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Virtually Be: Interaction between Physical and Virtual Actors in Theatrical Performances

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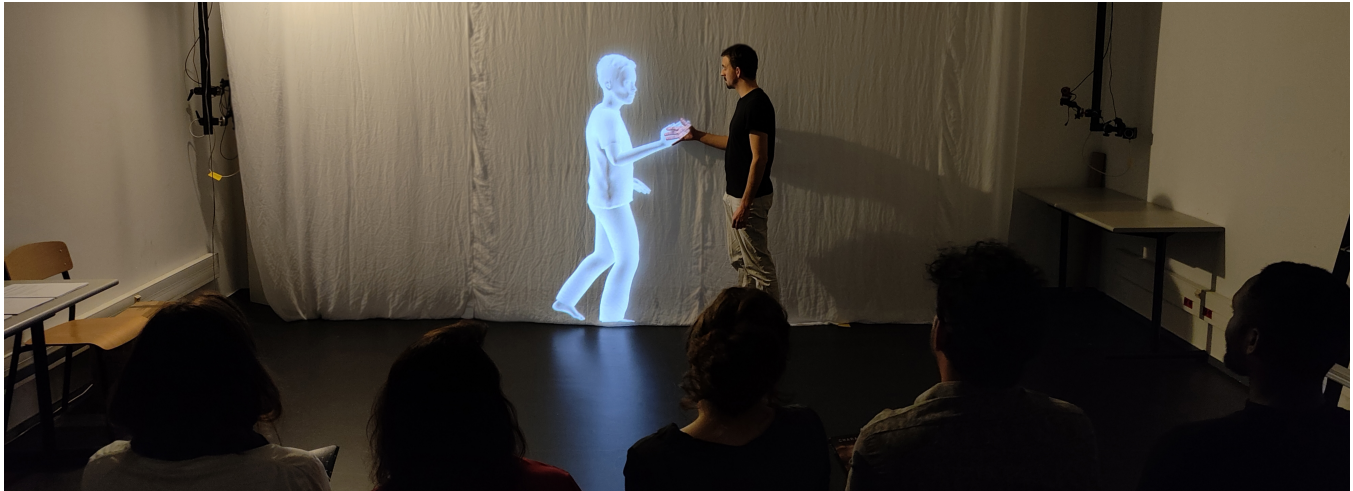


Figure 1: Virtual and physical actors performing together in front of spectators taking part in the experiment.

Abstract

The convergence between classical theatre and new technologies such as motion capture is opening up new artistic practices. In this interdisciplinary study, situated at the crossroads of experimental science and creation-research projects, we designed an experiment to assess spectators' perception of physical and virtual actors performing on stage. We were interested in investigating the way each actor would elicit a sense of social presence, with a particular focus on three sub-dimensions: co-presence, attentional allocation and perceived affective understanding. Spectators were exposed to three short scenes representative of different acting situations. Two asymmetric scenes depicted a situation where either the physical or the virtual actor was performing in a dynamic way, while both actors were active in the third scene. Results revealed significant interaction effects between the actor type (physical or virtual) and the acting dynamic for the considered dimension of social presence. However, we observed no significant difference when actors were performing simultaneously, suggesting that physical and virtual actors can harmoniously share a stage in active situations. It is

noteworthy that the results indicated that a passive virtual actor received more attention than a passive physical one, at a level comparable to that of an active physical actor. These findings have implications for the staging of theatrical performances that leverage the potential of motion capture and 3D character animation.

CCS Concepts

• **Applied computing** → **Performing arts**; • **Human-centered computing** → *Empirical studies in HCI*; • **Computing methodologies** → *Motion capture*.

Keywords

theater, motion capture, animation, performance

ACM Reference Format:

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1 Introduction

The convergence of technology and theatrical performance allows for the development of new practices and on-stage visual effects



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that offer new potentialities for stage directors, actors and spectators. Considering that scientific studies of such emerging artistic practices are still scarce, this study was designed to explore the impact of different types of interaction between a physical and a virtual actor on spectators' attention and sense of social presence [2, 17, 27] in the frame of theatrical performances.¹ In this context, a virtual actor could either be a digital character controlled in real-time by a second actor equipped with a motion-capture suit or a virtual character relying on pre-recorded animations.

Previous theatrical performances featuring virtual actors in the frame of creation-research projects proved to arouse the interest and curiosity of spectators (Figure 2) [8, 32–34]. Nevertheless, the complexity of designing a controlled experimental protocol for live performance limits the ability to gather empirical evidence to understand how virtual actors impact spectators' experience. The objective of this study was to design a scientific experiment based on short scenes played live in a controlled environment. The experiment employed psychometric assessment methods to analyze spectators' subjective experience and focus when observing a physical and a virtual actor performing together on stage. In this context, several technological factors may potentially draw the attention of spectators making it even more challenging for stage directors to ensure that actors are communicating their intention. These factors include both new potentialities and several limitations that must be considered when designing such a performance.

