INTRODUCTION

Definition of emotional memory and its classification in memory systems is nontrivial and varies between studies. Moreover, there is also substantial inconsistency in emotional memory testing (Cheke & Clayton, 2013). Emotional memory generally refers to the experiences/stimuli evoking emotional reactions and, in a narrow sense, is perceived as a part of declarative (explicit) memory, i.e., re-experiencing emotionally relevant events or events perceived in an emotional context (Buchanan & Adolphs, 2004).

Although emotion has long been studied, there is no single, widely accepted, definition. The key aspects of emotional theory changed with advances in methodology and research (see e.g., Izard, 2009; Tyng et al., 2017). For the purposes of our paper,
we consider emotion an affective experience of a certain valence that is clearly focused and triggered by an external stimulus, not a long-term affective state. We are aware that there are different approaches to describe emotions, e.g., discrete emotion theory vs. the dimensional model, and in specific cases we use the terminology used by the authors of the studies we cite.

Emotions impact all phases of memory processing (learning, coding, and both immediate and delayed retrieval and recognition; e.g., LaBar & Cabeza, 2006; Hamann, 2001). These processes are affected predominantly through the limbic system. Amygdala, hippocampus, and orbitofrontal cortex are parts of the emotional memory network that seem critically engaged whenever information elicits arousal, regardless of valence (Kensinger, 2009). Both the amygdala and the hippocampus structures of the medial temporal lobe are mutually functionally independent, but they interact and modulate each other. (Phelps, 2004). Amygdala modulates the encoding and the storage of hippocampal-dependent memories and the hippocampus influences amygdala response to episodic representations of the emotional significance and interpretation of events (Phelps, 2004). Amygdala is more or less specialized for the processing of emotion while hippocampal complex is necessary for declarative or episodic memory (Phelps, 2004).

Memory is not one unitary system, but various overlapping subsystems varying in content, storage, or neuronal mechanisms. For emotional-memory research, it is therefore important to consider the types of stimuli, their emotional impact, and the methodological characteristics of administered tasks. Grühn and Sharifian (2016) proposed the so-called Emotional Matrix of standard emotional stimuli (words, images, faces, and film stimuli) to help researchers choose the appropriate types of emotional stimuli. The Emotional Matrix (see Table 1) is originally a graphic representation of

Table 1 The Emotional Matrix of stimuli was adapted from Grühn and Sharifian (2016) and was applied to additional categories of stimuli in a modified form using a simplified scaling (for definitions see Introduction).

<table>
<thead>
<tr>
<th>Stimulus type</th>
<th>Ecological validity</th>
<th>Temporal resolution</th>
<th>Controllability</th>
<th>Complexity</th>
<th>Emotional intensity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Words</td>
<td>Low</td>
<td>High</td>
<td>High</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Sentences</td>
<td>Low</td>
<td>Medium/High</td>
<td>Medium/High</td>
<td>Low/Medium</td>
<td>Low/Medium</td>
</tr>
<tr>
<td>Stories</td>
<td>Low/Medium</td>
<td>Medium</td>
<td>Low/Medium</td>
<td>Medium</td>
<td>Medium/High</td>
</tr>
<tr>
<td>Autobiographical script</td>
<td>High</td>
<td>High*</td>
<td>Low</td>
<td>Medium</td>
<td>High</td>
</tr>
<tr>
<td>Images of objects</td>
<td>Low</td>
<td>High</td>
<td>Medium</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Images of faces</td>
<td>Low/Medium</td>
<td>High</td>
<td>Medium</td>
<td>Low</td>
<td>Low/Medium</td>
</tr>
<tr>
<td>Images of scenes</td>
<td>Low/Medium</td>
<td>High/Medium</td>
<td>Medium</td>
<td>Medium</td>
<td>Low/Medium</td>
</tr>
<tr>
<td>Film clips*</td>
<td>Medium</td>
<td>Medium/Low</td>
<td>Low/Medium</td>
<td>Medium/High</td>
<td>Medium</td>
</tr>
<tr>
<td>Virtual reality scenes</td>
<td>High</td>
<td>Medium/Low</td>
<td>Medium</td>
<td>Medium/High</td>
<td>Medium/High</td>
</tr>
</tbody>
</table>

