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Measuring the Interrelations Among Multiple Paradigms of Visual Attention: An Individual Differences Approach

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A large part of the empirical research in the field of visual attention has focused on various concrete paradigms. However, as yet, there has been no clear demonstration of whether or not these paradigms are indeed measuring the same underlying construct. We collected a very large data set (nearly 1.3 million trials) to address this question. We tested 257 participants on nine paradigms: conjunction search, configuration search, counting, tracking, feature access, spatial pattern, response selection, visual short-term memory, and change blindness. A fairly general attention factor was identified. Some of the participants were also tested on eight other paradigms. This general attention factor was found to be correlated with intelligence, visual marking, task switching, mental rotation, and Stroop task. On the other hand, a few paradigms that are very important in the attention literature (attentional capture, consonance-driven orienting, and inhibition of return) were found to be dissociated from this general attention factor.

Keywords: visual attention, individual differences, general attention factor

In recent decades, visual attention and related processes have been among the most rapidly growing fields in cognitive psychology and neuroscience. A large part, although by no means all, of the empirical research in these fields has been driven by very concrete paradigms, such as visual search (e.g., Treisman & Gelade, 1980), change blindness (e.g., Rensink, Oregan, & Clark, 1997), and attentional tracking (Pylyshyn & Storm, 1988). These paradigms have spawned thousands of studies and a very in-depth understanding has been gained of particular paradigms. However, it is hard to say how the knowledge gained from the various paradigms could work together to reveal the fundamental underlying construct, namely visual attention.

The central idea of the concept of attention is *a limit of information processing*. Visual search, for example, is considered to reflect attention because observers try to find goal-relevant information (i.e., targets) and exclude goal-irrelevant information (i.e., distractors), presumably because it is impossible to process all of the information efficiently due to the limit of information processing. All of these classic paradigms are reasonably related to the general concept of attention. But, to the best of our knowledge, there is no explicit agreement in the field as to whether or not the limits reflected in these paradigms are the same. On the one hand, it is perhaps not implausible that the same general attention factor is behind all of these different paradigms. On the other hand, it is also easily conceivable that these different paradigms could reflect *limits in the different stages of information processing;* if so, they would be dissociated from each other. The present study tries to explore the research question of the relationships between these multiple paradigms, specifically to see how unified (or how separable) they are, in order to shed light on the nature of the underlying limit(s). To start, we will consider the different ways of studying this question.

Previous Approaches

Before introducing the rationale of the present approach, let us first consider other approaches that have been attempted to achieve the goal of revealing the relationships between multiple visual attention paradigms. First, scientists have empirically tested the relationships between different paradigms based on dual-task performance (e.g., Alvarez, Horowitz, Arsenio, DiMase, & Wolfe, 2005). Even though these studies have shed useful light on this topic, they lack the power of comparing many paradigms simultaneously. Hypothetically, assume that we found that both paradigms A and B and paradigms A and C interfere with each other. Paradigms A and B therefore share some common attentional

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limit, as do paradigms A and C. However, we cannot know whether there is a general attentional limit for all three paradigms because what is shared between A and B could well be different from what is shared between A and C. Therefore, these studies shed little light on the overall picture across multiple paradigms.

Second, scientists have developed broad theories that try to incorporate these disparate paradigms into one framework. This has been a successful approach in other disciplines, such as physics; Newton's Laws, for example, led to a breakthrough in classical mechanics, largely because they explained phenomena that seemed to be totally irrelevant to each other, such as gravity on the Earth and the trajectory of planets. Nevertheless, how theoretical concepts should be interpreted in novel paradigms is often rather subjective in this field, thus making it difficult for these theories to make uncontroversial predictions. The seminal feature integration theory (Treisman & Gelade, 1980), for example, has substantially advanced our understanding of visual attention, but, apart from those paradigms that have been explicitly presented along with the theory (e.g., a visual search for a feature singleton), it is not always clear how conceptual notions such as "parallel feature processing" should be interpreted in a novel paradigm. The recent Boolean map theory has shown that "feature processing" is not parallel when all feature values have to be consciously accessed (Huang & Pashler, 2007; Huang, Treisman, & Pashler, 2007; Huang, 2010), thus making it clear that the implications of even a straightforward term could be difficult to interpret in a novel paradigm.

Other important theoretical frameworks have also been proposed to try to give a unified description across multiple paradigms. The biased competition model (Desimone & Duncan, 1995), for example, has tried to propose a unified neuronal explanation for a set of fairly diverse findings. Bundesen's TVA (theory of visual attention, Bundesen, 1990) approaches this question even more explicitly: it uses only a few variables to provide a good quantitative fitting for the behavioral results of multiple paradigms. From another perspective, Posner and Petersen (1990) have proposed three attentional networks (vigilance, orienting, and conflict resolution) and have provided support for this division from tasks such as the Attention Networks Test (ANT). Although there is no doubt that these theories/models have all shed very important light on the mechanisms of visual attention, it remains largely unclear how most classic attention paradigms are related to each other.

An Individual Differences Approach

In the present study, we take an approach that differs from those outlined above. We measure the performance of a group of human observers on many paradigms. The basic rationale of this individual differences analysis can be exemplified as follows: if observers' performances are correlated on paradigms A and B but these performances are not correlated with the performance on paradigm C, this means that A and B are related to each other in some way (e.g., they share part of their underlying mechanisms), but C is probably measuring something different. More sophisticated techniques (e.g., factor analysis) allow the "structure" of multiple paradigms to be extracted, as will be discussed below.

This approach has advantages over the two approaches outlined above. First, it allows the simultaneous comparison of many paradigms. Second, the conclusions that emerge from this analysis should be relatively objective, uncontaminated by the bias caused by the theoretical positions of particular researchers. Certainly, this approach also has its limitations. Unlike experimental designs, correlational studies cannot precisely determine the direction of causality. At the very least, this new approach can provide unique insights and should supplement the two approaches described above.

This individual differences approach has been widely applied in social psychology, developmental psychology, and some areas of cognitive psychology, such as intelligence and executive function (e.g., Engle, Tuholski, Laughlin, & Conway, 1999; Kane & Engle, 2000; Miyake et al., 2000), and has made a substantial impact. However, its application in the field of visual attention has been relatively limited; it has mainly been used in the ways described below.

Previous Studies on Individual Differences

In a series of studies, Engle, Kane, and their colleagues argued that individual working memory capacity is strongly related with executive attention (Kane & Engle, 2002; Engle, 2002; Engle & Kane, 2004; Kane, Bleckley, Conway, & Engle, 2001; Kane & Engle, 2003; Kane, Poole, Tuholski, & Engle, 2006). They compared the performance of observers with high and low working memory span in various tasks. In Kane et al. (2001), observers were required to detect targets in either cued or uncued locations; there was no difference between the two groups in the task involving the detection of cued targets, but the high-span group was significantly better than the low-span group in detecting uncued targets, suggesting that working memory capacity is not correlated with automatic orienting but is correlated with the voluntary attentional control process. Kane and Engle (2003) found consistent evidence for the working memory attention relation from a Stroop task. It is interesting that Kane et al. (2006) found that the performance of high and low working memory span groups was equivalent in feature search, conjunction search, and spatial configuration search tasks, suggesting that "executive attention" may differ from the "visual attention" involved in visual search tasks.

The individual differences approach has also been applied in the visual attention field to determine the interrelations between the multiple factors of one paradigm. Here, we will use attentional blink as an example. Arnell, Howe, Joanisse, and Klein (2006) showed that the magnitude of observers' attentional blink was only moderately predicted by their target 1 accuracy and not predicted at all by either their target 2 accuracy or single-target accuracy. This suggests that individual attentional blink magnitude is not well explained by general information-processing efficiency. On the other hand, Colzato, Spape, Pannebakker, and Hommel (2007) found that individual attentional blink magnitude was correlated (negatively) with working memory operation span but not with intelligence, and they argued for the possible role of individual processing limits in attentional blink. Arnell, Stokes, MacLean and Gicante (2010) further showed that it is not the static storage capacity, but rather the executive component, of visual working memory that affects individual attentional blink magnitude.

A third interesting application of the individual differences approach is its use in characterizing a distinctive feature of some unique observers. For example, Green and Bavelier (2003, see also Green & Bavelier, 2006, 2007) showed that habitual action video game players performed better than nonplayers in various cognitive tasks involving visual attention and working memory.

