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Visual-object ability: A new dimension of non-verbal intelligence

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ABSTRACT

The goal of the current research was to introduce a new component of intelligence: visual-object intelligence, that reflects one's ability to process information about visual appearances of objects and their pictorial properties (e.g., shape, color and texture) as well as to demonstrate that it is distinct from visual–spatial intelligence, which reflects one's ability to process information about spatial relations and manipulate objects in space. Study 1 investigated the relationship between performance on various measures of visual-object and visual–spatial abilities, and areas of specialization (visual art, science and humanities). Study 2 examined qualitative differences in approaches to interpreting visual abstract information between visual artists, scientists and humanities/social science professionals. Study 3 investigated qualitative differences in visual-object versus visual–spatial processing by examining how members of different professions generate, transform, inspect, and manipulate visual images. The results of the three studies demonstrated that visual-object ability satisfies the requirements of an independent component of intelligence: (1) it uniquely relates to specialization in visual art; (2) it supports processing of abstract visual-object information; and (3) it has unique quantitative and qualitative characteristics, distinct from those of visual–spatial processing.

1. Introduction

The notion of intelligence and its internal structure has been constantly changing throughout the last century. Historically, the definition of intelligence has moved from describing it as a general unitary entity with specific properties (Spearman, 1904) to describing it as a combination of multiple components (e.g., Sternberg, 1985; Thurstone, 1938) although not necessarily rejecting a common underlying factor, such as general intelligence (*g*). Overall, the mainstream definition of intelligence (Gottfredson, 1994, p. A18) describes it as "a mental capacity that involves the ability to reason, plan, solve problems, think abstractly, comprehend complex ideas, learn quickly and learn from experience", (see also 1997,[2] p. 13). Despite their differences in distinguishing components of intelligence, the existing approaches to the study of intelligence suggest that, in order to define a mental capacity or ability as an intelligence construct, it must meet the following principal requirements: (1) the ability must play a functional role, that is, it must be related to performance on complex tasks, such as educational or occupational tasks, and not just reflect a certain narrow ability, such as the ability to score highly on academic tests or perform laboratory tasks of low ecological value (Gardner, 1999; Gottfredson, 1997;

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[2] Gottfredson's "Mainstream Science on Intelligence" (1994) proposed a definition of intelligence signed by 51 prominent professors in the field of intelligence research. The paper was first published in the *Wall Street Journal*, and the reprinted in *Intelligence* with additional information and references (1997).

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Lubinsky, 2004; Sternberg, 1985), (2) it must support high-level information processing, such as abstract representations or symbolic encoding (Carpenter, Just, & Shell, 1990; Galton, 1880; Gardner, 1999; Gottfredson, 1997; Snyderman & Rothman, 1987), and (3) it must have unique qualitative and quantitative characteristics, supported by behavioral and/or neurological evidence, that distinguish it from other components of intelligence (Gardner, 1999). The focus of the current paper is to introduce a new dimension of intelligence: *visual-object intelligence*, which reflects one's ability to process information about the visual appearances of objects and their pictorial properties (e.g., shape, color and texture). This component of intelligence has so far been largely neglected and ill-defined, and the current research seeks to show that visual-object ability has all of the above attributes that characterize a dimension of intelligence.

Currently, the only widely accepted component of visual intelligence is *visual–spatial* ability, which is included in most commonly used measures of intelligence (e.g., Stanford-Binet: Roid, 2003, Wechsler Intelligence Scale: Wechsler, 1997). Visual–spatial ability represents a number of related subcomponents (e.g., spatial visualization, spatial relations) that have to do with how individuals deal with materials presented in space, or with how individuals orient themselves in space (Carroll, 1993). It was isolated from general intelligence and from verbal and numerical factors only after the 1920s, based on the results of factor analysis correlations among different intelligence tests (Smith, 1964). Subsequently, tests of spatial ability have been proven to be important criteria for predicting students' achievement in mathematics and a wide range of technical areas (see McGee (1979) for a review), and in predicting performance in engineering, mechanics and physics (Ghiselli, 1973; Hegarty & Just, 1989; Holliday, 1943; Kozhevnikov & Thornton, 2006; Smith, 1964). Beginning in the 1980s, cognitive psychology research has further characterized processing differences between individuals with high versus low visual–spatial ability for solving such spatial tasks as mental rotation (Carpenter, Just, Keller, Eddy, & Thulborn, 1999), mechanical, physics, and engineering problems (Hegarty & Just, 1989; Kozhevnikov, Motes, & Hegarty, 2007). These studies suggested that spatial ability is related to spatial working memory capacity as well as available central executive resources (see also Miyake, Friedman, Shah, Rettinger, & Hegarty, 2001). Thus, spatial ability was found to have all the essential characteristics of intelligence: ecological validity, capacity to support abstract spatial processing in engineering and scientific fields, as well as unique qualitative and quantitative characteristics supported by cognitive psychology research.

At the same time, other non-spatial components of visual ability have been neglected. Although factor analytical studies have revealed a number of visual ability factors, separate from spatial ability factors, such as the ability to apprehend and identify visual patterns or shapes in the presence of distracting stimuli (Closure Flexibility and Closure Speed factors; Carroll, 1993), they were considered only as minor factors whose predictive validity and relation to visual–spatial ability were unclear (e.g., Lohman, 1979). Furthermore, the ability to generate vivid colorful images of objects and scenes, as measured by the Vividness of Visual Imagery Questionnaire (Marks, 1973), was long thought to represent an aspect of visual–spatial ability, rather than constitute a separate imagery skill, despite the fact that the instruments assessing individual differences in imagery vividness have failed to establish significant correlations with spatial tasks (for review, see McKelvie, 1995).

Only recently has cognitive neuroscience provided strong evidence that visual processing of object properties is distinct from visual processing of spatial properties. Since the 1990s, it has been shown that higher-level visual areas of the brain are divided into two functionally and anatomically distinct pathways: the object pathway, and the spatial relations pathway (e.g., Kosslyn & Koenig, 1992; Ungerleider & Mishkin, 1982). The object (occipitotemporal or ventral) pathway processes information about the visual pictorial appearances of individual objects and scenes, in terms of their shape, color, brightness, texture, and size, while the spatial relations (occipitoparietal or dorsal) pathway processes information about the spatial relations among, and movements of, objects and their parts, and complex spatial transformations. The distinction between perceptual processing of object properties versus spatial relations extends to visual mental imagery and working memory (Farah, Hammond, Levine, & Calvanio, 1988; Kosslyn, 1994; Kosslyn & Koenig, 1992; Levine, Warach, & Farah, 1985; Mazard, Tzourio-Mazoyer, Crivello, Mazoyer, & Mellet, 2004). For example, Levine et al. (1985) demonstrated that lesions to temporal cortex disrupt performance on a spatial imagery task, but not on an object imagery task. In contrast, lesions to posterior parietal cortex have the reverse effects (see also Farah et al., 1988). Furthermore, recent evidence suggests that the visual–spatial sketchpad component of working memory consists of separate visual (object) and spatial subcomponents (Logie, 2003; Logie & Marchetti, 1991), which are underpinned by separate dorsal and ventral functional organizations, respectively (Courtney, Petit, Maisog, Ungerleider, & Haxby, 1998). The above object–spatial double-dissociation emphasizes that visual-object processing is functionally and anatomically independent from visual–spatial processing.

Recent research has also provided support for distinctions between visual-object and visual–spatial processing at the individual differences level (Kozhevnikov, Hegarty, & Mayer, 2002; Kozhevnikov, Kosslyn, & Shephard, 2005). Kozhevnikov et al. (2005) identified two types of individuals based on their imagery abilities: individuals with high object-imagery ability, called object visualizers, and individuals with high spatial-imagery ability, called spatial visualizers. While object visualizers used imagery to construct high-resolution images of the visual properties (e.g., shape and color) of individual objects and scenes, spatial visualizers used imagery to represent and transform spatial relations (e.g., location and configuration). It has also been shown that, in contrast to visual–spatial ability, which is associated with more efficient use of spatial resources in the dorsal pathway (Lamm, Bauer, Vitouch, & Gstattner, 1999; Vitouch, Bauer, Gittler, Leodolter, & Leodolter, 1997), visual-object ability is associated with more efficient use of visual-object resources in the ventral pathway (Motes, Malach, & Kozhevnikov, 2008).

Furthermore, based on the above distinction between visual-object and visual–spatial abilities, a number of theoretically-guided assessments of visual-object and visual–spatial ability have been developed, including objective performance measures as well as self-report cognitive style questionnaires assessing individuals' preferences to the use of visual-object versus visual–spatial modes of information processing (Blajenkova, Kozhevnikov, & Motes, 2006; Blazhenkova & Kozhevnikov, 2009; Kozhevnikov, Blazhenkova, & Becker, 2010; Kozhevnikov et al., 2005). These studies consistently demonstrated that all visual-object measures (objective performance measures and corresponding self-report questionnaires) and all visual–spatial ability measures loaded onto two distinct visual-object and visual–spatial factors, respectively, which were also separate from a verbal factor.

Despite the above behavioral and neuroscience evidence establishing the existence of visual-object ability as different from spatial ability, contemporary intelligence research still retains the implicit assumption that visual–spatial ability is the only form of visual intelligence, and thus, it is the only component of visual ability included in most psychometric assessments. It has been expected that this single visual–spatial ability dimension would predict performance in various professional fields that require any type of visual thinking and those individuals who have high abilities in science and math would also have high abilities in visual arts (e.g., Eisner, 1985; Gardner, 1999). For instance, Gardner proposed the existence of Spatial Intelligence (sometimes referred as visual–spatial), which he defined as the ability to recognize patterns in wide space and more confined areas. In this definition, visual–spatial intelligence is considered to be single, undifferentiated construct in which visual-object and visual–spatial intelligence are not distinguished from one another, and such different professionals as navigators, pilots, and surgeons, as well as artists, designers, decorators, photographers and architects all possess high levels of spatial intelligence.

In contrast to the view that visual–spatial intelligence is an undifferentiated construct, there is growing evidence that implies that members of different professions might generate different types of visual images and manipulate them in different ways, and that visual processing of object but not spatial properties might play a crucial role in the creative processes of visual artists (Kassels, 1991; Miller, 1996; Roe, 1975; Rosenberg, 1987; Winner & Pariser, 1985). Visual artists characterize their images as typically pictorial and bright, and report preferences primarily for object imagery, while scientists characterize their images as abstract and schematic and report preferences for spatial imagery (Blajenkova et al., 2006; Blazhenkova & Kozhevnikov, 2009; Lindauer, 1983). Indeed, several studies have shown that scientists surpass visual artists on visual–spatial ability tests, which required performing mental spatial transformations; while visual artists surpass scientists on tests which required generation of high-resolution, pictorial images (Kozhevnikov et al., 2005, 2010). Overall, these studies suggest that visual-object ability may have its own, unique predictive/ecological validity (success in visual arts and other fields that require generation of high-resolution, vivid images), irreducible to that of visual–spatial ability (e.g., success in scientific and engineering fields).

Regarding the capacity of visual-object ability to support abstract thinking, the prevailing view within the literature, originating with Galton (1880) and persisting even in contemporary literature, has been to associate visual-object ability with concrete visual thinking, low intelligence, and the inability to form abstract visual representations (Aspinwall, Shaw, & Presmeg, 1997; Brewer & Schommer-Aikins, 2006; Twyman, 1972). However, historical analysis demonstrated that visual art might portray not only concrete visual appearances of objects and scenes, (e.g., landscapes or portraits in Renaissance art), but also represent abstract content, such as pure emotions and concepts using color and shape (e.g., Cubism and Abstract Expressionism) (Miller, 1996). Thus, it is possible that the representations contained in abstract visual art comprise a unique and meaningful symbolic system, irreducible to that used in the visual–spatial domain. If "susceptibility to encoding in a symbol system", a key requirement of Gardner's (Gardner, 1983, pp. 62–69) definition of a component of intelligence, were demonstrated in the visual-object domain, this would further establish the uniqueness of the visual-object dimension of intelligence.

The main goal of the current research was to systematically investigate whether visual-object ability can be shown to satisfy all the three requirements of an independent component of intelligence: (1) unique ecological validity, (2) capacity to support abstract processing, and (3) unique qualitative and quantitative characteristics, irreducible to those of spatial and verbal components of intelligence. The current research consists of three studies. Study 1 investigated the relationship between performance on various measures of spatial and object abilities and areas of specialization (visual art, science and humanities/social science professional membership/college major). In particular, we examined whether object ability uniquely predicts specialization in a professional field (visual art). Study 2 examined whether object processing may support abstract representations and abstract thinking in the visual domain. In particular, this study examined the qualitative differences in approaches to interpreting visual abstract information between visual artists, scientists and humanities/social science professionals. Finally, Study 3 investigated the qualitative differences in object versus spatial processing by examining how members of different professions generate, transform, inspect, and manipulate visual images, and how they use imagery in their everyday lives.

2. Study 1

Study 1 aimed to establish the ecological validity of visual-object ability, that is, to examine whether object ability discriminatively relates to specialization in visual art, in the same way as spatial ability relates to specialization in physics, mathematics, and other natural sciences. In particular, this study investigated the relationship between object ability, spatial ability, and the respective fields of study/areas of specialization in college students (Study 1a) and members of different professions (Study 1b).

Study 1 drew upon previous research (Blajenkova et al., 2006; Blazhenkova & Kozhevnikov, 2009; Kozhevnikov et al., 2005, 2010) that demonstrated the relationship between the visual-object dimension and specialization in visual art. However, most of the previous studies did not explicitly designate their assessments as tapping visual-object ability (Casey et al., 1990; Rosenblatt & Winner, 1988) and often included only a single measure of visual-object ability, either based on a self-report assessment (Blajenkova et al., 2006; Blazhenkova & Kozhevnikov, 2009) or derived by collapsing scores on multiple tests into one variable (Kozhevnikov et al., 2010). The current study presents the first systematic comparison among members of different professions' performance across various measures of visual-object and visual–spatial ability, including subjective and objective paper-and-pencil, as well as computerized, measures.[3] The visual-object and visual–spatial abilities of visual artists and scientists (students and professionals) were contrasted with those of humanities and social science students and professionals. Humanities and social science students and professionals were included to serve as a control professional group, since the humanities and social sciences lend themselves to visual forms of information processing less readily than do natural sciences. In addition, the imagery used by humanities/science professionals is more along the lines of logical representations of concepts and relationships among concepts, rather than representing the arrangement of physical objects or graphs and data models (e.g., Wai, Lubinski, & Benbow, 2009). We hypothesized that visual-object ability would uniquely relate to specialization in visual art, while visual–spatial ability would uniquely relate to specialization in science, thus demonstrating unique predictive validity for object ability, separate from that of spatial ability. Furthermore, it was expected that object ability would not predict specialization in scientific nor in humanities/social science fields, thus demonstrating the discriminative validity of visual-object ability as a separate dimension of intelligence.

