Original Paper

Desensitizing Anxiety Through Imperceptible Change: A paradigm for single session exposure for fear of public speaking

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Abstract

Background: Exposure therapy (ET) for anxiety disorders involves introducing the client to the anxiety provoking situation over several treatment sessions. Each time, the client is exposed to a greater anxiety-provoking stimulus – for example, in the case of fear of heights, the client would successively experience being at a greater height. ET is effective, and its counterpart, virtual reality (VR) ET, where VR substitutes real world exposure, equally so. However, ET is expensive in time, requiring several sessions.

Objective: Here we introduce a paradigm concerned with public speaking anxiety, where the VR exposure occurs in a single session while the client is interacting with a virtual therapist. Over time the therapist transforms into an entire audience with mostly almost imperceptible changes. The objective was to compare the results of this method with traditional VRET and to compare both with a control condition.

Methods: We carried out a feasibility study comparing three conditions: the single exposure (n=16) as described above, a conventional multiple exposure (n=14) where the same content was delivered in successive segments over 5 sessions, and a control group (n=15) who interacted with a single virtual character to talk about everyday matters. A week later the participants were required to speak on a stage in front of a large audience in VR.

Results: The results showed that across most of a series of conventional public speaking anxiety measures the single condition was at least as effective in reducing anxiety as the multiple exposure method, and that these were better than the

control condition. For example, the 'Personal Report of Confidence of a Speaker' (PRCS) is a standard instrument for assessing public speaking anxiety where greater values indicate more anxiety. Using a Bayesian model, the posterior probabilities of improvement compared to a high baseline were 1.7 for both the single and multiple exposures compared to the control group. The 'State Perceived Index of Competence' (SPIC) was used as a measure of anticipatory anxiety for speaking on the stage in front of a large audience, where lower values indicate higher anxiety. The probabilities of improvement were just over 4 times greater for the single and multiple conditions compared to the control for a low baseline, and 489 (single) and 53 (multiple) times greater for a middle baseline.

Conclusions: Overall the results of this feasibility study show that for moderate public speaking anxiety the paradigm of gradual change in a single session is worth following up with further studies – with more severe levels of anxiety, and greater sample size, first with an RCT with non-patients, and subsequently, if the outcomes follow those that we have found with a full clinical trial with patients.

Keywords: Exposure therapy; virtual reality; gradual exposure; fear of public speaking; anxiety; change blindness.

Introduction

Exposure therapy (ET) for anxiety disorders (and other mental health conditions) involves the systematic desensitization over time of patients to feared stimuli or situations. For example, patients with fear of public speaking might be slowly introduced to situations of public speaking – in the first session perhaps to a photograph of an audience, in the next to a video, and then gradually building towards speaking to a live audience. This has proven over several decades to be an effective therapy [1, 2]. Virtual reality (VR) exposure therapy (VRET) employs the same technique, but with VR providing the stimuli, relying on the fact that people tend to respond realistically to events in VR [3] and thereby would exhibit anxiety in response to the feared situations. For example, in the case of fear of public speaking, a prerequisite for the success of VRET is that people should exhibit similar anxiety to a virtual audience as they would to a real audience, which has been shown to be the case, for example [4, 5]. This approach has been studied and used over the past three decades in the treatment of a variety of phobias and mental health disorders, including but not limited to social anxiety disorders, panic attacks, post-traumatic stress disorder, and generalized anxiety disorders [6, 7]. Early examples include [8-11] with a review of this early work in [12] and a meta-analysis in [13] which found a large effect size for VRET compared to control conditions and no disadvantage compared to in-vivo treatments. This was shown again in a randomized control trial that specifically considered social anxiety disorders [14]. Moreover, VRET has practical and logistic advantages since the entire treatment can take place in the office of the clinician, rather than arranging for outside visits for the patients to be exposed to real-life events (such as visiting a high floor of a building in the case of fear of heights or being exposed to a live audience in the case of public speaking

anxiety). Recent meta analyses have continued to show that VRET leads to therapeutic outcomes that are at least as successful as in vivo [15, 16], including the cases of severe anxiety, obsessive compulsive, and posttraumatic stress disorders [17], and specifically in relation to public speaking anxiety [18].

VRET has been extensively researched in the treatment of public speaking anxiety, for example, [14, 19-22] where individuals initially experience anxiety leading to behavioral, cognitive, and physiological symptoms when delivering or anticipating the delivery of a speech in front of an audience. A meta-analysis shows that VRET in exposure therapy for fear of public speaking is at least as effective as in vivo treatment [18]. ET for public speaking anxiety involves gradual exposure of individuals over various sessions to situations of public speaking, where at each successive session the situation becomes closer to speaking to a live audience. VRET follows the same idea, but with virtual audiences. VR, in particular, offers greater flexibility at low cost in the sense that aspects of the stimuli can easily be changed: audiences can be of different types and be reactive [5], parameters such as the size of the audience can be changed [14, 23, 24], including their appearance and behavior [5, 25], virtual location and context of the speech [21] (classrooms, lecture rooms, conference rooms etc.) as well as the representation of the self [26, 27], all can be straightforwardly changed.

Exposure therapy, whether in vivo or in VR, can be accompanied by cognitive therapy where the clinician attempts to help the patient reframe their anxious thoughts about the situation. For example, Freeman, Haselton et al. [28] used a simple form of cognitive behavioral exposure therapy with VR, where over five sessions, patients with fear of heights learned to overcome their fear. Their task was to move to various levels of a building accompanied by a virtual therapist, and at each level perform some tasks on a balcony overlooking an atrium below. Ultimately, they made it to the top floor, and their level of anxiety was significantly reduced compared to before the exposures and to a control condition.