Although very useful insights have been gained from each of the above-mentioned approaches, they have not directly helped to reveal the underlying relationships between multiple visual attention paradigms. Although the studies of Engle, Kane, and their colleagues (e.g., Kane & Engle, 2002; Engle, 2002; Engle & Kane, 2004) have focused on the relationships between different paradigms (i.e., working memory vs. executive attention), they did not simultaneously cover important visual attention paradigms (e.g., visual search, tracking, and change blindness). More importantly, Kane and colleagues (2006) seemed to imply that the "executive attention" they studied is separate from the "visual attention" studied by experimental psychologists.

To answer the question on the underlying relationships between multiple visual attention paradigms, the appropriate approach is to test many visual attention paradigms on one group of observers and to use exploratory factor analysis (EFA) to extract the constructs. To the best of our knowledge, this relatively straightforward approach has not been tried before. The reasons for this are not completely obvious, although we suspect there may be two reasons. First, the experimental and psychometric methods of studying "attention" remain relatively segregated; therefore, the studies based on psychometric methods have not systematically covered those paradigms that have mainly interested experimental psychologists. Second, perhaps the exceptionally large data demands of this approach make it impractical. Unlike many of the questionnaires studies, which can efficiently measure dozens of variables in one or two sessions, measuring the performance of observers on these attentional paradigms takes much longer. A separate session of decent length is needed to measure just one variable. To ensure reliable and clear-cut results, we collected a large set of data (about 3,200 separate sessions from 257 participants).

In the present study, we adopted a typical exploratory approach of individual differences analysis. In this approach, a researcher seeks to understand the empirical associations among a set of measurements. The specific technique we used, principal components analysis (PCA), calculates the pattern of correlations among a set of variables and attempts to reduce these variables to several principal components. More specifically, this technique, when applied to a set of variables, identifies coherent subsets that are relatively separate from each other and a coherent subset (i.e., a group of variables that are correlated with each other but largely uncorrelated with other subsets of variables) is combined into one factor (or principal component). The extracted factors are supposed to reflect the relatively independent underlying mechanisms that have caused the correlations among the variables.

Possible Relationships Between the Various Paradigms

In this field, when the term *attention* is used to refer to many different paradigms, researchers may, often implicitly, have very different assumptions. Some researchers (e.g., those who propose general theoretical frameworks, such as those mentioned above) may indeed intend to suggest that there is a general attentional limit that is shared by many, if not all, of these paradigms; for others, the term may be nothing more than a convenient label. Next, we will consider the possible relationships between the different paradigms and also how they could be distinguished based on the present study's individual differences data.

A General Attention Factor

First, there may be a general attention factor (i.e., a general attentional limit) that is shared by the majority of the paradigms that have been conventionally included in this field. This would manifest itself as a general factor shared by many of the paradigms. However, even if this pattern shows up in the results, before we can reach a conclusion on a general attention factor, one potential issue has to be addressed: the contribution of general cognitive ability. A century of research has shown that when performances are measured on a wide range of cognitive tasks, the correlations between them are usually all positive. Such findings led to Spearman's theory of the g factor (e.g., Spearman, 1927). Generally, a first factor, often defined as the *g factor*, will account for a large portion of the variance across all of the cognitive tasks tested, with the second and subsequent factors accounting for less of the variance. Normally, the impact of the g factor is reflected in very strong correlations with standard intelligence tests such as Raven's test (Raven, 1962). Therefore, to address this potential concern, we included Raven's test in our list of paradigms.

Paradigm-Specific Mechanisms

Second, given that in the various paradigms the nature of attention involved is rather different, there will probably be some mechanisms that are unique to each of the specific paradigms. A paradigm-specific mechanism would manifest itself as the gap between the portion of the variance that could be explained by the factor(s) and the portion of the "reliable" variance that could be estimated from the reliability of the measurement. For example, if for one paradigm, 30% of the variance can be explained by the factor(s) and the reliability of the measurement is 0.9, then the mechanism of this paradigm is mostly unique. Generally, given the apparent diversity of the different paradigms, one may expect that paradigm specific mechanisms would account for a fair amount of variance. The present study should shed light on this issue by determining the extent of such paradigm-specific mechanisms: are the mechanisms of these paradigms mostly unique or mostly shared with the others?

Semigeneral Mechanisms

Between the two possibilities mentioned above, there could be mechanisms that contribute to a few, but not all, of the paradigms in the field of attention. In the present study, we will see whether any such semigeneral mechanism is apparent in the data.

Choice of Paradigms and Outline of the Present Study

Although we have tried to study this topic systematically using a fairly large number of paradigms, the term attention, as we use it, still only refers to one subset of the concepts/areas covered by this word in the literature. As our main research interest is the topic of visual attention, the present study focuses on the selective processing and representation of visual information (primarily perceptual information, but sometimes also memorized information). We have therefore not covered attention in other modalities (e.g., auditory attention, Broadbent, 1958), vigilance (e.g., Mackworth, 1969), or attention in more central processing (e.g., Baddeley, 1986; see also Moosbrugger, Goldhammer, & Schweizer, 2006 for an attempt to distinguish this from perceptual attention based on individual differences).

The present study is divided into two steps: primary paradigms and secondary paradigms.

Primary Paradigms

Nine primary paradigms were completed by 257 participants, with a separate session for each paradigm. The nine primary paradigms were chosen based on the criterions that each paradigm had to be a classic paradigm in the field of visual attention, and/or conceptually characterize visual attention very well. Given these standards, we settled on nine paradigms: conjunction search, configuration search, counting, tracking, feature access, spatial pattern, response selection, visual short-term memory, and change blindness. In the pilot testing, we also included feature search (e.g., Treisman & Gelade, 1980), but this was removed from the list because its split-half reliability was lower than 0.7.

Secondary Paradigms

Some of the participants completed eight secondary paradigms, with a separate session for each paradigm. Among these secondary paradigms, five (visual marking, attentional capture, consonance-driven orienting, inhibition of return, and mental rotation) were included because they are also important attention paradigms. Stroop task and task switching were chosen because it has previously been reported that they are important functions of executive function (Miyake et al., 2000); therefore, including these paradigms can help us to understand the relationship between visual attention and executive function. Intelligence, as measured by Raven's test, was also included because it is often reported that intelligence is correlated with "mental capacities" (Engle et al., 1999) and also because, as mentioned above, we wanted to know to what extent the factor(s) that emerge from visual attention paradigms are caused by the g factor. In the pilot testing, we also included attentional blink (e.g., Raymond, Shapiro, & Arnell, 1992), priming of pop-out (e.g., Maljkovic & Nakayama, 1994), negative priming (e.g., Tipper & Driver, 1988), and contextual cueing (e.g., Chun & Jiang, 1998). However, these four paradigms were removed from the list because their split-half reliabilities were lower than 0.7.

Both the primary and secondary paradigms, together with some key references, are listed in Table 1. Further descriptions of the individual paradigms are given in the Method section.

The primary paradigms were tested using a large number of participants; therefore, PCA (see below) was performed to extract the general attention factor(s) from the nine variables measured in these nine paradigms. The secondary paradigms were tested using fewer (in some cases, much fewer) participants, and so we merely tested whether they were correlated with the attention factor(s) that had been extracted from the primary paradigms.

Method

Participants

The participants in this study were 257 students from South China Normal University, all of whom had normal or corrected-to-normal visual acuity.

Apparatus

The stimuli were presented on 1,024 × 768 pixel color monitors. The participants viewed the displays from a distance of about 60 cm and responded using a keyboard. The program was written in Microsoft Visual Basic 6.0.

