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Visual Working Memory Capacity for Emotional Facial Expressions

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Abstract

The capacity of visual working memory is limited to no more than four items. At the same time, it is limited not only by the number of objects, but also by the total amount of information that needs to be memorized, and the relation between the information load per object and the number of objects that can be stored into visual working memory is inverse. The objective of the present experiment was to compute visual working memory capacity for emotional facial expressions, and in order to do so, change detection tasks were applied. Pictures of human emotional facial expressions were presented to 24 participants in 1008 experimental trials, each of which began with a presentation of a fixation mark, which was followed by a short simultaneous presentation of six emotional facial expressions. After that, a blank screen was presented, and after such inter-stimulus interval, one facial expression was presented at one of previously occupied locations. Participants had to answer if the facial expression presented at test is different or identical as the expression presented at that same location before the retention interval. Memory capacity was estimated through accuracy of responding, by the formula constructed by Pashler (1988), adopted from signal detection theory. It was found that visual working memory capacity for emotional facial expressions equals 3.07, which is high compared to capacity for facial identities and other visual stimuli. The obtained results were explained within the framework of evolutionary psychology.

Keywords: visual working memory capacity, emotional facial expressions, change detection paradigm, evolution of facial expressions

Introduction

Amongst various methods in the field of visual working memory capacity research, the most common procedure is the change detection paradigm. The method usually comprises two successively presented displays of stimuli, divided by an inter-stimulus interval. These two displays, which might have differed in one

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segment during inter-stimulus interval, are presented to participants, whose task is to answer if they are identical or not (Rensink, 2002). Accuracy and speed of responding are then measured and analyzed together with other relevant variables, depending on the research design. One of the first scientists who investigated visual working memory by applying such a paradigm was Phillips (1974), who conducted several experiments in which he had tachistoscopically presented displays filled with dots. Each trial in his pioneering experiments consisted of two displays, separated by a variable inter-stimulus interval. The two displays could either be identical, or could differ in the addition or the removal of one dot, and participants' task was to detect if such a change had occurred or not during inter-stimuli interval within each trial. Phillips (1974) found that the performance was excellent with short inter-stimuli intervals (100 ms or shorter), while prolongation of the retention interval resulted in decreased change detection accuracy. Besides that finding, he also discovered that insertion of a mask between two displays causes impairment in performance only in conditions with short inter-stimuli intervals, while with longer intervals masking has practically no effect. Accordingly, Phillips (1974) attributed excellent performance with short retention intervals to iconic memory, and proposed that visual working memory is responsible for longer retention interval performance. He concluded that iconic memory has a vast capacity, but very short duration, in contrast to visual working memory, which is capable of storing only a small amount of information, but can keep it for a longer period of time. These conclusions by Phillips (1974) are still valid.

On the bases of Phillips' (1974) experiments, Pashler (1988) made an important contribution in the field of visual working memory-span research. Pashler (1988) was the first author who managed to develop a reasonably valid method of visual working memory capacity quantification. His procedure, which is going to be presented in detail later, was derived from signal detection theory, and has been used in the majority of later studies, aim of which was the estimation of visual working memory capacity for different types of stimuli. Four of such studies are crucial for the understanding of the present study: Vogel, Woodman, & Luck's (2001), Wheeler & Treisman's (2002), Alvarez & Cavanagh's (2004) and Eng, Chen & Jiang's (2005).

Vogel et al. (2001) measured visual working memory capacity for simple features and for conjunctions. To estimate capacity for simple features, they flashed arrays of 1, 2, 3, 4, 8 or 12 colored squares to participants for 100 ms. Each trial contained two displays of stimuli, separated by 900-ms blank interval, with a restriction that the number and location of stimuli could not change within a trial. Two arrays within each trial could either be the same, or could differ in color of only one square, and participants' task was to detect this kind of changes. Their performance was almost faultless for displays containing three or less squares, but their accuracy started to decline systematically at set size of four items. When different types of stimuli were used, and duration of retention interval was varied, results remained the same, and according to Pashler's (1988) method, Vogel et al. (2001) computed that visual working memory capacity equals approximately four objects, regardless of their type.

