Review Article

Innovations in digital interventions for psychological trauma: harnessing advances in cognitive science

Erik Andersson[1], Emily A. Holmes[1], David Kavanagh[2]

[1]Department of Clinical Neuroscience, Division of Psychology, Karolinska institute, Stockholm, Sweden; [2]Centre for Children's Health Research, Institute of Health and Biomedical Innovation, and School of Psychology and Counselling, Queensland University of Technology, Brisbane, Australia
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Correspondence to: Dr. Erik Andersson. Department of Clinical Neuroscience, Division of Psychology, Karolinska institute, Nobels väg 9, 171 77 Stockholm, Sweden. Email: erik.m.andersson@ki.se.

Abstract: A range of digital psychological interventions have demonstrated a positive impact on trauma-related problems in controlled trials, but there is room for further improvements in their form, reach and impact. Most to date have been adaptions of established face-to-face treatments. In this paper, we highlight a complementary emerging route to their development, which draws on advances in cognitive science theory and research and applies them to clinical contexts. Three examples are given regarding laboratory research with potential applications to digital interventions for trauma-related mental health problems: a digital game to reduce intrusive memories of trauma, novel cognitive techniques for worry, and digitally supported mental imagery to enhance motivation for functional behavior change. Much of this research is still at an early stage, meriting a balance of optimism and caution. However, even if only a few digital applications of cognitive science constitute substantial improvements to complement current treatments, their potential for large-scale use at low unit cost may provide significant benefits across populations.

Keywords: Technology; trauma; precision treatments; psychological treatments; intervention; post-traumatic stress disorder (PTSD); acute stress disorder (ASD)

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Psychological trauma is a global problem with profound impact on the affected individual and society as a whole, and the high prevalence of trauma related mental health reactions is likely to far outstrip the ability of standard face-to-face psychological treatments to address them (1). Digital interventions can address geographical, staffing and cost limitations in access to evidence-based treatments, and have the potential to substantially reduce the global burden of both fully developed mental health disorders such as acute stress disorder (ASD), post-traumatic stress disorder (PTSD), as well as related subthreshold symptoms (2). Fortunately, a range of digital interventions for trauma-related problems, including cognitive behavior therapy (CBT) delivered by videoconferences (3,4), Internet programs (2,5) and apps (6) have demonstrated positive effects in controlled trials. However, even the best digital tools do not provide full recovery for everyone (2,5,7,8), cannot reach everyone, or are not viewed as desirable to use, leaving substantial opportunity for further improvements.

Historically, most digital interventions for post-trauma reactions (2) and other mental health conditions (8) were adaptions of evidence-based face-to-face psychological treatments (such as forms of CBT) to a digital format (*Figure 1*, left side). While that pathway has been productive (9), this paper suggests a complementary approach to the development of digital treatments, which draws on theoretical insights and empirical findings from cognitive science, including advances in our understanding

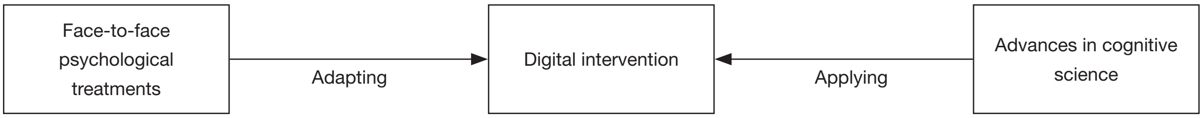

Figure 1 Two complementary developmental pathways to digital interventions.

of information processes underpinning perception, learning, memory, decision making and emotion (*Figure 1*, right side), see also (10). This approach uses digital tasks that have been tested in laboratory settings and analogue studies, applying them to clinical contexts including difficulties after psychological trauma. Such tools may constitute a component of a more complex digital intervention or face-to-face treatment, or be used as a stand-alone intervention for a specific symptom. When applied outside treatment sessions, they capitalize on the potential for digital devices to be constantly available, allowing users to access the tool for repeated practice whenever needed.

This alternative pathway to the development of digital interventions is highly consistent with the recent Lancet Psychiatry commission review of the future of psychological treatments (10), which suggested that: "*Technology-based treatments need to improve with advances in psychological theory and understanding of mechanisms of change*" (10). Such a mechanistic approach is also highly consistent with the way early behavioral treatments developed as applications of learning theory (11,12), and with the application pathway from neuroscience and chemistry to novel pharmaceuticals (13). In this paper, we provide three illustrations of digital interventions stemming from cognitive science, which have potential to address sequelae of psychological trauma.

