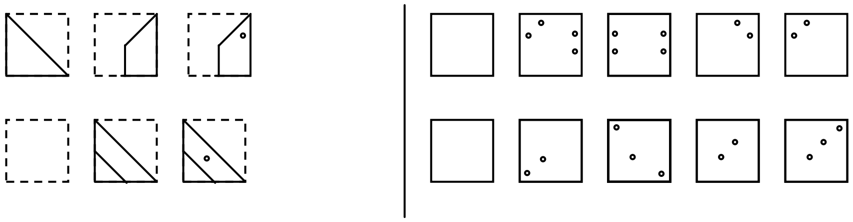
DESCRIPTIONS AND EXAMPLES OF THE ASSESSMENTS

Paper Folding Test (PFT)

According to Ekstrom et al. (1976), the Paper Folding Test measures spatial visualization ability, which is the ability to apprehend, encode and mentally manipulate abstract spatial forms. The Paper Folding *paper-and-pencil* Test (Ekstrom et al., 1976) consisted of 10 items. Each item consisted of successive drawings of two or three folds made to a square sheet of paper and a final drawing showing the folded paper with a hole punched through it. The participants were to select from among five drawings the one depicting how the paper would look when fully opened. They had 3 min to complete the test, and paper folding scores were calculated the number of correct answers minus the quotient of the number of incorrect answers divided by four.

Examples of items

In this test, you are to imagine the folding and unfolding of pieces of paper. In each row, the figures on the left represent a square piece of paper being folded, and the last of these figures has one or two small circles drawn on it to show where the paper has been punched after being folded. One of the five figures on the right correctly shows where the holes will be when the paper is unfolded. You are to decide which one of these figures is correct.



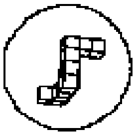
Mental Rotation Test (MRT)

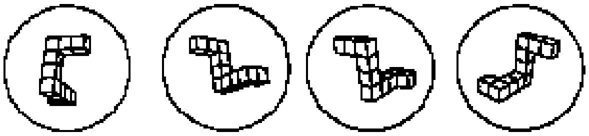
The Vandenberg-Kuse Mental Rotation Test (Vandenberg & Kuse, 1978) measures mental rotation transformation ability. The *paper-and-pencil* test consisted of 10 items. For each item, participants compared two-dimensional line drawings of three-dimensional geometric figures composed of cubes. Each item consisted of a criterion figure and four comparison figures. Two of the comparison figures were rotated versions of the criterion figure, and the other two comparison figures were rotated mirror images of the criterion figure. Participants were to indicate which two of the four figures were rotated versions of the criterion figure, and they had 3 min to complete the test. Mental rotation scores were calculated as the number of items in which both rotated images of the criterion figure were correctly identified.

The *computerized* version of the Shepard and Metzler (1971) Mental Rotation task, participants saw pairs of two-dimensional pictures of angular, three-dimensional forms. The right-hand forms in each pair were rotated, within the picture plane, from 0 to 180 degrees relative to the left-hand forms. Half the pairs contained identical shapes, and half contained mirror images. Participants were asked to judge whether the forms in each pair were the same or were mirror-images. There were 9 practice trials and 109 test trials.

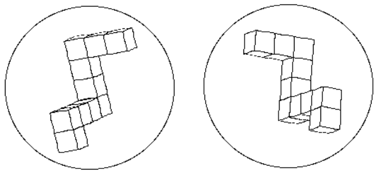
Examples of items

Paper-and-pencil test. For each problem there is a primary object on the far left. You are to determine which two of the four objects on the right are the same as the object on left.





Computerized test. Are these figures same of different?