Vogel et al. (2001) even demonstrated that storage of multi-feature objects does not consume more visual working memory capacity then storage of single-feature objects into visual working memory. In one of their experiments, they directly compared memory for objects defined by one simple feature to memory for that same objects defined by a conjunction of features. In all conditions they used bars as stimuli, and each stimulus in any of the conditions was defined by color and by orientation. In one condition, participants had to memorize only the color of bars; in another condition, they had to memorize only the orientation; and in the last (conjunction) condition, they were required to memorize both, color and orientation. In the conjunction condition, either the color or the orientation of only one item could change, while in the other two conditions, only color or only orientation of one item could alter. Therefore, in the conjunction condition, in sets of four objects, participants had to memorize eight features, while in the other two conditions they were required to store only four features. Vogel et al. (2001) found no difference in performance between these three conditions, and concluded that objects are stored into visual working memory as integrated units, similarly as verbal working memory stores information as chunks. Accordingly, they proposed that visual working memory capacity is not limited by the number of features, but by the number of objects. In one of their experiments, Vogel et al. (2001) demonstrated that at a set size of four objects, participants managed to retain 16 features distributed across 4 multi-feature objects equally well as 4 features distributed across 4 single-feature objects.

However, Wheeler & Treisman (2002) disagreed with Vogel et al.'s (2001) conclusions, after they had failed to replicate their results. Wheeler & Treisman (2002) believed that visual memory capacity depends on the complexity of visual material, similarly as verbal memory capacity depends on the complexity of verbal material (e.g. Baddeley, Thomson, & Buchanan, 1975; Schweickert & Boruff, 1986). Specifically, Wheeler & Treisman (2002) proposed that the number of elementary features that define objects affects visual working memory in a similar manner as, for example, long words consume more memory capacity then short words. One of the experiments in their study was composed of four conditions, with single-colored squares as stimuli. In all four conditions, objects were initially presented in duration of 150 ms, and in 50% of trials a change could occur during retention interval. The type of change depended on experimental condition. In the first condition, only the color of two squares could change. In the second condition, only the location of two squares could change. In the third condition, either the color of two squares, or the location of two squares could change, while in the last condition (binding condition), all colors presented, and all locations occupied remained the same, but colored squares could swap location. Participants were informed about all these possibilities. These four conditions were blocked, and each block of trials was presented in counterbalanced order. Analyses indicated that participants' performance was the worst in the condition in which colors had swapped their locations, and therefore, Wheeler and Treisman (2002) concluded that information about color and location were not automatically bound together as Vogel et al. (2001) had proposed, but into separate parallel stores instead.

Besides Wheeler & Treisman (2002), Alvarez & Cavanagh (2004) also disagreed with Vogel et al.'s (2001) model and reexamined it. Specifically, they checked Vogel et al.'s (2001) conclusion that the total number of features to be remembered is not the factor which determines visual working memory capacity for multi-feature objects. Alvarez & Cavanagh (2004) investigated whether visual working memory capacity is limited by the number of objects that need to be stored, or by the total amount of information that needs to be memorized, and for that purpose six classes of stimuli were used: Chinese characters, colors, letters, random polygons, shaded cubes and Snodgrass & Vanderwart's (1980) line drawings. The amount of visual information was assessed by measuring processing rate in visual search tasks for different kinds of stimuli, because the more visual information that must be analyzed per object, the slower the processing rate is. Alvaraz & Cavanagh (2004) found inverse relation between the information load per object and the number of objects that can be stored into visual working memory. In other words, they found that visual working memory capacity is limited by the total amount of information, and this kind of a trade-off between the complexity of objects and a total number of objects that can be stored in memory, is clearly contrary to Vogel et al.'s (2001) theory.

