The Value of Reaction-Time Measures in Presence Research: Empirical Findings and Future Perspectives

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Abstract

A series of experiments (N = 168) was conducted to test the capacity of Secondary Task Reaction Times (STRT) for Presence measurement. Based on recent theories, possible connections between reaction times and Presence were examined in users of a hypertext, a film, and a virtual environment that used the same visual materials. A Presence questionnaire was employed as comparative measure. Findings indicate rather unsystematic and weak convergence between STRT and subjective measures of Presence or underlying processes. A modified STRT paradigm for Presence research is suggested.

Keywords--- **Spatial Presence, secondary task reaction times, measurement, methodology, objective measure, experiment.**

1. Introduction

The progress of Presence research depends on both theoretical and methodological advances. Measuring Presence experiences through reliable and valid indicators produced by practical, robust, and efficient methods is a precondition to resolve many research questions and to improve the user-centered design of new Presence applications based on empirical data.

Today, a large variety of methods and instruments to measure Presence is available [1]. However, many of them have not been evaluated systematically. We simply do not know enough about most of the available questionnaires, scales, and apparative procedures in respect to their reliability, validity, and practicability. Without such systematic inquiry in the value of specific methods, the research community is in danger to rely on problematic or ineffective methodological grounds.

This paper introduces one piece of such methodological evaluation. It presents results from three experiments that tested the value and usefulness of one specific approach to measure (Spatial) Presence, which is entitled Secondary Task Reaction Times (STRT).

2. Secondary Task Reaction Times and Presence Research

STRT has been employed as a measure of *attention* by psychologists for a long time. It is based on theoretical assumptions about the limitation of an individual's cognitive capacities [2]. From this perspective, people constantly distribute their perceptual and cognitive resources across different modalities. The more resources are allocated to one channel of input, the less resources remain available for other channels. Secondary task measures are constructed upon the idea that the more attention an individual devotes to a certain activity or task (the so-called primary task), the less attention 'is left' for alternative activities (i. e., secondary tasks), and the more time the organism will need to accomplish such alternative activities. Consequently, the empirical information produced by this methodology is the response time of a message receiver to a secondary input that does not belong to the actual message. The longer the response to this input takes, the more attention is devoted to the primary task, that is, the message being received by the subject [3]. Specifically, STRT are considered to indicate the amount of resources a subject is allocating to encode (as opposed to memorize) a received message [4]. However, recent findings challenge this and other existing theories on attentional resource allocation and the type of resources measured by STRT reaction times [5]. In spite of those unresolved questions, STRT is in general capable to assess "attention, arousal, and involvement" ([3] p. 93) when applied in communication studies.

Several theoretical models of Presence highlight the importance of attentional processes (e.g., [6]). The MEC model of Spatial Presence [7] [8] defines attention allocation as a key step within the formation of Presence experiences. If STRT are capable to deliver process-based information on users' attention towards a virtual environment, these data would be of great interest for Presence researchers (see [9] for a similar dual-task approach to Presence measurement).

From the perspective of the MEC model [9], STRT might even offer greater opportunities to assess (components or facilitators of) Spatial Presence: The model expects Spatial Presence to occur only through additional cognitive processes that exceed mere attention allocation. These processes include the mental representation of the media space ('spatial situation model, SSM'). STRT may produce information on the complexity of such SSMs if it is applied to users of space-related media stimuli. Moreover, cognitive involvement is considered as an important facilitator of Presence by the MEC model. Higher cognitive activities (e.g., thinking, evaluating, counter-arguing) build on attentional processes and consume much cognitive capacity [9]. Variance in STRT could therefore also indicate variations in cognitive involvement, which would be an even more relevant measure for Presence researchers [7]. There is even a possibility that STRT could measure Presence experiences directly: For instance, if the arrival-departure metaphor of Presence [10] is applied, response times to a secondary signal from the spatial environment that a person has already 'departed from' should be much longer than response times to signals from the environment the user 'has arrived in'.

As a conclusion, the perspective of Presence theory suggests STRT to hold interesting capabilities to assess at least important foundational processes of Spatial Presence (i.e., attention and/or cognitive involvement) or even to address the intensity pf Spatial Presence itself.