2.1. Study 1a

2.1.1. Participants

The participants were 141 college (undergraduate and graduate) students majoring in visual art, science, or humanities/social science. The visual arts group ($N = 35$, 23 females, M age = 22.12; $SD = 3.63$) consisted of fine art, painting, sculpture, design and illustration majors. The science group, ($N = 56$, 21 females, M age = 22.71; $SD = 3.06$) consisted of students majoring in physics, biochemistry, engineering, computer science, and mathematics. The humanities/social science group ($N = 50$, 34 females, M age = 22.33; $SD = 2.86$) included students of various majors in the humanities or social sciences, such as history, philosophy, communications, English and psychology.

[3] Studies 1a and 1b were parts of a larger study reported in Kozhevnikov et al. (2010). The participant samples in Studies 1a and 1b were a subset of the sample used in Kozhevnikov et al. (2010).

2.1.2. Procedure and materials

All of the participants were administered three visual-object and three visual–spatial ability paper-and-pencil assessments that included both self-report rating and objective accuracy measures. The spatial tests were: the Paper Folding Test (PFT: Ekstrom, French, & Harman, 1976), the Mental Rotation Test (MRT: Vandenberg & Kuse, 1978) and the spatial scale of the Object–Spatial Imagery Questionnaire (OSIQ: Blajenkova et al., 2006). The object imagery measures were: the Vividness of Visual Imagery Questionnaire (VVIQ: Marks, 1973), the Degraded Pictures Test (DPT: Kozhevnikov et al., 2005), and the object scale of the OSIQ. The tests were administered in random order. Participants were tested in groups up to 30.

2.1.2.1. Paper Folding Test (PFT). According to Ekstrom et al. (1976), the PFT measures the ability to apprehend, encode and mentally manipulate abstract spatial forms. The PFT contains 10 items. Each item consists of successive drawings of two or three folds made on a square sheet of paper and a final drawing showing the folded paper with a hole punched through it. The participants selected from among five possible responses the one that depicted what the paper would look like when unfolded. They had 3 min to complete the test, and scores were calculated by subtracting the quotient of incorrect responses divided by four from the number of correct responses The Cronbach's α is .84 (Ekstrom et al., 1976).

2.1.2.2. Mental Rotation Test (MRT). The MRT (Vandenberg & Kuse, 1978) measures mental rotation transformation ability. The test consists of 10 items. For each item, participants compared two-dimensional line drawings of three-dimensional geometric figures composed of cubes. Each test item consists of a criterion figure and four comparison figures. Two of the comparison figures are rotated versions of the criterion figure, and the other two comparison figures are rotated mirror images of the criterion figure. Participants indicated which two of the four figures were identical 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. Internal reliability for the MRT was K-R 20 = .88 (Wilson et al., 1975).

2.1.2.3. Vividness of Visual Imagery Questionnaire (VVIQ). The VVIQ (Marks, 1973) is a frequently used self-report measure of the vividness of one's visual mental images. The VVIQ consists of 16 items, in which participants read verbal descriptions of scenes (e.g., "*The sun is rising above the horizon into a hazy sky. A strong wind blows on the trees and on the lake, causing waves*") and rate the subjective vividness of the evoked visual images. VVIQ scores were created by summing the 16 ratings, and for the VVIQ, Cronbach's $\alpha \approx 0.88$ (see McKelvie, 1995).

2.1.2.4. Degraded Pictures Test (DPT). The Degraded Pictures test (Kozhevnikov et al., 2005) is a measure of object recognition ability, requiring top-down processing which relies on the mechanisms that underlie object imagery. This test was designed to assess the ability to solve perceptual closure tasks that require identifying objects obscured by noisy backgrounds. In each trial, participants saw 20 degraded line drawings of common objects (e.g., umbrella, scissors) embedded in a background of visual noise, and were asked to identify the degraded object. Segments of bitmapped line drawings were deleted and random-noise (patches of black pixels) was added, so that not only was the integrity of the line drawing compromised, but there was interference from background noise. Participants had 3 min to identify the objects. Internal reliability for the DPT is K-R 20 = .62 (Blajenkova et al., 2006).

2.1.2.5. Object–Spatial Imagery Questionnaire (OSIQ). The OSIQ is a self-report questionnaire designed to assess individual preferences towards, and abilities in, using visual-object versus visual–spatial imagery (Blajenkova et al., 2006). The questionnaire consists of scaled items targeted to assess object and spatial imagery (15 each) preferences and experiences, as well as estimates of proficiency in object and spatial image processing (generation, maintenance, inspection and transformation), estimates of ability to perform tasks requiring the use of either object or spatial imagery, and ratings of qualitative characteristics of their images. For example, the object imagery scale consists of items like: "*My mental pictures are very detailed precise representations of the real things*" or "*I can close my eyes and easily picture a scene that I have experienced*", and the spatial imagery scale consists of items like, "*My images are more like schematic representations of things and events*" or "*I can easily rotate three-dimensional geometric figures*". Participants rated each questionnaire item on a 5-point scale. For each participant, the 15 items from each imagery dimension were averaged to create object and spatial scale scores. The internal reliability (Cronbach's α) for the object scale is 0.83, and for the spatial scale it is 0.79 (Blajenkova et al., 2006).

2.1.3. Results

First, to confirm that the object and spatial measures comprise two separate dimensions, Principal components analysis was performed on all measures. Two factors were revealed with Eigen values greater than 1, explaining 65.52% of the variance. All spatial measures (MRT, PFT, OSIQ spatial) loaded positively onto the first factor (loadings from Rotated Varimax Solution: .831, .813 and .682) but not onto the second (−.001, −.066, −.197), while all object measures (DPT, VVIQ, OSIQ object) loaded onto the second factor (loadings: .756, .813 and .787), but not onto the first (.206, −.229, −.354). Both factors clearly distinguish between object and spatial visual dimensions, supporting the internal reliability of the visual–spatial and visual-object constructs, consistent with the results of previous studies (Blajenkova et al., 2006; Blazhenkova & Kozhevnikov, 2009; Kozhevnikov et al., 2010). Furthermore, examination of intercorrelations between measures used in Study 1a (see Table 1) demonstrated that all spatial measures (including objective performance and self-assessments) correlated positively with each other, and all object measures correlated positively with each other; moreover, most spatial and object measures tended to correlate negatively.

Table 1
The Pearson product-moment correlations among the assessments administered in Study 1a.

	1.	2.	3.	4.	5.	6.
1. OSIQ object scale	–	.35**	.66**	−.31**	−.29**	−.28**
2. Degraded pictures		–	.35**	−.09	.05	.08
3. VVIQ			–	−.22**	−.24**	−.17*
4. OSIQ spatial scale				–	.40**	.41**
5. Paper folding					–	.53**
6. Mental rotation						–

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

Next, to examine the relationship between object ability, spatial ability, and fields of study/areas of specialization, following the recommendation for analyzing multiple dependent measures (Bray & Maxwell, 1982), we performed a MANOVA prior to univariate ANOVAs to investigate the differences between the groups. A MANOVA (Pillai's Trace) with specialization group as a predictor and all of the visual–spatial and visual-object ability assessments as criterion variables revealed a significant multivariate effect, $F(12, 268) = 13.018$, $p < .001$, $\eta^2 = .27$. Table 2 shows descriptive statistics and ANOVA results for all the assessments for each group.

For clearer visualization and comparison of the patterns across object and spatial assessments and field of study, *z*-scores were calculated for each assessment, and Fig. 1A and B shows the mean *z*-scores for the spatial and object assessments for each group.

Univariate ANOVAs revealed that the specialization groups differed in their performance on all measures of visual–spatial and visual-object ability significantly (all p's < .001). Tukey's HSD revealed that participants in the visual art group scored significantly higher on all object imagery assessments than those in the science and humanities/social science groups (p's < .001). Science majors' and humanities/social science majors' performances did not significantly differ on such visual-object ability tests as DPT and VVIQ, but science majors scored significantly lower than humanities/social science majors on the self-report OSIQ object scale ($p = .008$). Furthermore, Tukey's HSD revealed that science majors scored significantly higher on all spatial assessments than visual art and humanities/social science majors (p's < .001). Participants in the visual art and humanities/social science groups did not significantly differ on any of spatial measures. Overall, science majors tended to have higher spatial ability scores than visual art and humanities/social science majors; however, visual art majors tended to have higher object scores than sciences and humanities/social science majors.

2.1.4. Gender differences

Since gender is a recognized factor in individual differences in the visual domain (Blajenkova et al., 2006; Blazhenkova & Kozhevnikov, 2009; Linn & Petersen, 1985; Voyer, Voyer, & Bryden, 1995), examination of

Table 2
Descriptive statistics and ANOVA results for all assessments used in the Study 1a.

	Science M (SD)	Visual art M (SD)	Humanities/social science M (SD)	ANOVA $F(2, 138)$, p, η^2
Spatial imagery assessments				
PFT	7.80 (2.15)	4.79 (2.80)	5.58 (2.44)	19.75, $p < .001$, $\eta^2 = .223$
MRT	5.80 (2.60)	3.17 (2.23)	3.64 (2.17)	17.17, $p < .001$, $\eta^2 = .199$
OSIQ spatial scale	3.36 (.48)	2.52 (.56)	2.64 (.59)	34.63, $p < .001$, $\eta^2 = .334$
Object imagery assessments				
VVIQ	58.76 (9.25)	71.28 (7.49)	58.76 (9.28)	26.27, $p < .001$, $\eta^2 = .276$
DPT	5.90 (2.61)	9.00 (2.94)	6.57 (2.86)	13.84, $p < .001$, $\eta^2 = .167$
OSIQ object scale	3.26 (.65)	4.15 (.55)	3.61 (.53)	25.15, $p < .001$, $\eta^2 = .267$

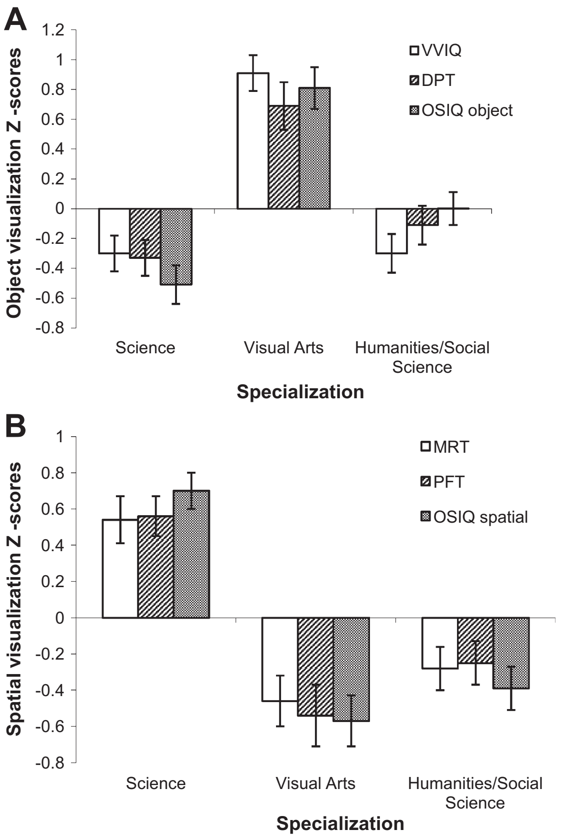

Fig. 1. Normalized object (A) and spatial (B) visualization scores for the different specialization majors in Study 1a. The bars represent ±1 SEM.

gender differences was performed.[4] Multivariate Analysis (Pillai's Trace) with gender added as second factor in addition to specialization group, and all of the visual–spatial and visual-object ability assessments as criterion variables, revealed a significant main effect of specialization $F(12, 262) = 11.554$, ($p < .001$), with $\eta^2 = .346$ representing a relatively large effect (see Cohen, 1992, for estimation criteria of effect sizes), a significant main effect of gender $F(6, 130) = 2.464$, ($p = .027$), with $\eta^2 = .102$ representing a relatively small effect, and no interaction was found between these factors. The pattern of specialization groups' differences on object and spatial visualization scores (see Fig. 1) remains qualitatively the same after controlling for gender; when gender was added as a covariate in MANOVA, the effect of specialization remained significant, $F(12, 266) = 12.11$, ($p < .001$), with $\eta^2 = .35$, representing a relatively large effect, although the effect of gender was also significant $F(6, 132) = 2.94$, ($p = .010$), with $\eta^2 = .12$, representing a relatively small effect. Univariate tests with gender as a factor revealed significant differences, in which females scored higher than males on object ability measures and males scored higher than females on spatial ability (see Table 3).

[4] The analysis for gender differences in the current research was performed only for Study 1a, because it used the largest number of participants with sufficiently balanced genders.

2.2. Study 1b

2.2.1. Participants

The participants were professional visual artists ($N = 16$, 8 females), scientists ($N = 24$, 6 females), and humanities/social science professionals ($N = 23$, 14 females) who all held college degrees and had at least two years of professional experience in their fields. The group of visual artists included professional painters and designers. The group of scientists included computer scientists, physicists, biologists, engineers, biochemists, and mathematicians. Finally, the group of humanities/social science professionals consisted of historians, philosophers, linguists, English professors, and journalists.

Table 3
Gender analysis results for Study 1a.

	Males M (SD)	Females M (SD)	ANOVA $F(1, 139)$, p, η^2
Spatial imagery assessments			
PFT	6.88 (2.97)	5.77 (2.43)	5.89, $p = .016$, $\eta^2 = .002$
MRT	5.41 (2.43)	3.55 (2.48)	19.92, $p < .001$, $\eta^2 = .057$
OSIQ spatial scale	3.09 (0.62)	2.74 (0.64)	11.17, $p = .001$, $\eta^2 = .015$
Object imagery assessments			
VVIQ	59.66 (9.91)	63.65 (10.39)	5.35, $p = .022$, $\eta^2 = .018$
DPT	6.41 (0.60)	7.30 (3.03)	3.02, $p = .084$, $\eta^2 = .009$
OSIQ object scale	3.44 (0.64)	3.74 (0.67)	7.46, $p = .007$, $\eta^2 = .018$

2.2.2. Procedure and materials

In addition to the paper-and-pencil tests used in Study 1, participants were administered computerized tests of visual-object and visual–spatial ability, which included measures of both accuracy and response time. The spatial tests were the paper-and-pencil PFT (Ekstrom et al., 1976), paper-and-pencil OSIQ spatial scale (Blajenkova et al., 2006) and the computerized MRT (Shepard & Metzler, 1971). The visual-object ability measures were the paper-and-pencil VVIQ (Marks, 1973), paper-and-pencil OSIQ object scale (Blajenkova et al., 2006), the computerized DPT (Kozhevnikov et al., 2005) and the computerized Grain Resolution Test (GRT: Kozhevnikov et al., 2005). The PFT, VVIQ and OSIQ were the same tests used in Study 1a. All participants were tested individually, and the order of the tests was randomized. The participants were strictly limited to 3 min for the PFT. No time limit was specified for any of the other tasks, but the participants were instructed to respond as accurately and quickly as possible.