*Clips from pre-existing movies or music clips; *Brief reminder of a personal event.
the five crucial characteristics of emotional stimuli: ecological validity (similarity of the emotional reaction to emotional experiences in real life), temporal resolution (“the time it takes to process (or to use) the emotional stimuli”), controllability (how easy or difficult it is to control stimuli in experimental settings), complexity (how complex the emotional stimuli could be), and emotional intensity (how intense the emotional response could be) (Grühn & Sharifian, 2016, p.147). However, not every emotional stimulus meets all five given characteristics adequately.

Frequently applied stimuli are presented as a list of emotional words (Adelman & Estes, 2013; Balconi & Cobelli, 2015; Goh et al., 2016; Yap & Seow, 2014), emotional images or photographs, facial-expressions images (Groß & Schwarzer, 2010; Johansson et al., 2004; Leigland et al., 2004; Kensinger & Schacter, 2006) or combinations of the stimuli mentioned above (e.g., words and faces – Di Simplicio et al., 2009; or voices and faces – Cortes et al., 2017). Even though some studies use personal experiences as stimuli (in a form of “autobiographical script”) (Manabu et al., 1998), we argue that most of these stimuli applied in classic studies are simplified and lack a direct association with real-life episodic memories (Bergmann et al., 2012; Chiu et al., 2013).

The aim of this paper is to discuss the methodological approaches across the current testing methods applied in the research of emotional memory – verbal stimuli (words, and stories), visual stimuli (images, facial expressions), and multisensory information stimuli (video sequences and virtual reality). We also discuss the advantages and disadvantages of each approach and compare them to the characteristics of the Emotional Matrix (Table 1). In real life, events are anchored in a complex spatial and temporal context and affected by the current conditions. Neuroimaging studies have even demonstrated a different brain activity pattern in “laboratory conditions” from those of “real world” memories (Chow & Rissman, 2017). Therefore, virtual reality (VR) as a new method applied in neuroscience research has the potential to become a suitable tool also in clinical conditions, particularly for research aimed at emotional memory.

**Verbal stimuli**

*Words*

Simple words represent one of the most common stimuli applied to study emotional memory, primarily for their easy administration and evaluation of results, and for high temporal resolution – people can process the emotional context quickly to elicit an emotional response (Grühn & Sharifian, 2016). Moreover, the method has high controllability – words are easily reproduced and allow the comparison of findings across studies (Grühn & Sharifian, 2016). Another advantage is that several word lists have been developed for research studies that are popular for “having a standardized set of stimuli with corresponding norms” (Grühn & Sharifian, 2016, p. 145). But in fact, this advantage can also be a major drawback, if the norms of a standard set of stimuli are wrong or outdated. Additionally, using norms from other languages might be problematic because words can differ in the number of the syllabus in the original and target language.

Some typical examples of word lists are Affective Norms for English Words (ANEW; Bradley & Lang, 1999), Age-dependent Evaluations of German Adjectives (AGE; Grühn & Smith, 2008), French Emotional Evaluation List (FEEL; Gilet et al., 2012), Dictionary of Affect (DoA; Whissell, 2009), or English EMOtional TERms (EMOTE; Grühn, 2016) with both nouns (EMOTE-N) and adjectives (EMOTE-A) versions. Some of them contain several thousand words, so another methodological question is what is the appropriate number of words that should be memorized.
An excessive number of words can overwhelm the respondent’s memory capacity. Memorability of words is also affected by word frequency and word length which are two major factors in affective cognitive processing (Grühn & Sharifian, 2016).