3. Method

Three experimental investigations were conducted to assess the methodological implications of STRT in the domain of Spatial Presence; we used a hypertext, a film, and a VR environment of similar narrative and visual quality.

3.1. Stimulus materials

A set of media stimuli that was based on the same narrative and visual content was produced. The intention of using several media was to paint a more complete picture of the value of STRT and to avoid dependence of findings on one specific medium. For this purpose, a hypertext environment (with mixed text and visual elements), a film, and an interactive virtual environment were produced that all displayed the same spatial environment, which was labelled "Mozart's house of learning" [10]. Each media stimulus was experimentally varied in order to create a broad range of Presence intensities (variance), which was required to test the reagibility of STRT to variations in Presence and/or facilitator processes. The specific settings of the three experiments are portrayed in the following sections.

3.1.1. Hypertext environment. The hypertext (HT) stimulus was similar to an old-fashioned role playing game where the location of the user is described by text and/or pictures. The museum was represented by single snapshots accompanied by explanatory and descriptive text.

This HT was experimentally varied in two ways. The first manipulated feature of the HT was the ratio between text and images. One half of the experiment's participants used a HT version that included large images and small text sections (expectably the "high Presence" condition because of more salient visuo-spatial information), whereas the other half interacted with a HT version that displayed large text areas and comparatively small images (low Presence condition). The other experimental factor was the type of navigation. One half of participants could move through the museum by selecting desired locations (floors, rooms) from drop-down menus (non-space-related navigation, low Presence condition); in contrast, the other half of participants used navigation points posited within the HT images (space-related intuitive navigation, high Presence condition). For instance, users could click a sign on a door to proceed to the next room or click on stairs to move to another level of the museum.

3.1.2. Film stimulus. The film stimulus was a non-interactive walkthrough of the museum. It was generated from the virtual reality stimulus (see 3.1.3.). Participants were placed in front of a screen and watched the virtual walk, which included all rooms of the virtual building.

To manipulate the capacity of this film to induce Spatial Presence, the field of view (FOV) covered by the screen was varied. Participants watched the film in one of two display configurations. One half of the participants viewed the film on a 21-inch computer monitor, which covered about 20 degrees of their FOV (horizontal). The other half was posited in front of a projection screen with a diagonal of about three meters, resulting in a covered FOV of approximately 61 degrees.

3.1.3. Virtual Environment. The virtual environment (VE) used in the third experiment (built with *WorldUp*) was the actual source of all visual and auditory information used in the HT and film stimuli. A large amount of exhibits such as paintings, instruments, historical musical notes and documents, as well as other details (information desks and tables, loudspeakers, benches etc.) were placed as virtual objects in the VE.

The VE was navigated through a computer mouse. Participants could use stairs to change between levels, enter any room of the museum, and perform simple interactions with different exhibition objects.

To create variance in Presence experiences, the same manipulation of the FOV as in the film study (20 versus 61 degrees horizontal, cf. 3.1.2.) was applied in the VE experiment.

3.2. STRT Procedure

In all three experiments, the same STRT procedure was applied to maximize comparability. In order to determine the specific quality of cognitive-perceptual resources that using the media environment would (not) consume, three types of probes were developed.

One type of probes addressed only the *visual* modality. A red square (about 10 x 10 cm) appeared on an additional monitor at the right side of the screen that displayed the actual media environment (HT, Film, or VE, respectively). In those studies that manipulated field of view (see 3.1.), the size of visual probes was adjusted to the size of the primary medium in order to keep the same ratio across experimental conditions (however, eccentricity of the probes was necessarily higher in the large FOV condition). The second type was an *auditory* signal (an alarm sound produced by a typical siren). It was played at a volume that pretests had found to enforce perception in spite of the auditory background of the primary medium (approximately 70 dB). The third type, finally, combined the red square and the alarm sound to form *audiovisual* probes.