2.2.2.1. Mental Rotation Test (MRT). In the computerized version of the Shepard and Metzler (1971) MRT, 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° 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 identical or mirror images. There were 9 practice trials and 109 test trials. RT and accuracy were measured. The internal reliability of the MRT is .88 (Kozhevnikov et al., 2005).

2.2.2.2. Degraded Pictures Test (DPT). The Degraded Pictures Test is a computerized version of the DPT used in Study 1a, and was designed to measure object visualization ability. It was composed of perceptual closure items, representing degraded line drawings of common objects. There were two practice trials and 12 test trials. RT and accuracy were measured. Internal reliability for the computerized DPT is K-R 20 = .74 (Blajenkova et al., 2006).

2.2.2.3. Grain Resolution Test (GRT). The test was designed to assess participants' ability to generate detailed, high-resolution images of individual objects (Kozhevnikov et al., 2005). 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 target objects had a finer texture, or denser grain. "Grain", in this test, refers to bits or particles per unit 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 pervolume (soda vs. shampoo). The task consisted of 2 practice and 20 test trials. RT and accuracy were measured. The internal reliability of the task for accuracy (Cronbach's α) is .62 (Kozhevnikov et al., 2005).

2.2.3. Results

Similarly to Study 1a, a MANOVA (Pillai's Trace) with professional group as a predictor and accuracy on all of the visual–spatial and visual-object ability assessments as criterion variables was conducted, and revealed a significant multivariate effect, $F(14, 110) = 4.45$, $p < .001$, $\eta^2 = .36$. Table 4 shows descriptive statistics and univariate ANOVA results for all assessments for each group.

Similar to Study 1a, *z*-scores were calculated for each assessment, and Fig. 2 shows the mean *z*-scores for all visual–spatial (Fig. 2A) and visual-object (Fig. 2B) ability assessments for each group.

Univariate ANOVAs revealed that the professional groups significantly differed in their accuracy on all object assessments: VVIQ ($p < .001$), DPT ($p = .011$), GRT ($p = .035$) and OSIQ object scale ($p < .001$). Tukey's HSD revealed that visual artists scored significantly higher on the object ability assessments than scientists (VVIQ: $p = .006$; DPT: $p = .012$; GRT: $p = .028$; OSIQ object scale: $p < .001$), and humanities/social science professionals (VVIQ: $p < .001$; DPT: $p = .032$; OSIQ object scale: $p < .001$). Furthermore, univariate ANOVAs revealed that the professional groups significantly differed in accuracy on all spatial assessments: the PFT ($p = .003$), MRT ($p < .001$) and OSIQ spatial scale ($p = .026$). Tukey's HSD revealed that scientists tended to score higher on spatial ability assessments than visual artists (PFT: $p = .003$; MRT: $p < .001$; OSIQ spatial scale: $p = .137$) and humanities/social science professionals (PFT: $p = .049$; MRT: $p = .019$; OSIQ spatial scale: $p = .028$).

Furthermore, we conducted univariate ANOVAs on response time measures. Results demonstrated that, overall, scientists were not faster than other groups, even on the spatial assessment (MRT: $p = .586$). As for object ability assessments, scientists tended to be slower than the two other groups on DPT ($p = .010$) and GRT ($p = .09$). Furthermore, to investigate the efficiency of visual-object and visual–spatial information processing while avoiding speed-accuracy trade-off confounds often reported in the literature (e.g., Lohman & Nichols, 1990), a visual processing efficiency measure was computed for each computerized visual-object as well as for the visual–spatial task, by dividing the proportion of correct responses by average response time.[5] The results of univariate ANOVAs revealed significant differences between groups on efficiency measures (see Table 4). Visual artists showed the highest efficiency on both visual-object tasks (DPT; $p = .02$; GRT; $p = .01$), while scientists showed the highest efficiency on the MRT ($p = .001$). Post-hoc results revealed that scientists were more efficient on the MRT than visual artists ($p = .002$) and humanities/social science professionals ($p = .028$). In contrast, visual artists tended to be more efficient on the DPT than scientists ($p = .017$) and humanities/social science professionals ($p = .089$). Visual artists were also more efficient on the GRT than scientists ($p = .007$).

[5] A natural logarithmic transformation was used to normalize skewed response time data. In the current study, the Kolmogorov–Smirnov test indicated that *ln*-transformed response time measures, as well as efficiency measures for all timed tests (MRT, DPT and GRT), did not differ significantly from a normal distribution (all $p > 0.2$).

Table 4
Descriptive statistics and ANOVA results for all assessments used in the Study 1b.

	Science *M* (*SD*)	Visual art *M* (*SD*)	Humanities/social science *M* (*SD*)	ANOVA $F(2, 62)$, p, η^2
Spatial imagery assessments				
PFT	6.68 (1.35)	4.43(2.48)	5.25 (2.26)	6.35, $p = .003$, $\eta^2 = .18$
MRT	88.88 (9.01)	73.75 (14.82)	79.73 (10.46)	9.25, $p < .001$, $\eta^2 = .24$
MRT RT (ms)	6817 (3525)	5915 (2945)	6005 (2905)	0.53, $p = .586$, $\eta^2 = .02$
MRT efficiency	.1040 (.015)	.0867 (.018)	.0928 (.010)	7.36, $p = .001$, $\eta^2 = .20$
OSIQ spatial scale	3.26 (.48)	2.90 (.49)	2.81 (.72)	3.86, $p = .026$, $\eta^2 = .11$
Object imagery assessments				
VVIQ	59.63 (11.65)	70.19 (7.96)	55.91 (9.71)	9.70, $p < .001$, $\eta^2 = .24$
GRT	10.25 (1.96)	11.75 (1.53)	10.70 (1.69)	3.55, $p = .035$, $\eta^2 = .11$
GRT RT (ms)	6557 (3104)	5405 (1538)	5135 (1610)	2.50, $p = .090$, $\eta^2 = .08$
GRT efficiency	.0588 (.010)	.0685 (.008)	.0629 (.010)	4.06, $p = .010$, $\eta^2 = .14$
DPT	5.28 (1.61)	6.96 (1.64)	5.48 (1.96)	4.90, $p = .011$, η^2=.14
DPT RT (ms)	10,724 (6060)	9238 (3492)	6605 (2906)	5.01, $p = .010$, $\eta^2 = .14$
DPT efficiency	.0487 (.016)	.0642 (.016)	.0524 (.019)	4.18, $p = .020$, $\eta^2 = .12$
OSIQ object scale	3.23 (.69)	4.18 (.45)	3.28 (.57)	14.48, p<.001, $\eta^2 = .33$

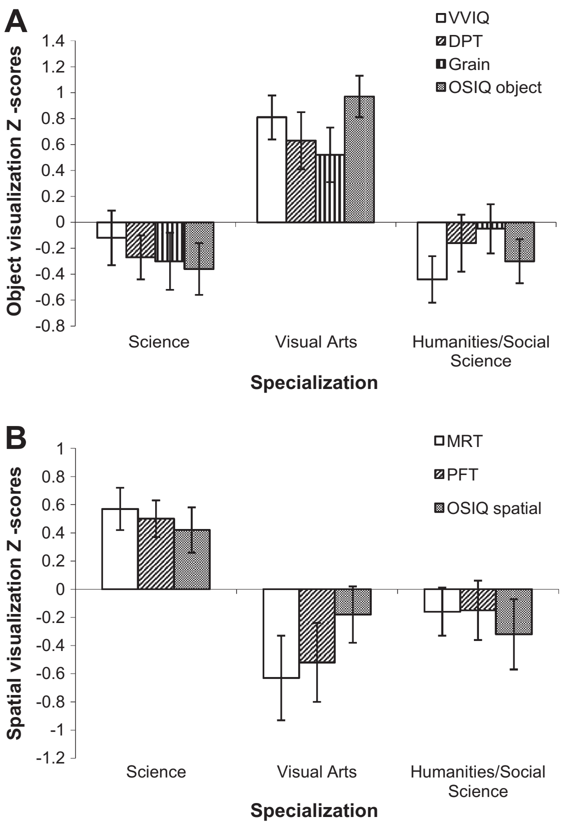

Fig. 2. Normalized object (A) and spatial (B) visualization scores for the different groups of professionals in Study 1b. The bars represents ±1 SEM.

2.2.4. Discussion

Consistent with previous studies (Blajenkova et al., 2006; Blazhenkova & Kozhevnikov, 2009; Kozhevnikov et al., 2005, 2010), the factor analyses in Study 1a demonstrated that all visual-object measures comprise a unique factor, different from visual–spatial factor. In addition, results of correlation analyses from Study 1a, consistent with previous research (Blajenkova et al., 2006; Blazhenkova & Kozhevnikov, 2009; Dean & Morris, 2003) demonstrated that the self-report instruments used (VVIQ, OSIQ) indeed are closely correlated with maximal-performance ability assessments, and that the self-report measures and objective performance measures assessing the same visual (object or spatial) processing dimension loaded onto the same factor. This indicates that individuals are usually aware of their most efficient mode of visual information processing, and that self-report measures could be reliably used to identify an individual's particular strengths and weaknesses in the use of object or spatial modes of information processing.

Furthermore, the unique predictive ecological validity of the visual-object domain was demonstrated using multiple measures of visual-object and visual–spatial ability; visual art professionals and students were significantly more accurate and efficient on all visual-object ability assessments (both self-reports and performance assessments) than science and humanities/social science groups, while science professionals and students were significantly more accurate and efficient on all visual–spatial imagery assessments than the other two groups. Thus, visual-object ability *uniquely* relates to specialization in visual art, in that visual art discriminatively predicts performance on object, but not on spatial, assessments Overall, our results indicate that visual-object ability is a reliable predictor of academic and professional specialization in visual art for college students and professionals.

In contrast, visual–spatial ability (in terms of both accuracy and efficiency) was found to be significantly related to specialization in science, consistent with previous findings reported in psychometric literature (Ferguson, 1977; Hegarty & Kozhevnikov, 1999; Pellegrino, Mumaw, & Shute, 1985). Furthermore, this study showed that visual–spatial ability *does not* predict specialization in visual art, which is inconsistent with the view often held in the contemporary literature (e.g., Eisner, 1985; Gardner, 1999; Perkins, 1994) that it is spatial ability that is important for specialization in visual art. Thus, the current study provides evidence of the unique discriminative power of both visual–spatial and visual-object abilities, in that the former predicts specialization in science but not visual art, while the latter predicts specialization in visual art but not science.

In addition, these results indicate that neither object nor spatial ability is a reliable predictor of specialization in humanities/social science fields, further supporting the discriminative validity of visual-object ability. Humanities/social science professionals might rely more on the use of verbal–analytical means, rather than on visual representations while solving tasks within their fields. Indeed, previous research (Wai et al., 2009) reported that, although humanities and social science majors and professionals are lower in spatial ability than students and professionals in STEM domains (science, technology, engineering and mathematics), they are higher in verbal ability (vocabulary, English composite, and reading comprehension). In addition, examination of GRE scores for different majors indicates that philosophy and other humanities and social sciences majors had the highest verbal scores (Graduate Record Examinations Board by Educational Testing Service, 2006–2007).

Finally, consistent with previous research (Blajenkova et al., 2006; Blazhenkova & Kozhevnikov, 2009; Campos & Sueiro, 1993; Collins & Kimura, 1997; Linn & Petersen, 1985; McKelvie, 1995; Voyer et al., 1995), our results demonstrated that females tended to outperform males on tasks that require visual-object processing, while males tended to outperform females on tasks that require visual–spatial processing. These findings provide additional support that visual-object and visual–spatial abilities are distinct from one another due to their opposite patterns of gender differences. However, although the main effect of gender was a significant predictor of visual abilities, its effect size was relatively small, in contrast to the considerable effect size of specialization, consistent with the results of other studies (e.g., Kozhevnikov et al., 2010). Moreover, results demonstrated that, when gender is statistically controlled for, the specialization effect remains significant, thus suggesting that the relationships between visual-object or visual–spatial ability and field of specialization exist independently of gender, and thus are irreducible to gender differences.

Overall, these results strongly support the ecological validity of the object imagery dimension, and its validity as an independent dimension of visual intelligence.

3. Study 2

Pictorial visual-object processing has long been viewed as contrary, and even a hindrance, to abstract thinking in math and science domains (e.g., Aspinwall et al., 1997; Twyman, 1972) that often require interpretation and manipulation of abstract spatial information, such as graph and diagrams. Indeed, the conclusions from Galton's (1880, p. 304) study on imagery that "over-readiness to perceive clear mental pictures is antagonistic to the acquirements of habits of highly generalized and abstract thought", implied that intellectuals do not use object imagery. Even in contemporary literature, following Galton's conclusions, only "intellectual" pursuits, such as mathematics and science, have been associated with the ability to form abstract representations (Brewer & Schommer-Aikins, 2006). Based on this assumption, visual art, which is rich in visual-object information, would contain only concrete representations, since the visual-object domain is unable to support abstract representations. This is doubtful, however, by virtue of the mere existence of abstract visual art.

The major goal of Study 2 was to demonstrate that object processing can support abstract visual-object representations in the same way as spatial processing supports abstract visual–spatial representations, and that the visual representations contained in abstract art indeed constitute a unique and meaningful symbolic system, irreducible to that used in the visual–spatial domain. To this end, we compared how groups of individuals of different object versus spatial processing capabilities interpreted abstract visual–spatial representations, such as kinematics graphs, and abstract visual-object representations, such as modern art. Kinematics graphs provide information about motion of objects via visual–spatial schematic representations, which convey abstract concepts and relationships (e.g., position, velocity, or acceleration as a function of time). Abstract visual art provides information in a visual-object pictorial form, using colors and shapes, but at the same time conveying abstract concepts, feelings, and emotions that are not directly reflected by their literal forms.