Another key factor is an appropriate word selection (i.e., abstract/concrete nouns; Ponari et al., 2018). The modality in which the word is presented (e.g., written/spoken words) (Kauschke et al., 2019) and the type of memory task (e.g., spontaneous recall, yes/no recognition) are also important methodological aspects. Processing of emotional stimuli may be also influenced even by their arousal or valence axis (Balconi & Cobelli, 2015; Kever et al., 2019). Valence expresses how positive or negative the stimulus is for an individual, while arousal describes the intensity, how much the stimulus is exciting or calming. These two dimensions have discrepant roles in memory modulation, and they are also neurologically distinguishable (Kensinger & Corkin, 2003; LaBar & Cabeza, 2006).

Furthermore, the emotional words may contain not only generally shared meanings and characteristics relevant for cognitive processing, but also a subjective connotation for each of tested individuals (Grühn & Sharifian, 2016). In an experimental study, Grühn (2016) recommends establishing the meaning of the particular word for different individuals by creating a context for the words using specific instructions or priming conditions to elicit strong emotional reactions. Riegel et al. (2015) also states that words should be memorized in the context of sentences or stories for better control over their meaning. Even so, only a few studies (e.g., Cahill & McGaugh, 1995; Arntz et al., 2005) applied a complex story as a stimulus to study memory.

Stories and narratives

Literary fiction represents a potentially more ecologically valid method in comparison to simple words. Reading fiction can cause a strong emotional experience (Oatley, 1995, 2002) – current emotions, under momentary perceptions of the story or characters, and emotions induced by text resembling our personal experience (Mar et al., 2011). However, even though emotions that occur while reading are comparable to emotions encountered during everyday experience (Oatley & Duncan, 1994), they tend to be less intense (Mar et al., 2011).

The induction of emotions may be influenced by different aspects of the text (Braun & Cupchik, 2001) and by identification with a character that is more likely in the case of first-person narratives (Kerr, 2005). Moreover, we cannot exclude the „story effect“ (novelty or personal memorability) on memory in contrast to the emotional effect (Burke et al., 1992). Bestgen (1994) pointed out the structural importance of sentences and suggested that the emotional curve can be linked to the “interestingness” of stories but also to the clarity and understandability of the text. Longer, well-crafted, canonical stories were rated more immersive (Green & Brock, 2000). However, while reading a long story, we cannot exclude fatigue (Altmann et al., 2012). We should also consider that moral evaluations, empathy with the story characters, and the enjoyment of reading may influence or even reverse the evaluation of the story content (Altmann, et al., 2012; Parkinson et al., 2011; Raney, 2002). Further, literary fiction may also lack subjective significance, which is one of the important aspects of cognitive processing (Grühn & Sharifian, 2016), and a critical component of real-world memories (Misra et al., 2018).

This shortcoming may be overcome by using personal narratives (autobiographical memories), which represent a specific sequence of personal events in the past (Dolcos et al., 2004; Linde, 2015). Moreover, autobiographical memories are involuntary, and spontaneous, with no preceding attempt to recall them (Allé et al., 2020). On the other
hand, the accuracy of memories of past experiences or events is questionable. Not all memories are able to elicit the feeling of “re-experiencing” a remembered situation, and some memories might be altered (Holland & Kensinger, 2010). While some researchers believe that our ability to restore and recall memories of past events is quite accurate, others argue that memories are only an approximate reconstruction of past events (Misra et al., 2018). Misra et al. (2018) attribute the possible reason for this ambiguity to huge variability in the content of individuals’ memories, what makes difficult to compare them between individuals and to replicate the studies.

However, even if narratives are not necessarily real, they can provide a simulation of reality and evoke vivid emotions (Willems et al., 2020). The “narrative mode” is the way in which humans most easily receive and transmit information and convey the temporally evolving world we live in. Nevertheless, narratives often comprise many superimposed, intercorrelated parameters (e.g., phonemes, words, sentences, social interactions, actions, characters, events, and narrative context), contain many confounding variables making interpretation more difficult, and they, therefore, lack the experimental control (Willems et al., 2020). Some researchers also see narratives as confounded with time, too esoteric, niche, or contrived stimuli with poor generalizability.