From these types of probes, a unified sequence was composed (with DirectRT software by Empirisoft, 2004). The duration of the sequence was – as the exposure times to the media stimuli – seven minutes. Within this time, 13 probes (5 visual, 4 auditory, and 4 audiovisual) were 'fired'. Each participant received the same STRT sequence. A source of unsystematic variation was, however, the program's logic to *wait* for a reaction of the participant before it continued with the probe sequence.

Participants who were exposed to the STRT measure were instructed to respond as quickly as possible to any of the mentioned types of probes by pressing the 'Spacebar' button of a computer keyboard which was unrelated to using and navigating the actual media environment. The interfaces of the interactive stimuli (HT and VE, see 3.1.) only required participants' right hand, so they could keep their left hand on the response key. Variance in motor behavior that could have biased response times were thus avoided.

Boxplot inspection was used to identify extraordinarily long response times (mostly above 1.5 sec). Corrected response times were computed to three mean index variables, one for each type of probe. These variables were used throughout the analysis.

As STRT is highly obtrusive, it was reasoned that the method could affect the actual Presence experience it was intended to measure. Thus, obtrusiveness of the method was assessed by applying the STRT procedure only to half of the participants. This strategy allowed for more rigorous testing of the method's potential for Presence measurement (see 3.3.).

3.3. Comparative Measures and Analytical Strategy

To generate baseline data for comparative analyses, an ex-post Presence questionnaire was applied in addition to the STRT procedure. The scales of the MEC-SPQ [10] were employed to measure the precursor / correlate processes of Spatial Presence – attention, strength of spatial situation model (SSM), cognitive involvement, suspension of disbelief, and the two dimensions of Spatial Presence (self-location within media space and ascription of possible action to media environment: SPSL and SPPA) elaborated in the MEC model of Spatial Presence [9].

The first step of the analytic strategy was to compute ANOVAs for each experimental setup (analysis per medium) to test the effect of Presence manipulation on STRT. For comparisons, MEC-SPQ scales from all participants were also included in this analysis.

Second, only those participants who performed both STRT and the ex-post questionnaire were examined. Correlations between response time indices and MEC-SPQ scales were computed to uncover substantial covariance between objective and subjective data. This analysis was repeated for all three media.

Third, a media comparison (independently of experimental condition within medium) was performed to detect potentially similar patterns of objective and subjective data across media. For this purpose, STRT values of those participants who had performed this measure were compared to MEC-SPQ scales only from those participants who had *not* performed the STRT procedure. This way, the obtrusive effect of STRT on (Presence) experiences was expected to be uncovered.

3.4. Procedure

Participants of all three experiments were recruited from several universities of a mid-size German city. They were offered 10 € as financial compensation. In each study, participants were randomly assigned to one experimental condition (between-subject design); gender was balanced between conditions.

On arrival in the laboratory, participants were briefly informed about the procedure of the experiment and then exposed to the stimulus (hypertext, film, or VR, respectively) for seven minutes. Prior to exposure, participants of the hypertext and VR experiments received a brief instruction on how to use the mouse to navigate through the museum. Similarly, the STRT procedure was introduced to those participants who were asked to perform this additional measure. After the seven minutes of exposure, the experimenter asked the participants to fill in the MEC-SPQ. Subsequently, s/he was thanked, received the financial compensation and additional information. Overall, experimental sessions lasted between about 25 and 40 minutes (due to participants' varying reading speeds).

For the hypertext study, 79 participants were recruited. 36 of them used the HT version with drop down navigation (low Presence condition), 43 the intuitive navigation (high Presence condition); 40 people had large text sections and small images (low Presence), and 39 small text sections and large images (high Presence) on the screen. Within each excondition, at least 8 individuals performed the additional STRT measure (35 individuals overall). Another 42 individuals participated in the film experiment (21 in the small FOV and 21 in the large FOV condition), 19 of them performed the STRT procedure (10 participants in the large FOV condition). Finally, 47 students accepted to participate in the VR experiment. 25 used the small FOV version, the remaining 22 were confronted with the large FOV version. 21 of these participants performed the STRT procedure (11 in the large FOV condition). All in all, 168 students participated in the experiments, and 75 of them produced STRT data sets.