First and foremost, there is a lack of knowledge regarding the impact of the novelty effect associated with avatars in this type of emerging theatrical performance. One might inquire whether such a virtual representation would prompt participants to direct their attention more towards the virtual actors than the physical ones. It is unclear whether the integration of motion capture, with associated technological limitations constraining performers' acting, will align with spectators' expectations. To address these questions, we were interested in applying an empirical scientific approach to artistic practices in order to share guidelines, techniques and exercises with theater artists working with motion capture and virtual avatars.

The following section presents related works on theatre and new technologies, along with an overview of previous creation-research projects. It also discusses social presence in conjunction with audience attention. Section 3 presents the design of the study, the experimental protocol and the procedure. Results are reported in Section 4 and discussed in Section 5. Section 6 underlines the limits of the experiment and potential future work. Finally, Section 7 summarizes the contributions of this experiment and concludes the paper.

2 Related Work

2.1 Theater and New Technologies

To the best of our knowledge, research that attempt to combine theatrical practices, modern technologies and scientific investigations could be conveniently divided into two groups: those focusing

exclusively on theater makers and those considering both artists and spectators' feedback using diverse types of questionnaires and interviews. To the first category we could subsume a range of experiments including rehearsing in virtual environments [22, 29, 30], motion capture and 3D environment visualization while performing [13], improving actors' training using motion capture [35], exploring the potential of VR to animate avatars of different scales [14]. Examples in the second category include research on the integration of real-time motion capture in a dance-performance [21], an investigation on motion recognition being performed by 2D and 3D avatars [18], and a study about human-robot interaction in the frame of theatre performance [23].

In their experiment, Slater *et al.* [29] studied the impact of virtually rehearsing using both desktop displays and a virtual reality headset allowing a director and two actors to remotely collaborate for four days before a live performance. The concept of co-presence, along with other collaboration indicators, was also considered in the frame of this experiment. Their results indicated an improvement over time during the four days, which, according to qualitative feedback, allowed to reach a performance level in a way that would not have been achievable using more traditional remote communication technologies such as video conferencing, given that the actors did not share the same physical space.

Both Normand *et al.* [22] and Steptoe *et al.* [30] investigated the use of shared virtual environments for rehearsing movie scenes or theatrical performance while being geographically separated. In their studies, participants had different immersion setups: a first participant in Barcelona was immersed in virtual reality using a headset and a full body-tracking suit, while a second one used a Cave system in London, and a third participant could also assist as an observer. This setup was designed to explore the efficiency of such a training configuration, as well as the impact of immersion asymmetry on the quality of acting.

While technology can support staging and rehearsals for theatrical performance, mixed reality was also used as a way to support actors performing motion capture. In an effort to overcome temporal constraints and optimize training periods for limited-scale productions, [13] developed a mixed reality application that enabled actors to visualize a virtual environment, thereby providing additional context and enhancing their immersion. The objective of this proof of concept was to provide context that would benefit the acting mood, offering relevant contextual stimuli.

Still with the aim of optimizing performance, the research of Wang [35] was intended to explore if use of motion capture would improve teaching and learning of specific movements inherent to classical Chinese opera. A traditional method was compared to a new one supported by body tracking. Teachers gave feedback to both groups, after which students repeated the gestures. Results highlighted a strong and positive impact of motion capture in this context.

Kammerlander's *et al.* [14] question a particular problem: interaction between virtual characters with different scales. They compared a condition in which performers had a visual feedback projected on a screen with a condition in which they were immersed together in virtual reality. This study demonstrated the efficiency of the immersive condition to favor interactions, but highlighted the lack of facial expressiveness.

¹This paper is an extension of a previously published experimental protocol. This protocol has been adapted to accommodate operational constraints. The document includes an extended section on related work and the results of the experiment, along with a discussion.

Similarly, recent studies employed real-time systems to embody virtual animals for motion-capture purposes. These studies aimed at investigating the impact of these systems on actors' quality of experience, as well as the potential benefits in terms of performance and acting [12].

All of the aforementioned studies provide interesting perspectives on rehearsing and training processes, but do not investigate in which way these implementations could influence spectators' experience. The creation-research project entitled 100d11A0N1C00E1 [21] relied on real-time motion capture in a dance-performance. In a complex environment, physical performers were interacting with shadows, videos and a virtual character moving on multiple screens on stage. Interviews were conducted with actors and spectators. The dancers' comments focused on their experience with new technologies and their observation on adapting their body language. On the other hand, spectators tried to explain what they saw and gave abstract but fascinated opinions on the potential for further integration of new technologies in such performance.

Closely related to our study, [23] staged a realistic robot interacting with an actress in a dramatic scene. The woman had a cancer and the robot was supposed to support her emotionally, talk about death and recite a poem. The aim was to understand how people perceived the robot's mind, attractiveness and the weight of its words. The study proves that audience could feel emotions of the android, acknowledge its physical and vocal beauty and even find a robot being more pure than a human. However there is no significant difference observed between the perceived attractiveness between a robot and a woman-actress and the poem recited by robot doesn't seem more enhanced. To the best of our knowledge, this is the only project investigating the perception of human-machine interaction by an audience, but remaining focused on the technological aspect.