Example 1: a visual game to reduce intrusive memories of trauma

One example of applying ideas from cognitive science towards the development of a digital intervention is our own research on preventing intrusive memories following a traumatic event (14). Intrusive memories of traumatic events often take the form of emotional mental images, such as the sight of a car crash with injured people in vivid color. These intrusive images can both be highly distressing and disruptive to daily life (15). Mental imagery is usually defined as a perceptual experience in the absence of external sensory input (16). It can occur in any sensory modality, and may involve multiple modalities. Mental imagery is more closely linked to emotion than are verbal descriptions, perhaps partly because it simulates actual sensory experience, and may even sometimes be confused with it (17).

Unlike most traditional psychological therapy techniques, the emerging line of research on traumatic mental imagery focuses on targeting just this one core clinical feature of post-traumatic distress rather than the whole disorder. Importantly, this intervention was initially designed to help prevent the emergence of symptoms (rather than be a treatment for an established disorder). A preventive target both provides an additional rationale for the single-symptom focus, and expands the potential application of the technique to the attenuation of subclinical or transient reactions in their own right, as well as potentially averting more severe disorders such as PTSD.

This preventive behavioral intervention approach draws on research showing that engaging in a visuospatial task (tasks that demand using visual memory and visual attention) competes with visual mental imagery for working memory resources (18). If cognitive task interference occurs at the time when image-based memories are being encoded and stored for the longer term ('memory consolidation')—a time when the memory is still labile—then the concurrent cognitive task could interfere with the formation of intrusive memories of trauma (19,20).

Laboratory experiments indeed suggest that when similar cognitive tasks compete for shared resources, they interfere with each other; for example, visuospatial pattern-tapping task (tapping a pattern) reduces the ability to hold a visual mental image in mind, making it both less vivid and less emotional (21). A digital example of such a visuospatial task is the game Tetris, which can be played on any digital device, and involves matching moving colored tiles on a screen. A series of laboratory experiments have been conducted with healthy participants and experimental stress (22). These studies demonstrated that using the competing digital visual task within the supposed time window of memory consolidation (an estimated 6 hours after an event) led to a reduction in the frequency of intrusive memories of the experimental trauma over the subsequent week (19,23).

An initial proof-of-concept randomized controlled trial by Iyadurai *et al.* (14) was delivered in a hospital emergency department within 6 hours of a traumatic motor vehicle accident. It compared effects of a Tetris-based intervention (a trauma memory reminder cue plus approximately 20 min of Tetris game play) with an attention-placebo control (a trauma reminder followed by a written activity log for about 20 min without visual tasks). The primary outcome was the number of intrusive trauma memories measured daily over the subsequent week. Results supported the superior efficacy of the Tetris intervention compared with the control condition: there were fewer intrusive memories overall, and time-series analyses showed that the incidence of these intrusions declined more quickly. Convergent findings were found on a measure of clinical post-trauma intrusion symptoms at 1 week, but not on other symptom clusters or at 1 month (14).

Similar findings were found in a clinical trial by Horsch *et al.* (24) who tested the Tetris intervention with women in hospital who had experienced a traumatic childbirth in the previous few hours. The treatment group received usual care plus the Tetris intervention (20 min of game play in the same context in which the trauma occurred) versus a control group of usual care. In this case, no reminder cue was given before the Tetris intervention, as mothers were still in the same hospital context as one where the traumatic incident occurred. Mothers who played Tetris had almost two-thirds fewer intrusive memories over the following week than did the control group. At 1 month, there was a lower rate of PTSD in the treatment condition, but this additional finding should be treated cautiously given the small scale of the study and the fact that it was not the primary outcome measure (24).

There is clearly potential to refine the digital aspects of this approach. Other games may be more engaging of cognitive resources or attractive to users, and other types of game play may further improve the intervention's efficacy or longevity of effects. Conversely, some digital tasks such as ones that are more verbally based may not work or could even worsen memories. However, as findings are mixed, this is an area requiring further research (23,25).

Many additional research steps will be required to move from proof of concept trials towards a fully-fledged intervention with established efficacy, although current results are promising. Advantages of the intervention include its brevity (a single session of about 30 min), the fact that it does not require a highly skilled therapist, and that it does not require talking about the trauma in detail. Such an approach could be readily scalable at low unit cost, which is required for large-scale prevention of negative sequelae from exposure to psychological trauma.