**Visual stimuli**

*Images/photographs*

Visual stimuli (images or photographs) represent, in addition to verbal stimuli, another frequently used type of stimuli in emotional memory research (Greenwald et al., 1993; Lang et al., 2005). They are easy to administer or implement in an experiment and they can be used for various populations (children, neuropsychiatric patients, healthy controls, people with language processing problems or with limited language ability, or for non-native speakers) (Maffei & Angrilli, 2019) and in a wide range of experimental designs, from simple observation to more complex tasks.

There are several validated, commonly used and freely available image batteries. Over 40 of them (see complete list in [www.face-rec.org/databases/](http://www.face-rec.org/databases/)) are based on facial expression, such as The Karolinska Directed Emotional Faces (KDEF; Lundqvist et al., 1998) and Pictures of Facial Affect (POFA; Ekman & Friesen 1976). Other batteries consist of emotional scenes. Some of them focus on specific emotions like disgust or anger (e.g., Michalowski et al., 2017 or Haberkamp et al., 2017), others, such as International Affective Picture System (IAPS; Lang et al., 2007) or The Nencki Affective Picture System (NAPS; Marchewka et al., 2014), on a whole spectrum of emotions.

Despite mentioned advantages, there are several limitations of these databases. The popularity of mentioned databases may have negative consequences in the form of habituation effects (IAPS; Dan-Glauser & Scherer, 2011). Especially, when study participants must be recruited from specific cohorts as in the case of extreme chronotypes or neuropsychiatric subjects (Marchewka et al., 2014) and took part in more experiments (Dan-Glauser & Scherer, 2011). Some of these stimuli are predominantly based on American trends and culture (Carretié et al., 2019) and are more vulnerable to cultural variances. Significant differences between Asian and Euro-American participants and among different Western countries were also found in valence and arousal ratings (Soares et al., 2015). So, the cultural differences in emotional stimuli processing may play an important role in adequate selection of emotional stimuli. In addition, several databases were created decades ago, and the emotional effects of such pictures may vary for different contexts (Carretié et al., 2019). Moreover, the image parameters like size,
luminance and complexity (Bradley et al., 2007; Marchewka et al., 2014; Wiens et al., 2011) can influence the affective processing of visual stimuli (e.g., brighter images are evaluated as more positive; Lakens et al., 2013). To the best of our knowledge, NAPS is the only pictorial database which includes the luminance and complexity details of the photographs (Carretié et al., 2019; Marchewka et al., 2014).

**Facial expressions**

Another commonly used pictorial material in emotional memory research is images of facial expressions. The recognition and remembering of faces are among the key aspects of everyday social situations. Nevertheless, studies reported inconsistent results as demonstrated better recognition of negative (e.g., Righi et al., 2012; Sergerie et al., 2005, 2007), or positive faces (e.g., Shimamura et al., 2007; 2011). However, these types of studies are often based on a single negative facial expression but using different emotions (e.g., anger, fear, or sadness) what makes difficult to compare various studies.

As noted by authors of one of the newest emotional scene batteries “EmoMadrid” (Carretié et al., 2019), databases of facial expressions more frequently have a discrete affective frame evaluated as a list of basic emotions (e.g., Ekman 1999), while databases of emotional scenes usually have a dimensional frame based on the valence scale and the arousal scale (e.g., Russel, 1979). The difference in affective frames made comparison of the two types of pictorial batteries problematic, so Thom et al. (2014) compared them within the same dimensional frame (arousal and pleasantness). Based on such self-reports, emotional scenes can reach a higher valence and arousal than facial expressions (e.g., Thom et al., 2014; Carretié et al, 2019). Compared to simple visual stimuli such as faces, objects or written words, spatial scenes present a considerably higher variability in luminance/brightness, spatial frequency information, or chromatic complexity (Carretié et al., 2019).