Table 1
Key References and Descriptive Statistics for the Nine Primary Paradigms and Eight Secondary Paradigms

	Paradigm	Key references	Mean (*SD*)	*N*	Skewness	Kurtosis
Nine Primary Paradigms ($N = 257$)	Conjunction Search	Treisman & Gelade, 1980	77 msec/item (25)	257	−0.26	0.17
	Configuration Search	Egeth & Dagenbach, 1991	67 msec/item (21)	257	0.12	−0.02
	Counting	Gelman & Gallistel, 1978	33 msec/item (7)	257	−0.29	0.08
	Tracking	Pylyshyn & Storm, 1988	2.91 items (0.72)	257	0.27	−0.11
	Feature access	Duncan, 1980	38 msec (23)	257	−0.02	−0.21
	Spatial pattern	Barlow & Reeves, 1979	121 msec (74)	257	−0.03	−0.13
	Response selection	Passingham, 1993	647 msec (112)	257	−0.11	0.06
	Visual short-term memory	Phillips, 1974	2.64 items (0.58)	257	0.39	0.31
	Change blindness	Rensink, Oregan, & Clark, 1997	0.479 (0.112)	257	−0.35	−0.25
Eight Secondary Paradigms ($N < 257$)	Intelligence (Raven's test)	Raven, 1962	55.5 (3.6)	247	−0.05	0.06
	Visual marking	Watson & Humphreys, 1997	54.1% (23.2%)	95	−0.42	0.29
	Attentional capture	Yantis & Jonides, 1984	11.4% (7.4%)	95	0.15	0.46
	Consonance-driven orienting	Soto et al., 2008	0.885 (0.173)	95	0.69	−0.72
	Inhibition of return	Posner & Cohen, 1984	29 msec (23)	95	−0.08	−0.47
	Task switching	Monsell, 2003	284 msec (144)	95	0.42	0.02
	Mental rotation	Shepard & Metzler, 1971	238 msec (147)	94	0.51	−0.46
	Stroop task	Macleod, 1991	106 msec (52)	95	−0.43	−0.08

Note. In each session, if the measurement was response time, we excluded the outliers (values outside 3 standard deviations). Variables that were skewed and/or kurtotic were transformed to achieve approximate normality. For each variable, reliability was estimated by calculating the split-half (odd-even) correlations, and the Spearman-Brown formula was used for adjustment. See text for details of the measurements.

Primary Paradigm 1: Conjunction Search

A conjunction search is a search for a target, defined as the conjunction of two features, among distractors with only one of these features. In the present study, it was the search for a target, defined as the conjunction of an orientation (right-tilted) and a size (large), among distractors with either only the orientation (i.e., right-tilted but small) or the size (i.e., large but left-tilted).

In each trial, a small, white fixation cross was presented in the center of the display for 400 ms. This was followed by a short blank interval (400 ms), after which the stimuli were presented and remained on the screen until a response had been made. The stimuli were either 4 or 12 white bars on a black background and were distributed within a 15.6 cm × 15.6 cm region (see Figure 1a). The bars could be either large or small and either 45° left-tilted or 45° right-tilted. One bar (i.e., the target defined as a conjunction of size and orientation) was large and right-tilted; the rest were either small and right-tilted or large and left-tilted. There was a small ditch on either the left or right side of each bar, and the position of the ditch (i.e., left or right) was randomly determined for each bar. The participants attempted to decide whether the target's ditch was on the left or right side. They then pressed one of two adjacent keys (*j* for left side or *k* for right side) to indicate their response. They were asked to respond as quickly and accurately as possible (i.e., a speeded response). After responding, the participants heard either a pleasant or an unpleasant tone to indicate whether or not their response was correct, and the next trial began 400 ms later. The participants completed 10 blocks (47 trials per block). The first block was regarded as practice and excluded from the analysis.

This paradigm was measured by the slope (i.e., the extra time needed to process each additional item in the search task, specifically, (RT [12 items] − RT [4 items])/8. The search slope is a typical way of measuring how attention-demanding a search task is (e.g., Treisman & Gelade, 1980; Wolfe, 1994).

Primary Paradigm 2: Configuration Search

A configuration search is a search for a target, defined as a specific spatial configuration of features, among distractors with the same features but a different spatial configuration. In the present study, it was the search for a target, defined as the spatial configuration of "white above black," among distractors with the different spatial configuration of "black above white."

In each trial, a small white fixation cross was presented in the center of the display for 400 ms. This was followed by a short blank interval (400 ms), after which the stimuli were presented; the stimuli remained on the screen until a response had been made. The stimuli were either 4 or 12 two-segment squares on a black background and were distributed in a 15.6 cm × 15.6 cm region (see Figure 1b). The top and the bottom half of the target square were, respectively, white and black, whereas the other squares had a black top half and a white bottom half. There was a small ditch on either the left or right side of each bar, and the position of this

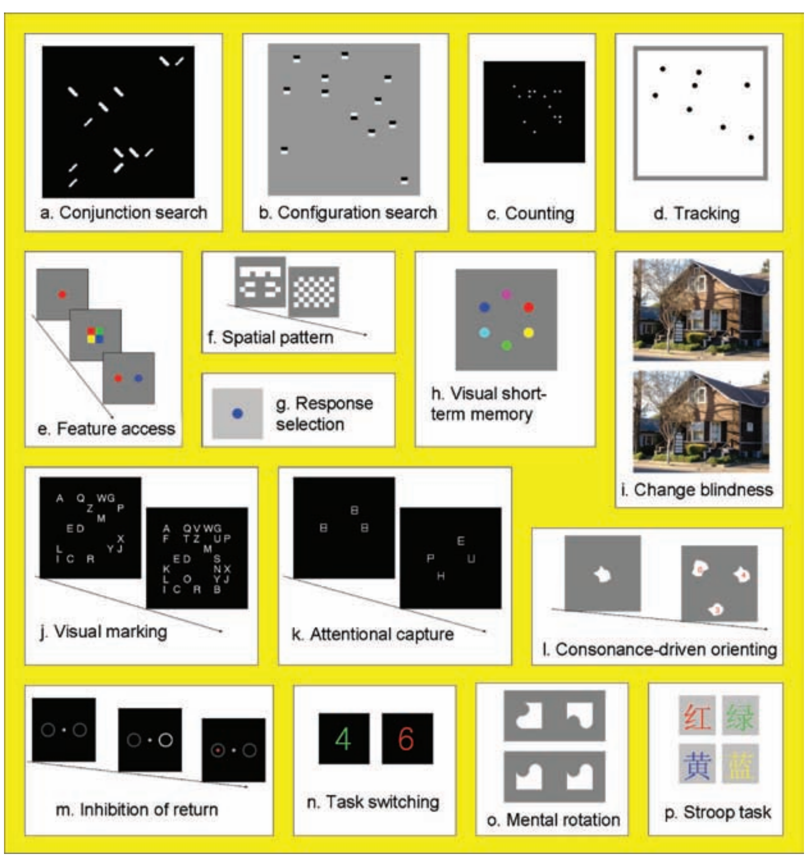

Figure 1. Methods for the nine primary and eight secondary paradigms.

ditch (i.e., left or right) was randomly determined for each square. The participants attempted to decide whether the ditch beside the target was on the left or right side. They then pressed one of two adjacent keys (*j* for left side or *k* for right side) to indicate their response. They were asked to respond as quickly and accurately as possible (i.e., a speeded response). After responding, the participants heard either a pleasant or an unpleasant tone to indicate whether or not their response was correct, and the next trial began 400 ms later. The participants completed 10 blocks (51 trials per block). The first block was regarded as practice and excluded from the analysis.

This paradigm was measured by the slope (i.e., the extra time needed to process each additional item in the search task, specifically, (RT [12 items] − RT [4 items])/8. The search slope is a typical way of measuring how attention-demanding a search task is (e.g., Treisman & Gelade, 1980; Wolfe, 1994).

Primary Paradigm 3: Counting

Counting involves counting the number of items (e.g., white balls in the present study) in a display.

In each trial, a small white fixation cross was presented in the center of the display for 400 ms. This was followed by a short blank interval (400 ms), after which the stimuli were presented; the stimuli remained on the screen until a response had been made. The stimuli were 3, 4, 13, or 14 white dots (diameter = 0.23 cm) on a black background distributed within a 10.4 cm × 10.4 cm region (see Figure 1c). The participants attempted to decide whether there was an even (i.e., 4 or 14) or odd (i.e., 3 or 13) number of dots in the display. They then pressed one of two adjacent keys (*j* for an odd number or *k* for an even number) to indicate their response. They were asked to respond as quickly and accurately as possible (i.e., a speeded response). After responding, the participants heard either a pleasant or an unpleasant tone to indicate whether or not their response was correct, and the next trial began 400 ms later. The participants completed 10 blocks (40 trials per block). The first block was regarded as practice and excluded from the analysis.

This paradigm was measured by the counting slope (i.e., the time needed to count each additional item, specifically, (RT [13 items] + RT [14 items] − RT [3 items] − RT [4 items])/20. The counting slope is a typical way of measuring how difficult a counting task is (e.g., Gelman & Gallistel, 1978).

Primary Paradigm 4: Tracking

Tracking involves keeping track of a subset among several visually identical items (e.g., black balls in the present study) that move around on random trajectories.