With the proposed research, our ambition was to explore a subtle non-verbal connection that could be created on stage between a physical actor and an animated avatar with motion capture on the audience's reaction to different types of interaction. Our investigation was based on a theory of four interaction patterns introduced by Ternova in the context of her creation-research entitled Patrick and Venus [31] and lately applied in the projects The Wizard Without Shadow [32] and Salomé [33]:

- (1) Drawing spectators' attention to either the physical world or to the virtual world by emphasizing one over the other.
- (2) Letting spectators choose the object of their attention by presenting unrelated and parallel actions in the real and the virtual worlds.
- (3) Creating a harmonious attention flow by connecting the real and the virtual worlds.
- (4) Disturbing spectators' attention by superimposing real and the virtual worlds on stage.

However, the relevance of these interactions in drawing spectators' attention in the expected way cannot be asserted, as the aforementioned performances involved numerous uncontrolled variables. The intricate and multifaceted nature of the virtual environments surrounding the virtual actors could potentially influence the accuracy of attentional assessments. A number of technical factors could also influence the experimental results. These include an unbalanced scenography, with one world being more prominent

than the other; inconsistent virtual camera movements; dynamic lighting in the physical and virtual environments; varying appearances and morphological features of the virtual actors and so on. Moreover, in the aforementioned creation-research projects, participants were not formally invited to share their perception of the scenes and discuss how they directed their attention towards the proposed content. Consequently, the design of the experiment reported in this paper aimed at creating a controlled environment in order to conduct a psychometric assessment of the proposed types of actor-avatar interaction on spectators' attention and sense of social presence with physical and virtual actors.

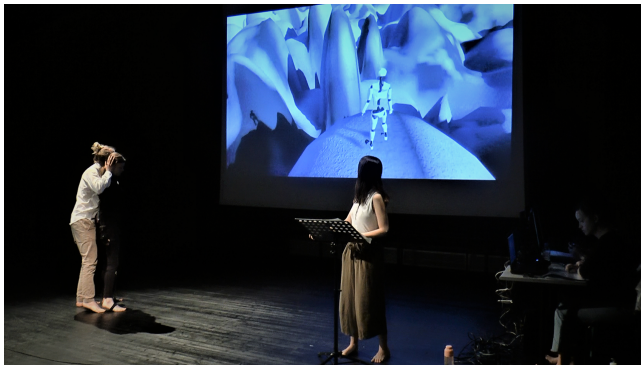
2.2 Social Presence and Audience Attention

Social presence was initially defined by Short et al. [28] as "the degree of salience of the other person in the interaction and the consequent salience of the interpersonal relationships". The sense of social presence with virtual characters has been primarily investigated in research on immersive virtual environments, particularly in relation to social interactions with avatars (human-controlled virtual characters) and autonomous agents (computer-controlled virtual characters) [7]. Nevertheless, this sense can emerge in different computer-mediated communication contexts, including text-based communication [25] and even in traditional media such as books [17]. The concept of presence has also been considered by theater artists and researchers [3]. Their work focused on conceptualizing the presence of staged virtual characters [4], motion perception and somaesthetic sensations [16, 19], as well as technical challenges of enabling interactions between physical and virtual actors [5]. Nowadays, the human-computer interaction (HCI) community tends to define the concept of social presence in virtual environments as the sense of being there together [27]. A more detailed definition of this concept, which will be considered in the context of this experiment, was introduced by Harms and Biocca [11]:

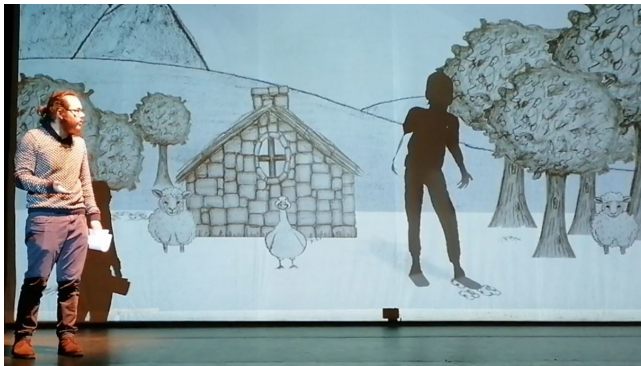
"Social presence in a mutual interaction with a perceived entity refers to the degree of initial awareness, allocated attention, the capacity for both content and affective comprehension, and the capacity for both affective and behavioral interdependence with said entity."

A considerable body of research in the field of HCI focused on identifying the factors that influence the sense of social presence in both multi-user and virtual character interactions. In their meta-analysis, Oh et al. [24] identified three key predictors of social presence, namely immersion, context and individual. The immersion predictor is related to the level of interactivity, the type of display or the audio quality. The context predictor encompasses factors such as the personality and traits of virtual humans, physical proximity, social cues, and so forth. The individual predictor, in contrast, refers to demographic variables and psychological traits of the user.