**Video sequences**

Importantly, although pictorial stimuli, especially scenes, can be visually complex, they lack the temporal dynamics of real-life experiences as they are static – this represents their most critical shortcoming. In contrast, integration of multisensory information in video sequences enables us to overcome these shortcomings. Previous research has indicated that audio-visual congruent presentation, in comparison to audio-only presentation, can lead to a more intense emotional response (e.g., higher response in skin conductance). Audio-visual integration occurred in both the positive stimuli and the negative stimuli (Pan et al., 2019). Moreover, video sequences allow us to simulate some real-life conditions including the dynamics of the scene and thus increase the ecological validity of the task. As Gross and Levenson (1995) state: “Films also have a relatively high degree of ecological validity, in so far as emotions are often evoked by dynamic visual and auditory stimuli that are external to the individual” (p. 88). Moreover, video is not only sufficient to evoke basic emotions (fear, disgust), but might also evoke even more complex feelings (Rottenberg et al., 2007; Schaefer et al., 2010). Despite these facts, only few studies have used used videos to study emotional memory (e.g., Samide et al., 2019).

There are several video databases that can be used to study emotional memory (e.g., Database for emotion Analysis Using Physiological Signals; DEAP; DECAF database, Abadi et al., 2015; FilmStim database, Shaefer et al., 2010; Kolestra et al., 2011; MAHNOB – HCI database, Soleymani et al., 2011). However, there are some methodological questions concerning the use of video clips as a study material. For example, it can be difficult to determine the length of the presented stimulus. While
for “more basic” emotions (fear, disgust) a short clip can be sufficient, to evoke more complex feelings (e.g., disappointment) a longer clip might be necessary to understand the context of an event (Maffei & Agrilli, 2019). This may lead to some limitations in the application of video recordings. For example, film sequences, which are taken from popular media – movies, music clips, or TV shows can be processed differently from autobiographical events, because participants are aware that the depicted events are fictional (Abraham et al., 2008). These stimuli may also be familiar to some respondents, which can affect both memory (Tulving et al., 1996) and emotion processing (Ishai et al., 2004). Another shortcoming of video sequences is the restriction to strict observation of the social situations presented. Even though video clips can capture social interaction with its dynamics and mimic details, the problem is that respondents cannot actively participate in the social interaction (Parsons et al., 2017). Therefore, interactive tools that would allow direct participation of the tested person in the social situations (such as virtual reality scenarios presented below) are rising in popularity. This phenomenon is described in terms of the “second-person neuroscience” approach applied frequently in current neurobehavioral studies (Redcay & Schilbach, 2019).

Virtual reality in emotional memory research

Virtual reality (VR), a computer-simulated environment that reflects and directly interacts with the real world, is a relatively new tool in neuroscience. The main advantage of VR scenes for basic and applied research is the combination of the above-mentioned simulation of realistic human interactions in complex environments with complete control over the presented stimuli. In comparison to above listed standard methods, VR allows the study of human behavior in potentially ecologically valid situations while maintaining controlled laboratory conditions (Bohil et al., 2011).

Although there is evidence that standard techniques for memory testing are comparable to VR (Mazurek et al., 2021), there are fundamental reasons why VR may provide several benefits for testing specific situations including emotional memory and other affects-inducing phenomena (for review see Plechatá et al., 2021).

Realistic experience created in simulated virtual scenes is associated with a so-called sense of presence, an illusion that we are present in a virtual environment while physically present in the real world (Slater, 2018). This feeling usually increases with the degree of immersion in the virtual world, which is causally related to the technological properties of the virtual environment, such as panoramic 3D displays with a fast response to our actions (e.g., image response to head rotation). The application of immersive VR in clinical research or in the study of emotional response is substantially supported by the assumption of a more authentic reaction to an emotional stimulus simulated using VR (in comparison to the above-mentioned methods). This effect is often used in exposure therapy in the treatment of phobias, where the feeling of presence in a virtual environment plays a key role in the effectiveness of the therapy. From the point of view of the emotional reaction, the feeling of presence is a key element for its induction in a virtual environment. Study comparing non-immersive (desktop) and immersive VR setup eliciting anger or fear supports this hypothesis while showing increased affective response in immersive VR condition (Susindar et al., 2019).