In each trial, eight black balls were randomly placed within a 14.6 cm × 14.6 cm white region (see Figure 1d). At the beginning of each trial, four balls (i.e., the target balls) flashed for 2 seconds. After the flashing stopped, the items began to move around on random trajectories at a speed of 6 cm/second. After 10 seconds of movement, the position of each item was covered by a button. The participants then attempted to identify the four target items by clicking the corresponding buttons. After four clicks, either a pleasant or unpleasant tone would sound to indicate whether or not all four responses were correct, and the next trial began 400 ms later. The participants completed nine blocks (9 trials per block). The first block was regarded as practice and excluded from the analysis.

This paradigm was measured using an estimate of the number of items that can be tracked (calculated from the average accuracy). Estimate of tracking capacity is a typical way of measuring tracking ability (e.g., Pylyshyn & Storm, 1988).

Primary Paradigm 5: Feature Access

Feature access involves perceiving a feature (e.g., the colors of balls in the present study) in a brief and masked display.

In each trial, a small white fixation cross was presented in the center of the display for 400 ms. This was followed by a short blank interval (400 ms), after which the stimuli were presented for a short period and then covered by masks. Each stimulus was a colored ball that could be red, green, yellow, or blue. The exposure duration of the stimuli was adjusted for each individual participant so that their overall performances were moderate. The masks remained on the display for 200 ms and then disappeared. Immediately following the disappearance of the mask, the test display was presented showing two items, only one of which had appeared in the stimulus display; this test display remained on the screen until a response had been made. One sequence (stimulus → mask → test display) is shown in Figure 1e. The participants attempted to decide which of the two items in the test display had been presented in the stimulus display. They then pressed one of two adjacent keys (*j* for the left item and *k* for the right item) to indicate their response. They were asked to respond as accurately as possible, but were under no time pressure (i.e., an unspeeded response). After responding, the participants heard either a pleasant or an unpleasant tone to indicate whether or not their response was correct, and the next trial began 400 ms later. The participants completed 10 blocks (40 trials per block). The first block was regarded as practice and excluded from the analysis.

This paradigm was measured by the exposure duration threshold, which was the exposure duration required to do this task to an accuracy of 75%. Exposure duration (or, sometimes, accuracy in a brief display of fixed duration) is a typical way of measuring the access of information (Duncan, 1980).

Primary Paradigm 6: Spatial Pattern

Spatial pattern involves perceiving a spatial pattern or relationship (e.g., the presence of symmetry in the present study).

In each trial, a small white fixation cross was presented in the center of the display for 400 ms. This was followed by a short blank interval (400 ms), after which the stimuli were presented for a short period and then covered by masks (as shown in Figure 1f). The stimuli were white patterns, which could be either symmetrical or asymmetrical. The exposure duration of the stimuli was adjusted for each individual participant so that their overall performances were moderate. The masks remained on the display for 200 ms and then disappeared. The participants attempted to decide whether the pattern was symmetrical or asymmetrical. They then pressed one of two adjacent keys (*j* for the left item and *k* for the right item) to indicate their response. They were asked to respond as accurately as possible, but were under no time pressure (i.e., an unspeeded response). After responding, the participants heard either a pleasant or an unpleasant tone to indicate whether or not their response was correct, and the next trial began 400 ms later. The participants completed 10 blocks (40 trials per block). The first block was regarded as practice and excluded from the analysis.

This paradigm was measured by the exposure duration threshold, which was the exposure duration required to do this task to an accuracy of 75%. Exposure duration (or, sometimes, accuracy in a brief display of fixed duration) is a typical way of measuring the ability to perceive a spatial pattern (Barlow & Reeves, 1979).

Primary Paradigm 7: Response Selection

Response selection involves quickly selecting appropriate responses according to a rather complex rule of mapping.

In each trial, a small white fixation cross was presented in the center of the display for 400 ms. This was followed by a short blank interval (400 ms), after which the stimuli were presented and remained on the screen until a response had been made. Each stimulus was a colored ball that could be red, green, yellow, or blue (Figure 1g). The participants attempted to decide the color of the ball. They then pressed one of four adjacent keys (*g* for red, *h* for green, *j* for yellow, *k* for blue) to indicate their response. They were asked to respond as quickly and accurately as possible (i.e., a speeded response). After responding, the participants heard either a pleasant or an unpleasant tone to indicate whether or not their response was correct, and the next trial began 400 ms later. The participants completed 10 blocks (50 trials per block). The first block was regarded as practice and excluded from the analysis.

This paradigm was measured by the average response time. Response time in a selection involving a rather complex rule of mapping is a typical way of measuring response selection ability (Passingham, 1993).

Primary Paradigm 8: Visual Short-Term Memory

Visual short-term memory involves memorizing a set of information in preparation for a test on one piece of this information.

In each trial, a small white fixation cross was presented in the center of the display for 400 ms. This was followed by a short blank interval (400 ms), after which the stimuli were presented. In a stimulus display (see Figure 1h), six balls (diameter 1.04 cm) of different colors, randomly created from eight possible colors (red, green, blue, yellow, purple, cyan, black, and white), were presented on a gray background. The six balls were evenly placed in a circle around the center of the screen at angles of 30°, 90°, 150°, 210°, 270°, and 330°, respectively, (right side = 0°) and in positions that were 5.2 cm from the center. The stimuli were presented for 800 ms and then disappeared. Following the offset of the stimuli, six arrays of buttons were presented, each placed in a position corresponding to the outer side of one of the six balls. Each array consisted of eight colored buttons corresponding to the eight possible colors. The participants attempted to push the button in each array that corresponded to the color of the ball in that particular position in the stimuli display. The participants were asked to respond as accurately as possible, but were under no time pressure (i.e., unspeeded response). After each response, the array, including the chosen button, was completely disabled so that only one response could be made for each color. Also, in all of the remaining arrays, the buttons of the reported color were disabled so that a color could not be reported more than once in each trial. A ball of the reported color was presented in the chosen location to allow the participant to see the choice he or she had made. After the participants had made responses in all six arrays, a digit flashed in the center of the screen to show the score (i.e., the number of correct responses), and the next trial began 400 ms later. The participants completed 10 blocks (14 trials per block). The first block was regarded as practice and excluded from the analysis.

This paradigm was measured using an estimate of capacity (i.e., the number of items that can be stored), which was calculated from the average accuracy. Estimate of storage capacity is a typical way of measuring visual short-term memory (e.g., Pashler, 1988).

Primary Paradigm 9: Change Blindness

Change blindness is the phenomenon that individuals often fail to detect a rather large change between two alternating scenes.

In each trial, a small white fixation cross was presented in the center of the display for 400 ms. This was followed by a short blank interval (400 ms), after which the stimuli were presented. To generate the stimuli, we chose 200 full-color 640 × 480 natural scene images. Moderate changes were manually made to these images to generate 200 pairs, each one of which was used in one trial (see Figure 1i). Frames A and B were presented alternately for four loops (i.e., ABABABAB), the duration of each frame and of each interframe interval being 300 msec and 200 msec, respectively. After the last frame, 10 buttons were presented on the screen: one button (i.e., the target button) was positioned at the point of change between the two frames and the other nine were randomly placed. The participants attempted to press the target button. They were asked to respond as accurately as possible, but were under no time pressure (i.e., an unspeeded response). After responding, the participants heard either a pleasant or an unpleasant tone to indicate whether or not their response was correct, and the next trial began 400 ms later. The participants completed eight blocks (25 trials per block). The first block was regarded as practice and excluded from the analysis.

This paradigm was measured by the average accuracy in response (i.e., the average number of correct responses). Accuracy in detecting changes in alternating natural scenes is a typical way of measuring the ability to detect changes (e.g., Rensink et al., 1997).

Secondary Paradigm 1: Intelligence (Raven's Test)

This was the only "paper and pencil" task in this study. The participants attempted to finish the Raven's Progressive Matrices Test (the standard matrices: 5 sets × 12 items) and their scores were manually graded. Raven's Test is a typical test of human intelligence (Raven, 1962).

Secondary Paradigm 2: Visual Marking

Visual marking is the phenomenon that if some items are presented prior to others, observers can effectively "mark" and exclude these old items, thus enabling them to search for a target among the new items more efficiently than when all of the items are presented simultaneously.