Example 2: re-thinking worrisome thoughts using novel cognitive techniques

Excessive worry is also a feature of post-traumatic stress (26-28) and has been shown to impair working memory capacity for concurrent cognitive tasks (29). Impaired working memory may in turn lead to inefficient problem-solving, which can perpetuate or exaggerate the worry and decrease everyday functioning.

A particularly innovative line of research lead by Hirsch (30-32) has indicated that it is specifically the verbal (rather than visual) form of worry that impairs working memory. If high-worriers are instructed to approach worry thoughts using imagery-based thinking, they benefit from less subsequent intrusions relative to worriers using verbally based techniques (30,31). These and other ingenious studies have culminated in a theoretical model of how cognitive processes can combine to produce and maintain excessive worry (33). Worry in a verbal rather than imagery-based form is held to increase selective attention to threats, which in turn depletes residual working memory functioning, so that participants who uses verbal-worry techniques may have difficulty detaching their attention from possible threats (34,35). Based on this research and theoretical work, worried individuals could be trained to approach their worrisome thoughts by generating an image of the situation and describe this image vividly using all senses and as being there in the present moment (30,31). The worrier could practice at home when they experience worry and homework assignments could be cued by an audio script on their phone. This is in turn predicted to reduce the amount of time spent worrying.

An alternative way to encourage imagery-based cognitions rather than verbal ones may be to reformulate abstract negative thoughts in a more specific and concrete way (which makes them more image-based). This relatively simple technique has been shown to reduce intrusive memories from a stressful film when conducted in the laboratory (36). It also appears promising with a clinical younger population with depressive and anxiety symptoms when delivered via the internet within a larger CBT package (37).

Some imagery-based exposure exercises are often already incorporated in both face-to-face and digital CBTs for worry. In these exposure exercises, the patient visualizes their most frightening scenario and retains the mental image until they are no longer fearful (38). However, mental imagery could be used also in other ways. For instance, imagery rescripting—a technique aimed to systematically transform and manipulate certain aspects of a maladaptive mental image—has been shown to reduce aversive intrusive images for past traumatic events (39). This technique may also work for thoughts about future negative events that are the focus of worry—as has begun to be examined for 'flash-forwards' (flashbulb images of anticipated future events) in bipolar disorder (40). Imagery rescripting could be supported by phone-based audios, which could be individually tailored in face-to-face sessions, or may use generic scripts that could be applied to new worries or used as a stand-alone self-management tool. As yet, it is not clear whether imagery rescripting for one catastrophic image may not only make that image less distressing, but also inhibit and reduce the subsequent chain of other worry thoughts. If so, that would significantly increase the utility of this approach.

Other cognitive strategies are also opened up that could apply to digital formats. Hirsch *et al.* (32) found that participants who engaged in verbal thinking about positive outcomes when experiencing worry had significant reductions of intrusions compared with participants who focused on negative outcomes. Another intervention approach could therefore involve training worriers to focus on positive aspects of thoughts about future events. More specifically, one task could be to record the worry thoughts on the phone and the phone would prompt the worrier to respond to questions focusing on the possible positive aspects e.g., "*What are some of the positive outcomes of this thought? How might this turn out OK? What would be positive about that specific scenario?*" (32). Indeed, one study showed that positive ideation training (irrespective of whether it involved verbal or imagery-based thinking) decreased both anxiety and worry (41). Other trials that attempt to modify negative cognitive biases are currently underway (42).

A clinically important question is whether targeting worry with a digital intervention may have cascade effect on other symptoms or comorbid problems. If the digital intervention freed up working memory resources, that could potentially lead to more effective coping with other trauma symptoms. For example, a trial by Freeman *et al.* (43) demonstrated that therapeutic reductions in worry led to long-term attenuation of delusions in 150 patients with psychotic symptoms. Whether similar generalization of improvements can be obtained with trauma symptoms remains to be tested.

Example 3: digitally supported mental imagery to enhance motivation: Functional Imagery Training (FIT)

A key challenge for any treatment is its ability to engage people in sessions and in applying what they learn in their everyday life, and engagement in treatment for trauma reactions is no exception (44). This issue may be particularly difficult when—as in treatments that involve recalling or encountering a traumatic experience (e.g. exposure to the trauma memory) (45)—the sessions or homework tasks elicit highly aversive emotions. Accordingly, exposure-based treatments often show high dropout rates, especially when applied in usual care (46).