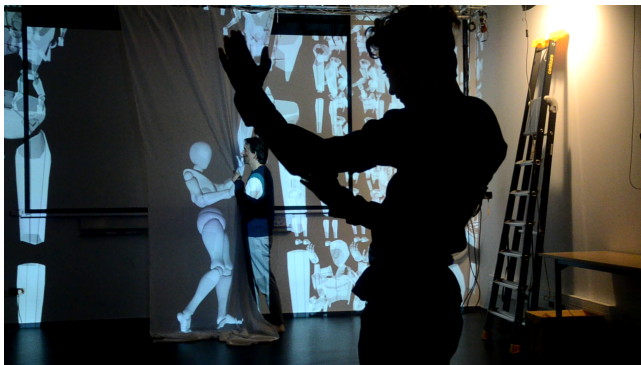
In recent years, the majority of social presence research explored situations where bilateral communication was possible with avatars and autonomous agents [6, 15]. It has been demonstrated that interacting with virtual humans believed to be controlled by another person would induce a higher sense of social presence than when interacting with an autonomous social entity [1]. Such results may



(a) Patrick and Venus



(b) The Wizard Without Shadow



(c) Salomé

Figure 2: Staging of creation-research projects featuring physical and virtual actors interacting together. Virtual actors are either controlled in real-time using motion capture technologies (Sub-figures 2a, 2c) or animated with pre-recorded animations (Sub-figure 2b).

be of particular importance when considering the sense of social presence of a physical actor interacting with a virtual one, especially when using real-time motion-capture suits versus pre-recorded animations. However, in the frame of the proposed experiment, our objective was to investigate the way spectators could experience a sense of social presence with these two types of actors when no direct (actor/spectator) interaction is possible.

In their model, Biocca *et al.* [2], Harms and Biocca [11] identified six dimensions that contribute to social presence: co-presence, attentional allocation, perceived message understanding, perceived affective understanding, perceived emotional interdependence and perceived behavioral interdependence. In the frame of theatrical performances, with limited interactions between the actors and the spectators, some of these dimensions cannot be used to trigger and maintain a sense of social presence over time. Consequently, our investigation was narrowed down to three dimensions that have the potential to elicit a sense of social presence in spectators, even in the absence of dyadic interaction when attending a theatrical performance: co-presence, attentional allocation, and perceived affective understanding [11]. Co-presence can be defined as the degree to which the observer believes he/she is not alone or secluded. One must be aware of the other. Attentional allocation refers to the amount of attention the user allocates to the interactant. Lastly, the perceived affective understanding dimension is described as users' ability to understand their interactant's emotional and attitudinal states. Considering these three dimensions of social presence, we designed an experimental study to investigate the way physical and virtual actors could draw spectators' attention and elicit a sense of social presence while simultaneously performing on stage.

The interaction patterns introduced by [31] were considered in the experimental design to challenge this theoretical creation-research approach in a controlled scientific experiment.

3 Materials and Methods

3.1 Experimental Conditions

The experiment involved inviting participants (spectators) to observe a sequence of three minimalist scenes performed simultaneously by a physical and a virtual actor. The purpose of the experiment was to investigate the way attention is directed in theatrical performances that rely on technologically mediated presence of actors. As in classical theater, participants were seated in front of the stage, which consisted of an empty performing space with a white screen at the back of the stage to project the virtual actor. Two independent variables were considered for this experiment:

- **Actor type:** Physical Actor (PA) or Virtual Actor (VA).
- **Acting Dynamic:** active Physical World (PW), active Virtual World (VW) and both Worlds active (Ws).

In the PW condition, the physical actor was engaged in active performance, whereas in the VW condition, the virtual actor was the primary performer. In the Ws condition, both actors were performing simultaneously. However, a potential condition in which both actors were to be passive was excluded, as it was considered irrelevant (no line of action [26]) to theatrical performance. A within-subject design was employed for this experiment, meaning that all participants were exposed to all experimental conditions in a counterbalanced order. In each scene, the active performer replicated similar movements. While it would have been possible to control the virtual actor in real time using a motion capture suit, its animations were pre-recorded in order to ensure that all participants attended a similar show. The actors were separated at the beginning of the scene, one on each side of the stage. As the actors performed, the distance between them was progressively reduced until they gave the illusion that they touched each other (Figure

1). In the PW condition, the physical actor approached the virtual actor. The virtual actor observed the physical actor's behavior while remaining passive. In the VW condition, the situation was reversed and the physical actor observed the virtual actor performing the same actions. Finally, in the Ws condition, both actors approached each other until they reached the center of the stage (Figure 1). Participants completed the post-exposure questionnaires after each scene.

3.2 Actors and Environments

The physical actor selected to perform was also responsible for recording the virtual actor's animations, ensuring a symmetric performance. The actor had previous experience with motion capture and was also a classical theatre performer. Such an experience was required to ensure he was conscious of what was introduced as the two circles of presence [9]: proprioceptive consciousness of the virtual body and awareness of the virtual space of acting. It was also necessary for the actor to have a good understanding of the specificities and constraints of playing with a virtual actor, as they shared a common circle of attention, a definition derived from Stanislavski's system [36] meaning a vivid consciousness of the presence of the second actor.