Vividness of Visual Imagery Questionnaire (VVIQ)

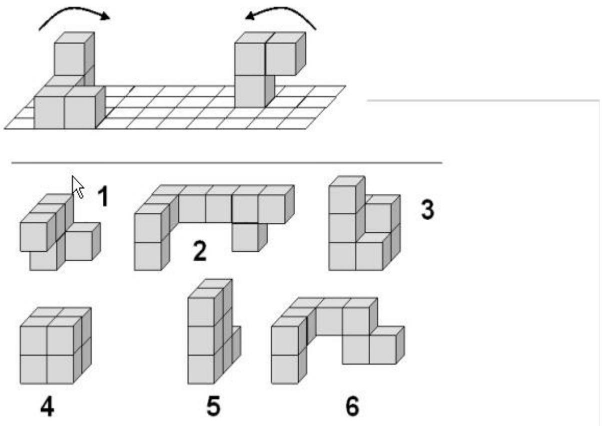
The VVIQ (Marks, 1973) is a frequently used self-report measure of the vividness of visual mental images (see McKelvie, 1995). The VVIQ consisted of 16 items in which the participants rated the vividness of mental images they were asked to create (e.g., *The sun is rising above the horizon into a hazy sky*; and *A strong wind blows on the trees and on the lake, causing waves*). VVIQ scores were created by summing the 16 ratings.

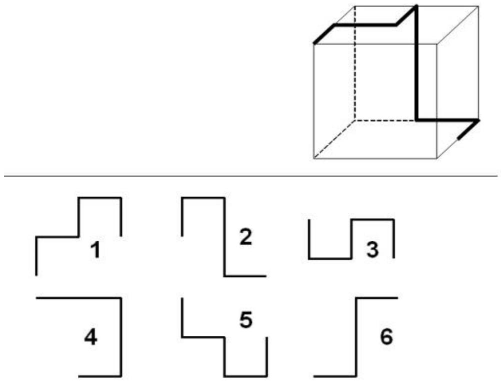
Spatial Imagery Test

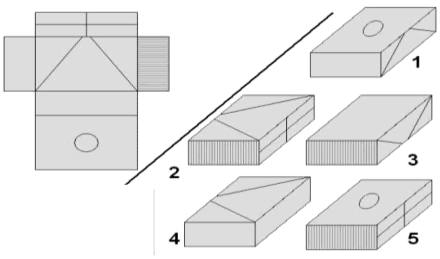
The Spatial Imagery Test from the *computerized* Imagery Testing Battery (Version 1.0) consisted of the three types of spatial imagery tasks: Wire Frame, Figure Rotation and Combination, and Folded Box problems. Each Wire Frame problem consisted of viewing a two-dimensional rendering of a three-dimensional transparent cube with a “wire” (i.e., a thin black line) running along the surfaces of the cube. The participants were to select from among six two-dimensional line-drawings the drawing that depicted how the wire would look from a specified new perspective (e.g., from beneath). Each Figure Rotation and Combination problem consisted of viewing two-dimensional renderings of two three-dimensional figures composed of cubes placed on a grid. The participants were to imagine combining the figures by rotating the figure on the left 90° to the right and by rotating the figure on the right 90° to the left. Then participants were to indicate which one of six rendered models corresponded to the combined figure. Finally, each Folded Box problem consisted of viewing a rendering of an unfolded template of a rectangular box that had distinct patterns on each of its sides. Participants were to imagine folding the template into a box and then to determine which one of five models corresponded to the folded template. The Spatial Imagery Test had 30 problems (12 Wire Frame, 9 Rotation and Combination, and 9 Folded Box problems), and for each problem, both reaction time and accuracy were recorded.

Examples of items

1. Wire Frame 2. Rotation and Combination 3. Folded Box



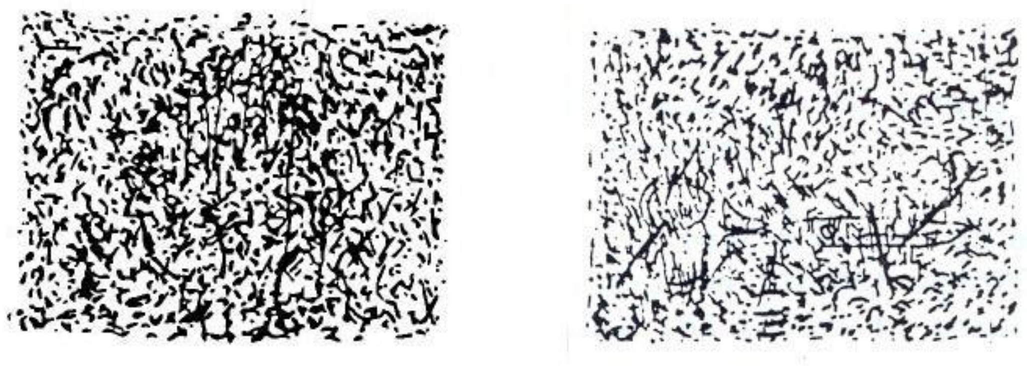




Degraded Pictures Test (DPT)