In order to directly test Vogel et al.’s (2001) versus Wheeler & Treisman’s (2002) and Alvarez & Cavanagh’s (2004) theory, Švegar & Domijan (2007) conducted a research using lines defined by length (long/short), orientation (0º, 45º, 90º and 135º), and color (red, green, blue), as stimuli. They presented pairs of displays containing four such objects, divided by 900-ms retention interval, to participants. The experiment consisted of two conditions, and in all trials of both of the experimental conditions, only two or none of the features could change during the retention interval. In the first condition, two features of only one object could change, and in the second condition, the change was distributed over two objects (one feature per object). If objects are stored into memory as integrated units, as Vogel et al. (2001) had suggested, then participants should have made less errors in the condition when two objects had changed. However, analyses showed no differences in performance between these two conditions, and that result suggested that features are separately stored into visual working memory, in conformity with Wheeler & Treisman’s (2002) theory. The conclusions of Švegar & Domijan (2007) are also in conformity with the model of Alvarez & Cavanagh (2004), according to which, visual working memory capacity is limited by the total amount of information, rather than by the total number of objects.

Besides their central finding that visual working memory capacity is limited by the total amount of information that needs to be stored, Alvarez & Cavanagh's (2004) results also indicated that in terms of the number of objects, visual working memory capacity differs across different categories of stimuli – it varies from 1.5 to 4.5 objects. When estimated by Pashler's (1988) method, visual working memory capacity equals 1.57 items for shaded cubes, 2.04 for random polynoms, 2.76 for Chinese characters, 3.65 for letters and 4.43 items for colors (Alvarez & Cavanagh, 2004).

In a study similar to Alvarez & Cavanagh's (2004), Eng et al. (2005) used a change detection task to measure visual working memory capacity for six types of stimuli of different complexity (colors, letters, polygons, squiggles, cubes, and faces), and found that the estimated capacity decreased for more complex stimuli, suggesting that perceptual complexity was an important factor in determining visual working memory capacity. In the condition of prolonged exposure of stimuli (3000 ms), Eng et al. (2005) discovered that visual working memory capacity equals approximately 2 items for faces and cubes, 2.5 items for squiggles and polygons and 3.5 items for colors and letters.

The aim of the present study was to estimate visual working memory capacity for emotional facial expressions, and compare it to the capacity for other types of stimuli, specifically to the capacity for facial identities. Therefore, in contrast to the study of Eng et al. (2005) in which neutral facial expressions of different people were used as stimuli, in the present study facial identity was held constant within trials, while emotional expressions varied.

The processing of facial emotional expressions is usually investigated via visual search tasks, dot probe paradigm, eye-movement monitoring, backward masking of stimuli and similar methods. Various studies using these procedures have shown that recognition of emotional states of other people is one of the most important purposes of human perception. One of the most frequent findings emerging from such experiments is the conclusion that detection of angry facial expressions is prioritized by our cognitive system, because detection of facial threat is an evolutional advantage (Calvo, Avero, & Lundqvist, 2006; Fox, Russo, Bowles & Dutton, 2000).

Each emotional expression is determined by several facial micro expressions and, at the same time, different emotional expressions share communal micro expressions. For example, frightened and surprised expressions share two mutual features – opened mouth and widely opened eyes, while facial expressions of disgust and anger are both characterized by lowered eyebrows which are also pulled together towards the root of nose. Thus, facial emotional expressions, as a stimuli class, can be considered as rather complex and therefore visual working memory capacity for emotional expressions is expected to be low.

Method

Participants

Twenty-four psychology students from University of Rijeka, Croatia, participated in the experiment (age range 20-26). The number of male and female participants was equal, and all of them gave the informed consent and reported to have normal or corrected to normal visual acuity.