The meta-analysis of Lim, Aryadoust et al. [29] found an average of 6 VR sessions each lasting around 37 minutes amongst effective VRET interventions. Another meta study [30] found that up to 12 sessions were necessary, spread over a week for effective treatment. This is similar to the finding in [18] which reported between 5 and 12 sessions in the articles studied, and Chesham, Malouff et al. [15] found up to 14 sessions. Although not in the context of an exposure therapy intervention it was argued by Boetje and van Ginkel [31] that the optimum number of VR sessions for reducing public speaking anxiety cannot be globally set since the characteristics of the VR treatments varied among the reviewed studies. Following from this Lim, Aryadoust et al. [29] argued that the number and length of sessions should be considered as a function of severity of the patient's condition.

Here we introduce a new paradigm based on the idea of VRET but where there is a single VR session during which there are advances towards a situation that would spark greater anxiety, with changes occurring almost imperceptibly. The participant

with fear of public speaking is engaged in conversation by a virtual counselor who explains the issues behind fear of public speaking and encourages the participants to speak about their own public speaking problems and gives them various exercises to do. The counselor is represented by a virtual human character, who stands in front of and facing the participant and talks and gestures in a natural way. After a while, a copy of the counselor emerges from behind his virtual body, so that there are two identical instances of him, although only the original one continues the dialogue, while the other one moves off to the side and continues listening. As time progresses this division process continues, where the additional copies emerge. Also, after a while the new copies gradually transform into different virtual human characters. This process continues mainly in peripheral vision and the changes are imperceptible. Over time one after another of the standing virtual characters adopt a seated position. By the end of the session, the participants find themselves speaking in front of an entire seated audience.

The idea behind why this approach may be effective is to consider at which point would the anxiety provoked by public speaking become active. First the participant is speaking to only one (virtual) person. Then it is two, but it is the same person – the counselor. But two is not an audience; nor is three. If three was not an audience, are four? If four is ok, does one more matter? Generally, if the participant is comfortable speaking to n people, then imperceptibly making the audience n+1 should make no difference (for $n > 1$). Also, the changes take place slowly (except for the first), so there is no obvious moment when the client is not speaking to an audience, and then is speaking to an audience. The hypothesis is that people can learn through this process that just as it is possible to speak to one person without anxiety, so the gradual transition to an audience should not generate anxiety. There is no point of discontinuity where at one moment the participant is suddenly speaking to an audience whereas a moment ago was not. The hypothesis is that this learning will carry over to subsequent speeches in front of even larger audiences.

We carried out an experiment to explore the utility of this new paradigm. The participants were not patients, but people who report some level of fear of public speaking. Hence, this was not a clinical trial but a feasibility study to assess the efficacy of the paradigm.

Methods

Ethics

The experiment was approved by the Comissió Bioètica of Universitat de Barcelona, and participants gave written and informed consent. All methods were performed in accordance with the relevant guidelines and regulations.

Experimental Design

We conducted the experiment with 45 participants using a between-groups design, with a single factor (Exposure) with three levels: ‘Single Exposure’ (n = 16),

'Multiple Exposure' (n = 14) and 'Control' (n = 15). In the Single Exposure condition participants experienced the scenario as described above – where one counselor eventually morphed into an entire audience. The Multiple Exposures group experienced a traditional VR exposure therapy, where they had five exposures, each with an increasing audience size over approximately 3 weeks with two sessions per week (Figure 1). The virtual environment, virtual counselor, and conversation were identical in these two conditions. Additionally, there was a Control Group where participants conversed with a gender-matched virtual human who asked general questions of the participants such as their name, job, skills, and interests (hobbies) and also talked about themselves (Figures 2A-B). The purpose of the control group was to check that simple exposure to any VR where the participant was required to talk would also be sufficient to reduce anxiety.

Figure 1. The scenario. (A) A male participant embodied in a male virtual body with a virtual mirror to his left. The inset shows the person with the head-mounted display and controllers. (B) Single Exposure - the virtual counselor talks to the client, while 'new' copies of him divide and gradually transform into different virtual human characters. (C) Multiple Exposures - session 2, where the participant is exposed to three virtual characters forming the audience. (D) The full audience in both the Single and Multiple conditions.

Figure 2. The control condition and the concert scenario. (A-B) The virtual humans for the control condition. (C) The virtual audience seen from the stage from the viewpoint of the participant in front of the microphone prior to introducing the band Dire Straits. (D) The view from the audience once the concert had started.

At the end of the session (Single, Multiple after the end of their fifth session, Control) participants were told that they should return one week later, where they would be on a stage in front of a large audience in a theatre in VR and would be required to introduce a performance by the band 'Dire Straits' (Figure 2C-D). This final exposure was for testing. A historic (1980s) band was chosen so that participants would need to do some research to find out more about it. Moreover, since the presentation in front of the large audience was to be several days later, we could assess anticipatory anxiety.

The experimental scenarios are illustrated in the Multimedia Appendix 1 which shows a movie of the various conditions.

Recruitment

Participants were recruited by advertisement around the campus of the University of Barcelona and through social media. Participants had a moderate level of public speaking anxiety. During recruitment, potential candidates underwent a screening process to identify those eligible to participate (PRCS-12 [32] and LSAS. [33]), see Multimedia Appendix 2, which also includes details of inclusion and exclusion criteria.