Previous research (Kozhevnikov & Thornton, 2006; Kozhevnikov et al., 2002, 2005) has shown that individuals highly proficient in spatial processing (including scientists and high-spatial individuals who have not had any prior formal scientific background) interpreted kinematics graphs in an abstract way, while individual of low spatial proficiency interpreted them literally, as pictures. However, no studies had yet been conducted to examine how individuals interpret abstract visual art information depending on their proficiency in visual-object processing. If pictorial visual-object imagery is simply a concrete form of spatial imagery, it follows that proficiency in spatial processing would also help in interpreting abstract visual-object information. If individuals of high proficiency in spatial processing are unable to do so, while individuals of high proficiency in object processing are, this would suggest that the visual-object domain conveys a type of abstract information entirely unique from visual–spatial abstract information. Study 2a examined differences in how visual artists, scientists, and humanities professionals interpreted kinematics graphs and modern abstract art. Study 2b compared interpretations of kinematics graphs and abstract visual art given by individuals of different level of visual-object and visual–spatial abilities without any formal background in visual art, in order to rule out any potential effect that training in art interpretation might have on grasping the information represented in abstract art.

3.1. Study 2a

3.1.1. Participants

The same members of different professions, 24 scientists, 16 visual artists, and 23 humanities/social science professionals, who participated in Study 1b, also participated in Study 2a.

3.1.2. Procedure and materials

All participants were asked to complete two tasks, the Kinematics Graph Interpretation Task and the Abstract Art Interpretation Task.

The Kinematics Graph Interpretation Task was designed to examine different approaches in interpreting spatial abstract visual information (Kozhevnikov et al., 2002). Participants viewed two kinematics graphs: Graph 1 depicted changes in an object's position over time and Graph 2 depicted changes in an object's velocity over time (Fig. 3).

The participants were then asked to visualize a real-life situation depicted by each graph, write a short description of what happened to the object that led to generation of these particular graphs, and then to draw another graph describing the same motion as the original, but translating the position versus time graph (Graph 1) to velocity versus time, and velocity versus time graph (Graph 2) to position versus time. The correct description of the Graph 1 is that the object is initially at rest (its position remains constant during the first time interval of the graph), then moves at a constant velocity (its position changes linearly with time during the second interval), and then it is at rest again (its position remains constant during the final interval). The corresponding velocity versus time graph (translation task for Graph 1) consisted of a horizontal line at $v = 0$ for the first interval, a horizontal line at a non-zero (negative) velocity for the second interval, and a horizontal line at $v = 0$ for the third segment. The correct description of the Graph 2 is that the object is moving with constant acceleration (its velocity increases linearly in the first interval of the graph), then moving with constant velocity (its velocity remains the same during the second interval of the graph), and then moving with constant deceleration (its velocity decreases linearly during the last interval). The corresponding position versus time graph (translation task for Graph 2) had a parabolic change in position in the first step, a linear change in the second step, and a further parabolic change in the third step.

The Abstract Art Interpretation Task was designed to examine different approaches in the interpretation of abstract visual-object information. In this task, participants were asked to describe the meanings and feelings expressed by two abstract visual art paintings. Painting 1 (Fig. 4) is an abstract art piece by L. Berryhill, named "Breakthrough", representing the idea of liberation through adversity. Painting 2 (Fig. 4) is by W. Kandinsky, named "Kleine Welten V" (*German*: Small Worlds 5). According to art history reviews (e.g., Koehler, 1998), Kandinsky represented in this painting a plan for a utopian city, and the life within, in both a physical and metaphorical sense, i.e., the "small world" with its soul and dynamics. In Painting 1, emotions expressed in the piece are much more violent and easily accessible than in Painting 2, due to its complementary splashes of color which extend beyond the scope of the picture frame.

The participants were presented with these paintings without the names of either the artists or the works. All participants indicated that they had never seen these paintings before. The participants answered the following questions: "*What does this picture bring to your mind? What is drawn here? What mood/emotions/feeling does this picture evoke? How would you title this picture?*"

3.1.3. Results

3.1.3.1. Graph interpretation task. For the Graph Interpretation Task, consistently with the previous categorization suggested by Kozhevnikov et al. (2002), participants' responses were coded into three categories according to the degree to which they reflected the abstract content of the graph: (a) *literal–pictorial interpretations*, in which participants interpreted the graph literally, as a pictorial illustration of a situation, and when translating a graph into different ordinate, they replicated the literal shape of the original graph, (b) *irrelevant interpretations*, in which participants interpreted the graph in terms of irrelevant, but not pictorial, features of the graph, and their translation reflected little to none of the information given in the original graph, or (c) *abstract schematic interpretations*, in which participants referred to the graph as a non-literal spatial representation of movement over time (independent of whether the actual interpretation was correct or incorrect) and when translating a graph into a different ordinate axis they attempted to reflect the stepwise changes in motion meaningfully. Most participants' interpretations of the graphs were highly consistent with their translations of a graph into a different ordinate axis in the sense that the responses to both components of the task fell into the same category. Only very few participants (6.56%) produced translations of one graph to another that were inconsistent with their description of the original graph (in these cases, responses were coded into the category that less reflected the abstract content of the graph).

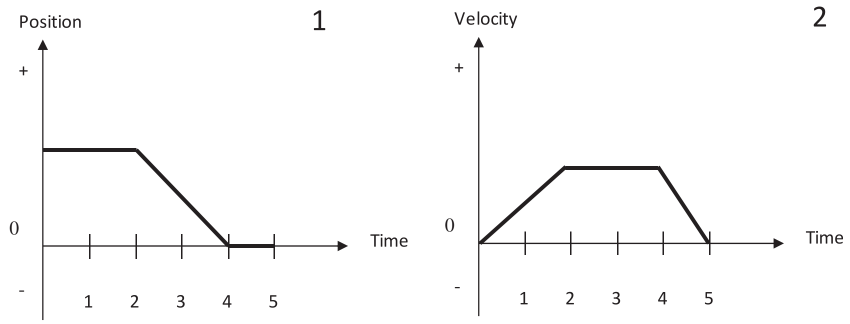

Fig. 3. Kinematics Graph Interpretation Task: Graph 1 and Graph 2.

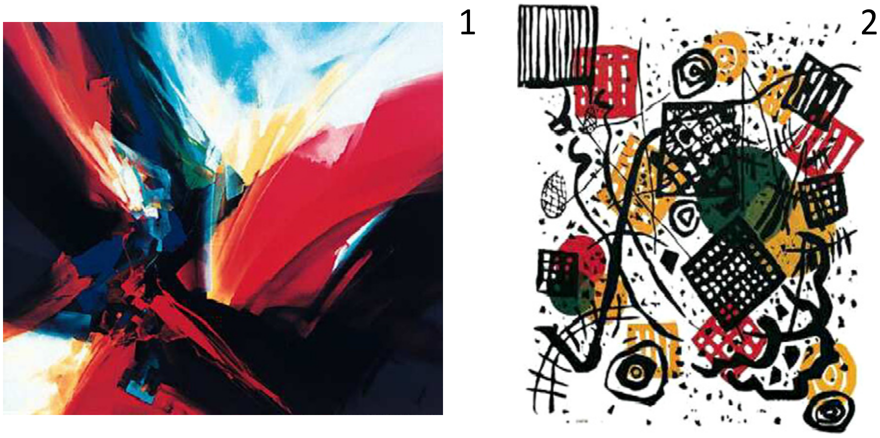

Fig. 4. Abstract Art Interpretation Task: Painting 1 and Painting 2.

Two independent raters analyzed the participants' responses to the graph interpretation task, with an inter-rater reliability of 0.93. Chi-square analysis revealed significant differences between professionals' interpretations of Graph 1 ($\chi^2(4) = 35.439$, $p = .001$) and Graph 2 ($\chi^2(4) = 28.459$, $p = .001$) (see Fig. 5a and b).

Consistent with previous findings (Kozhevnikov et al., 2005), most of the *scientists* (Graph 1: 70.8%; Graph 2: 75.0%) produced abstract/schematic interpretations of the object's movement represented on both graphs, while most of the *visual artists* (Graph 1: 93.8%; Graph 2: 56.2%) produced literal/pictorial interpretations of the object's movement.

Most of the scientists interpreted the visual information provided by the graphs part-by-part, and described the object's motion in steps (i.e., "*1. Object at rest; 2. It suddenly starts motion with constant velocity; 3. It suddenly stops and no motion again*" for Graph 1, or—*there is a permanent motion of an object having 3 steps:(1) speeding up; (2) motion at constant speed, (3) slowing down; position of object is changing constantly until its full stop* for Graph 2). In most cases, scientists did not refer to any specific object, referring to the actor in the graph as "it" or "an object", if at all.

In contrast, most visual artists interpreted both graph problems as literal pictorial illustrations of a situation or the object's trajectory, and did not attempt to interpret the graphs as abstract schematic representations. The artists consistently referred to the global shape of the graph and expected the shape of the graph to resemble the path of the actual motion. For both graphs, the pictorial literal interpretations given by the majority of artists emphasized the shape of the graph, with a specific object performing the motion (e.g., "*a plane landing at airport, a squirrel climbing down a tree*" referring to the downward slope of Graph 1, "*the balloon was flying up, moving forward, and then going down*" for Graph 2), and in some cases, the shape of the graph was interpreted literally, but in the horizontal plane (e.g., "*car is changing lanes*"). Consistently with their verbal interpretations, their drawn interpretations converting position versus time to velocity versus time for Graph 1 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). Similarly, for Graph 2, visual artists provided mostly literal interpretations, and created drawings that replicated the shape of the original graph.

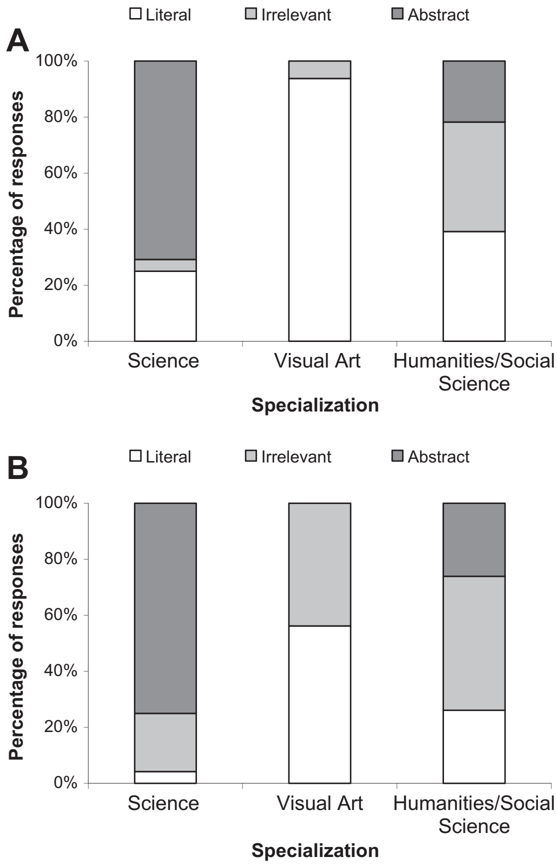

Fig. 5. Interpretations of the kinematics graph by members of different professions: (A) Graph 1 and (B) Graph 2.

Humanities/social science professionals provided a comparable proportion of answers in each category. Interestingly, they had the greatest number of irrelevant answers, which consisted of vague and general descriptions unrelated to the graphs (e.g., *the weather is quiet and calm, the wind is 3–5 m/s, the wind is favorable*), as well as metaphorical descriptions (“*someone died, the end of the wash cycle*”), and lacked any sense of a real object movement, contrary to the task instructions. Participants who gave irrelevant interpretations either tended to be totally confused by the task and refused to answer, or they drew straight lines as a symbol of continuous movement, or drew meaningless lines or pictures of unrelated graphs, such as histograms.

The examples of typical abstract/schematic, pictorial and irrelevant responses are given in Fig. 6.

Given that members of different professions possess different degrees of familiarity with the tasks presented to them (e.g., scientists are more familiar with graph interpretation tasks, while visual artists have more experience with art interpretation), we further examined the relationship between type of graph interpretation (literal, irrelevant, abstract) and participants' level of visual–spatial and visual-object abilities, while controlling for professional membership.

A MANOVA (Pillai's Trace) was conducted, with type of graph interpretation as predictor (literal, irrelevant, abstract), visual-ability scores (*Z*-object and *Z*-spatial[6]) as criterion variables, and professional group (visual artists, scientists, and humanities) added as a covariate. For Graph 1, the MANOVA revealed a significant multivariate effect for visual scores $F(4, 118) = 5.56$, $p < .001$, $\eta^2 = .16$, and the effect of profession was not significant, $F(2, 58) = 1.90$, $p = .15$, $\eta^2 = .06$. Follow-up ANOVAs revealed significant differences for both *Z*-spatial ($F(2, 62) = 10.11$, $p < .001$, $\eta^2 = .26$) and *Z*-object ($F(2, 62) = 4.27$, $p = .018$, $\eta^2 = .13$) scores between groups of participants who gave different types of interpretations. Post-hoc tests (Tukey's HSD) revealed that those who gave abstract graph interpretations had significantly higher spatial scores than those of who gave literal or irrelevant interpretations (both $ps < .001$). Those who gave abstract interpretations had significantly lower object scores ($p = .03$) than those who gave literal interpretations.

Similarly, for Graph 2, after the effect of professional group was statistically controlled, a MANOVA revealed a significant multivariate effect for visual-ability scores, $F(4, 118) = 6.14$, $p < .001$, $\eta^2 = .19$, and the effect of profession was not significant: $F(2, 58) = 3.12$, $p = .053$, $\eta^2 = .09$. Follow-up ANOVAs revealed significant differences for both *Z*-spatial ($F(2, 62) = 10.80$, $p < .001$, $\eta^2 = .27$) and *Z*-object ($F(2, 62) = 5.54$, $p < .01$, $\eta^2 = .16$) scores between groups of participants who gave different type of interpretations. Those participants who gave abstract graph interpretations had significantly higher spatial scores than those of who gave literal or irrelevant interpretations (both $ps < .001$), while those who gave abstract interpretations had significantly lower object scores ($p = .03$) than those who have literal interpretations.

[6] *Z*-object and *Z*-spatial scores were calculated by averaging *z*-scores for all object and spatial assessments, respectively, which were administered to the participants in Study 1b.