There is an opportunity to apply laboratory research on mental imagery to amplify motivation for engaging in treatment. The close relationship of mental imagery with emotions has already been mentioned above (17). As articulated in elaborated intrusion theory (47,48), relationships between mental imagery and affect are not restricted to emotions, but also extend to desires for experiences that we expect to give us pleasure or alleviate discomfort (49,50).

The experience of feeling motivated in a particular moment involves cognitions about the desired outcomes we anticipate from investing effort in a particular action (51). An implication is that the desire is only one requirement for motivation: we also need to believe we can undertake the actions required to obtain the outcome (self-efficacy) (52). There is now substantial evidence that desire cognitions commonly involve sensory imagery, and—consistent with the role of mental imagery in emotions—that more affectively intense desires are associated with more vivid mental imagery (53). Stronger, imagery-based desires are associated with greater goal achievement, including control of problematic behaviors (54). Mental imagery is also important for self-efficacy, which is most powerfully enhanced by memories of relevant past successes, especially when they involve episodic imagery (i.e., recreation of events over time) that is associated with positive affect (55).

The elaboration of desire-related imagery requires space in visuospatial working memory, which is substantiated by the fact that the imagery vividness and desire intensity are modified in the laboratory by concurrent visuospatial tasks (56), as was used in the reduction of trauma imagery in

Example 1 above. Related research on desires has typically focused on helping people deal with dysfunctional craving (49,50), but it is also relevant to motivation. Conflicts between desires or goals are commonplace experiences but are especially important in situations where a functional behavior (such as attending a trauma exposure session) is aversive in the very short-term, but very positive later on. The two sets of desires are likely to involve the elaboration of imagery that will be in competition for working memory. Unfortunately, short-term incentives tend to be more vivid and highly valued, so even when recovery is much more important to the person, imagery about aversive aspects of attending the session are more likely to capture cognitive resources. The challenge for successfully building motivation is to enhance functional imagery that is sufficiently vivid and emotionally intense at the time when a behavioral choice is being made, that it makes the functional choice (e.g., addressing the trauma reaction) the more attractive option and inhibits imagery that would undermine motivation, such as short-term benefits of avoidance.

This theoretical and empirical work has important potential applications to eliciting and enhancing motivations, including motivation for treatment. The association between mental imagery and motivation has long been recognized and exploited in sports psychology. People who engage more frequently in physical activity use mental imagery more (57), and elite footballers are more likely to use mental imagery than are recreational ones (58). This mental imagery is not only about optimal movements or strategies, but also about succeeding in a competition or receiving benefits such as feeling energized (59). Such mental imagery is likely to boost both self-efficacy and desire to invest effort and persist in the face of setbacks (47,55).

The most widely accepted current approach to building motivation for therapeutic change remains motivational interviewing (MI) (60,61), which uses an empathic, client-centered approach to help participants explore incentives and potential for change. While MI has established efficacy across a range of problem domains, average effects are relatively small (62,63) or are not well maintained (64). If the MI session used mental imagery rather than verbal discussion—as suggested by a cognitive science perspective—and if participants who were committed to functional changes were shown how to use motivational imagery by themselves, effects may be increased.

A psychological intervention known as FIT (65,66), which does this, has indeed shown stronger effects than MI in a trial on weight reduction (67). FIT is sometimes applied as a face-to-face treatment, but more often it is a blended treatment, where a mobile phone app is used to cue motivational mental imagery using reminders and the person's own photos, and to sustain attention on these multisensory, episodic images using audio guides (65,66). An app ('Fitz') that uses an avatar to deliver a simplified version of FIT (to reduce or avoid the need for therapist input) has just been developed and is under test.

Adaptations of FIT may also have applications for trauma-exposed people that go beyond engagement in treatment. For example, some people deal with distress after trauma by engaging in problematic alcohol or other drug use (68), and drug use has potential both to retard recovery and to introduce additional problems (69). FIT could be applied to address this co-occurring substance use. For example, a trial that is currently underway, delivers FIT sessions over the phone, to help people with alcohol use disorder to create imagery about advantages of reduction or abstinence, and times they have had better control. Participants who are committed to make a change subsequently practice imagery about how they will stay in control in coming situations, and the benefits they will receive from their success. However, substance use is just one example. FIT is potentially applicable to any behavioral goal.