In accordance with previous creation-research projects (Figure 2), a white virtual character, modeled after the physical actor and matched in size, was used as virtual actor. As people tend to be less prone to accept virtual characters' flaw as they get closer to realistic human appearance [10, 20], such a virtual representation ensured that participants would not be disturbed by the lack of facial expressions. The virtual content of the experience was developed using Unreal Engine 4. The environment was designed to be dark and minimalist to ensure that participants focused on the actors' interactions. The physical stage was divided into three spaces: an empty stage with simple lighting, a screen at the back of the stage onto which the virtual actor was projected, and the spectator seats facing the stage, allowing up to six participants to attend the show.

3.3 Participants

34 participants aged from 20 to 39 ($M = 24.70, SD = 3.84$) with prior theater experience but who do not attend very often (not more often than once or twice a month, not less than once every six months) were recruited for this experiment. Participants self-reported a high familiarity with information technology ($M = 5.09, SD = 1.14$), a high 3D modeling ($M = 5.15, SD = .93$) and a fairly high programming experience ($M = 4.09, SD = 1.33$), a modest motion capture ($M = 1.82, SD = .83$) and theater experience ($M = 1.21, SD = 1.20$) on 7-point Likert scales. The observed correlations between participants' previous experience and the considered dependent variables of this study were found to be very marginal.

3.4 Procedure and Measures

3.4.1 Instructions and Pre-experiment Questionnaire. Prior to the experiment, participants were required to sign a consent form and complete a pre-experiment questionnaire. This questionnaire collected anonymous demographic data, including age, gender, information technology expertise, programming and 3D modeling

Table 1: Post-exposure questionnaire adapted from [11]. Items range from 1 to 7 on semantic differential scales.

| Co-presence |
|---|
| I noticed the physical/virtual actor. |
| The physical/virtual actor's presence was obvious to me. |
| The physical/virtual actor caught my attention. |
| Attentional Allocation |
| I was easily distracted from the physical/virtual actor.* |
| I remained focused on the physical/virtual actor throughout the action. |
| The physical/virtual actor did not receive my full attention.* |
| Perceived Affective Understanding |
| I could tell how the physical/virtual actor felt. |
| The physical/virtual actor's emotions were not clear to me.* |
| I could describe physical/virtual actor's feelings accurately. |

(*) indicates reverse-scored items for negatively worded sentences.

experience, as well as their knowledge of theatre and motion capture. Following the completion of the demographic questionnaire, participants were given the necessary instructions to take part in the experiment. The experimenter then proceeded to explain that they were about to attend a theatrical performance featuring a physical and a virtual actor. Additionally, participants were informed that they would be required to complete a questionnaire between each of the three scenes. This questionnaire was designed to assess their perceptions and feelings about the actors' performance.

3.4.2 Performance and Measures. The actors performed the three scenes sequentially. The duration of each scene was approximately one and a half minutes. A brief intermission was observed between each scene, during which participants were requested to complete the post-exposure questionnaire. This questionnaire was adapted from the Networked Minds Social Presence Questionnaire [2, 11] (Table 1) to assess their level of co-presence, their attentional allocation and their perceived affective understanding with each actor. As aforementioned, three of the six dimensions of the original questionnaire were considered in this study, as the others require either a verbal interaction (perceived message understanding) or a mutual interaction between the interactants (perceived emotional interdependence, perceived behavioral interdependence). Furthermore, half of the items per dimension were excluded due to the absence of reciprocity in the spectator-actor interaction. The final questionnaire consisted of nine items based on seven-point semantic differential scales, which were to be completed twice per scene (once for each actor). The experiment was conducted over a period of 30 minutes. The sequence of the three scenes was counterbalanced.

3.5 Hypotheses

- **H1:** Spectators feel a higher sense of co-presence (H1.1), a higher attention allocation towards (H1.2) and a higher

perceived affective understanding (H1.3) with the active performer regardless of his/her nature (physical or virtual).

- **H2:** When both actors are active simultaneously, the unusual aspect of the virtual actor induces a higher sense of co-presence (H2.1) and a higher attentional allocation (H2.2).
- **H3:** When both actors are active simultaneously, the expressiveness of the physical actor induces a higher perceived affective understanding.

4 Results

Data were tested for normality and sphericity. The Shapiro–Wilk’s test revealed that some data were not normally distributed ($p < .05$), especially for the co-presence dimension. Nevertheless, we used two-way repeated measures ANOVAs to analyze the collected data, as such tests are considered fairly robust to deviations from normality and sphericity was assumed for every dependent variable. Differences are considered significant when $p < .05$. Bonferroni corrections were applied for relevant post-hoc comparisons.

4.1 Co-presence

There was a statistically significant two-way interaction between actor type and acting dynamic on co-presence (Figure 3a), $F(2, 66) = 24.322, p < .001$, partial eta squared = .258. Significant simple main effects of acting dynamic were observed for the physical $F(2, 66) = 22.014, p < .001$, and the virtual actors $F(2, 66) = 7.654, p < .001$.