In each trial, a small white fixation cross was presented in the center of the display for 400 ms. This was followed by a short blank interval (400 ms), after which the stimuli were presented. The stimuli were 25 white letters on a black background. All of the letters were different from each other. In each trial, only one of the letters *F* and *H* appeared and this letter was the target of the trial; the other 24 letters always appeared in the display. The 25 letters were divided into two subsets: the target subset, which had nine letters (i.e., the target and 8 other letters), and the distractor subset, which had 16 letters. There were three conditions: the *target-only* condition, in which only the target subset were presented; the *gap* condition, in which the target subset was presented 400 msec after the distractor subset; and the *all* condition, in which both the target and the distractor subsets were presented simultaneously. The sequence of one sample trial in the gap condition is presented in Figure 1j. The presented letters remained on the screen until a response had been made. The participants attempted to decide the identity of the target. They then pressed one of two adjacent keys (*j* for target *F* or *k* for target *H*) to indicate their response. They were asked to respond as quickly and accurately as possible (i.e., a speeded response). After responding, the participants heard either a pleasant or an unpleasant tone to indicate whether or not their response was correct, and the next trial began 400 ms later. The participants completed 12 blocks (84 trials per block). The blocks alternated between the three conditions (i.e., target-only, gap, and all). The first three blocks were regarded as practice and excluded from the analysis.

This paradigm was measured by the percentage of time saved by the preview: (RT [all] − RT[gap])/(RT[all] − RT[target-only]). The amount (or percentage) of time that is saved by the preview is a typical way of measuring the effectiveness of visual marking (e.g., Watson & Humphreys, 1997).

Secondary Paradigm 3: Attentional Capture

Attentional capture is the phenomenon that attention tends to be automatically drawn toward a newly presented item rather than to an item that has already existed in the display.

In each trial, a small white fixation cross was presented in the center of the display for 400 ms. This was followed by a short blank interval (400 ms), after which the prime display was presented. The prime display remained for 800 msec and was then replaced by the stimuli display, which remained on the screen until a response had been made. The stimuli were four letters: one target (*F* or *H*) and three distractors (randomly chosen from *U*, *S*, *P*, and *E*). The four letters were randomly placed in four of six possible locations; these locations were at angles of 30°, 90°, 150°, 210°, 270°, and 330°, respectively, on a circle around the center of the screen (right side = 0°). The prime display consisted of three "日" symbols, which were randomly placed on three of the four locations to be occupied by letters in the stimuli display. The sequence of one sample trial is presented in Figure 1k. The participants attempted to decide the identity of the target. They then pressed one of two adjacent keys (*j* for target *F* or *k* for target *H*) to indicate their response. They were asked to respond as quickly and accurately as possible (i.e., a speeded response). After responding, the participants heard either a pleasant or an unpleasant tone to indicate whether or not their response was correct, and the next trial began 400 ms later. The participants completed 10 blocks (70 trials per block). The first block was regarded as practice and excluded from the analysis.

This paradigm was measured by the percentage increase in the response time for the "old" condition (i.e., when the target appeared in a location that was previously occupied by a "日") compared to the "new" condition (i.e., when the target appeared in a location that was not previously occupied by a "日"). The amount (or percentage) of time difference between "old" and "new" conditions is a typical way of measuring the effectiveness of attentional capture (e.g., Yantis & Jonides, 1984).

Secondary Paradigm 4: Consonance-Driven Orienting

Consonance-driven orienting is the phenomenon that attention tends to be drawn more to an item that resembles the content of visual short-term memory than to an item that does not.

In each trial, a small white fixation cross was presented in the center of the display for 400 ms. This was followed by a short blank interval (400 ms), after which a random-shaped white target pattern was presented in the center of the display. The target pattern remained on the screen for 800 msec and then disappeared. As the target patterns disappeared, three white patterns were simultaneously placed evenly on a circle around the center of the screen. The shape of one of these patterns was identical to the target pattern; the shapes of the other two patterns were randomly generated. The participants were explicitly instructed that the three patterns were irrelevant to their tasks. After another 800 msec, three red digits were superimposed on the three patterns. A sample of these frames is presented in Figure 1l. After another 800 msec, both the white patterns and the red digits disappeared. The test display was then presented. The participants attempted to perform two tasks in the test display by clicking buttons with a mouse to (1) select the target pattern from a choice of two possible patterns and (2) to report, given the choice of all 10 digits, one of the red digits. The participants were explicitly instructed that reporting any of the three digits was sufficient for the task. For both tasks, the participants were asked to respond as accurately as possible, but were under no time pressure (i.e., an unspeeded response). After each response, the participants heard either a pleasant or an unpleasant tone to indicate whether or not their response was correct. The next trial began 400 ms after both responses had been made. The participants completed 10 blocks (35 trials per block). The first block was regarded as practice and excluded from the analysis.

This paradigm was measured by determining, in relation to all reports of any of the presented red digits, the percentage of responses that reported the red digit on the pattern identical to the target pattern. The frequency of reporting the "primed" item is a typical way of measuring the effectiveness of consonance-driven orienting (e.g., Soto, Hodsoll, Rotshtein, & Humphreys, 2008; Huang & Pashler, 2006)

Secondary Paradigm 5: Inhibition of Return

Inhibition of return is the phenomenon that when the temporal gap between a cue and a target is about half a second or longer, detecting a target on a precued location is slower than on a location that is not precued.

In each trial, a small white fixation dot was presented in the center of the display. Two gray circles appeared on the left and right sides of the fixation dots 400 msec later. After a further 800 msec, one of the gray circles turned white; it remained white for 50 msec and then turn back to gray. This “white flash” served as the exogenous cue. Subsequently, a red target dot appeared in one of the circles, either simultaneously with the offset of the white flash or 500 msec later (a 50% probability of each option). The sequence of one sample trial is presented in Figure 1m. The locations of both the exogenous cue and the target dot (i.e., left or right circle) were randomly determined for each trial; therefore, the probability that they resided on the same circle or on different circles was 50% in each case. The participants attempted to detect the presence of the target dot, and then pressed one key (*j*) to indicate their response. They were asked to respond as quickly as possible (i.e., a speeded response). A key press before the presentation of the target dot was considered an incorrect response. After responding, the participants heard either a pleasant or an unpleasant tone to indicate whether or not their response was correct, and the next trial began 400 ms later. The participants completed 10 blocks (80 trials per block). The first block was regarded as practice and excluded from the analysis.

This paradigm was measured by the difference between response times for detecting a target dot at the cued and uncued location in trials in which targets appeared 500 msec after the offset of the cues. The response time (RT) difference between the cued and uncued condition (i.e., RT[cued] − RT[uncued]) when targets appear long after cues is a typical way of measuring the occurrence of inhibition of return (e.g., Posner & Cohen, 1984).

Secondary Paradigm 6: Task Switching

Task switching is the phenomenon that when required to switch between two tasks, observers perform more slowly than when they constantly perform the same task.

In each trial, a small white fixation cross was presented in the center of the display for 400 ms. This was followed by a short blank interval (400 ms), after which a digit (0–9) was presented. This digit could be either red or green, indicating two possible tasks. If the digit was red, the participants performed Task 1 (determining whether the digit was odd or even) and then pressed one of two adjacent keys (*j* for an odd number or *k* for an even number) to indicate their response; if the digit was green, the participants performed Task 2 (determining whether the digit was small (i.e., ≤ 4) or large (i.e., ≥ 5)) and then pressed one of two adjacent keys (*j* for a number ≤ 4 or *k* for a number ≥ 5) to indicate their response. They were asked to respond as quickly and accurately as possible (i.e., a speeded response). Examples of the red and green digits are presented in Figure 1n. After responding, the participants heard either a pleasant or an unpleasant tone to indicate whether or not their response was correct, and the next trial began 400 ms later. There were two types of blocks: in task-repetition blocks, the digit remained the same color across the whole block (i.e., the participants performed the same task across the whole block); in task-alternation blocks, the digit alternated between red and green from trial to trial (i.e., the tasks alternated from trial to trial). The blocks switched between task-repetition and task-alternation blocks. The participants completed 10 blocks (65 trials per block). The first two blocks were regarded as practice and excluded from the analysis.

This paradigm was measured by the percentage increase in response time for the task-alternation trials compared to the task-repetition trials. The RT difference between the task-alternation and task-repetition condition (i.e., RT[alternation] − RT[repetition]) is a typical way of measuring the cost of task switching (e.g., Monsell, 2003).