FIT differs from other examples in this paper, in that it initially involved the translation of laboratory-based research into a new face-to-face treatment, where an app was sometimes used adjunctively to support home practice of mental imagery. Now, it is being investigated as a blended treatment or one that might even be delivered just in a digital format.

Discussion

These above three examples should be seen as just illustrative examples rather than providing an exhaustive list of potential applications of cognitive science to the development of digital tools for the sequelae of psychological trauma. Furthermore, new advances in cognitive science theory and research will offer a rich array of further inspiration to be mined by developers of new digital techniques. Not all of these interventions will have sufficient acceptance or impact to allow widespread uptake in a real world setting—in fact, as the application of biological science to drug development has taught us, there are likely to be more failures than successes (70). The focus on one mechanism or process may also sometimes limit the extent that the tool impacts on overall functioning, given the varied combinations of problems that often occur after trauma (e.g. it is possible to have 636,120 different combinations of PTSD symptoms) (71). However, it is also possible that changes in some symptoms may have a cascade effect on others, or that more than one tool may be used sequentially or in concert to address multiple problems.

Many of the laboratory-based advances in cognitive science already use some form of digital tools (e.g., to run an experiment in a laboratory). In one sense, the refinement and application of these tools to clinical practice is a much smaller leap than the translation of face-to-face treatments to digital interventions, although the laboratory versions often involve relatively simple and unengaging software rather than utilizing sophisticated digital designs. If the application already uses a commercial game like Tetris, the familiarity and acceptability of the game format together with the sophistication of the app and its rewarding aspects, are likely to make it relatively easy to encourage its widespread use. However, few commercial games are used repeatedly for a long period. While that is not a problem for the application of Tetris in the way described above, it may produce challenges if an app required regular use over an extended period.

As exemplified by FIT and suggested by the example on worry, the pathway from scientific advances to digital treatments may sometimes be more complicated than suggested by *Figure 1*. As in FIT, the advance can sometimes flow via an innovation in face-to-face treatment, with the digital aspect blended in or (as with traditional face-to-face treatments) as a later adaptation. Even where the core intervention tool is digital, it may still remain situated within a face-to-face or remotely delivered session, either as the sole context for its use or to deliver training in optimizing its impact. Some may never effectively translate to a solely digital form of delivery or may need substantial further development to do so.

The "application" pathway from cognitive science requires a different form of collaboration to the one the digital intervention field is most familiar with. Rather than only involving joint work by therapists/researchers, developers and designers, it requires that applied cognitive scientists also join the efforts, as well as colleagues more expert in information technologies. Just as the current collaborations involve bridging disciplinary understanding and language, so does this new pathway. However, as with current collaborations, it also opens up exciting new ways to conceptualize and sharpen interventions. This could accelerate research progress and create opportunities of cross-fertilization between researchers and industry, and it ultimately would help us improve outreach to underserved populations after traumatic events around the globe.

Traumatic events can come suddenly, at full scale and anywhere in the world. There is a need for fast-response digital interventions that can be marketed and delivered widely, regardless of distance, language or national boundary, and to moving populations (such as refugees) or communities whose infrastructure has been disrupted by natural disasters or war. Poverty, loss of possessions and disruption of power or web access present substantial challenges to digital applications in some of these contexts, although mobile apps currently offer partial solutions to access problems.

Despite these challenges, we see the "application" pathway in *Figure 1* as potentially opening up exciting new horizons in digital interventions. At this point much of this work is still at an early stage, meriting a balance of optimism and caution. However, even if only a few digital innovations that are derived from cognitive science prove to give substantial benefit, those tools have the potential to make interventions for trauma more cost-efficient and effective. Critically, some may also be available on a scale that benefits whole communities or nations. Given the millions worldwide who inevitably will experience future traumatic events, this objective should be our aspiration.

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Footnote

Conflicts of Interest: EA Holmes reports serving on the board of MQ: Transforming Mental Health, and as Associate Editor of Behaviour Research and Therapy. She receives book royalties from Oxford University Press. D Kavanagh holds a Research Capacity-Building chair at Queensland University of Technology and is an Adjunct Professor at the University of Queensland. E Andersson has no conflicts of interest to declare.

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