While in general, research suggests a positive relationship between the degree of immersion and arousal-inducing emotions, such as fear and anger, this relationship has not been confirmed in studies aimed at positive emotions, such as happiness or a state of relaxation (Diemer et al., 2015; Visch et al., 2010). Importantly, direct comparison of virtual and real-world natural scenarios showed that emotions and affective states
The reason why VR is so effective in such a wide range of domains is the high level of realism provided by the simulations. Nevertheless, as with any other new technology, these benefits come with some negative side effects that must be considered. First, most VR headsets create the illusion of depth using small LCD monitors projecting to individual eyes that are positioned remarkably close to the eyes, potentially creating problems related to fixed accommodation distance present for extended time periods. The length of the virtual memory task or frequent breaks should be therefore taken into consideration when the VR experiment is planned. Cybersickness symptoms should also be considered in case of immersive VR, caused mainly by a discrepancy between visual and proprioceptive information (e.g., moving around the virtual scene while sitting in front of the computer). However, these side effects can be eliminated to some extent using advanced technologies (Bohil et al., 2011), which provide a faster response between observed movement and image generation, and by real linking head, body and hand movements to movements and interactions in VR.

Despite these disadvantages, VR enables us to study emotional memory in complex situations, while maintaining good control over the presented stimuli. Compared to other above listed standard methods, the use of VR is especially beneficial for studying social interactions that are difficult to reduce to the mere emotional valence of words and images. For example, while photographs of faces are problematic in the research of emotional memory due to the absence of dynamics and real interactions, VR avatars – computer simulations of human figures, seem to be a valid tool for recognizing emotions from facial expressions (Faita et al., 2015). We, therefore, argue that VR represents a more valid tool to study emotional memory than other methods often reduced to a simple list of words or photographs. Moreover, VR also allows us to study emotional memory in situations with one’s own virtual body present (Bréchet et al., 2019).

As far as we know, VR has not yet been used specifically to study emotional memory, but studies have been published on the use of VR in the field of mood induction procedures, where VR should replace non-interactive tools such as video, photography, or music. These methods are specially designed to induce a certain mood in laboratory conditions and allow the study of the influence of these conditions on mental functions (Baños et al., 2012; Felnhofer et al., 2015). Studies confirm the efficiency of this tool to elicit an emotional response and confirm that immersive VR leads to a greater sense of presence compared to standard mood induction methods (Baños et al., 2006). Immersive VR also allows us to induce specific emotions, such as joy, anger, or anxiety (Felnhofer et al., 2015). It has even been shown that an immersive virtual experience evokes a similarly strong emotional response as exposure to the same object in real life (Marín-Morales et al., 2019), which points to the ecological validity of this approach.

**DISCUSSION**

The present article summarizes the current methodological approaches to the study of emotional memory, the advantages and limitations of various approaches and the stimuli they use, and suggests the possibility of using a new approach in the form of virtual reality (VR) scenarios. The current findings in emotional memory research are
often ambiguous, and such an ambiguity in behavioral testing may be caused partly by the inconsistency of emotional memory definitions (Cheke & Clayton, 2013), but even more importantly by inconsistency in methodology (Misra et al., 2018). The question of reliable methodology for studying emotional memory is crucial as it has important implications for understanding the clinical conditions associated with negative affective biases in encoding and retrieving emotional memories (Dolcos et al., 2004). Further research may help also to understand its basic mechanisms and their disruption in psychiatric disorders (Engen & Anderson, 2018). Very important point in selection of the appropriate stimuli is to decide if we aim to elicit basic emotion or more complex emotion with specific affective state (positive/negative). Simpler stimuli, such as faces or words, with low interindividual variability are suitable to provoke basic emotions, while more complex stimuli (video, VR, etc.) can be used to evoke also complex emotions even though they are very subjective. Therefore, it is crucial to develop methods that would allow both good control over experimental conditions with low individual variability, while evoking complex emotions.

Currently, heterogeneous study designs with either verbal or visual stimuli are used. Most of the behavioral and neuroimaging studies targeting emotional memory use fewer complex stimuli in laboratory conditions. However, types of stimuli, their arousal, and the methodological aspects of experiments differ across studies.