In line with H1.1, post-hoc pairwise comparisons indicated that co-presence scores were significantly higher in favor of the active physical actor ($M = 6.55, SD = .66$) compared to the passive physical actor ($M = 5.65, SD = 1.23$), $p = .004$, Cohen’s $d = .916$, mean difference of .90 (95% CI [.181, 1.623]) in asymmetric scenes (PW and VW). Co-presence scores were also significantly higher in favor of the active virtual actor ($M = 6.57, SD = .50$) compared to the passive virtual actor ($M = 5.65, SD = 1.23$), $p < .001$, Cohen’s $d = .936$, mean difference of .92 (95% CI [.287, 1.555]).

However, H2.1 was not supported as no significant difference in co-presence scores was observed when both actors were active at the same time.

4.2 Attentional Allocation

There was a statistically significant two-way interaction between actor type and acting dynamic on attentional allocation (Figure 3b), $F(2, 66) = 17.212, p < .001$, partial eta squared = .218. Significant simple main effects of acting dynamic were observed for the physical $F(2, 66) = 17.234, p < .001$, and the virtual actors $F(2, 66) = 11.522, p < .001$.

H1.2 was also supported as post-hoc pairwise comparisons indicated that attentional allocation scores were significantly higher in favor of the active physical actor ($M = 4.42, SD = 1.28$) compared to the passive physical actor ($M = 2.96, SD = .97$), $p < .001$, Cohen’s $d = 1.290$, mean difference of 1.46 (95% CI [.687, 2.235]) in asymmetric scenes (PW and VW). Attentional allocation scores were also significantly higher in favor of the active virtual actor ($M = 4.99, SD = 1.16$) compared to the passive virtual actor ($M = 3.77, SD = 1.34$), $p < .001$, Cohen’s $d = 1.082$, mean difference of 1.23 (95% CI [.452, 1.999]).

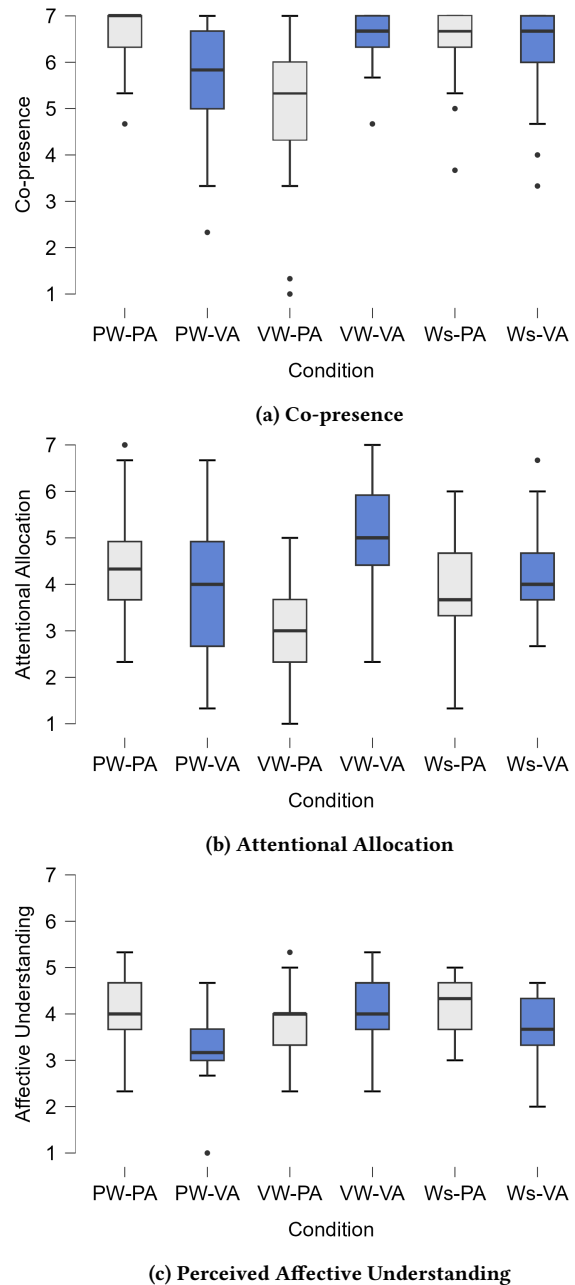


Figure 3: Social presence boxplots (Co-presence, Attentional Allocation and Perceived Affective Understanding) for each acting dynamic (active Physical World (PW), active Virtual World (VW) and both Worlds active (Ws)) and each actor (Physical Actor (PA) and Virtual Actor (VA)).

Additional post-hoc analyses revealed a significant difference between passive actors. The passive physical actor ($M = 2.96, SD = .97$) received significantly less attentional allocation than the passive virtual actor ($M = 3.77, SD = .23$), $p = .042$, Cohen’s $d = 0.710$, mean difference of .81 (95% CI [.016, 1.593]).

H2.2 was not supported as no significant difference in attentional allocation scores was observed when both actors were active at the same time.

4.3 Perceived Affective Understanding

There was a statistically significant two-way interaction between actor type and acting dynamic on perceived affective understanding (Figure 3c), $F(2, 66) = 9.255, p < .001$, partial eta squared = .103. Significant simple main effects of acting dynamic were observed for the physical $F(2, 66) = 4.152, p = .020$, and the virtual actors $F(2, 66) = 10.042, p < .001$.