3.1.3.2. Art interpretation task. A coding system consistent with that used in the graph interpretation task was applied to the art interpretation task. Responses to questions about the meaning and emotional content conveyed by the paintings were classified into three principal qualitative categories: (a) *literal/pictorial interpretations*, in which participants interpreted the painting in terms of its surface features, such as colors or concrete objects resembling the shapes in the paintings, and indicated superficial or lack of emotions (b) *irrelevant interpretations*, in which participants descriptions were irrelevant to the painting's appearance or emotional content, vague and confused, or missing entirely (c) *abstract/conceptual interpretations*, in which participants referred to the paintings in terms of conceptual and emotional content that was not directly depicted but was related to the ideas expressed by artists.

Three participants failed to give any interpretations of Painting 1, and four participants failed to give interpretations of Painting 2. Their data were excluded from further analysis. All other responses were rated by two coders, and inter-rater reliability was 0.94. All participants indicated that they had never seen these paintings before. Chi-square analysis revealed significant differences between professionals' interpretations of Painting 1 ($\chi^2(4) = 21.714$, $p < .001$) and Painting 2 ($\chi^2(4) = 23.443$, $p < .001$) (see Fig. 7a and b).

Thus contrary to the widespread notion that pictorial information does not support abstract representations, most visual artists provided abstract, rather than literal–pictorial interpretations of visual information. For Painting 1, visual artists (62.5%) provided interpretations that contained the ideas of breakthrough in both conceptual and emotional meaning (*crash and liberation, breakthrough, eruption, war, catastrophe, extreme tension*). Most of the visual artists included emotional attributions in their descriptions of art, even when simply describing the content or naming the picture. They expressed intense and complex emotions, which in fact correspond to the concept of “breakthrough” (e.g., *explosion of emotions, fear, anxiety, horror, bursting, alarm, disturbance, extreme tension*).

Similarly, for Painting 2, most visual artists (75.0%) provided interpretations that attributed meanings reflecting dynamics, complex life, an especially city life and city landscape (*a city, sort of abstract version of movement through a city lights, buildings, a joyful representation of a craziness of city night, a city, a loud party, a whole bunch of different things but working together, moving together, party, hip hop in life, streets, tracks, theater, the Earth and people's thoughts above it*).

In contrast to visual artists, 81.8% of scientists provided literal/pictorial interpretations to Painting 1 and 61.9% of scientists provided literal/pictorial interpretations for Painting 2. Their responses reflected surface characteristics of apparent visual features (e.g., *different colors: blue, black, red, yellow, white; sharp edges in red* for Painting 1; *jumble of color* for Painting 2). Moreover, they tended to give descriptions demonstrating understanding of content as random, non-meaningful combinations of lines, shapes and colors (e.g., *mess, trash, some shapes, no order, stains, squares, cubes, circles* for Painting 1; *conglomeration of swatches* for Painting 2) or attempts to synthesize the pat-

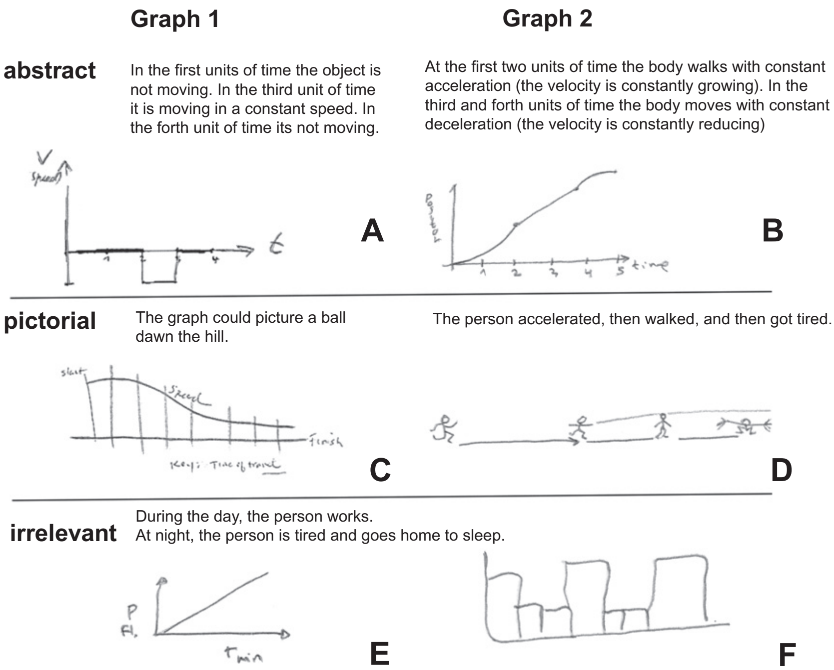

Fig. 6. Examples of different types of interpretations of the kinematics graphs.

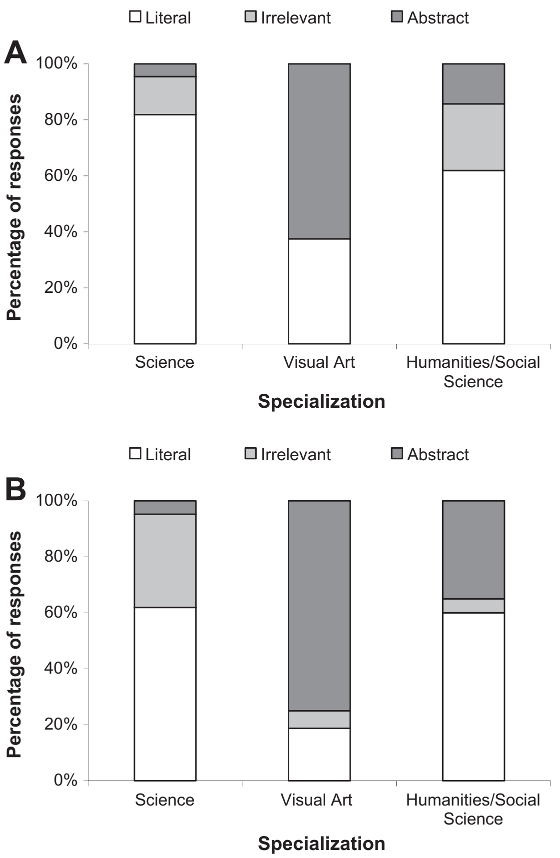

Fig. 7. Interpretations of abstract art by members of different professions: (A) Painting 1 and (B) Painting 2.

terns in the paintings into concrete objects, ("*crystals of ice; pieces of ice, glass, mountains* for Painting 1; *confetti at the party, blanket design with some random pattern*" for Painting 2). Typically, in Painting 1, 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. Scientists expressed fewer feelings overall than artists; half of the 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., *everything happens together* for Painting 1; *there is a lot to be done here, this will take a lot of work, thinking about something, don't like, mess* for Painting 2).

Only a relatively small percentage of humanities/social science professionals gave abstract interpretations to paintings (14.3% for Painting1 and 35.0% for Painting 2), The majority of humanities/social science professional tended to provide either irrelevant answers or literal interpretations (*don't see anything, this is an abstract painting, complicated, don't want to figure out, abstract, nothing, bad drawing, It brings to mind the idea that people may in fact create art for no reason. I think if there is a message or emotion behind this creation that's too esoteric for anyone the outside world to understand*). Interestingly, humanities/social science professionals tended to come up with broad digressive metaphors, instead of emotional descriptions (e.g., *excitement and diversity, a clash of order and chaos, ecstasy of mind*).

Furthermore, we conducted a MANOVA (Pillai's Trace) with type of art interpretation as predictor (literal, irrelevant, abstract), visual-ability scores (Z-object and Z-spatial as calculated in Study 1b) as criterion variables, and professional group (visual art, science, and humanities) added as a covariate. For Painting 1, a MANOVA revealed a significant multivariate effect for visual-ability scores, $F(4, 112) = 3.17$, $p = .02$, $\eta^2 = .11$, and the effect of professional group was significant: $F(2, 55) = 4.38$, $p = .02$, $\eta^2 = .14$. Follow-up ANOVA, with Z-spatial as a criterion variable and professional group added as a covariate, revealed that the effect for Z-spatial ($F < 1$) was not significant, while the effect of profession was, $F(1, 59) = 7.77$, $p < .005$, $\eta^2 = .12$. However, ANOVA with Z-object as a criterion variable and professional group added as a covariate revealed a significant effect for Z-object ($F(2, 59) = 6.99$, $p = .002$, $\eta^2 = .20$), and the effect of profession was not significant ($F < 1$). Those participants who gave abstract interpretations for Painting 1 had significantly higher object scores than those of who gave literal ($p = .002$) or irrelevant interpretations ($p = .02$).

For Painting 2, after the effect of professional group was covaried out, a MANOVA revealed a significant multivariate effect for visual-ability scores, $F(4, 106) = 3.84$, $p < .001$, $\eta^2 = .13$. The effect of profession was not significant: $F(2, 52) = 4.41$, $p = .053$, $\eta^2 = .14$. Follow-up ANOVAs revealed significant differences for both Z-object ($F(2, 56) = 6.42$, $p < .01$, $\eta^2 = .20$) and Z-spatial ($F(2, 56) = 3.43$, $p < .05$, $\eta^2 = .12$) scores between groups of participants who gave different type of interpretations. Those participants who gave abstract interpretations of Painting 2 had significantly higher object scores than those who gave literal ($p = .009$) or irrelevant interpretations ($p = .03$). Those who gave abstract interpretations had significantly lower spatial scores ($p = .023$) than those who gave literal interpretations.

3.2. Study 2b

Study 2b was conducted in order to further investigate the findings of Study 2a, and rule out the possibility that the effects found in Study 2a might be due to art professionals' prior experience in art interpretation and exposure to abstract art. It is possible that visual artists' ability to interpret the visual-object information in abstract art is a result of extensive training in semantically associating certain colors or image motifs with certain concepts and emotions. The goal of Study 2b was to account for this possibility by excluding all participants with any prior background with abstract art and art interpretation.

3.2.1. Participants

The participants were the same college (undergraduate and graduate) students who participated in Study 1a, except for the students majoring in visual art and those who indicated that they had prior background in visual art or had taken visual art classes before. Overall, 83 students participated in this study.

3.2.2. Procedure and materials

Participants were asked to complete the Abstract Art Interpretation (Painting 1) and Graph Interpretation Tasks (Graph 1), as described in Study 2a.

3.2.3. Results

For Graph 1, ANOVA revealed significant differences for spatial ($F(2, 81) = 9.68$, $p < .001$, $\eta^2 = .19$), but not for object ($F < 1$), ability scores between groups of participants who gave different types of interpretations. Post-hoc tests (Tukey's HSD) revealed that those who gave abstract graph interpretations had significantly higher spatial scores than those who gave literal interpretations ($p < .001$). The groups who gave literal or irrelevant interpretations did not differ ($p = .92$).

In contrast, for Painting 1, ANOVA revealed significant differences for object ($F(2, 81) = 6.53$, $p = .002$, $\eta^2 = .14$), but not for spatial ($F < 1$), ability scores between groups of participants who gave different types of interpretations. Post-hoc tests (Tukey's HSD) revealed that those who gave abstract interpretations of Painting 1 had significantly higher object scores than those of who gave literal ($p < .002$) or irrelevant interpretations ($p = .014$), while the latter groups did not differ between one another ($p = .98$).

3.2.4. Discussion

Overall, the results of Study 2, from both the *Abstract Art Interpretation Task* and *Graph interpretation task* showed that individuals proficient in object visual processing tended to interpret abstract visual information in qualitatively different ways from individuals proficient in spatial visual processing. Visual artists tended to interpret abstract art as abstract representations, but scientists and humanities/social science professionals 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, while humanities/social science professionals did not have any clear tendency to either type of interpretation. Compared to other professionals, humanities/social science professionals gave the most irrelevant responses, possibly because they may have been confused by the tasks, or they attempted to solve them by purely verbal-analytical approaches.

In addition, even after controlling for the effect of profession (Study 2a), a significant difference was found between the object and spatial scores of groups who gave different types of interpretations. Those individuals who gave abstract graph interpretations had significantly higher spatial scores than those who have literal or irrelevant interpretations. In contrast, those who gave abstract art interpretations had significantly higher object scores than those who gave literal or irrelevant interpretations. Furthermore, as the results of Study 2b showed, the above relationship between visual-object ability scores and "abstract" responses to the art interpretation task remained significant, even for participants without any prior background in visual art. Thus, our results indicate that proficiency in spatial processing (due to experience or natural ability) is not sufficient for supporting abstract representations in the visual-object domain. Since proficiency in the spatial domain does not help to interpret visual-object information abstractly, thus, we conclude that visual-object imagery cannot be considered a concrete form of visual–spatial reasoning, but constitutes an independent domain that supports its own abstract visual-object representations.

Furthermore, the results showed that humanities/social science professionals do not necessarily form abstract representations in either the visual–spatial or visual-object domain, contrary to the view that characterizes those strong in abstract verbal processing as more inclined to think abstractly in general (see Jonassen & Grabowski, 1993; Kirby, Moore, & Schofield, 1988). Therefore, the current results suggest that abstract verbal thinking may not be beneficial for visual-object and visual–spatial tasks, and that abstract thinking is domain-specific (i.e., verbal, object or spatial).

Overall, these results, contrary to the claims of Galton (1880) and his followers (Brewer & Schommer-Aikins, 2006), suggest that pictorial visual-object imagery does not impede abstract thinking, but in fact supports a different type of abstract thinking. The representations contained in abstract art indeed comprise a unique symbolic system, whose content is consistently meaningful and accessible across individuals, and is irreducible to that used in the visual–spatial domain, thus confirming that the visual-object dimension fulfils the "susceptibility to encoding in a symbol system" requirement of Gardner's (Gardner, 1983, pp. 62–69) definition of a component of intelligence.

4. Study 3

Study 3 sought to provide evidence for the unique qualitative characteristics (Study 3a) and unique functional role (Study 3b) of visual-object processing by comparing the subjective visual imagery experiences of members of different professions (visual artists, scientists and humanities/social science professionals).