Instruments and stimuli

Stimuli presentation and data collection were controlled by a PC-computer. Stimuli were displayed on a 17-inch monitor with resolution of 1024 x 768 pixels and responses were collected by keyboard.

Calvo & Lundqvist's (2008) adaptations of facial stimuli from The Karolinska Directed Emotional Faces (KDEF) database (Lundqvist, Flykt, & Öhman, 1998), together with stimuli from The Averaged Karolinska Directed Emotional Faces (AKDEF) database (Lundqvist & Litton, 1998) were used in the present study.

Every participant went through four experimental sessions, and was exposed to only one set of stimuli per session. Each set of stimuli was comprised of seven pictures displaying six emotional expressions (frightened, angry, disgusted, happy, sad and surprised) and a neutral expression. In order to keep idiosyncratic facial features constant, pictures within a set differed only by facial emotional expression, while facial identity was held constant within each set. In other words, each set of stimuli contained different facial expressions of the same model, so the only variable aspect of stimuli within each set was the emotional expression. Color was removed from Calvo & Lundqvist's (2008) adaptation of KDEF stimuli, while the AKDEF stimuli were left intact.

Procedure

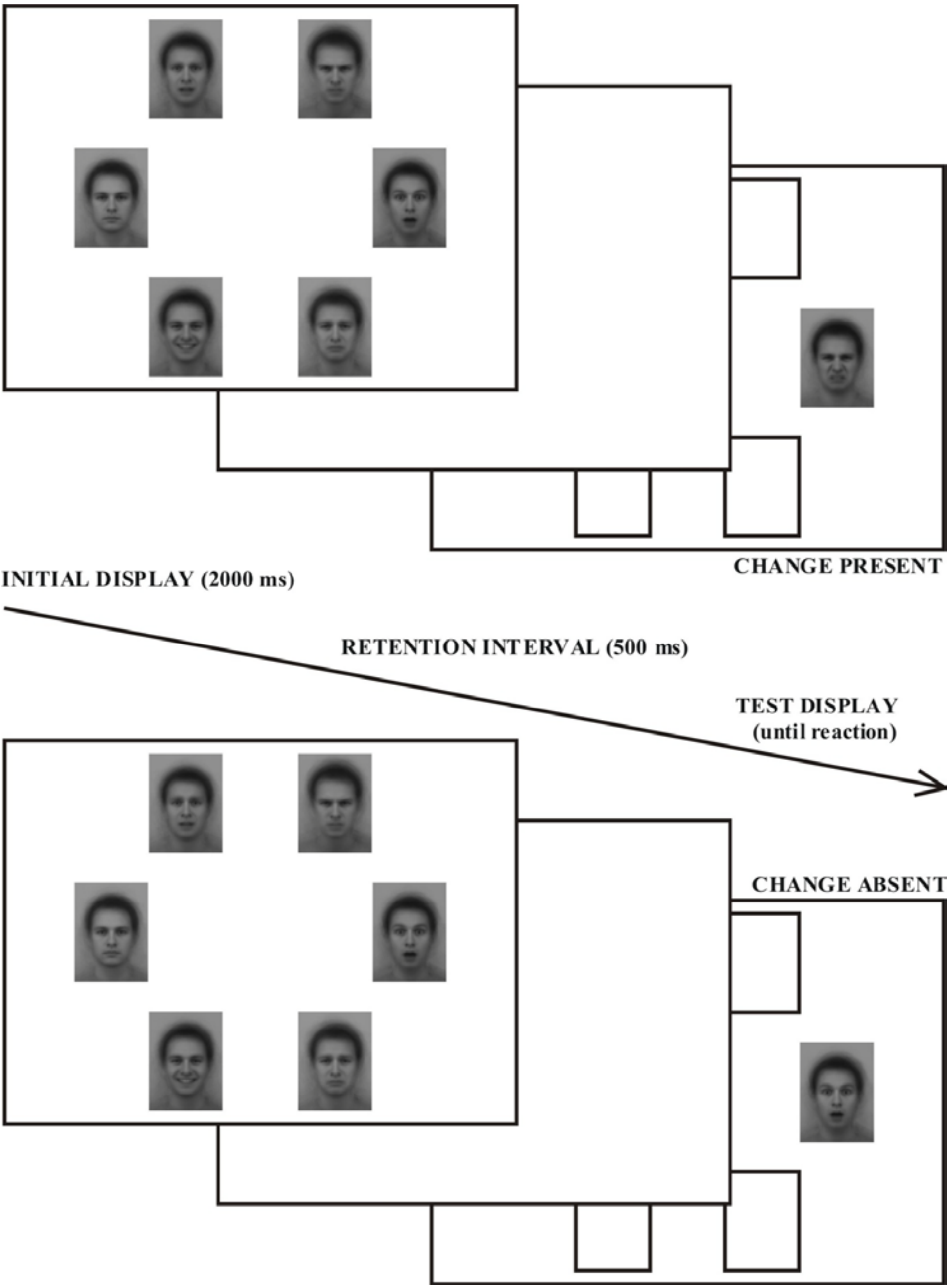
Each of four sessions was composed of 252 experimental trials and lasted for approximately 30 minutes, so in order to ease such a difficult activity, participants took 7-days break between two experimental sessions. Therefore, every participant went through a total of 1008 experimental trials.