4. Results

4.1. Experimental analysis

In this section, results of two MANOVAs for each experiment are presented. The first analysis tests the effects of experimental manipulation on Presence and its precursor processes as measured by MEC-SPQ scales, based on data from all subjects; the second tests the effects of the independent variable(s) on average response times to STRT probes and is thus necessarily based only on data from the

75 people who had performed STRT procedures. Subsequently to these two analyses, findings are briefly compared. The actual discussion is left for section 5.

4.1.1. Findings from hypertext experiment. A two-factor MANOVA (type of navigation x text/image ratio on screen) was computed to analyse experimental data for the hypertext study. Dependent variables were the scales on attention, SSM, involvement, SOD, Spatial Presence / Self-Location (SPSL), and Spatial Presence / Ascription of possible actions to media space (SPPA), which were all included in the MEC-SPQ.

Findings indicate a multivariate effect of navigation type ($F(6, 70) = 2.39$, $p < .05$), but no effect of text/image ratio and no interaction between factors. Type of navigation affected both dimensions of Presence ($F = 10.25$, $p < .01$ for SPSL; $F = 7.00$, $p = .01$ for SPPA) in the hypothesized direction: SPSL was larger for intuitive space-related navigation ($M = 2.73$, $SD = .87$) than for drop-down menu navigation ($M = 2.15$; $SD = .75$); similarly, SPPA was higher for space-related navigation ($M = 2.36$. $SD = .83$) than in the drop-down menu condition ($M = 1.90$, $SD = .65$). Values of the other MEC-SPQ scales (attention, etc.) were not affected by navigation types.

The ANOVA was repeated for those participants who had performed the STRT measurement ($n = 35$). Dependent variables were the average response times to visual, auditory, and audiovisual probes. Average response time values ranged from 471 *msec* to 610 *msec* across experimental conditions and type of probes, with standard deviations between 87 and 226 *msec*.

No multivariate or univariate effects of any of the manipulated factors on any of the response time variables were observed (all *F*s < 1). In addition, the main effect of navigation type on Presence that had been observed for the complete sample did not occur in the MEC-SPQ data of the STRT subsample, which indicates the effect of the STRT procedure on questionnaire results (obstrusiveness). As a conclusion, the hypertext experiment did not reveal a pattern that would allow to link STRT values to Presence experiences.

4.1.2. Findings from the film experiment. For the film study, a one-factor MANOVA was computed that used size of FOV (small versus large) as the only independent variable and all MEC-SPQ scales (see 4.1.1.) as dependent measures. No effect of FOV on Presence experiences or any of the related variables was detected in the questionnaire data.

In the second MANOVA (that examined only those subjects who had performed the STRT procedure, $n = 19$) FOV did again not display a significant multivariate effect and did not affect any of response time values systematically.

4.1.3. Findings from VR experiment. The MANOVAs computed for the VR study were identical with the analysis of film data. Questionnaire data again did not indicate any multivarate or univariate effect of FOV on Presence or its precursors. The MANOVA that used STRT data in addition to scale values from the STRT subsample ($n = 21$) did not find a multivariate effect and only a marginally significant influence of FOV on reaction times to auditory response times ($F = 3.02$, $p < .10$). For the other two types of probes, response times remained unaffected (both *F*s < 1).

4.2. Correlational analysis

4.2.1. Findings from hypertext experiment. Relationships between STRT values and subjective data as measured by the MEC-SPQ scales were generally weak in the HT study. Most *r* remained below +/- .20 and were not significant ($n = 35$). The strongest observed correlation occurred between the attention scale and response time index for auditory probes ($r = -.42$, $p < .01$). The negative direction opposed the hypothesized positive relationship between attention to the primary medium and response time to secondary input (see 2.1.).

4.2.2. Findings from film experiment. In general, correlations ($n = 19$) between questinnaire data and STRT values were higher in the film experiment than in the hypertext study. However, most of them were again negative, which contradicted the hypothesized relationship between STRT and Presence (precursors). A stable pattern of negative correlations was observed for SPSL ($r = -.42$, -.30 and -.33 for visual, auditory, and audiovisual probes, all *ns*); similarly, all correlations between response times and SPPA and between response times and attention were negative, with slightly lower coefficients. In contrast, all correlations between STRT and involvement scale values were rather weak, but positive ($r = .09$, .17, and .20, respectively). This finding was in line with expectations, however, the negative correlations between STRT and attention as well as Presence were unexpected and puzzling.