Materials

We used a wide field-of-view stereo head-tracked, head-mounted display (HMD), through which the participants were embodied in a life-sized (gender matched) virtual body from a first-person perspective, spatially coincident with, and visually substituting their real body. Through upper body tracking, the virtual body moved synchronously with their own body movements. They saw a reflection of the virtual body from the neck down in a virtual mirror and when directly looking toward themselves. Full details of hardware and programming implementation are given in Multimedia Appendix 3, which also contains the scripts of the dialogues between the virtual counselors and the participants.

Response Variables

There were two types of response variables. First, after the VR exposures, a questionnaire ('VR Questionnaire') was administered concerning the level of body ownership and agency over the virtual body and general responses to the virtual audience. These questions are shown in Multimedia Appendix 4. Second, (Table 1) shows the response variables that directly relate to public speaking anxiety. Further details of these are given in Multimedia Appendix 5.

Table 1. The response variables. A variable prefixed with 'pre' refers to administration of the questionnaire prior to the VR interview exposure, 'post' means after the VR interview exposure and just before the VR concert exposure, 'after' refers to after the concert.

Variable	Interpretation	Ref.
preIAT *postIAT*	Implicit Association Test for fear of negative evaluation *Range*: -2 to 2. *Negative scores*: Automatic preference for Self/Rejected, Other/Liked *Positive Scores*: Automatic preference between Other/Rejected, Self/Liked	[34]
prePRCA24 *postPRCA24*	Communication apprehension - level of anxiety triggered by the real or anticipated communication. *Scores*: 24 to 120. Higher scores indicate more anxiety.	[35]
preSPIC *postSPIC* *afterSPIC*	State Perceived Index of Competence: *Scores*: 15 to 105. Higher values mean feeling better about self and considered as more competent performance.	[36]
postSTAI	Short-form STAI administered before the concert speech. *Scores*: 8 to 32. Greater scores mean more comfort.	[37, 38]

Procedures

During the first visit of participants to the VR laboratory they were given an information sheet to read, and after they agreed to continue with the experiment, they were given a consent form to sign. Next, they completed a series of questionnaires assessing their fear of public speaking and negative evaluation (*prePRCA24*, *preSPIC*, *preIAT*) that also served as baseline measures, as well as other demographic data (see Multimedia Appendix 6 for details). Before the experiment started, participants were fitted with the head-mounted display (HMD) and body tracking equipment. The view seen through the HMD was calibrated for each person. Participants in the Multiple Exposure group returned approximately two days later for the second exposure and so on until they completed all five treatment sessions. After the last VR exposure participants completed a post-VR experience questionnaire. One week after participants' single (Single or Control Exposure group) or final exposure (Multiple Exposures group), they returned for the follow-up session where they had to give the 'Dire Straits' welcome speech. Before delivering the speech, they completed the questionnaires assessing their fear of public speaking and negative evaluation again (*postIAT*, *postPRCA24*, *postSPIC*, *postSTAI*). When they finished and came out of the virtual environment, they completed a post-VR questionnaire and the perceived index of competence questionnaire (*afterSPIC*) related to the speech they had just delivered. Then they were debriefed about the purpose of the study and compensated and left the laboratory.

Statistical Methods

We are not making statistical inferences about the questionnaire variables related to the VR experience (such as body ownership, in Multimedia Appendix 4), but only wish to check that the results conform with earlier studies. Hence we only consider these response variables at the descriptive level.

For the variables specifically related to anxiety we use a Bayesian statistical model detailed below – equivalent to one way ANOVA for all but one response variable and a logistic model for *postIAT*. This results in posterior distributions for each of the parameters of the model, from which we can compute any probabilities of interest. The model includes all response variables simultaneously, so there is no issue with multiple comparisons (which results in problems in the interpretation of significance levels in classical null hypothesis testing).

For each response variable (*postIAT, postPRCA24, postSPIC, afterSPIC*) the linear predictor, which relates the independent variables to the mean of the response variables, is of the form:

$$Condition + Covariate + Covariate \times Condition \; [+ familiarity]$$

Condition refers to the main effects of Control, Multiple and Single. *Covariate* refers to the *pre* variables in (Table 1). *Covariate*×*Condition* is the interaction effect. The

covariate *familiarity* refers to the scores on a question about the familiarity of participants with the 'Dire Straits' band. Since the *SPIC* variables and *postSTAI* relate to preparation for giving a talk about Dire Straits, we also include *familiarity* for these response variables as a covariate based on the results of Figure 7.4 in Multimedia Appendix 7 which shows a lower level of *familiarity* for the Multiple condition compared with the other conditions. There is no *pre* covariate for *postSTAI*.

The linear predictor for each response variable is therefore of the form:

$$\eta_i = \mu + \alpha_{cond[i]} + \beta C_i + \gamma_{cond[i]} C_i \; [+ \lambda F_i] \qquad i = 1, 2, \ldots, n = 45 \tag{1}$$

This is a standard ANOVA model where:

μ is the grand mean,

$$cond[i] = \begin{cases} 1, control \\ 2, multiple \\ 3, single \end{cases}$$

α_j is the main effect for condition,
γ_j is the interaction between condition and the covariate, where $j = 1$ (control), 2 (multiple), 3 (single), with $\alpha_1 = \gamma_1 = 0$ so that Multiple and Single are compared against the Control.

C_i is the pre variable as a covariate (e.g., *preIAT*)
F_i is *familiarity* (this is used for *postSPIC*, *afterSPIC* and *postSTAI*).

Since in the case of *postSTAI* there is no *pre* covariate, the corresponding model is reduced to the main effect together with F_i.