Subjective reports have been a great source of information in research on visual processing due to the subjective nature of certain aspects of visual imagery experiences, and the limitations of assessing imagery by direct objective measures (for review see McAvinue & Robertson, 2007). The examination of biographical documents containing self-reports of prominent scientists and visual artists has been one of the most significant sources of insights to the nature and role of imagery in creative processes (Miller, 1996; Shepard, 1978). Although there have been a number of studies that examined the subjective descriptions of imagery using self-reports (questionnaires or interviews) of scientists and visual artists (Galton, 1880; Lindauer, 1983; Patrick, 1937; Roe, 1975; Rosenberg, 1987), no research has systematically compared the imagery experiences of professional groups using a theoretical approach that distinguishes between visual-object and visual–spatial processing. Study 3a analyzed and compared the imagery experiences, in terms of visual-object and visual–spatial imagery, of visual artists, scientists and humanities/social science professionals using Kosslyn's theory of mental imagery (Kosslyn, 1980, 1994; Kosslyn, Ganis, & Thompson, 2001; Kosslyn, Thompson, & Ganis, 2006), which identified four main components of visual processing: generation, maintenance, inspection, and transformation. *Image generation* occurs when mental image of an object is constructed by evoking its appearance from long-term memory, and may involve representations of either objects' visual appearances or visual–spatial maps. *Image inspection* involves processes similar to visual perception, in which images are recognized based on their characteristics and such properties as shape or spatial relations can be further inspected. *Image maintenance* occurs by re-activating the visual memory representations in either visual-object or visual–spatial processing systems. Finally, *image transformation* modifies these representations in terms of either visual appearance or layout and structure, and occurs when one visualizes how the scene or object would appear if it were physically manipulated (Kosslyn et al., 2001, 2006). Kosslyn's theory of imagery, however, does not systematically investigate these different stages of visual processing along the object–spatial dimension, and tends to associate some components of visual processing with either object or spatial imagery (for example, spatial imagery is associated with image transformation, and object imagery with image maintenance and inspection).

Study 3b sought to provide insight to the differences in the functional role of imagery in members of different professions as well as to examine the link between visual-object imagery and emotional processing.

4.1. Study 3a

4.1.1. Participants

Members of different professions, 18 scientists, 17 visual artists, and 14 humanities/social science professionals who held college degrees and had at least two years of professional experience in their fields participated in the current study. Participants were interviewed about the use of visual imagery in their work. Three scientists were not included in the analysis, since they refused to proceed with the interviews, claiming that they do not use visual thinking in their work, but instead use solely analytical thinking. One visual artist was also not included in the study since he claimed that he does not use visual processing and makes conceptual art.

4.1.2. Procedure and materials

The qualitative structural interviews lasted from 20 to 40 min (depending on the value of received information and the depth to which participants discussed their subjective visualization experiences). The interview guide included questions about qualitative characteristics of participants' imagery at different stages of image processing (generation, maintenance, inspection and transformation).

The interview procedure was conducted in correspondence with the interview guide; however, the order and formulation of the questions was relatively flexible. Spontaneous answers were encouraged. Close attention was paid to qualitative descriptions of the specific visual-object versus visual–spatial characteristics of professionals' images during image generation, inspection, maintenance and transformation. Protocol analysis was used to interpret the obtained qualitative data.

4.1.3. Results

All imagery-related statements were classified and coded into mutually exclusive categories describing qualitative aspects of participants' imagery experiences at the four stages of image processing (Kosslyn, 1994). Responses were coded by two raters, with an inter-rater reliability of .84. The final categorizations of responses were decided by consensus. Selected examples of imagery-related statements from professionals' self-reports are presented in Table 5.

4.1.3.1. Image generation. The participants were asked, using specific examples, to describe their image generation during performance of work-related tasks. First, to assess whether their images could be characterized as *visual-object or visual–spatial*, participants were asked to describe the characteristics of their generated images in terms of color, detail, brightness and realism versus schematism and spatial configuration. Second, to assess whether their images are created *holistically or sequentially* participants were asked to describe the process of their image generation. Finally, participants were asked whether their image generation was *controlled or uncontrolled*.

4.1.3.1.1. Visual-object versus visual–spatial characteristics of generated images. Responses were coded into three categories: "object", "spatial", or "mixed". Responses were classified as "object" when the participant described her images as primarily vivid, colorful and rich in other pictorial visual properties (e.g., texture and detail), and "spatial" when the participant described her images representing mostly structural but not pictorial properties. Responses were coded as "mixed" when individual participants reported that their images might have either "object" or "spatial" characteristics, depending on the situation.

Chi-square analysis revealed significant differences between the groups ($\chi^2(4) = 46.410$, $p < .001$), and professional groups' percentages of different categories of responses are presented in Fig. 8.

Most visual artists' responses were categorized as "object", since they described their generated images as pictorial, vivid, and detailed, with color as the most salient characteristic. In contrast, most scientists' responses were categorized as "spatial", since they described their images as sketch-like and primarily representing spatial structural features, but lacking fine pictorial features such as texture and shades of color. Scientists usually did not report generation of colorful images, and even when they did, they reported that color serves as a marker, distinguishing different parts of a structure (e.g., different parts of chemical molecular model). In contrast to visual artists and scientists, who reported that they primarily use either visual-object or visual–spatial images, humanities/social science professionals tended to fall into the "mixed" category. They reported generation of either visual-object or visual–spatial images, depending on the situation, although they usually describe their images as vague, dim, and reflective of the context that triggered the image (e.g., detailed textual descriptions).

4.1.3.1.2. Holism of image generation. Responses on the progression of image generation were coded into three categories: "holistic", in which images were generated as global units and were complete upon generation, "sequential", in which images were generated part-by-part, or "mixed".

Chi-square analysis revealed significant differences between the groups ($\chi^2(4) = 14.311$, $p = .006$), and professional groups' percentages of different categories of responses are presented in Fig. 9.

Most visual artists' responses were categorized as "holistic", since artists often claimed that their images are typically generated as single units that have a complete structure, including colors that represent the image's first characteristics to appear. Global shape is also generated from the beginning, all at once, with the image's finer details appearing later. Most scientists' image generation fell into the "sequential" category; they tend to generate their images sequentially, connecting parts in a logical structure, moving stepwise from a reasonable origin to the next level of the spatial assembly of an image. Humanities/social science professionals' responses were mostly categorized as "mixed", since they generate their images part-by-part or as a whole depending on the type of image. In general, images that tended to be pictorial and colorful (visual-object images) were generated as wholes, while visual–spatial images were generated sequentially. Overall, however, humanities/social science professional's images tended not to contain many details, unless details were explicitly provided by the text.

4.1.3.1.3. Control of image generation. Responses on the intentionality of image generation were coded into three categories: "uncontrolled", in which images were generated spontaneously, without (or even against), participants' conscious will, "controlled", in which images were generated with purposeful effort, or "mixed". Chi-square analysis revealed significant differences between the groups ($\chi^2(4) = 26.430$, $p < .001$), see Fig. 10.

Most visual artists' responses were categorized as "uncontrolled", since reported spontaneous image generation that occurs almost constantly, triggered by their life, work events, and emotional experiences. Usually, image generation occurs immediately, and is experienced as a sudden onset of inspiration. Many visual artists feel that their visual images are generated not of their own volition, and that their images come from an independent objective reality – an "image-space" that persists beyond and independently of the individual. All scientists' responses fell into the "controlled" category; they reported that they were in complete control of the generation of their mental images, in terms of both frequency/time of occurrence and content. Scientists view their mental images as tools to be used for effective problem solving, which are easily accessed and easily discarded. Humanities/social science professionals' responses were mostly categorized as "uncontrolled", since humanities/social science professionals reported they generate uncontrolled object images when they are triggered by stimuli such as highly descriptive text, however some of them (23.1%) were categorized as "mixed", since in addition to text-triggered uncontrolled images, they also generate controlled spatial images when they are used to solve or analyze problems such as complex verbal structures.

4.1.3.2. Image inspection. First, to assess whether images were *intentionally or unintentionally* inspected, participants were asked whether or not they consciously inspect their images. Second, to assess whether their images had *apparent or ambiguous* meanings upon inspection, participants were asked about their degree of awareness of the content of their mental images.

Table 5
Examples of imagery-related statements from professionals participating in Study 3a.

Category	Visual art	Science	Humanities/social science
Image generation			
Visual-object vs. visual–spatial characteristics of generated images	When I think of something in my head, it's always colorful. I dream in colors, when I close my eyes I see colors. And everything, yeah, everything is very detailed	My image is more like schematic because it's a question of how small optical devices connect to each other and I just have to imagine how to put them the optimal way	I have two variants – if this is a scientific text, then I imagine some sort of structure, and if this is something more concrete such as philosophy of history, then I have more concrete images
Holism of image generation	Images come in flash, it's almost a little muse, so real you just have to grab the idea and visualize it	I imagine part-by-part, first the original part and how it should be, from which side, and how other parts are connected to this part. Then I proceed to the second, third, and then I have the whole structure	When I read a historical text I imagine the epoch, the image appears immediately, but not very bright, though, like a background... and if. I have to analyze the text I, investigate the historical periods, so I see images part-by-part. There are images of logical structure, like square boxes and connecting lines
Control of image generation	There are images that come from nowhere...	I use my imagery when I want...	Pictures just happen to jump into my mind as a result of thinking of something When I need to think about structure of my lecture, I purposefully imagine something like a schematical outline of a lecture
Image inspection			
Intentionality image inspection	Some image comes and then I examine it in details. In order to understand how I should do it, I have to watch it for even 20 min. This is long process	I don't need to examine my images, because I just need to find an optimal way to connect all the stuff together and it's not a question of examination	I feel like if I want to focus on my image, I can do it, but usually I just don't want to
Accessibility of image meanings	I have these weird colors and creepy images, but I don't know what they are... but I can translate them into paintings	They are clear because images are secondary. I just know what it is, like these lines are a complicated structure of my data, and I precisely know what it means; I don't have to guess, it's crystal clear	My images usually just reflections of what I read, like illustrations, of course I understand what they mean, but they are not very important anyway
Image maintenance			
Control of image maintenance	I never really forget about my first idea. So... I always have this image in my head of what I want to do, or this feeling that I want to express. I always have a visual image in my head, no matter what like... it's just, it's always there	I can see it my as long as it's needed, until I understand how to resolve the problem	I don't really try to hold images on purpose, they enter in my mind just when I read about something
Persistence of image maintenance	Sometimes the image is so persistent, it just standing in my eyes	My images are persistent only for the time I need to think about them	Images live their own lives and they disappear very quickly
Image transformation			
Visual-object versus visual–spatial characteristics of image transformation	It is like in a maze game... when I walk along the corridor and suddenly find myself in the dead end – I have to do everything over again! An image changes itself completely, if I feel that something is needed to be transformed	I don't care about colors, and don't change them. As for sizes...most of the stuff is made under a standard size... but I can put parts together and connect them	Why do I need to transform my images? They are not important for my work
Intentionality of image transformation	Sometimes it is hard to control my images; they just change their color and shape themselves	While the image is under construction I change little bit of all of those to express how I see them internally. I modify them because of criticism or because it was not understood very well	It is not easy at all to add details, because I have no imagination so I can't make things up

4.1.3.2.1. Intentionality of image inspection. Responses were coded into four categories: "intentional", "non-intentional", "mixed" and "none". Responses were coded as "intentional" when participants purposely inspected their images, "non-intentional" if inspection occurred but was not intentional, and "mixed" if inspection may occur intentionally or non-intentionally. The "none" category was included to account for considerable amount of participants who reported that they do not inspect their images at all. Chi-square analysis revealed significant differences between the groups ($\chi^2(6) = 14.379$, $p = .026$), see Fig. 11.

Visual artists' responses were primarily categorized as "intentional", since artists reported that they consciously and purposely inspect their images. They reported that image inspection is an important part of their visual processing, and that it can take considerable amounts of time. Visual artists investigate their visual images for a number of purposes: to see more details, to understand the images' meanings, and to understand how to create an art work from these images. About half of the scientists' responses were categorized as "none"; these scientists claimed to not inspect their images at all. The other half of the scientists' responses was categorized as "non-intentional", mostly because they reported that image inspection happened automatically during application of the image to a problem-solving task. For example, they might use

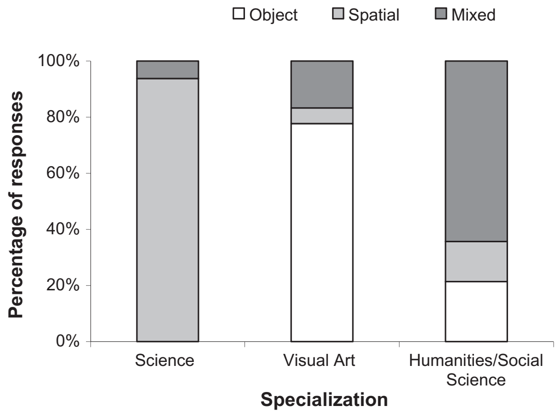

Fig. 8. Visual-object versus visual–spatial characteristics of generated images.

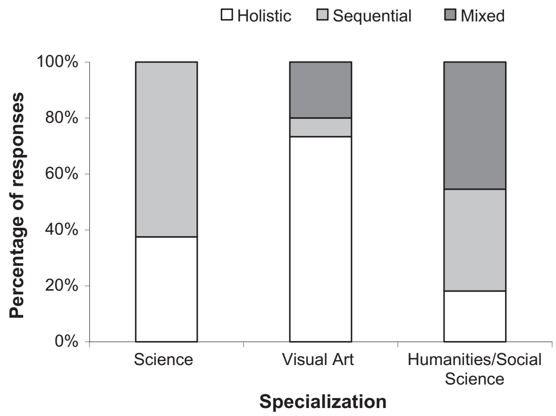

Fig. 9. Holism of image generation.

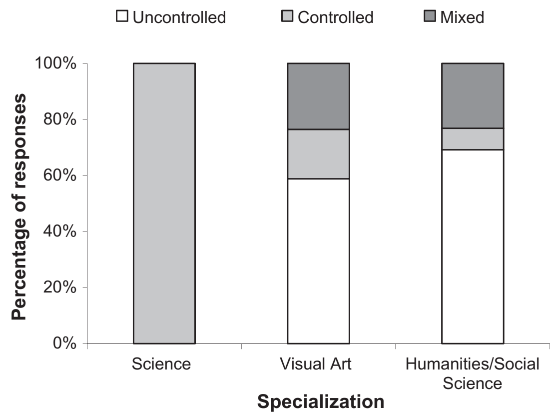

Fig. 10. Control of image generation.

inspection to understand the spatial arrangement or structure of a mechanical device or chemical configuration, and inspection of such images would occur when the scientists attempt to better understand the structure of the device or molecule, but not the image itself. Humanities/social science professionals' responses were mostly coded as "none"; they tended to report not inspecting their images at all, since imagery is secondary to their verbal processing, and not very important for their work. They also reported problems focusing on their images, and that they were not motivated to do so.