4.2.3. Findings from VR experiment. In the VR study, correlations (n = 21) were generally weaker than in the film study and more similar to the results on hypertext (4.2.1.). Whereas relationships between STRT and attention were again (weak, but) negative, rather strong positive correlations were observed between STRT and involvement ($r = .25$, .36, and .50 for visual, auditory, and audiovisual probes, with only the last coffefficient reaching statistical significance, $p < .05$). These results suggest that there maybe a stable relationship between involvement and STRT.

4.3. Media Comparison

For the media comparison, experimental conditions within each medium were ignored, which is partly justified by the failure to create effective manipulations (see 4.1.). The scope of the media comparison was to find out if average subjective values and average probe response times display similar patterns across media. If, for instance, the Presence scales would reveal higher scores for VR than for hypertext, and STRT data would display the same pattern, this would indicate a general convergence between measures. To avoid obtrusiveness effects, this analysis included questionnaire data only from those subjects who had *not* performed the STRT procedures (see 3.3.). Figure 2 displays average scale values for the most important MEC-SPQ constructs (attention, involvement, SPSL, and SPPA). Media differences occurred only in SPSL, which was substantially lower in hypertext than in the other media. SPPA was higher for VR than for hypertext and film.

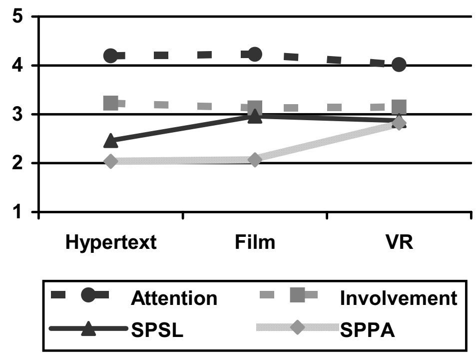

Figure 2 Average MEC-SPQ values across media (participants without STRT measurement)

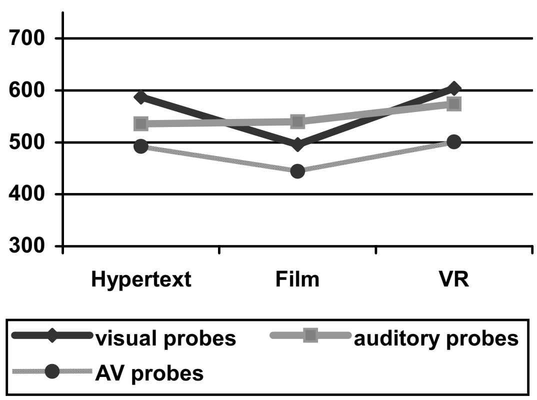

Figure 3 Average STRT values (in *msec*) across media for three probe types (see 3.4. for *n* of each medium/study)

The only interesting pattern that emerges is that response times to visual (and audiovisual) probes are faster in the film experiment than in the two other media/studies (figure 3). As film was the only non-interactive medium that was investigated, this result suggests that *visual* attention is more effectively bound by interactive media in which users have to make decisions and solve tasks (e.g., navigation) by themselves instead of merely witnessing a ready-made media product. Subjective measures do not reflect this pattern, however. In fact, the cross-media curves created by STRT data display not much congruity with the according subjective measures.

5. Discussion

Our studies produced in part unexpected covariance between STRT and questionnaire data, in part plausible connections, and mostly weak to no relationships that do not allow for a unified interpretation. Results indicate that STRT may assess involvement and, to some extent, visual attention. These conclusions would be in line with conventional STRT methodology as it is applied in TV research. Contradictory to past STRT research is the negative correlation of STRT with the attention scale (especially film and VR studies), which might be explained by the assumption that participants took the subjective attention measure as general scale of vigilance that referred to both the medium *and* to the secondary task: Highly alert people would be attentive to the medium *and* watching out for the next probe such behaviour would lead to a negative correlation between STRT and the attention scale.