The Degraded Pictures test was composed of several perceptual closure problems and was designed to measure object imagery. The Degraded Picture Test was considered to require object rather than spatial imagery, because top-down processing has to be used to complete obscured portions of the object, and this top-down completion process should rely on the mechanisms that underlie object imagery (see Kosslyn, 1994). Additionally, imagery vividness ratings have been shown to predict performance on perceptual closure tasks (Wallace, 1990), and furthermore, Kozhevnikov et al. (in press) found that object visualizers were more accurate than spatial visualizers at identifying the objects in degraded pictures. The *pencil-and-paper* and *computerized versions* of the Degraded Pictures Test each consisted of the same 20 items. Each item was a degraded line-drawing of a common object (e.g., umbrella, scissors, table). The degrading was accomplished by deleting segments of bitmapped line-drawings and adding random-noise (patches of black pixels). For both the pencil-and-paper and computerized tests, participants were to identify the objects in the 20 degraded pictures. For the paper-and-pencil version of the test, participants had 4 min to complete the test. For the computerized version of the test, one picture at a time was presented, and there were no time limit for the completion of the test. After identifying the object, the participant used a computer mouse to click a button on the screen to stop the software timer that started when the degraded picture appeared (i.e., to record the reaction time), and then the participant typed the name of the object.

Examples of items



Grain Resolution Test (GRT)

This test was designed to assess participants' ability to generate detailed, high-resolution images of individual objects (Kozhevnikov et al., 2005). The task consisted of 2 practice and 20 test trials. On each trial of this task, participants saw a pair of names of objects on the computer screen, and were asked to identify which of the two named objects had a finer texture, or denser grain. "Grain" referred to bits or particles per unit of area or volume. Some examples of grain include the density of spots per area (leopard skin vs. giraffe skin), number of particles per unit of volume (a heap of grains of salt vs. a heap of poppy seeds), and number of air bubbles per volume (soda vs. shampoo).

Advanced Progressive Matrices (APM)

The APM (Raven et al., 1998) consisted of a set of 36 items. Each item contained an arrangement of spatial figures that were organized in a certain logical pattern. The participant's task was to find which of eight possible figures best completed the pattern.

WAIS-III: Similarities

The Similarities test from the WAIS-III (Wechsler, 1997) consisted of 19 pairs of words. Participants were to describe the conceptual similarity between the two words (e.g., *in what way are RED and BLUE alike*, where the correct answer indicated that they are both colors). Responses were scored according to the WAIS-III instructions, and scores on each item varied according to the degree to which the response described a primary, general property pertinent to both items in the pair.

Advanced Vocabulary Test (AVT)

The Advanced Vocabulary Test consisted of 18 items in which participants were to choose which word among five had the same meaning or nearly the same meaning as a target word. The Advanced Vocabulary Test measures “availability and flexibility in the use of multiple meanings of words” (Ekstrom et al., 1976).

Arranging Words (AW)

The Arranging Words test (Ekstrom et al., 1976) requires the ability to formulate thoughts in a verbal format, and to produce new sentences according to certain rules. In this task, participants were asked to write as many sentences as they could using four specified words (e.g., for the words “take”, “few”, “land” and “little”, the appropriate sentences could be “A few little boats take supplies to land” or “Few crops take little land”). All four words had to be used in each sentence in the same form as given, and sentences must differ from one another by more than merely one or two changed words. Participants had 3 min. to complete the test. To assess the fluency of speech production, the scores were computed as the total number of the written words.

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