In the case of verbal stimuli, the most frequently applied paradigms employ simple word lists, mostly due to their relatively easy and fast administration, possibility of group administration and good experimental control, however, simple word lists can be too simplistic. Therefore, words memorized in the context of sentences or stories might be more ecologically valid (Riegel et al., 2015). Even other aspects, such as story contents (Parkinson et al., 2011; Raney, 2002) or personal connotations (Altman et al., 2012) might affect the measured emotional experience (Bestgen, 1994; Braun & Cupchik, 2001; Kerr, 2005).

Nevertheless, verbal experiments using word lists or short stories as a simple presenting material lack real-life conditions and are less intense. Based on The Emotional Matrix (Grühn & Sharifian, 2016), they may also lack the complexity and emotional intensity that seems to be an important factor in text remembering (Legros, 1988; Martins, 1993). For this reason, personal narratives (autobiographical memories) can represent a more ecologically valid situation, but the interindividual comparability and accuracy of personal memories is a subject of debate (Holland & Kensinger, 2010; Misra, et al., 2018).

The most frequently used visual stimuli are emotional scenes and facial expressions. However, existing databases of facial expressions and emotional scenes tend to have different affective frames (list of basic emotions vs. dimensional model for the latter), which makes the comparison of results problematic (e.g., Ekman, 1999). Another difference is that emotional scenes may represent various degrees of arousal and valence and can reach higher arousal than facial expressions (Carretié et al., 2019). There are also additional methodological problems associated with visual image materials – e.g., repeated use of the same stimuli for the same participants (Dan-Glauser & Scherer, 2011), low cultural variability or problematic definition of luminance and other objective parameters of the stimuli (Lakens et al., 2013), and most importantly the lack of temporal dynamics and real-life experience.

Due to the above listed limitations, some studies applied video sequences as acquisition material. However, many such studies tested the paradigm in an insufficient number of respondents (e.g., Chen et al., 2017) and the results cannot be generalized. Moreover, video sequences that are taken from movies, music videos or TV shows
can be treated differently from autobiographical events, as participants recognize the displayed events as fictional (Abraham et al., 2008) or even familiar (Tulving et al., 1996). The most crucial limitation is that even though video clips can capture social interaction, they do not allow the respondent to actively participate in the social interaction (Parson et al., 2017).

As outlined in previous sections, one of the most critical aspects of emotional stimuli is their ecological validity (Grühn & Sharifian, 2016) that affects how strongly is the simulated situation perceived as close to real emotional experience of everyday life. Emotional experiences are more understandable in context, but highly standardized emotional stimuli (such as images, words, etc.) typically lose such contextual information (Grühn & Sharifian, 2016). Emotional scenes, video recordings, film clips or written stories can be more complex, but they often lack the interactivity and temporal dynamics of real-life experiences (Carretié et al., 2019). On the other hand, the studies using personal experiences (such as autobiographical script paradigm) where stimuli are more personally relevant and vivid, however, recalled memories are often influenced by their subjective value, which makes intersubjective comparison more difficult (Bergmann et al., 2012; Chiu et al., 2013).

We propose that virtual reality is applicable and suitable in the study of emotional memory. This tool meets all the conditions for use in testing emotional memory according to the Emotional Matrix – ecological validity, temporal resolution, controllability, complexity, and emotional intensity (Grühn & Sharifian, 2016). It is particularly important to mention that none of the other methods (words, pictures, etc.) meet all the conditions. It is a method with great potential, enabling very realistic simulations of real-life events. Virtual reality is, therefore, a promising tool for exploring emotional memory.