Every trial began with the presentation of a fixation mark, in duration of 250 ms, which was followed by the presentation of the initial stimuli display that subtended 13.29 º x 12.27 º of visual angle. The initial stimuli display consisted of six different facial expressions, each of which occupied 3.38 º x 2.58 º of visual angle. When generating initial stimuli displays, six pictures were randomly pulled from a set of seven pictures, with the restriction that two or more identical expressions could never be present at the same display. These six facial expressions were then randomly located at six spatial positions. After being exposed for 2000 ms, the initial stimuli display was erased and blank screen was presented for 500 ms, and after that the test display appeared. Single test displays were used in this experiment, which means that only one facial expression was presented per test display, and it was placed on one of six locations previously occupied in the initial display. In half of all trials (all trials containing no change), facial expression of the test face was the same as the expression of the face previously occupying its location in the initial display, while in the other half of all trials (all trials containing a change), the facial expression presented at test display was the expression which was not presented at all at initial display (Figure 1).

After the presentation of the test display, participants were instructed to hit the "1" key if a change occurred (if the emotion in the test display differs from the emotion occupying relevant location in the initial display), or to hit the "0" key if a change did not occur during the retention interval (if the emotion in the test display is the same as the emotion presented at the relevant location in the initial display). They were emphasized to aim for accuracy, not speed, and instructed to respond by chance in trials in which they were uncertain if a change had occurred or not.

Immediate feedback followed each reaction. If the response was correct, the word "correct" appeared in blue color at the centre of display, and if their answer was wrong, then the word "incorrect" was presented in red color. The experiment was conducted in a self-paced manner – after the presentation of feedback, which lasted for 500 ms, participants had to press the "space bar" in order to start a new trial.

Figure 1. *A Trial Containing a Change and a Trial Containing no Change*



Results

Visual working memory capacity was quantified by Pashler’s (1988) method. The procedure is adopted from signal detection theory, and it is applicable in change detection tasks in which one or none of stimuli may change during the retention interval between two successively presented displays. Analogously to signal detection theory, each change detection task has four possible outcomes: *hit* (change occurs and observer detects it), *miss* (change occurs, but observer fails to detect it), *false alarm* (change does not occur, but observer reports it occurred) and *correct rejection* (change does not occur and observer correctly reports it had not occurred). Only hits and false alarms (together with set size) are relevant for Pashler's (1988) formula. Hit rate is a proportion of "change present" answers in all trials containing a change. Analogously, false alarm rate is a proportion of "change present" answers in all trials that do not contain a change. It is important to emphasize that a hit may not occur in trials that do not contain a change, and analogously a false alarm may not occur in trials containing no change.