Findings suggest further problems with the subjective measure of Presence and its precursors. The faster response times to visual probes in the film experiment was not reflected in subjective measures. Moreover, the expectably 'safe' manipulation of Presence (FOV in film and VR experiments) did not produce systematic variations in the MEC-SPQ scales.

One possible explanation for these unexpected results is that participants might have used an implicit media-specific baseline of what they would have expected to be the 'maximum possible value' when using a given medium. For instance, a low Presence rating made by a participant of the VR stimulus may result from that person's consideration that still much more intense Presence experiences would have been conceivable when using a VR environment. At the same time, the low rating may, in absolute terms, still mean a much stronger Presence experience than the person would have had when using the hypertext environment (even if the person would have made a high Presence rating when using that medium). If participants have performed such relativizations when filling in the subjective measures, this would necessarily cause difficulties to identify a stable convergence between subjective measures and objective data such as STRT values, since objective data are not sensitive to such media-specific adjustments of values. Consequently, the mixed results found in the present studies should not be solely attributed to the STRT procedure.

Some additional methodological problems of the reported studies need to be addressed. One major limitation is the low power of the research design, especially due to the small number of people who actually have produced STRT values. Although the realized samples would have had sufficient sizes to detect clear and non-ambiguous patterns in subjective and objective data, they certainly do not allow for sophisticated re-analysis, e.g., to repeat analysis for several subgroups within the STRT subsample.

Moreover, the concrete STRT procedure applied in the present studies is only one possible operationalization. Alternatively, the visual probes could appear on the screen that displays the primary stimulus. In a similar fashion, alternative options for auditory probe design could be envisioned.

The majority of results illustrates the problems of STRT. Primarily its obstrusiveness [11] is a limitation in the context of Presence research, because Presence is a highly fragile experience that may be massively altered by disturbing visual or auditory signals. From this perspective, the findings do not contain indications of advantages that could compensate for the high obtrusiveness of STRT. Therefore, the main conclusion of this series of experiments is that the methodological cost/benefit ratio of STRT seems to be not very positive. However, this recommendation is only valid for conventional STRT procedures like those executed in the reported studies.

6. Outlook: Advancing STRT to „Spatial STRT“ in order to assess space-related cognition (and Presence?)

The basic idea behind the STRT paradigm is to assess the availability of attentional and/or cognitive resources that remain when a person is engaged in a certain task (e.g., media use). Thus, the conceptual target of STRT is a rather broad-defined human capacity, which may have contributed to the mixed results reported in this paper (see also [4]).

One possible improvement of STRT that may be especially useful in the context of Presence measurement is to narrow the (conceptual) focus of what STRT can measure. Instead of addressing any kind of cognitive resources through measuring response times to any kind of probe, specific processing resources might be targeted by designing special types of reaction tasks. In the context of Presence measurement, it would be interesting to assess *space*-related cognitive capacities. From the perspective of the MEC model, for instance, space-related secondary task reaction times (sSTRT) may be capable to quantify the strength or salience of a user's mental representation of the media space (SSM) or even the intensity of Spatial Presence itself.

We are currently exploring the potential use of sSTRT. This modified methodology uses spatial and non-spatial ('flat') stimuli and requires participants to decide about spatiality or non-spatiality as quickly as possible. If users' space-related processing resources are bound by the primary medium (which would be an indicator for strong SSM or even high Presence), they should need more time to make that decision (response time) and should make more mistakes (error rate), which would create two interpretable output variables of sSTRT that could be directly linked to theoretical models of Presence. At least one major experiment will be conducted to find out if the sSTRT methodology is capable to deliver results that holds greater benefits for Presence measurement than what we have found for conventional STRT.

Acknowledgements

The research presented in this paper was funded by the European Commission (project "Presence: Measurement, Effects, Conditions", IST-2001-37661). We thankfully acknowledge the Commission's support. We also thank all partners of the MEC project for their support in respect to Presence theory and measurement, as well as in regard to the development and production of stimulus materials.

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