H1.3 was partially supported as post-hoc pairwise comparisons revealed no significant difference in perceived affective understanding scores between the active and passive physical actors. However, perceived affective understanding scores were significantly higher in favor of the active virtual actor ($M = 4.00, SD = .70$) compared to the passive virtual actor ($M = 3.32, SD = .64$), $p < .001$, Cohen's $d = 1.017$, mean difference of .68 (95% CI [.219, 1.135]).

H3 was not supported, as no significant difference in perceived affective understanding scores was observed when both actors were active at the same time.

5 Discussion

We designed an experimental study to analyze the way physical and virtual actors are perceived by spectators attending theatrical performances relying on new technologies such as motion capture and 3D character animation [8, 33]. Applying a scientific method to creation-research, we developed a protocol to assess three dimensions of social presence [2, 24] that spectators would have been susceptible to feel toward both actors performing together on stage. In this context, we assessed participants' sense of co-presence with the actors, their attentional allocation as well as their affective understanding [11] during three short scenes representative of different acting situations. Following a within-subject design, the physical and the virtual actors were either respectively active and passive in two asymmetrical scenes and both active at the same time in a third scene. Subjective assessments of social presence with each actor were conducted via psychometric questionnaires following each scene presented in a counterbalanced order. Despite the constraints inherent to live performance, as discussed in the limitation section, statistical analyses revealed significant differences in line with our hypotheses. Additional post-hoc analyses also revealed unexpected yet insightful guidelines for theatrical practices.

5.1 Virtual Actors and Social Presence

We observed significant interaction effects between the actor type and the acting dynamic for co-presence, attentional allocation and perceived affective understanding. These interaction effects acknowledge the importance of considering the way in which virtual actors are experienced by an audience compared to physical actors for staging such performances. Indeed, results indicated that depending on the interaction dynamic, each actor type could be perceived differently by the audience. These results further reinforce the rationale behind the experimental design, which took into account the simultaneous presence of two actors on stage rather

than considering each actor type at a time. In this context, the considered acting dynamic variable was not merely a means of describing the active or passive dynamic of each actor. It was rather a way of depicting an overall situation in which the state of one actor could impact the perception of the other.

We initially hypothesized that the active actor would have elicited a higher sense of co-presence (H1.1), a higher attentional allocation towards (H1.2) and a higher perceived affective understanding (H1.3) regardless of his/her nature (physical or virtual). We observed significant simple main effects of the acting dynamic for both physical and virtual actors on spectators' sense of co-presence with post-hoc pairwise comparisons indicating that active actors induced a higher presence awareness (H1.1). Similar results in favor of active actors were observed in terms of attentional allocation (H1.2). In addition, subsequent post-hoc analyses revealed significant differences between the passive actors. The passive virtual actor received significantly more attention than the passive physical actor. Descriptive statistics also indicate that a passive virtual actor could reach a similar level of attention compared to an active physical one, whereas the opposite is not true. This is of particular importance when it comes to staging performance and will be further discussed in the following section.

In terms of perceived affective understanding, while we observed statistically significant simple main effects of the acting dynamic in favor of active actors, post-hoc analyses revealed no significant difference between the active and passive physical actors. However, a significant difference was observed between the virtual actors in favor of the active one, which partially support H1.3. This result may be explained by the fact that the passive physical actor may have preserved several visual cues potentially favoring the perception of his affective state, such as facial micro-expressions even with body language reduced to a minimum. This type of micro-expression was not displayed on the passive virtual actor as no facial tracking technology was used in the frame of this experiment. This emphasizes the fact that performers acting through virtual representations in such conditions must pay attention to their physical acting to strengthen the expressiveness of their virtual bodies.

Our second and third hypotheses focused on the interactive situation, where both actor types were active at the same time. It was hypothesized that the unusual aspect of the virtual actor would have induced a higher sense of co-presence (H2.1) and attentional allocation (H2.2). We also hypothesized that the expressiveness of the physical actor would have induced a higher perceived affective understanding in this interactive context (H3). It is notable that no significant difference was observed in this regard. This indicates that in an active situation, both actor types are well balanced, allowing spectators to allocate their attention and affective understanding between the actors. Taken together, these observations are encouraging for performers and artists wishing to explore new theatrical practices based on motion capture and virtual character animation.

5.2 Implications for Theatrical Performances

As evidenced by the aforementioned results, it is of paramount importance to consider the impact of a virtual actor on spectators'

attention when staging theatrical performances. Numerous conclusions could be drawn from this experience. While a physical actor can stay on stage without maintaining audience engagement when not acting in a dynamic way, results indicated that virtual actors do, in fact, maintain some level of interest, even when not actively performing. Such results corroborate partly Ternova's previous assumptions based on preliminary practical experiences [31–33] regarding the potential of different interaction types in drawing spectators' attention, but empirical evidence highlights the asymmetrical nature of the actors.