Secondary Paradigm 7: Mental Rotation

Mental rotation is the task of judging, after appropriate rotation, whether two patterns are identical.

In each trial, a small white fixation cross was presented in the center of the display for 400 ms. This was followed by a short blank interval (400 ms), after which the stimuli were presented and remained on the screen until a response had been made. The stimuli were two patterns that could be either identical or mirror-reflections of each other. In half of the trials, one of the patterns was rotated 90°or −90°. Two examples of “identical” displays, with and without rotation respectively, are presented in Figure 1o. The participants attempted to decide whether the two patterns were identical or mirror reflections of each other (after rotation, if necessary). They then pressed one of two adjacent keys (*j* for identical or *k* for mirror-reflection of each other) to indicate their response. They were asked to respond as quickly and accurately as possible (i.e., a speeded response). After responding, the participants heard either a pleasant or an unpleasant tone to indicate whether or not their response was correct, and the next trial began 400 ms later. The participants completed 10 blocks (60 trials per block). The first block was regarded as practice and excluded from the analysis.

This paradigm was measured by the difference in response times between trials in which one of the patterns was rotated and trials with no such rotation. The RT difference between the rotated and no-rotation condition (i.e., RT[rotated] − RT[no-rotation]) is a typical way of measuring the cost of mental rotation (e.g., Shepard & Metzler, 1971).

Secondary Paradigm 8: Stroop Task

Stroop task is the phenomenon that when required to name one feature of a stimulus, observers respond more slowly if that name conflicts with another aspect of the stimulus. In the present study, this involved naming the color of words that are color names themselves (e.g., if the word “green” was colored red, the observers should name the feature “red”).

In each trial, a small white fixation cross was presented in the center of the display for 400 ms. This was followed by a short blank interval (400 ms), after which the stimuli were presented and remained on the screen until a response had been made. The stimulus in each display was one Chinese character that could be colored red, green, yellow, or blue. The characters could be “红”, “绿”, “黄”, or “蓝”, which respectively mean “red”, “green”, “yellow”, and “blue”. The color and identity of the character were consistent in 50% of the trials, but were inconsistent in the other 50%. Four examples of characters (two consistent characters on the top of two inconsistent characters) are presented in Figure 1p. The participants attempted to decide the color of the character. They then pressed one of four adjacent keys (*g* for red, *h* for green, *j* for yellow, or *k* for blue) to indicate their response.

They were asked to respond as quickly and accurately as possible (i.e., a speeded response). After responding, the participants heard either a pleasant or an unpleasant tone to indicate whether or not their response was correct, and the next trial began 400 ms later. The participants completed 10 blocks (100 trials per block). The first block was regarded as practice and excluded from the analysis.

This paradigm was measured by the difference in response times between the consistent and inconsistent trials. The RT difference between the consistent and inconsistent condition (i.e., RT[inconsistent] − RT[consistent]) is a typical way of measuring the magnitude of the Stroop effect (e.g., Macleod, 1991).

Results and Discussion

Transformations and Outlier Analysis

In each session, if the measurement was response time, we excluded the outliers (values outside 3 standard deviations). Logarithmic transformations (with reflections if necessary) were applied to variables that were skewed and/or kurtotic to achieve approximate normality. Also, to simplify the presentation of data, all of the variables that correlated negatively with the general attention factor (see below) were reflected (i.e., × −1); this transformation made no difference to the statistical analysis. Specifically, six primary paradigms (conjunction and configuration search, counting, feature access, spatial pattern, and response selection) and three secondary paradigms (mental rotation, task switching, and Stroop task) were reflected. This reflection means that smaller values in the original measurements of these paradigms (e.g., shallower slopes in search and counting tasks, less switch cost, less Stroop effect) imply better performance.

"Preprocessing" or "Conditioning" the data

Descriptive Statistics

The descriptive statistics of the measures used in the study, including the mean, the standard deviation, skewness, and kurtosis, are shown in Table 1. The reliabilities of these measures are shown in Table 2. For each variable, reliability was estimated by calculating the split-half (odd-even) correlations and the Spearman-Brown formula was used for adjustment. All of the 17 paradigms met the minimum reliability of 0.7.

The results for all 17 paradigms replicated the typical findings reported in the literature. As shown in Table 1, the paradigms that measured absolute performances were generally in the typical range. Conjunction search showed a somewhat greater than typical slope (77 msec/item), although this was only because we intentionally used a difficult conjunction search task (i.e., fine feature differences) in order to ensure that the conjunction and configuration searches were of similar levels of difficulty. In the visual marking paradigm, there was a significant preview advantage (54.1%, $p < .001$). In the attentional capture paradigm, there was a significant new-item advantage (11.4%, $p < .001$). In the consonance-driven orienting task, the memorized item was reported 88.5% of the time, which was much higher than the baseline of 33.3% ($p < .001$). In the inhibition of return paradigm, the average response time for the cued items was 29 msec longer than that for the uncued items ($p < .001$). In the task-switching paradigm, the average response time in the switched trials was 284 msec longer than that in the repeated trials ($p < .001$). In the Stroop task, the

Table 2
The Correlation Between the General Attention Factor (Extracted From the 9 Primary Paradigms) and All of the Paradigms.

	Correlation	*P* value	Reliability	Variance explained	Paradigm-specific variance
Nine Primary Paradigms					
1. Conjunction Search	0.56	<0.00001	0.91	0.31	0.60
2. Configuration Search	0.67	<0.00001	0.90	0.45	0.45
3. Counting	0.56	<0.00001	0.95	0.31	0.63
4. Tracking	0.67	<0.00001	0.96	0.44	0.51
5. Feature access	0.53	<0.00001	0.94	0.29	0.66
6. Spatial pattern	0.65	<0.00001	0.95	0.42	0.53
7. Response selection	0.58	<0.00001	0.96	0.34	0.62
8. Visual short-term memory	0.56	<0.00001	0.97	0.31	0.65
9. Change blindness	0.54	<0.00001	0.93	0.29	0.65
Eight Secondary Paradigms					
1. Intelligence (Raven's test)	0.27	<0.00002	0.77	0.07	0.70
2. Visual marking	0.36	<0.0005	0.91	0.13	0.78
3. Attentional capture	0.02	>0.5, n.s.	0.84	0.00	0.84
4. Consonance-driven orienting	0.09	>0.1, n.s.	0.97	0.01	0.96
5. Inhibition of return	0.08	>0.1, n.s.	0.78	0.01	0.77
6. Task switching	0.40	<0.001	0.90	0.16	0.74
7. Mental rotation	0.33	<0.002	0.95	0.11	0.84
8. Stroop task	0.20	<0.05	0.71	0.04	0.67

Note. For the primary paradigms, the correlations of all nine paradigms with the general attention factor were fairly high, ranging from 0.534 To 0.671 (average of 0.591), thus suggesting that this attention factor accounts for a substantial portion of all of these paradigms. For the secondary paradigms, five (intelligence as measured by Raven's test, mental rotation, visual marking, task switching, and Stroop task) correlated significantly with the attention factor, and so they also share the same general attention factor as the nine primary paradigms. More interesting, the three other paradigms (attentional capture, consonance-driven orienting, and inhibition of return) were found to be uncorrelated with the attention factor.

average response time in the inconsistent trials was 106 msec longer than that in the consistent trials ($p < .001$).

Factor Analysis Step I: A General Factor for the Nine Primary Paradigms

We ran PCA on the nine primary paradigms. The correlation matrix is shown in Table 3, although only the nine primary paradigms were included in this analysis. The scatterplot and the Scree plot (along with the simulation from a parallel analysis) are respectively shown in Figure 2a and b. Clearly, there is one, and only one, factor (i.e., a general attention factor) behind these nine paradigms. This single factor explained 35% of the total variance, and there was a substantial drop between the first and second factor. The loadings (i.e., correlations) of all of the nine paradigms on this general attention factor and the *p* values are shown in Table 2. The loadings were all fairly high, ranging from 0.53 to 0.67 (average 0.59), thus suggesting that this general attention factor accounts for a substantial portion of all of these paradigms.

Factor Analysis Step II: Correlations Between the Attention Factor and the Eight Secondary Paradigms

We calculated the correlations between the attention factor and the eight secondary paradigms. The correlations and *p* values are shown in Table 2. It should be mentioned that the attention factor here is defined in the same way as above (i.e., determined by the PCA of the nine primary paradigms), and is *not* extracted from a new PCA including both primary and secondary paradigms.