4.1.3.2.2. Accessibility of image meanings. Responses were coded into three categories: "apparent", "ambiguous", and "mixed", depending on whether or not participants were aware of the meanings of their visual images when inspecting them. Responses were classified as "ambiguous" when participants described images' meanings as undefined or multifarious. Responses were classified as "apparent" when participants had no doubt in their interpretations of single meanings to their images when consciously assessing them. Chi-square analysis revealed significant differences between the groups ($\chi^2(4) = 21.623$, $p < .001$), see Fig. 12.

Most visual artists' responses were characterized as "ambiguous", since they tended to report that their images had multiple or confusing meanings. In many cases, the meanings of their visual images were not fully consciously accessible. According to visual artists' reports, awareness of an image's identity and semantic content often comes only after the visual image has been inspected, or even after artwork based on the image has been created. In contrast to visual artists, scientists' responses were all coded as "apparent"; scientists always knew exactly what their images meant before or immediately upon generating them, and their images do not have multiple or ambiguous meanings. The majority of humanities/social science professionals' responses was coded as "apparent" since they did not report ambiguous images, but their images were usually unattended.

4.1.3.3. Image maintenance. Professionals were asked about maintenance of their images. First, to assess whether their image maintenance (keeping images online in a short-term memory) was were *effortless or effortful*, participants were asked whether their image maintenance is consciously controlled or spontaneous. Second, to assess whether their images were *persistent or non-persistent*, participants were asked about time

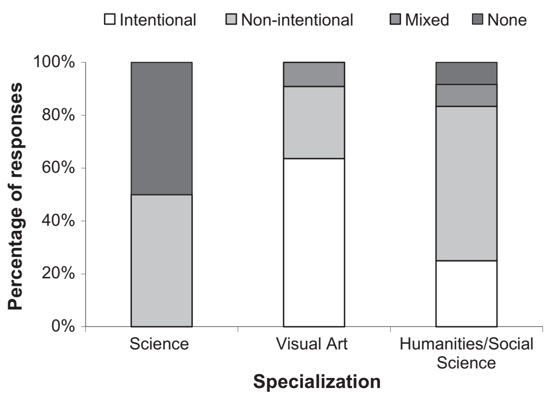

Fig. 11. Intentionality of image inspection.

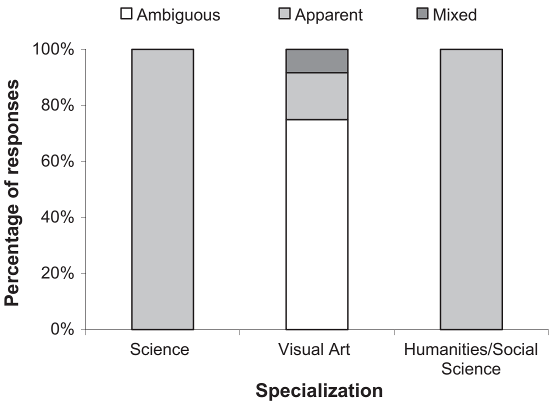

Fig. 12. Accessibility of image meanings.

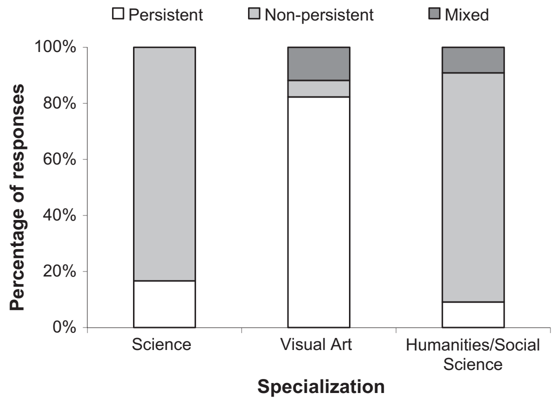

Fig. 14. Persistence of image maintenance.

course of image maintenance and whether images could be easily discarded.

4.1.3.3.1. Control of imagery maintenance. Responses were coded into three categories: "effortless", "effortful" and "mixed", depending on whether the control of imagery maintenance was reported as requiring effort or not. Chi-square analysis revealed significant differences between the groups ($\chi^2(4) = 15.687$, $p = .003$), see Fig. 13.

Most visual artists' responses were coded as "effortless", since they reported that image maintenance usually happens automatically, without conscious control or effort. Their images are naturally maintained, effortlessly memorized, and easily evoked after delay. All scientists' responses, in contrast to visual artists', fell into the "effortful" category, since they reported that the control of their mental images required conscious effort, and that their images exist in their minds generally only when they consciously think of them. Even though scientists reported that they are able to purposefully maintain their images, they tended to maintain only parts of images that were relevant for a specific current problem solving. Humanities/social science professionals generally reported a tendency to maintain their ideas in a verbal-conceptual, rather than visual form.

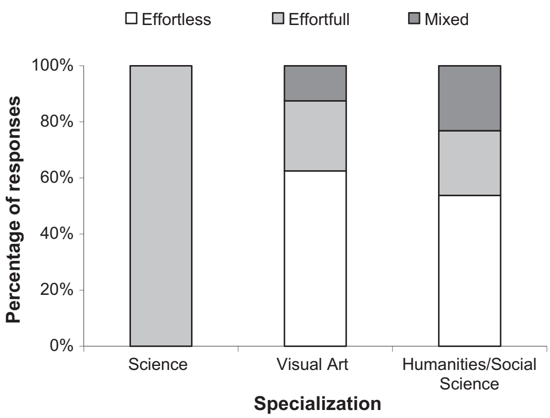

Fig. 13. Control of imagery maintenance.

4.1.3.3.2. Persistence of imagery maintenance. Participant's descriptions of image maintenance were coded into three categories: "persistent", "non-persistent" and "mixed". Chi-square analysis revealed significant differences between the groups ($\chi^2(4) = 21.013$, $p < .001$), see Fig. 14.

Most visual artists' responses fell into the "persistent" category; artists reported that their images tended to be persistent, without being consciously maintained, even to the point that the artists sometimes had difficulty forgetting their images. Scientists' responses were mostly coded as "non-persistent", since scientists tended to report that their images are persistent only to the degree they want them to be, and that they have no problems discarding these images after they have finished using them. Most humanities/social science professionals' responses were coded as "non-persistent". Regardless of whether their images are object or spatial, humanities/social science professionals tend not to maintain them for a long time. Even when conscious effort is applied to maintain their images, their images still tend to lose quality and fade quickly.

4.1.3.4. Image transformation. Participants were asked questions about image transformation. First, to assess which characteristics of images, *visual-object or visual–spatial*, they transform, participants were asked about which specific properties of their images (e.g., color, shapes, details, orientations, etc.) they change. Second, to assess whether their image transformation is *intentional or unintentional*, participants were asked whether they intentionally change their images and for what purposes they might do so.

4.1.3.4.1. Visual-object versus visual–spatial characteristics of image transformation. Participants' descriptions of which characteristics of their images were transformed were coded into four categories: "object", "spatial" (depending on whether these images' characteristics tended towards being pictorial versus schematic), "mixed" (when participants performed object or spatial transformations depending on the type of image), and "none". Responses were classified as "object" when they described the transformation of such characteristics as vividness, color, shape and other pictorial visual properties, and "spatial" when they described the transformation of such characteristics as spatial configuration, orientation, and location, and "mixed" when they included both. The "none" category was included to account for considerable amount of participants who reported that they do not transform their images at all. Chi-square analysis revealed significant differences between the groups ($\chi^2(6) = 30.224$, $p < .001$), see Fig. 15.

Some visual artists' responses were categorized as "either", since the artists reported that they perform both spatial and object transformations on their images. They reported performing spatial transformations when changing the composition and arrangement of a mental image in order for it to be translated to physical form, and object transformations when they changed colors, textures and shapes. Other responses were categorized as "object", when artists reported that they only perform transformations on the visual-object characteristics of their images, only a few responses fell into the "spatial" category. A considerable portion of visual artists' responses were categorized as "none"; many artists reported that they do not perform any transformations on their mental images, but rather they recognize finer details or see new aspects their images through trying to understand them.

Scientists' responses were all categorized as "spatial"; they reported that they manipulate and transform only the spatial properties of their images, such as spatial configuration, but do not change (or even attend) the object properties of their images, such as color or texture. Humanities/social science professionals' responses tended to fall into the "none" and "either" categories, since they tend not to transform their images, since imagery processing is not important for their work. They sometimes transform their spatial schematic images in order to rearrange the structure of their concepts generated by a text, but they typically do not change anything in object images that accompany their verbal thinking.

4.1.3.4.2. Intentionality of image transformation. Responses were coded into four categories: "intentional", "unintentional" "mixed" and "none" depending on whether image transformation was performed purposely. The "none" category was included to account for reports that indicated that participants do not transform their images at all. Chi-square analysis revealed significant differences between the groups ($\chi^2(6) = 15.051$, $p = .020$), see Fig. 16.

Visual artists' responses were mostly categorized as "unintentional", since they reported that they transform their images unintentionally. In many cases, visual artists reported that their images "live their own lives", highly influenced by emotion, and change their properties independent of conscious effort, and sometimes even contrary to it. Scientists' responses mostly fell into the "intentional" category; they often reported that they can easily transform their images and that these transformations are fully intentional. Scientists reported that they usually change their images for rational, logical reasons related to efficient problem solving. Humanities/social science professionals' responses tended to fall into the "none" and "unintentional" categories, since they reported that they usually either do not change their images, simply because they do not pay much attention to them, or that they were able to manipulate their schematic images, primarily changing their spatial arrangement, but they could not change their spontaneous visual background images generated by text.

4.2. Study 3b

4.2.1. Participants

Study 3b consisted of interviews with the same professionals who participated in Study 2a.

4.2.2. Procedure and materials

The qualitative structural interviews lasted from 20 to 40 min. Participants were asked questions about the specific *functional role of visual imagery* in solving professional tasks, and whether it hindered or facilitated completion of these tasks. Additionally, analysis was performed on spontaneous responses about *emotional processing* in relation to visual imagery used by professionals (specific questions about this were not asked, but many participants volunteered this information). Spontaneous answers were encouraged. Close attention was paid to qualitative descriptions of the specific visual-object versus visual–spatial characteristics of professionals' images during use of imagery at work.

4.2.3. Results

The coding procedure was the same as described in Study 3a. Examples of imagery-related statements from professionals' self-reports are presented in Table 6.

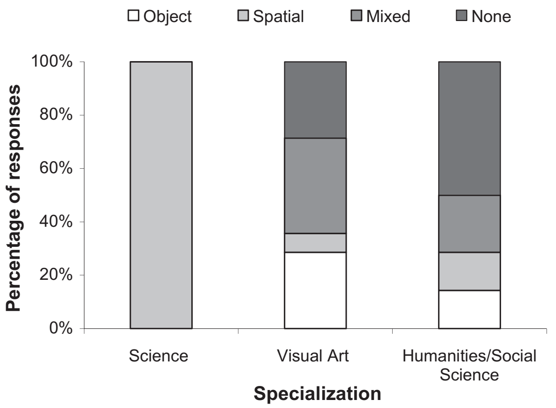

Fig. 15. Visual-object versus visual–spatial characteristics of image transformation.

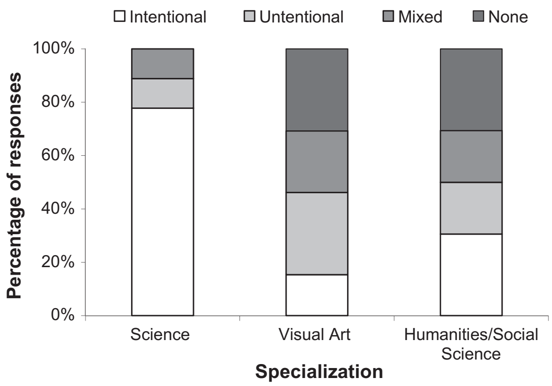

Fig. 16. Intentionality of image transformation.

4.2.3.1. Functional role of visual-object versus visual–spatial imagery. Professionals were asked about the role of visual imagery and its specific functions at different stages of their working processes. Depending on their reported degree of use of imagery for their work, participants' responses were coded into the following categories: "hindering", "epiphenomenal", "important", and "very important". Responses were coded as "hindering" when participants described their visual imagery as an obstacle to successful completion of their work, whether it distracted, misled or otherwise impeded their work. Responses were coded as "epiphenomenal" when participants described their imagery experiences as a secondary by-product of thought that neither facilitates nor hinders their work. Responses were coded as "important" if participants described their imagery experiences as helpful only in some stages or work (such as planning or estimation of results). Responses were coded as "very important" when participants described their imagery experiences as crucial for successful work performance, usually at all stages. Chi-square analysis revealed significant differences between the groups ($\chi^2(6) = 43.029$, $p < .001$), see Fig. 17.

All visual artists' responses were coded as "very important"; they all reported that visual imagery is crucial for most or all parts of their working process. Visual artists use their imagery at multiple stages of the art-making process: as inspiration for beginning artwork (image is generated spontaneously), during the planning of details of artwork (image is inspected and more details appear), during implementation of their ideas (image is maintained during execution of the artwork, e.g., drawing, sculpting or painting), and at the final stage of estimating the artwork.

Most scientists' responses were categorized as "important". Scientists, like visual artists, also appreciate the great role of imagery for their work, but they attribute less importance to the use imagery than do visual artists. Scientists tend to use imagery mostly for problem solving: during the planning of work (e.g., outlining the logical structures of research, schematizing the parts of a problem and their interactions), setting up experimental environments (e.g., assembling optics networks), understanding relationships among data (e.g., comprehending graphs and diagrams), or when solving a problem that has a visual solution that is more efficient than a verbal–analytical solution (e.g., 3D chemical structures, circuit diagrams, vector and free body computations).

Humanities/social science professionals' responses were mostly coded as "epiphenomenal", since they generally do not recognize imagery as important for their work, and most consider imagery as a background phenomenon that arises while reading a text. Some responses were also categorized as "hindering", in cases where humanities/social science professional reported that their background images could distract them from comprehending their work-related materials. None of them considered imagery as "very important".

4.2.3.2. Role of emotion in visual-object versus visual–spatial imagery. Even though participants were not explicitly asked about role of emotion in their imagery processes, some of them mentioned emotions without any prompting. Depending on the reported emotional content of their imagery for their work, participants' responses were coded into the following categories: "present", "absent" and "not mentioned". Responses were coded as "present" when participants spontaneously mentioned emotions, primarily in relation to imagery generation, maintenance, and control of these processes. Responses were coded as "absent" when participants spontaneously mentioned that their visual imagery was entirely devoid of emotion. Other responses were coded as "not mentioned". Chi-square analysis revealed significant differences between the groups ($\chi^2(4) = 15.929$, $p = .003$), see Fig. 18.