There are a couple of ways to interpret this result. One could argue that the unusual aspect of a virtual actor displayed on stage would arouse spectators' interest. Consequently, the novelty effect would impact theatrical performances until it became a more common practice. While it is encouraging from a theatrical perspective that virtual actors are susceptible to induce a sense of social presence in spectators, it is yet unclear how this potential novelty effect would interfere with the diegesis and the performance's content itself. It is possible that spectators' attentional allocation was driven by their interest in technology, leading them to wonder how such an actor is controlled rather than focusing on the artistic content.

Apart from this potential novelty effect, the visual salience induced by the character design of a virtual actor could also contribute to attracting spectators' attention. As highlighted by previous creation-research projects, a wide variety of designs and shading methods contributing to the overall aesthetic of the scene can be considered when designing and staging such performances (Figure 2b). Directors could benefit from these potentialities and could also enhance actors' performance by implementing additional visual effects and new movements inaccessible to the human body.

In this context, theatrical practices relying on new technologies would benefit from further research. It is nevertheless encouraging observing from an experimental standpoint that virtual actors are susceptible to induce a similar level of co-presence, attentional allocation and perceived affective understanding compared to physical actors when acting simultaneously on stage. This is a promising result for upcoming artistic and scientific projects. While theatrical acting is challenging to explore using experimental scientific methods, we believe that this kind of research is beneficial for theatrical practice relying on new technologies and could contribute to bringing much more clarity and awareness to the staging process. They could become a valid ground to elaboration of staging theories and practical approaches that can be helpful for the theatre-makers who merge new technologies with theatre.

6 Limitations and Future Work

This research, crossroads of experimental and creation-research studies, aimed at paving the way for future experiments attempting to combine theatrical art and science. Nevertheless, despite our best efforts to overcome the inherent limitations of designing a scientifically valid experimental protocol and maintaining an ecologically valid environment, it is important to acknowledge that certain limitations remain.

In this experiment, spectators were simultaneously exposed to both types of actor (physical and virtual) due to the necessity of interaction between the actors. This entailed that participants were

required to complete two post-experiment questionnaires per scene, with each questionnaire assessing their sense of social presence with one of the actors. In this context, we also attempted to limit the number of independent variables to a minimum. Further research would be necessary to evaluate the impact of virtual actors' appearance, including factors such as morphology, textures, shading, and so forth. It can be argued that the salience of the virtual actor is heavily influenced by both the acting dynamic and visual appearance. In this experiment, the morphology of the virtual actor was based on that of the physical actor, but its shading was very bright and salient (Figure: 1). Future investigations could also consider replacing the avatar of the performer with a pre-recorded video to further investigate the impact of the perceived nature of the virtual actor. It may also be relevant to examine the influence of different modalities to display avatars on stage. In particular, consider using augmented reality headsets to further reinforce the illusion that the avatar and the actor are co-located and interact with each other in the same environment.

In addition to subjective measures, objective behavioral indicators are also considered in experimental research using eye-tracking technologies for the assessment of participants' attention. Although this could have provided additional insights into spectators' attention and focus, it would have been complicated to equip several participants at the same time, which was beyond the scope of this study given the pragmatic limitation of hardware resources availability. On the other hand, it was important to keep the situation as close to a performance presentation as possible in order to measure the spectators' reaction in theater-like conditions. It would be beneficial for future research to consider replicating similar experiments under more controlled conditions, with one participant at a time, in order to accurately capture behavioral responses to such stimuli.

7 Conclusion

We designed an experimental protocol to apply a scientific assessment to theatrical creation-research projects. The objective was to investigate the way in which spectators would direct their attention towards physical and virtual actors displayed on stage and interacting together. The actor type (physical and virtual) and the acting dynamic between the actors were considered as independent variables. Three short scenes were presented to the spectators in a counterbalanced order. In the first scene, the physical actor was active and approached the virtual one. The opposite situation was depicted in a second scene. Both actors were active at the same time in a third scene. A fourth scene, in which both actors would have been passive, was not included in the experimental design as it was deemed irrelevant from a theatrical performance perspective by the artists.

The primary findings of this study indicated that there were significant interaction effects between the actor type and the acting dynamic for each considered dimension of social presence: co-presence, attentional allocation and perceived affective understanding. However, no significant difference was observed when both actors were active simultaneously. This suggests that both actor types were well balanced on stage in active situations and that it is worth considering scenes where a physical and a virtual actor act together. In accordance with the formulated hypotheses,

it was observed that active actors induced a higher sense of co-presence and attentional allocation than passive actors. Additional post-hoc analyses revealed a significantly higher attentional allocation towards the passive virtual compared to the passive physical actor. Consequently, it can be stated that it is more challenging to draw spectators' attention towards a physical actor in asymmetrical scenes when sharing the stage with a virtual actor. These findings are of particular importance for the staging of theatrical performances and provide useful guidelines for artists with the ambition of integrating virtual actors into their practices.

Contributions

A.T. and G.Go. conceptualized the study. A.T., G.Go. and G.Ga designed the details of the experiment. A.T. stage the performance. G.Go. analyzed the data. G.Go. wrote the paper draft. A.T., G.Go and G.Ga contributed to the proofreading and the final version.

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