In the case of all responses variables except for *postIAT*, we use an ANOVA model with a covariate, so that the mean (μ_i) of the response variable (y_i) is set equal to the linear predictor:

$$\mu_i = \eta_i$$

In standard ANOVA the likelihood (i.e., the distribution of the response variable conditional on the parameters) is required to have a normal distribution. Here we can be more flexible and let the likelihood follow a Student t distribution. This has the advantage that it has wider dispersion than the normal, thus allowing for potential outliers, but also for high enough degrees of freedom it approximates the normal, and for degrees of freedom of about 30 or more it is indistinguishable. Hence the likelihood is:

$$y_i \sim Student\_t(\upsilon, \mu_i, \sigma)$$

where $\upsilon > 1$ is the degrees of freedom parameters, μ_i is the mean, and σ is the scale parameter. Smaller values of υ and larger values of σ correspond to greater dispersion with respect to the symmetric distributions around μ_i. For larger $\upsilon > 30$ (approximately) the distribution is equal to the normal distribution with mean μ_i and standard deviation σ.

In the case of *postIAT* this model did not produce a good fit to the data. This is because IAT is bounded by the values [-2,2] by construction. Hence, we normalized the *postIAT* and *preIAT* values by transforming them to a [0,1] scale. Then we used the Beta distribution for the likelihood: Beta being chosen because the probability density is bound to [0,1], and the distribution can take on many different shapes (symmetric about 0.5, J shaped, inverse J shaped, uniform, etc.) and therefore can adapt to the data. Hence in the case of IAT the model is:

$$y_i \sim Beta(\phi\mu_i, \phi(1-\mu_i))$$

where $\phi > 0$ is a scaling parameter, and the mean of the distribution is μ_i. In order to ensure that $\mu_i \in [0,1]$ we use the logit link function between the mean and the linear predictor, with inverse:

$$\mu_i = \frac{1}{1+e^{-\eta_i}}$$

This is a standard logistic model.

We use weakly informative prior distributions – i.e., proper probability distributions with very wide variance [39, 40]:

All $\beta_j \sim normal(mean = 0, SD = 100)$ hence the prior 95% credible intervals are -200 to 200. All $\sigma, \upsilon, \phi \sim Gamma(2,0.1)$ hence the 95% prior credible intervals are 2.4 to 55.7.

All response variables are in the same overall model, so that the parameters are, for example, denoted μ_{prc}, $\alpha_{prc,j}$, $\beta_{prc}\gamma_{prc,j}\nu_{prc}$, σ_{prc} in the case of postPRCA24, and the others are shown Multimedia Appendix 8, Table 8.1.

The analysis was carried out with the probabilistic programming language Stan [41] using the rstan interface in R [42]. 3000 iterations were used with 4 chains, and all simulations converged successfully with all Rhat = 1 indicating that the results of the chains properly mixed.

Results

Participant Statistics

The 45 participants had mean ± SD age 26.1 ± 7.36, 27 identified as female, 14 as male, and the remaining 4 as other, or preferred not to say. The detailed demographics are provided in Multimedia Appendix 6.

Descriptive Statistics for the VR Questionnaire Results

The median levels of body ownership and agency were high, and in line with the results of previous experimental studies (for example [43]), though body ownership and agency were of peripheral interest in this study, and the participants only saw their virtual body in a mirror for a short period prior to the discussion with the virtual human, and prior to introducing the band in the second phase. Positive responses to the audience were middle to high in the Single and Multiple conditions, but somewhat lower in the Control condition. Full details and analysis of these responses are available in the Multimedia Appendix 7.

Descriptive Statistics for the Anxiety Related Results

(Table 2) shows means and standard errors of the response variables that directly relate to public speaking from (Table 1). It also shows the effect sizes (Cohen's d) for the difference between post and pre measures, and the effect sizes for the differences *post - pre* comparing between conditions. The *post - pre* effect sizes for the Control group are all small except for *afterSPIC* which is medium. Comparing the Single and Multiple conditions, the *post - pre* effect sizes for Single are always at least as strong as those for the Multiple conditions, the change in IAT shows a medium effect size for both conditions, it is medium for *afterSPIC* in the Single condition, and small for the others. Since *postSTAI* was only measured just before the concert speech, there is no *post - pre* effect size.

Most of the effect sizes for comparison between the conditions are small to medium, except for the difference between the Single and Control conditions, where the effect size is large for *afterSPIC*.

The effect-sizes are crude overall measures, and do not take into account the relationship between *pre* and *post* measures, nor include the covariate *familiarity* (how much participants were familiar with the band Dire Straits). We now consider the statistical model that includes covariates.

Table 2. Means and Standard Errors of the response variables by condition, paired Cohen's d effect sizes for the differences between post and premeasures, and Cohen's d for the post-pre values comparing between conditions.

Condition	**IAT**	**PRCA24**	**postSPIC**	**afterSPIC**	**postSTAI**
Single Exposure					
Mean	0.35	5.38	-2.31	5.88	23.2
S.E.	0.15	2.49	3.00	2.94	1.27
Cohen's d post-pre	0.62	0.26	-0.21	0.58	
Multiple Exposure					
Mean	0.30	0.00	2.29	-5.36	20.7
S.E.	0.17	3.36	4.77	6.84	0.93
Cohen's d post-pre	0.59	0.00	0.16	-0.32	
Control					
Mean	-0.10	4.93	-7.20	-11.73	20.6
S.E.	0.20	2.50	2.31	3.35	1.28
Cohen's d *post - pre*	-0.18	0.24	-0.35	-0.50	
Cohen's d comparing conditions on *post - pre*					
Single vs Multiple	0.075	0.478	-0.306	0.577	0.539
Single vs Control	0.639	0.045	0.459	1.423	0.489
Multiple vs Control	0.564	-0.441	0.680	0.317	0.026

Statistical Analysis of the Anxiety Related Results

Summaries of all the posterior distributions of the parameters of the model are given in Multimedia Appendix 8 with further details of the results including model goodness of fit, and the availability of the data and programs for analysis.