In comparison to the above listed methods, emotional scenes simulated in VR environments may present a particularly useful tool. VR technology enables us to simulate complex and real-world situations in different contexts and allows experimenters a unique opportunity to explore human behavior in potentially ecologically valid situations in controlled laboratory conditions (Bohil et al., 2011). Based on factors evaluated in the Emotional Matrix (Grühn & Sharifian, 2016), VR can potentially bring some advantages in comparison to other types of stimuli, such as controllability, complexity, or emotional intensity (for comparison of methods see Table 1). To evoke the most complex and realistic experience that will evoke emotions, it is beneficial to use a virtual reality with high immersion (e.g., VR headsets) presented in first-person view that simultaneously allows high control over all variables (objects, timing, etc.). The participant may experience the feelings of presence in the virtual scene important for the research of emotional memory (Botella et al., 2009; Schubert et al., 2001). In addition, virtual reality environments are advantageous for studying episodic emotional memories, as all variables can be controlled, events can be standardized, presented in real-time, and experienced from the first-person egocentric perspective. Moreover, they are potentially evoking narrative and temporal aspects of events (Bergouignan et al., 2014; Pause et al., 2013). However, the crucial advantage of scenarios applied in VR in contrast to all above mentioned methods is the possibility of direct interaction of the tested subject, who is co-actor in the scene, not mere observer (see “second-person neuroscience” discussed above). The potential application of VR paradigms in memory research can be also demonstrated in the application of the virtual Episodic Memory Task (vEMT) designed to address the contextual cues of episodic memory in ecologically valid situations (episodes) (Fajnerová et al., 2017). Similar or even more complex situations can be extended with an emotional paradigm.
The main benefit of virtual reality paradigms in means of emotional memory research is however the ability to evoke emotions by dynamic visual and auditory stimuli (Uhrig et al., 2016) utilized in rich multisensory stimulation of VR paradigms. These benefits have been demonstrated in Virtual reality exposure therapy (VRET) (Kim et al., 2007), where the emotion evoked by the simulated exposure situation can help to reduce a person’s fear, anxiety, or compulsive behavior (Francová et al., 2019). VRET also seems to be potentially useful in the treatment of different types of traumas, and in the reduction of PTSD symptoms (Kothgassner et al., 2019). However, studies that would apply complex emotionally salient virtual scenes in behavioral or imaging research of emotional memory are still scarce (e.g. Cadet et al., 2022).

CONCLUSION

In this review, we summarized the pros and cons of various methodological approaches and pointed out a potentially useful new line of research in emotional memory using virtual reality. We propose that virtual reality is applicable and suitable in the study of emotional memory. This tool meets all the conditions for emotional memory research according to the Emotional Matrix – ecological validity, temporal resolution, controllability, complexity, and emotional intensity (Grühn & Sharifian, 2016). It is particularly important to mention that none of the other methods (words, pictures, etc.) meet all the conditions. It is an assessment with great potential, enabling very realistic simulations of real-life events enabling direct interaction. Virtual reality is, therefore, a promising tool to study emotional memory.

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SOUHRN

Metodologické přístupy ve výzkumu emoční paměti

Emoce mají zásadní vliv na různé kognitivní procesy u lidí, včetně pozornosti, vnímání, učení a paměti. Dlouhodobé vzpomínky jsou ovlivněny nejen emocemi prožitými při jejich učení, ale také emočním stavem při jejich vybavování. Termín „emoční paměť“ je často spojován s epizodickou pamětí a s mentálním cestováním v čase, emoce však ovlivňují každý aspekt paměti (např. jak declarativní paměť, tak nedeklarativní paměť). V této přehledové studii autoři diskutují metodologické výhody a omezení některých metod, jejichž využití přispívá k lepšímu pochopení emoční paměti.

Užití virtuální reality při testování emoční paměti je konečně svědectvím vývoje většiny oblastí věd, které se věnují poznávání člověka a jeho vztahu k vnějšímu světu. Virtuální realita umožňuje vytvářet obrazy, které připomínají stopy našich počínání a významněji jsou s nimi spojeny emocionální aspekty.

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Tento přehledový výzkum obohacuje existující přístupy k pochopení emoční paměti a poskytuje nové perspektivy pro další výzkum. Virtuální realita se využívá jako nový nástroj pro vědectví, který poskytuje výhody v tom, že umožňuje vytvářet vtipné, reálné obrazy, které připomínají stopy našich počínání a významněji jsou s nimi spojeny emocionální aspekty.