Many visual artists spontaneously mentioned that their visual images contained emotional content. This often took the form of their images being emotionally motivated, based on emotional experiences, or intended to convey emotion throughout their artwork. Some visual artists also reported that they use imagery in their everyday lives in order to regulate, manipulate and control their own emotions. Most scientists' responses were coded as "not mentioned", since very few of them mentioned emotions at all. Moreover, a few scientists even claimed that the ease of manipulation and control, as well as transience of their image was in part due to their images' lack of emotional content. Scientists reported that they use their visual images for problem solving, and their aesthetic/emotional value does not play any role. Some humanities/social science professionals' responses, unlike those of scientists', were coded as "present". Those images that contained emotional value tended to be visual-object images.

Table 6
Selected examples of imagery-related statements from professionals' participating in Study 3b.

Category	Visual art	Science	Humanities/social science
Functional role of visual-object vs. visual–spatial imagery	I see images in my head and then I just transfer them onto paper. I draw what I imagine, so it's critical for me to have imagery. Usually, I see an image, and the next task is to find the material and technique to draw it	Imagery helps me to understand how all the data is related. I visualize how hinges will route whether it is going to be a direct one to one, when trying to think of trees and the structure of the tree and how it actually structures itself	Images are just accompanying my thoughts, they are not really important
Role of emotion in visual-object vs. visual–spatial imagery	Instead of throwing a glass at the wall to break it, when I really want to, I can just imagine it – imagine how it will break into tiny pieces, and how they will scatter. Then, I can collect them back together in my imagery. This calms me down	My images are not emotional	Images are usually transient, and appear mostly during emotional descriptions of the text

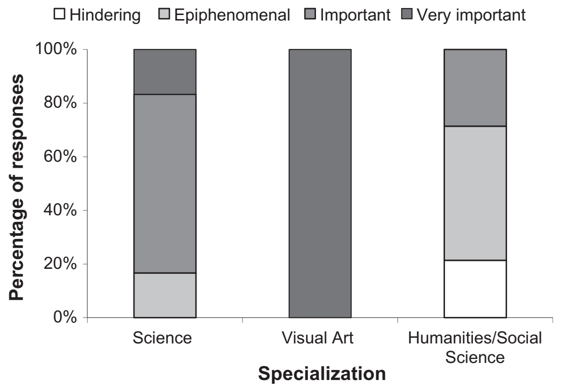

Fig. 17. Functional role of visual-object versus visual–spatial imagery.

Overall, across professional groups, emotional content was ascribed only to visual-object imagery, and never to visual–spatial imagery. The professionals' reports support the suggested link between object imagery and emotion. Individuals with predominantly visual-object imagery experiences (visual artists and some humanities/social science professionals) admit the role of emotional inspiration and emotional content in the creation and evaluation of their work, and appreciate emotions in art. In contrast, individuals who tend towards more visual–spatial and verbal–analytical processing (scientists and most humanities/social science professionals) tend to talk neither in terms of emotions nor report that emotions are important for their work.

4.2.4. Discussion

The current study demonstrated qualitative differences in the subjective characteristics of the visual imagery experiences of members of different professional groups, most notably pronounced between visual artists and scientists. These findings further support the distinction between visual-object and visual–spatial abilities found in Study 1 and Study 2. Overall, visual artists reported visual experiences that could be primarily characterized as visual-object, whereas scientists reported visual experiences that could be characterized as primarily visual–spatial. Humanities/social science professionals, overall, reported less use of imagery, with no clear preference to using either visual-object or visual–spatial mode of information processing.

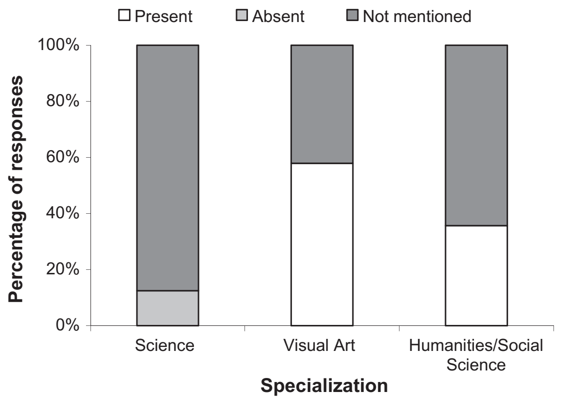

Fig. 18. Role of emotion in visual-object versus visual–spatial imagery.

Specifically, the results of Study 3a demonstrated qualitative differences between visual-object and visual–spatial imagery processes described by professionals across all stages of visual processing (image generation, inspection, maintenance and transformation). At the *generation* stage, visual artists describe their images as vivid, pictorial, rich in color, detail and texture, and generated holistically, as single perceptual units, with fine details present upon generation, and content that is not always deliberately generated. In contrast, scientists described their images as mostly schematic, reflecting primarily the structural properties of objects and scenes. Scientists' images tended to be generated intentionally and primarily in a sequential way, part-by-part. During the *inspection stage*, visual artists tend to intentionally inspect their visual images in detail, in order to explore their images' meanings, which are often ambiguous and multifaceted. In contrast, scientists' images are less likely to be purposely inspected, since scientists' images are usually generated specifically for rational, logical tasks, and thus their meanings tend to be unambiguous and apparent upon generation. During image *maintenance*, visual artists' images are stable, and often persistent. Visual artists tended to maintain their images effortlessly, in contrast to scientists, who generally maintain only specific parts of their images only through conscious effort. At the image *transformation* stage, a considerable amount of visual artists reported that their images were highly resistant to transformations, to the point that it is often easier for such artists to create a new image than try to transform a current one. In cases when they do perform transformations, they transform primarily visual-object properties (e.g., color, and shape) of their images, but not purely visual–spatial properties (e.g., rearranging the visual–spatial structure). Scientists, in contrast, report themselves to be very efficient in spatial transformation, and do not regard object transformation as relevant. These results expand Kosslyn's theory of imagery, indicating that all four stages of imagery processing exist independently in visual-object and visual–spatial imagery and that there are qualitative differences between visual-object and visual–spatial imagery at all four stages.

Study 3b revealed differences between visual artists and scientists in the functional role of imagery in their work. Visual artists reported that visual-object imagery is necessary for most or all parts of the creation of artistic works, and is a major source of inspiration. Scientists reported the importance of visual–spatial imagery for their work, especially for problem solving and planning purposes. Visual artists report that their emotions facilitate their visual-object processing (e.g., image generation, memory), while scientists associate no emotions with visual–spatial processing, and furthermore, they try to prevent their images from having any emotional content, claiming that emotions would interfere with visual–spatial processes.

As for humanities/social science professionals, our results show that they tended to describe their imagery processes without any clear preference to either the visual-object or visual–spatial imagery. Humanities/social science professionals were more flexible than scientists or visual artists in switching between spatial and object modes of information processing, depending on task demands However, they did not report the same level of proficiency in spatial imagery as scientists, or in object imagery as visual artists. It is possible that their imagery is mediated by verbal processing, unlike mental imagery of artists and scientists, and that humanities/social science professionals use symbolic means as intermediate representations that allow a certain level of control and flexibility in image manipulation compared to unmediated processing (see also Vygotsky, 1986).

Overall, Study 3a and 3b provide evidence that visual-object processing, which is primarily employed by visual artists, is qualitatively different at all its stages from visual–spatial processing, which is primarily employed by scientists, further supporting the validity of visual-object ability as a unique dimension of intelligence.

5. General discussion

The current research is the first to establish *visual-object ability* as a legitimate dimension of intelligence by providing evidence that visual-object ability indeed satisfies all of the suggested requirements of an independent dimension of intelligence: (1) unique ecological validity; (2) capacity to support abstract processing; and (3) unique qualitative and quantitative characteristics, irreducible to spatial and verbal components of intelligence. Our results are in line with multicomponential theories of intelligence that do not necessarily dispute the existence of *g*, but suggest that specific abilities (that may in part be mediated by g) are important for determining specific life outcomes; we claim that visual-object ability is one such domain-specific component of intelligence.

Contrary to the suggestions of Galton (1880) and his followers, our findings suggest that *abstract representations do exist in the visual-object domain*. Consistently with our results, there are many theoretical works on the semiotics of visual art and design, which suggest that visual art as a system has its own symbolic language with unique syntax, function and cultural meaning (Gage, 1999; Gombrich, 1982; Goodman, 1968). Overall, our findings that visual-object ability supports abstract processing addresses the claims of many researchers regarding the relationship between intelligence and abstract processing; the high-level abstract processing intelligence requirement identified by Gottfredson (1997), the proposal that intelligence is related to the ability to derive abstract relations by Carpenter et al. (1990), and the capacity of communication in symbolic form and concept formation described as fundamental dimensions of intelligence (Horn, 1985; Humphreys, 1985; Sternberg, 1985; Vygotsky, 1978).

Furthermore, our findings suggest that visual-object imagery has unique qualitative characteristics at all four stages of image processing, and that the properties of visual-object imagery at different stages of processing are intrinsically linked; they might be seen as emergent properties of the holistic nature of visual-object processing. Likewise, the properties of visual–spatial processing at different stages might be seen as emergent from the sequential nature of visual–spatial processing. The found differences between the holistic nature of visual-object processing and the sequential nature of visual–spatial processing as reported by visual artists and scientists, respectively, are consistent with cognitive neuroscience evidence on the distinction between object and spatial imagery. There is neuroscience evidence that object images are generated by pattern activation in a visual buffer (i.e., topographically organized areas in the occipital lobe, V1 and V2) on the basis of information stored in long-term memory, and encoded globally as discrete perceptual units. In contrast, spatial images are generated sequentially, part-by-part, via successive shifts of attention to represent spatial relations between objects or their parts (for a review, see Kosslyn, 1994; Kosslyn et al., 2006). In general, global encoding and processing of images by visual-object system would hinder flexible image transformations, but facilitate image generation and recognition, since the time needed to generate and activate an object image should not depend on an image's complexity. In contrast, sequential processing of images by visual–spatial system facilitates flexible spatial transformations but not image generation or maintenance. Since scientists comprehend the structure of a scene by parts, their visual–spatial images seem to be more flexible and transformable. In contrast, visual artists' images encoded as single, global perceptual units which are not easily transformable: parts of the image are locked into place with one another thus, one part is difficult to transform without transforming the others. Thus, both the object and the spatial types of imagery are uniquely suited for effective visual processing at different stages for different tasks.

Contemporary neuroscience theories (e.g., Jung & Haier, 2007; Prabhakaran & Rypma, 2007) suggest the role of domain-specific areas as vital to intelligence, but emphasize the role of interaction between these domain-specific areas and higher level functions related to attention and the central executive component of working memory, which are associated with *g*, and reside in the frontal and prefrontal cortex (Duncan & Owen, 2000; Gray, Chabris, & Braver, 2003). One interesting future research direction would be to investigate the neural correlates of visual-object intelligence by exploring functional connectivity and interactions between frontal areas of the brain and neural networks underlying object processing (ventral pathway). It has been shown that spatial ability is related to spatial working memory capacity, and as well as available central executive resources (see Miyake et al., 2001). Future studies are needed to investigate whether visual-object ability could be in a similar way related to object working memory capacity as well as central executive resources.

In addition, the results of our research suggested that visual-object imagery may be uniquely related to emotional processing consistently with those of Downey, Mountstephen, Lloyd, Hansen, and Stough (2008) who found that the Understanding Emotions measure significantly predicted scores for scholastic achievement in art, whereas the Emotional Management and Emotional Control measures were found to significantly predict scholastic achievement in math and science. The found relationship between visual-object processing and emotion further establishes the ecological validity of the visual-object imagery dimension, and suggests that visual-object imagery might be connected to other emotionally moderated cognitive processes. For example, visual-object imagery can be advantageous for fast intuitive decisions based on limited or degraded information, for making immediate manifold connections, for memorizing, and for empathy, self-awareness and social behavior. Future studies are required to systematically investigate the specific role of visual-object imagery in these constructs.

Another important direction for future research would be to further develop visual-object intelligence assessments. Current IQ tests either fully ignore visual-object ability or assess visual-object and visual–spatial ability as a single unitary construct (nevertheless mostly tapping spatial, but not object, ability). Research by Kozhevnikov et al. (2005) investigated the relationship between the object–spatial dimensions and such traditional *g* IQ measures as Raven Matrices and Verbal WASI and found that WASI is unrelated to both visual-object and visual–spatial abilities, while performance on Raven's matrices tends to correlate with visual–spatial ability (see also Blajenkova et al., 2006). It would be the ultimate goal to include assessments of visual-object intelligence in standardized testing in both psychometric and academic environments, since no existing IQ tests fully tap visual-object ability, and general intelligence instruments, such as Raven's Matrices (Raven, Raven, & Court, 1998), which are based on verbal-analytical and spatial measures, are intrinsically biased towards spatial and verbal ability.

Research has, in general, noted that visual ability was a neglected dimension in talent searches, despite its unique predictive validity (Webb, Lubinski, & Benbow, 2007), and criticized the existing system of identification of giftedness that is currently mainly restricted to verbal and mathematical ability, despite the purported intent of seeking and developing talents across multiple dimensions. Although some talent search programs include assessments of visual–spatial intelligence, there are no currently existing assessment procedures for visual-object intelligence. Developing and improving measures of visual-object ability will lead to high visual-object intelligence individuals not being neglected in terms of intelligence assessment and talent search, and bolster professional membership in fields that require such abilities.

Similarly, our findings strongly suggest the need to develop appropriate training procedures to improve performance on visual-object tasks and comprehension of visual-object representations. While much attention has been paid in educational research to training visual–spatial abilities (e.g., (Kozhevnikov & Thornton, 2006; Lohman & Nichols, 1990; Lord & Holland, 1997; Pallrand & Seeber, 1984), training of visual-object abilities has not received as much attention. Assessment and training procedures for visual-object ability would be of great value for identifying visual-object gifted individuals, and helping them to realize their full potential and efficiently develop their skills in a professional field.

Recently there has been a great increase in the importance of object information and object–abstract representations in various media, including educational media, movies, advertisements and contemporary art. Also contemporary media tends to use rapidly presented, emotionally charged visual stimuli that need to be processed holistically and quickly. Thus, in contemporary society, due to new task demands, the role of visual-object intelligence has been increasing, and thus, recognizing visual-object ability as a type of intelligence and developing individuals' visual-object abilities might be critical not only for success in visual arts, but also in a wide range of professions and in everyday performance.

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