The main concern of interest is to check whether the Single Exposure condition is at least as effective in contributing to a diminution of anxiety compared to the Multiple Exposure condition, and whether these are different to the Control. We consider each response variable in turn, noting that all credible intervals (CI) are substantially narrower than their priors.

IAT. The interaction terms for Multiple and Single have credible intervals mainly in the positive region with very high (Single, 0.945) and moderately high (Multiple, 0.817) probabilities of being positive. In other words, greater values of *preIAT* are associated with greater levels of *postIAT*. Moreover, the two CIs are similar in their range. The coefficient of *preIAT* for the Control group shows no evidence of being different from 0 (the probability of it being positive is 0.458). These results point to there being no or little difference between the Multiple and Single Exposures with respect to their effect on IAT, and each of these are different from the Control group.

Hence *postIAT* increases with *preIAT* for the Multiple and Single groups. However, for the Single group the probability that the rate of increase (the slope) is greater than 1 is 0.835 whereas it is 0.601 for the Multiple groups.

PRCA24. In the Control condition there is clearly a positive slope between *postPRCA24* and *prePRCA24* (Prob = 1.000, β_{prc}, Table S4). This slope is reduced in the case of both Multiple with probability (Prob = 1 – 0.023 = 0.977) and Single with probability (1 – 0.077 = 0.923). The CIs for the interaction terms for Multiple and Single are similar. While both Multiple and Single Exposure may reduce the slopes of *postPRCA24* on *prePRCA24* there is no important difference between them, and they are both different from the Control. Hence the Single and Multiple interventions reduce the proportional increase of *postPRCA24* with respect to *prePRCA24*.

postSPIC. This was administered prior to the participant presenting Dire Straits in front of the virtual audience. In the Control condition *postSPIC* is positively linearly related to *preSPIC* (prob = 1.000 that the coefficient is positive). For Multiple there is a high main effect (mean 47.78, prob = 1.000) but the slope on *preSPIC* is reduced compared to the Control (by -0.67, prob = 1 – 0.002 = 0.998 of being negative). Single also has a high main effect (26.29, prob of being positive 0.895), and the slope on *preSPIC* is reduced by mean -0.33 with probability of being negative 1 - 0.142 = 0.858. The *familiarity* variable is positively associated with *postSPIC* (prob = 0.810) consistent with the likelihood that the presentation task would be less stressful for those with prior knowledge of Dire Straits.

afterSPIC. This was administered after the presentation of Dire Straits to the audience. As before the Control condition is positively associated with *preSPIC* (prob = 1.000). The Multiple condition has a strong positive main effect (68.06, probability of being positive = 0.999) but with a reduction in slope on *preSPIC* (-1.02, prob = 1 – 0.001 = 0.999 of being negative). The Single condition also has a strong positive main effect (51.42, prob 0.968) but decrease in slope on *preSPIC* (-0.52, prob = 1 – 0.096 = 0.904). There is a high probability (0.970) that *familiarity* with Dire Straits is positively associated with *afterSPIC*. For both *postSPIC* and *afterSPIC* there is a difference for both Multiple and Single exposures compared with the Control.

postSTAI. The Single and Multiple conditions have similar posterior distributions, and their main effects are greater than the Control. *postSTAI* is positively associated with *familiarity*.

From the statistical model, posterior distributions of each response variable can be obtained for any values of the covariates and the *familiarity* variable using Eq. 1. (Figure 3) shows all the posterior distributions conditional on the covariates being: 10% greater than the lowest possible value, the middle value, and 10% lower than the highest possible value. Hence, if the range of the variable is $xmin$ to $xmax$, and $d = xmax - xmin$, then these values are $xmin + 0.1d,\ (xmin + xmax)/2,\ xmax - 0.1d$, respectively. From (Figure 3) it can be seen that the Control distributions are

clearly different from the Multiple and Single. Multiple gives better results than Single only the case of *postPRCA24*, conditional on *prePRCA24* being at the highest level as defined above, but in this case both Multiple and Single are superior in their effects than the Control. For *postAIT*, *postSPIC*, *afterSPIC* and *postSTAI* the Single condition is always at least as good as the Multiple.