Supposing that participants held a certain amount of items in memory, when one of them changed, hit would follow, but if the changed item was not stored in memory, miss would occur. When participants did not detect a change, they would answer "change absent", but it must be taken into account that in a certain proportion of the trials they were guessing. Guessing is here the synonym for false alarms, which occurs when "change present" answer is given in trials that do not contain a change. Along with the variables mentioned and set size, Pashler (1988) gave the formula for determining visual working memory capacity:

$$H = \frac{C}{IP} + \frac{IP - C}{IP} * FA$$

C is visual working memory capacity;
H is hit rate;
IP is total number of items presented in a display;
FA is the guessing rate or false alarm rate (the proportion of no-change trials in which the subject guesses that there was a change);
(C / IP) is the proportion of trials in which an item that is stored in memory changes;
(IP – C) is the number of presented objects that are not stored in memory;
(IP – C) / IP is the proportion of trials in which an item that is not stored in memory changes.

Thus, Pashler (1988) presumes that the probability of a hit (H) equals the proportion of correct detections of a change in cases when changed item was stored in working memory (C / IP), added up with guessing. When the equation above is transformed, a formula for visual working memory capacity assessment can be extracted:

$$C = \frac{IP*(H - FA)}{1 - FA}$$

In order to estimate visual working memory capacity in the present study, hit and false alarm rates were first computed, and then entered into the equation above, separately for each participant. To obtain a hit rate, total number of hits was divided by the number of all trials containing a change separately for each participant. Analogously, for computing false alarm rate, the number of false alarms was divided by the number of all trials that do not contain a change, for each participant separately. Mean hit rates equaled 0.66 (*SD*=0.07) while mean false alarm rates equaled 0.29 (*SD*=0.09). When these values are entered into Pashler's (1988) equation, the formula revealed that mean visual working memory capacity for emotional facial expressions equals 3.07 (*SD*=0.51), ranging from 1.53 through 4.02 expressions.

Discussion

Visual working memory capacity for emotional facial expressions equals 3.07 items. Thus, we can store, retain and process information of about three facial expressions simultaneously in our visual working memory. However, this result must be interpreted with caution because external validity of this conclusion is questionable since no other experiments were conducted so far in order to assess visual working memory capacity, but nevertheless, the obtained estimate of memory capacity is very high compared to capacities for other classes of stimuli. While capacity for the simplest possible visual stimuli, such as colors, ranges between 3.5 to 4.4 items (Alvarez & Cavanagh, 2004; Eng et al., 2005; Vogel et al., 2001; Wheeler & Treisman, 2002), the capacity for emotional expressions is just slightly lower. When compared to memory capacity for facial identities, memory capacity for emotional expressions is superior. While information of only 2 facial identities can be held in memory (Eng et al., 2005), information of 3 facial expressions can be retained. Even though the results of Eng et al.'s (2005) experiment and the findings of the present study are not directly comparable due to some methodological differences, superiority of memory capacity for facial expressions over memory capacity for facial identities could even be underestimated because of these methodological distinctions. For example, in the present study, memory capacity of 3 items for emotional expressions was obtained with exposition of stimuli in duration of 2 seconds, while memory capacity of 2 items for facial identities in the study of Eng et al. (2005) was yielded under condition in which the exposition lasted for 3 seconds. When the exposition of stimuli in the study of Eng et al. (2005) was shortened to 1 second, then the memory capacity for facial identities was decreased to 1.5.

So, why does our cognitive system assign great importance to facial emotional expressions and prioritizes them even over facial identities? From an evolutionary point of view, the capability to recognize the emotional state of other people is one of the most important purposes in human perception, because perceived and expressed emotional states govern the undertaking of action, and can even be critical for survival. Perceived emotions are thus an important factor for social behavior and for the entire human cognition: from decision-making and problem solving to intelligence. In everyday interaction, we continuously monitor and interpret emotional expressions of other people, and the face reveals an ocean of social signals and is the dominant medium for transmitting emotional information (Knapp, 1978).