Out of the eight secondary paradigms, five (intelligence as measured by Raven's test, mental rotation, visual marking, task switching, and Stroop task) correlated significantly with the general attention factor. Therefore, they also share the same general attention factor as the nine primary paradigms.

More interestingly, the three other secondary paradigms (attentional capture, consonance-driven orienting, and inhibition of return) were found to be uncorrelated with the attention factor. The reliabilities of all of these three paradigms were fairly high (see Table 2). Therefore, we can confidently say that the mechanisms underlying attentional capture, consonance-driven orienting, and inhibition of return are dissociated from the general attention factor.

General Discussion

Below, we discuss the general message of the present study as well as its implications for a few specific paradigms.

The Nature of the General Attention Factor

The PCA suggested that there is a general attention factor. What is the nature of this general attention factor? A precise answer to this question cannot be given based on the present data. If we adopt the conceptualization of attention most commonly used in previous studies, then we could speculate that this attention factor is perhaps some kind of representational resource that can be flexibly used for many tasks: a greater quantity of (or a faster rate of using) this representational resource leads to superior performance in all of these paradigms. When performing a tracking task, for example, this resource is used to mark the tracked items, and a greater amount of this resource will lead to more markers. When performing a conjunction search, this resource is used to make feature comparisons, and a greater amount of this resource will lead to more efficient feature-based selections. When performing a visual short-term memory task, this resource is used to represent the memorized items, and a greater amount of this resource will lead to a greater memory capacity. Certainly, by suggesting a common representational resource, we are not implying that the underlying

Table 3
Correlation Matrix for the Nine Primary Tasks and the Eight Secondary Tasks

	P1	P2	P3	P4	P5	P6	P7	P8	P9	S1	S2	S3	S4	S5	S6	S7
Nine Primary Paradigms																
1. Conjunction Search																
2. Configuration Search	0.29															
3. Counting	0.27	0.22														
4. Tracking	0.30	0.30	0.40													
5. Feature access	0.17	0.29	0.16	0.30												
6. Spatial pattern	0.23	0.45	0.20	0.32	0.37											
7. Response selection	0.22	0.41	0.31	0.23	0.22	0.29										
8. Visual short-term memory	0.22	0.23	0.32	0.30	0.20	0.23	0.26									
9. Change blindness	0.29	0.28	0.12	0.32	0.18	0.28	0.16	0.27								
Eight Secondary Paradigms																
1. Intelligence (Raven's test)	0.15	0.23	0.15	0.13	0.04	0.12	0.21	0.14	0.27							
2. Visual marking	0.08	0.31	0.23	0.30	0.14	0.31	0.20	0.26	0.05	0.26						
3. Attentional capture	0.02	−0.01	−0.02	−0.04	0.06	−0.06	0.34	−0.12	−0.14	0.10	−0.01					
4. Consonance-driven orienting	−0.13	0.18	−0.07	0.21	0.05	0.16	−0.03	0.06	−0.06	0.04	0.12	−0.07				
5. Inhibition of return	−0.08	0.00	0.22	0.10	0.02	−0.02	0.17	0.04	−0.04	0.02	0.10	−0.02	−0.03			
6. Task switching	0.29	0.18	0.46	0.16	0.21	0.22	0.45	0.13	0.05	0.12	0.16	0.12	−0.17	0.06		
7. Mental rotation	0.24	0.19	0.33	0.05	0.26	0.19	0.20	0.27	0.10	0.03	0.06	0.11	−0.06	0.05	0.30	
8. Stroop task	0.20	0.20	0.10	0.00	0.17	0.09	0.20	0.11	0.03	0.12	0.00	−0.02	0.07	−0.11	0.27	0.17

Note. For correlations amongst the primary tasks ($N = 257$) and the intelligence ($N = 247$), an r above 0.12 would be significant, whereas for correlations involving one or two of the other secondary paradigms ($N = 94$ or 95), an r above 0.20 would be significant.

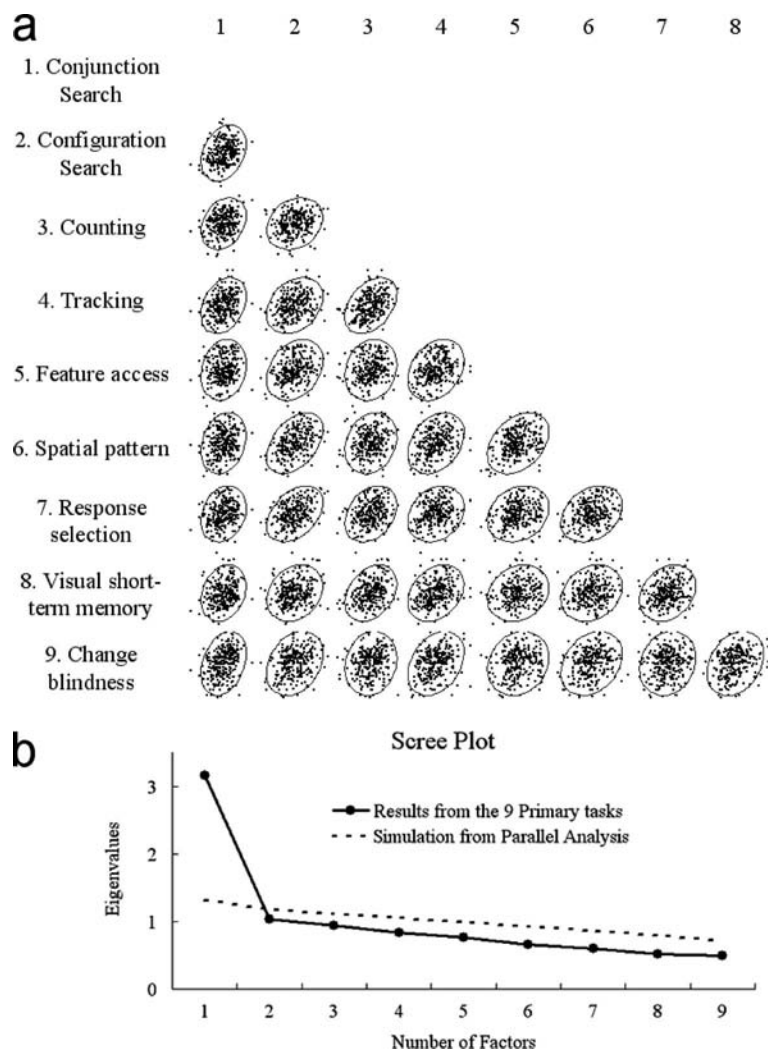

Figure 2. The Scatterplots (a) and Scree plot (b) in the principal components analysis of the nine primary paradigms. Only one factor could be identified from this analysis. The clear absence of a secondary factor suggests a fairly general attention factor.

mechanisms for these functions are equal to each other. Nevertheless, it is not implausible that all of these different functions rely partly on one pool of attentional resource, even though to accomplish these different functions, this resource will be used by different mechanisms.

We also identified a few paradigms that seem to be dissociated from the general attention factor despite their popularity in the literature on attention, namely consonance-driven orienting, attentional capture, and inhibition of return. Although the precise reasons for their dissociation from the general attention factor cannot be determined based on the present data, a plausible reason may be that these paradigms measure some types of *biases* rather than *absolute performances*: consonance-driven orienting measures the bias toward memorized items, whereas attentional capture and inhibition of return measure the biases toward new items. It is conceivable that participants could have more or less of these biases regardless of the quantity of their resource. For example, in the inhibition of return paradigm, an observer with more resource will generally be faster at detecting the target at both cued and uncued locations and the observer's preference toward the new items could well be irrelevant to the whole quantity of the resource. This dissociation certainly does not make these paradigms any less interesting, but it does suggest that they should be considered separately from other attention studies and that one should be cautious when drawing conclusions on the attention factor based on these paradigms.

Lack of Semigeneral Factors

The most important result of the present study is the lack of semigeneral factors. In other words, it is impossible to identify a small number (e.g., two) of dissociable mechanisms behind these paradigms. If there is any semigeneral mechanism that contributes selectively to a few paradigms (e.g., a search mechanism that contributes to conjunction and configuration search, but not to the other paradigms), then there will be an identifiable secondary factor. In other words, the present study not only shows that disparate paradigms are related to one general attention factor, but also that this general attention factor is the *only shared mechanism* in these paradigms.