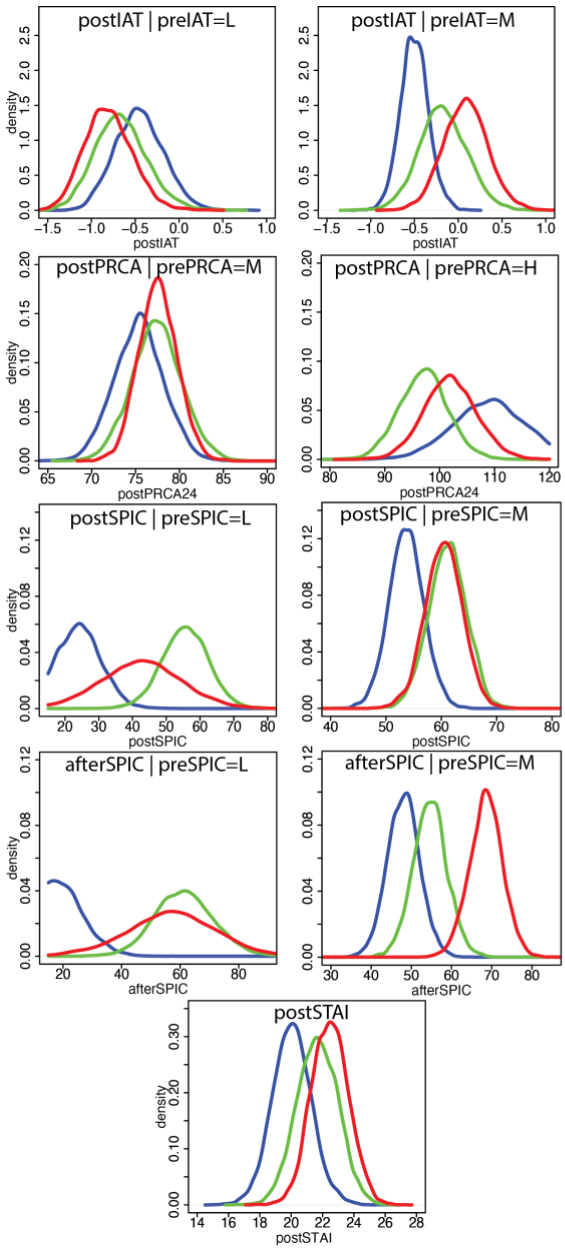

Figure 3. Posterior distributions for each response variable using Eq. (1). The red curves are for the Single condition, green for the Multiple and blue for the Control. For all except *postSTAI* these are conditional distributions with the pre variable = (L)owest, (M)iddle or (H)ighest values. For *postSTAI* it is the unconditional distribution. The *familiarity* variable is set at its median=3.

(Table 3) shows probabilities computed from the distributions of (Figure 3) – in particular the probabilities of *improvement*. In the case of all variables except *postPRCA24* improvement corresponds to an increase in the post score compared to the pre score. For *postPRCA24* improvement corresponds to a decrease in score. For *postSTAI* there was no pre score. Formally, the probabilities are:

$$P(post > x \mid pre = x, observed\ data)$$

where $x = Lowest, Middle$ of all variables except *postPRCA24*.

For *postPRCA24* the probabilities are:

$$P(post < x \mid pre = x, observed\ data)$$

and $x = Middle, Highest$. In the case of *postSTAI* there is no conditioning on $pre = x$.

Table 3. Probabilities of the response variables showing an improvement by the three conditions. The values for Lowest, Middle and Highest are for the pre variates, e.g., *preIAT* in the case of IAT. The symbol '~' stands for '>' or ´<´depending on the variable concerned.

Response Variable	**Condition**	**Lowest**	**Middle**	**Highest**	**Prob ~ Lowest**	**Prob ~ Middle**	**Prob ~ Highest**
postIAT		-1.6	0	1.6	>	>	
	Control				1.000	0.001	
	Multiple				1.000	0.257	
	Single				1.000	0.631	
postPRCA24		33.6	72.0	110.4		<	<
	Control					0.116	0.577
	Multiple					0.029	0.998
	Single					0.006	0.958
postSPIC		24	60	96	>	>	
	Control				0.006	0.023	
	Multiple				0.000	0.632	
	Single				0.026	0.556	
afterSPIC		24	60	96	>	>	
	Control				0.232	0.002	
	Multiple				1.000	0.107	
	Single				0.980	0.978	
postSTAI		10.4	20	29.6	>	>	
	Control				1.000	0.510	
	Multiple				1.000	0.900	
	Single				1.000	0.982	

For PRCA24 since lower values indicate better outcomes with respect to public speaking anxiety we are only interested in the probabilities that *postPRCA24* (after the exposure) is less than when *prePRCA24* is equal to the Middle and Highest before the exposure – i.e., these indicate improvement. For all the other variables it is higher values that represent better outcomes, so we are interested in the probabilities that the post values are greater than the pre values for the Lowest and Middle pre settings. *Prob ~ Lowest* means *Prob > Lowest* or *Prob < Lowest* depending on whether the symbol above the column of probabilities is > or <. For example, the probability that postPRCA20 < 110.4 conditional on *prePRCA24* = 110.4, is 0.958 in the Single condition. For *postSTAI* there are no pre values so the probability that *postSTAI* >20 is 0.510 in the Control condition and 0.900 in the Multiple condition. Where relevant in Eq. (1) the *familiarity* variable is set at its median value 3.

From (Table 3) it can be seen that the Control condition has the least probabilities of improvement in every case but two (IAT Lowest and PRCA24 Middle). Generally, the Single condition is only notably worse than the Multiple condition in the case of *postPRCA24* Middle, but in this case the probabilities are in any case very low. For *afterSPIC* the Single condition has a probability of improvement more than 9 times greater than Multiple for the Middle score.

We can also consider the odds of improvement, i.e., ratios of probabilities. In the case of *postIAT* with the *preIAT* at the Middle setting the odds of improvement of Multiple compared to Control are 0.257/0.001 = 257 for Multiple compared to Control, and 0.631/0.257 = 2.1 for Single compared to Multiple. For *postPRCS24* with the Highest *prePRCS24*, the odds of improvement of Multiple and Single over Control are 1.7. For *postSPIC* the odds of improvement for the Middle value of *preSPIC* over Control are 27 for Multiple and 24 for Single. For *afterSPIC* in the case of Lowest, Multiple and Single have odds of improvement of 4.2 and 4.3 respectively, and in the case of Middle, Multiple has odds of 53 over Control, and Single odds of 9 over Multiple. For *postSTAI* and the Middle setting for the covariate, the odds are 1.8 and 1.9 for Multiple and Single respectively over control.