For example, since rapid response to a presence of potential threat in the environment is an obvious evolutional advantage, fast detection of facial expression of anger has large adaptive value. Fast detection of facial threat is thus assumed to be prioritized by our cognitive system in order to initiate immediate action (Calvo et al. 2006; Fox et al., 2000). There is a lot of empirical data supporting this presumption, especially in studies using visual search tasks (Calvo et al., 2006; Fox et al., 2000; Hansen & Hansen, 1988; Horstmann & Bauland, 2006) or dot probe paradigm (Mogg & Bradley, 1999).

On the other hand, some authors argue that distressing emotional experience of a person attracts attention, regardless of whether it represents danger or not. Therefore, according to their standpoint, angry faces do not capture attention only because they represent danger, but also because they show negative affect. Thus, the negativity hypothesis presumes that a sad face should be prioritized as well as an angry one, when compared to positive expressions (Calvo et al., 2006), and that standpoint also received experimental support (Eastwood, Smilek, & Merikle, 2001; Hahn & Gronlund, 2007; Horstmann, 2007).

Also, Martin, Williams, & Clark (1991) argue that positive emotional expressions can capture attention as effectively as negative ones, and that standpoint is called the emotionality hypothesis. According to the emotionality hypothesis, special attention is paid to all emotional events, while neutral expression are not prioritized by our cognitive system (Calvo et al., 2006; Fox et al., 2000). The emotionality hypothesis received support from various experiments using visual search tasks and eye-movement monitoring paradigm (Calvo et al., 2006; Fox et al., 2000; Williams, Moss, Bradshaw, & Mattingley, 2005). For example, all emotional faces receive first eye-fixation more often than neutral faces, and also, all emotional faces are more likely to be re-fixated than neutral ones, which reveals late attentional engagement on emotional faces (Calvo et al., 2006). Besides that, search performance is better for emotional faces among neutral distracters compared to neutral targets among emotional distracters (Williams et al., 2005). There are also several studies (particularly speed recognition and backward masking studies) indicating the superiority of happy over neutral facial expressions (Esteves & Öhman, 1993; Hugdahl, Iversen, & Johnsen, 1993; Leppänen & Hietanen, 2004; Milders, Sahraie, & Logan, 2008; Palermo & Coltheart, 2004). Their findings, which follow the idea that smiling is a behavioral mechanism crucial for cooperative interactions (Mehu, Grammer, & Dumbar, 2007) are also in accordance with the emotionality hypothesis.

When all previously mentioned findings are considered together with the conclusion of the present study, it is plausible to presume that high visual working memory capacity for emotional expressions is the result of evolutional development, because assigning high priority to emotional facial expressions is adaptive for observers. We clearly benefit from detecting, recognizing and memorizing the location of emotional faces in a crowd, because these processes prepare us for the undertaking of necessary actions. For example, fast detection of angry faces allows us to rapidly respond to a presence of a potential threat in the environment. On the other hand, if we are directed towards happy expressions, we have a better chance to initiate a productive cooperative relationship, romantic intercourse or other beneficial social interaction. Thus, the capability to recognize, encode and retain information about emotional facial expressions in visual working memory has large adaptive value and is an important evolutional advantage.

Prospective research should be directed towards examination of external validity of the findings obtained in the present study, by conducting additional control experiments, using stimuli from some other sets of emotional facial expressions, in which variables such as set size, retention interval and exposition interval would be manipulated with. Also, it would be valuable to conduct an experiment in which performance in visual search tasks and change detection tasks would be directly compared for emotional facial expressions and facial identities. By doing so, a much more precise insight about the nature of relevant underlying cognitive mechanisms would be obtained.

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