To further clarify this, Figure 3 illustrates the difference between two types of model. In Figure 3, rectangles of different colors are used to represent different paradigms, and their shared regions represent their shared mechanism (i.e., shared variance). In one hypothetical model (Figure 3a), all of the underlying mechanisms are divided into two parts: a general attention factor that is shared by all of the paradigms and a mechanism that is unique to each of the paradigms. In another hypothetical model (Figure 3b), there are some mechanisms that are shared by *some, but not all,* of the paradigms (i.e., "local sharing"). The present study supports a model that is more like the one in panel a. Thus, the essence of our finding as illustrated in Figure 3 is the absence of these regions of local sharing.

Saying that there is local sharing is equivalent to saying that some pairs of paradigms are more similar to each other than other pairs. In other words, the present results suggest that there is no such "difference in similarity" and that any pairs of the nine paradigms are equally similar (e.g., the configuration search is no more similar to the conjunction search than it is to tracking).

Large Portions of Paradigm-Specific Mechanisms

Another important result of the present study is that the portions of paradigm-specific mechanisms seem to be rather large. As mentioned earlier, 35% of the variance of the nine primary paradigms can be explained by the general attention factor. On the other hand, the reliability of these nine paradigms is generally high (see Table 2), so only very small portions of the variance in the data are caused by random errors in measurements.

For all paradigms, the portions of variance explainable by the general attention factor (i.e., the factor loadings squared), the portions of reliable variance (i.e., the reliability), and the portions of paradigm-specific variance (i.e., the difference between the previous two) are presented in Table 2. On average, about 63% of the reliable variance of the primary paradigms are attributed to paradigm-specific mechanisms. In some sense, for each paradigm, most of its mechanism is unique rather than shared with other paradigms. Therefore, the predictability from results of one paradigm to results of another paradigm will probably be modest. In other words, researchers should not assume that findings based on one paradigm of visual attention can always be generalized to another paradigm of visual attention.

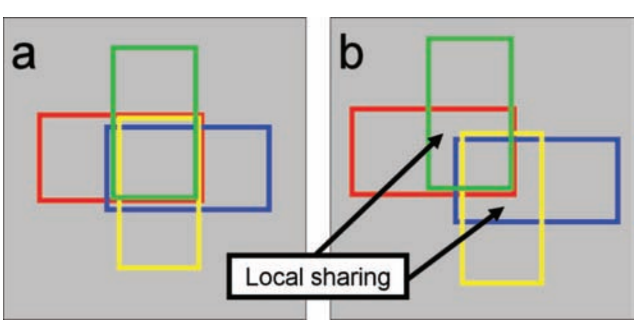

Figure 3. Illustrating the general implication of the present study. Rectangles of different colors represent different paradigms, and their shared regions represent their shared mechanism (i.e., shared variance). Panel *a* illustrates a hypothetical model in which all of the underlying mechanisms are divided into two parts: the general attention factor that is shared by all paradigms and the mechanism that is unique to each of the paradigms. Panel *b* illustrates a hypothetical model in which there are also some mechanisms that are shared by some, but not all, of the paradigms. The present study argues against these regions of "local sharing" and therefore supports a model that is like the one in panel *a*.

Is Inhibition of Return Really a "Marker" of Attention?

The present study has important implications regarding the nature of inhibition of return. Some researchers have proposed that inhibition of return functionally marks locations that have been visited by visual attention and therefore ensures that visual attention is paid to new locations so that a scene can be scanned more efficiently (e.g., Klein, 1988). If inhibition of return does contribute significantly to the efficiency of visual search, observers with a greater inhibition of return should perform better in visual search tasks. However, this prediction is not confirmed by the present data. Therefore, it seems that inhibition of return has little significant impact on visual search.

Limitations of the Present Study

The present study has four limitations that need to be discussed here and explored further in future studies.

The contribution of the *g* factor. The first limitation concerns the interpretation of the general attention factor in relation to the *g* factor. When a set of cognitive tasks is tested, a first factor, often defined as the *g* factor, will generally account for a large portion of the variance across all of the tasks tested. Normally, the impact of the *g* factor is reflected in very strong correlations with standard intelligence tests such as Raven's test. As mentioned earlier, we included Raven's test in our list of paradigms so that we could find out whether or not the general attention factor we identified is caused by the *g* factor. In the present results, as expected, the general attention factor was found to correlate with the performance on Raven's test. However, this correlation was rather modest (0.27) and thus suggests that the general attention factor is not mainly caused by the *g* factor.

It should be mentioned that the contribution of the *g* factor could have been underestimated because the results of Raven's test in the present study were very high and therefore their ability to measure the *g* factor was probably reduced. For a few reasons, it still seems unlikely that the general attention factor is caused completely by the *g* factor. First, we partialed out the Raven's test from each of the nine variables (i.e., the primary paradigms), and this caused little change to the correlations between them (on average, 0.27→0.26). This argues against a simple g interpretation. Second, we repeated the PCA including Raven's test. The Raven's test still had a relatively low loading (0.37) on the "new first principal component," and the magnitude of increase (0.27 → 0.37) was comparable to a simulated random variable. This again argues against a simple g interpretation. Third, the reliability of the Raven's test was fairly high (0.77), and, therefore, it seems that its ability to measure the g factor was not dramatically reduced.

Admittedly, we still cannot completely rule out the possibility that the general attention factor here can be completely attributed to the *g* factor. If future studies indeed confirm this possibility, how would that affect the implications of the present study? In such a case, there would be no general attention factor, and so our interpretation on the "general resource" would have to be revised. However, the two other important conclusions of this study, namely the absence of semigeneral factors and the large portions of paradigm-specific mechanisms, would still be correct.

Local fragmentations. The second limitation concerns *possible local fragmentations*. Although we argue that there is only one general "attention" factor behind the tested paradigms, there will inevitably be local fragmentations. One can certainly imagine using several different searches or tracking tasks that are very similar to each other in terms of stimuli and procedure; in such cases, eventually and inevitably, these tasks will share more mechanisms with each other than just the general attention factor. Although, by using such an approach, one can characterize some local fragmentations very precisely, it is impossible to enjoy this precision and keep breadth at the same time because there would simply be too many paradigms. The present study intended to depict the overall picture; therefore, we allocated our testing to disparate paradigms. In other words, although we do not deny the possibility of local fragmentations, which should definitely be explored in the future, we do suggest that, globally, the attention factor is very general and cannot be divided into a couple of large submechanisms.

Possible global fragmentations. The third issue is that there could well be some important global fragmentations (i.e., semigeneral factors) that were not revealed in the present paradigms we have tested. There are important conceptual distinctions (or dichotomies) that have been made in the literature based on behavior or neuroimaging data (e.g., stimulus driven vs. goal driven attention: Corbetta & Shulman, 2002; temporal vs. spatial attention; selection vs. access: Duncan, 1980). Therefore, it is certainly likely that at least some of these conceptual distinctions will have corresponding semigeneral factors in individual differences of some set of paradigms, and future studies with paradigms specifically designed to explore these distinctions are required to address these issues.

Highly correlated factors. The fourth limitation is that the present study is, in some sense, a *null finding*. Although we have found the absence of a secondary factor, the possibility still remains that there are actually two separate attention mechanisms, but that these two mechanisms correlate so highly with each other that they become statistically undistinguishable. Although we cannot rule out this possibility, the present study used a fairly large sample and testing sessions of decent lengths, so it seems reasonable to say that, for the purpose of characterizing visual attention from the data, no noticeable division could be found. Future studies should further explore this issue by using an even larger sample and/or limiting the scope of research to a subset.

General Implications

Taken together, the present studies indicate that (1) there is one general attention factor behind the various paradigms; (2) there are no semigeneral mechanisms that contribute to some of the paradigms, but not the others; and (3) there is a substantial portion of a paradigm-specific mechanism in each paradigm.

How will these conclusions affect our understanding of visual attention? We believe that the answer to this question depends heavily on the (often implicit) prior assumptions made by particular researchers. Perhaps those who have assumed that visual attention is mostly a general mechanism will be surprised to learn how large the portion of a paradigm-specific mechanism is, whereas those who have assumed that visual attention is merely a label for various arbitrary tasks will be surprised to learn that a general attention factor exists. In general, the absence of semigeneral mechanisms seems to be the most informative finding because there are strong reasons from previous studies to believe that they exist and, to the best of our knowledge, no previous theory or finding entails the lack of such mechanisms. Overall, the present results provide us with useful constraints and guides on how we should conceptualize a theory of attention.

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