Discussion

Principal Results

Exposure therapy typically requires multiple sessions with patients gradually being exposed to increasing levels of anxiety-producing stimuli. Here we have introduced a new paradigm based on gradual change within a single session. The participant begins by talking to a standing single counselor, but by the end of the session that single counselor has morphed into a seated audience. We elicited response variables prior to the virtual reality exposure, and then both before and after participants introduced a band in front of a large virtual theatre audience. The single session method was compared with a traditional VR exposure therapy over 5 sessions, and with a control group. The results indicate that the Single exposure most often

results in outcomes that are at least as favorable as the Multiple exposure on most measures, and that both the Single and Multiple conditions result in outcomes that are typically better than those of the Control group.

Comparison with Prior Work

The results as represented by the effect sizes (Table 2) are mostly moderate. There is a clear distinction between the Control group and the treatment groups, and the effect sizes for *post - pre* range from 0 to 0.62 (considering absolute values). However, our results compare well with the meta study reported in [15], where across the 9 studies using VRET for social anxiety that met their inclusion criteria, and the 13 sets of results within those studies, the *post - pre* effect sizes (Hedges g) ranged from -0.56 to 1.57, with the median being 0.486 and interquartile range 0.054 to 0.604. Considering 6 studies that compared VRET with a waiting group the overall effect size was 0.82. Similarly a meta study was reported in [16] of 13 articles on social and performance anxiety. Overall, the median effect size (Hedge's g) was 0.61 with interquartile range 0.14 to 0.91. (Hedge's g and Cohen's d are similar). For comparison only with a waiting list group the median effect size was 0.91 (IQR: 0.68 to 1.33) and for comparison with in vivo 0.61 (IQR: 0.14 to 0.91). A recent meta-analysis [29] found similar (in fact slightly lower) effect sizes across 92 studies on public speaking anxiety. A further recent meta study is reported in [18] with higher effect sizes, although breakdowns across individual studies and measures were not presented. As a further example Wallach, Safir et al. [20] carried out a randomized control trial, where there were 3 groups CBT, CBT in VR (VRCBT) and a Waiting List, and 12 sessions of exposure therapy. There was no difference between CBT and VRCBT so these were combined. Across a range of variables, comparisons of the Waiting List group with the treatment group found effect sizes for anxiety reduction in the range 0.58-1.00. Good results were maintained in a one year follow-up [44]. Anderson, Price et al. [14] carried out a study comparing in vivo exposure therapy (6 sessions) with VR exposure therapy (4 sessions) and a waiting list. Across a number of measures, effect sizes (Cohen's d) compared the VR treatment with the waiting list (posttreatment controlling for pretreatment). Comparing VR with the waiting list the median effect size was 0.74 (IQR: 0.63 to 0.93) and comparing in vivo with the waiting list the median was 0.72 (IQR: 0.48 to 1). In a 12-month follow-up the maximum effect size was 0.61. The effect sizes for all these studies were across a range of different instruments. In general evidence suggests that results from VR exposure therapy do generalize to real life [45].

The effect sizes found in our study are in line with findings in the literature. However, the effect size is a blunt instrument dealing only with overall average effects. We propose that the type of analysis illustrated in (Figure 3) gives richer information. Here we can see immediately the differential effects of the treatments depending on the starting state of the participants. For example, if the IAT is low to start with (greater self-rejection) all the conditions lead to an improvement. However, at the medium level of initial IAT there is a differential effect of the three methods, with the Single method resulting in greater probability of higher IAT scores, and the Control group clearly ineffective. This can be seen even more clearly

in the case of both *postSPIC* (anticipatory prior to the concert announcement) and *afterSPIC* (after the concert announcement).

The idea of single session exposure therapy has been discussed before, though with a quite different paradigm. Lindner, Miloff et al. [46] introduced one-session VR exposure therapy for public speaking anxiety, with strong positive results compared to a waiting list group. However, this involved an extensive 3-hour intervention, including a VR session, followed also by a 4-week in vivo transition program. The paradigm was similar to an earlier one for treatment of spider phobia, which had similar positive results [47].

Exposure therapy is thought to be effective due to either habituation through systematic desensitization, or alternatively due to classical extinction [1, 48-50]. In the latter the stimulus (an audience) is presented multiple times but in conditions where the normal response is avoided through inhibitory control. It is unlikely that the new paradigm presented here can be explained either through habituation or extinction. While there is exposure it is implicit rather than explicit – i.e., the focus of the participant is on the discussion with the single individual throughout. Moreover, the situation, at least to start with, is a bizarre one, with multiple copies of the same individual appearing but taking no part in the proceedings. We postulate that the positive effect of the treatment occurs through generalization from speaking to a single individual: the participant implicitly learns that speaking to an audience is not different from speaking to an individual - if the latter is possible without anxiety, then so is the former.

The model of social anxiety disorder proposed by Clark and Wells [51] is useful in understanding the outcome. While the model applies to the more general situation, public speaking anxiety is a specific case of social anxiety. In particular, some of the elements that contribute to instances of social anxiety are relevant to the gradual and implicit exposure paradigm. One component of the model is 'perceived social danger' where individuals predict their own negative performance. In the present case there is a conversation with an individual, and the required performance is carefully guided (e.g., read out numbers from 1 to 20, or a piece of text, or describe a movie). 'Anticipatory anxiety leading to worry' is where individuals focus on past or imagined failures and thereby predict their own negative behavior. This again is unlikely to occur in the situation where participants are talking to a single individual, moreover where the conversation is precisely about public speaking anxiety, and where there is counseling about how to prepare for a talk. 'Processing of self as a social object' where individuals' own negative model of themselves is projected onto others, so that they think that others perceive them in this negative way. However, the conversation with the single individual, someone who apparently understands and gives advice about public speaking anxiety, may militate against this. The participant is not in a situation of being evaluated, but rather one where help and advice is available. Overall, we suggest that the encounter with the counselor provides an opportunity for implicit learning that a talk in front of an audience is not fundamentally different from talking with an individual. It is an

example of where a single positive experience of talking in front of an audience could generalize to other situations. Using a very different method Shadinger, Katsion et al. [52] found that when college students were instructed to make positive affirmative statements about their forthcoming public speaking performance, this reduced their anticipatory anxiety, suggesting that a single positive experience can generalize.

Nevertheless, although the conversation is with a single individual an audience does gradually emerge, with changes taking place largely in peripheral vision, with the focus of attention on the counselor. Suppose that some individuals experience a degree of change blindness [53, 54] where they were not consciously aware of the growing audience most of the time. In this case how could it be possible that the audience might have an influence? Laloyaux, Devue et al. [55] showed that in change blindness, when participants do not consciously see the changes, these nevertheless influence their subsequent decision making. Even though the audience might hardly be noticed during the time of the conversation, though it is obvious by the end, participants still might be influenced by the fact that they are having a conversation with a growing audience present. Change blindness has been observed in VR [56, 57], and our recent study shows that it operates with respect to virtual bodies that are subject to gradual change even though participants are looking towards them all the time [58].

Limitations

Although some outcome measures were taken after the introduction of the band at the virtual concert, and hence 7 days after the main VR treatment, there is a need for longer term follow-up for this new paradigm. Here we were concerned to provide an initial evaluation, and the positive results are encouraging to undertake an RCT with a larger sample, and then later a clinical study with longer term follow-up. The RCT would also include individuals with a higher level of public speaking anxiety.

Consumer VR devices that are entering the market now have built-in eye and facial tracking. Eye tracking especially would be useful to determine how much participants do indeed pay attention to the emerging audience, and eye tracking and facial expression tracking could also provide real-time measures of the extent of ongoing anxiety. Furthermore, the method by which the audience is introduced can be explored. Our approach was based on the idea of maintaining the whole exposure as a conversation with a single individual and emphasizing that by the fact that all new characters emerged from and were initially clones of that individual. Moreover, we adopted the method that the copies would gradually transform into other characters, and eventually sit down. It is possible that similar results might have been obtained had characters appeared one by one at different places in the room. Here again an audience would gradually form, but not related to the counselor. Our view is that the connection with the counselor is essential (to maintain the idea that this was a conversation with an individual and not with a group) but this would be interesting to study. Another possibility is that the entire audience might gradually become visible over the course of the conversation, already as different seated

characters. While this is possible, again our view is that the morphing of the counselor into an audience is an essential part of the method.

Conclusions

Our initial results in testing the feasibility of this paradigm are encouraging and worthy of further research. Although we have used the gradual change method in the context of public speaking anxiety, it could be also used for other anxiety states. For example, for fear of heights the participant could be talking to a virtual counselor, initially at the same level, but imperceptibly the adjacent ground level could move lower and lower, until ultimately the participant and counsellor are standing near a precipice. With, for example, a phobia of spiders, the participant could interact with a butterfly, that gradually morphs into a spider. In the case of agoraphobia, the participant might start talking with a counselor in a closed safe space, that gradually morphs into an open shopping area. Further studies of this paradigm are needed in a variety of situations in order to test its efficacy.

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Authors' Contributions

DB designed the experiment, implemented the scenarios, carried out the experiment, prepared the data, wrote the paper.
TJ contributed to experiment design, reviewed the paper.
ABP contributed to the implementation of the scenarios, reviewed the paper.
GS contributed to the carrying out of the experiment, reviewed the paper.
MS original concept, designed the experiment, carried out the statistical analysis, wrote the paper, obtained the funding.

Conflicts of Interest

The method presented in this paper is the subject of a patent application by the University of Barcelona. MS is a founder of the spin-off company Virtual Bodyworks which works in the field of diversity, equity and inclusion. No other authors have competing interests.

Abbreviations

ET: Exposure Therapy
VR: Virtual Reality
VRET: Virtual Reality Exposure Therapy
CBT: Cognitive Behavioral Therapy

VRCBT: Virtual Reality Cognitive Behavioral Therapy
PRCS: Personal Report of Confidence as a Speaker
LSAS: Liebowitz Social Anxiety Scale
IAT: Implicit Association Test
SPIC: State Perceived Index of Competence
STAI: State-Trait Anxiety Inventory
CI: Credible Interval
SD: Standard Deviation
IQR: Interquartile Range
RCT: Randomized Control Trial

Multimedia Appendix 1
An mp4 file for the movie illustrating the experimental scenarios

Multimedia Appendix 2
A docx file giving details about recruitment

Multimedia Appendix 3
A docx file giving details about implementation

Multimedia Appendix 4
A docx file showing the VR questionnaire

Multimedia Appendix 5
A docx file giving details about the reponse variables

Multimedia Appendix 6
A docx file giving participant statistics

Multimedia Appendix 7
A docx file giving results of the VR questionnaire

Multimedia Appendix 8
A docx file giving more details about the posterior distributions

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