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# Beyond my Real Body: Characterization, Impacts, Applications and Perspectives of “Dissimilar” Avatars in Virtual Reality

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**Abstract**— In virtual reality, the avatar - the user’s digital representation - is an important element which can drastically influence the immersive experience. In this paper, we especially focus on the use of “dissimilar” avatars i.e., avatars diverging from the real appearance of the user, whether they preserve an anthropomorphic aspect or not. Previous studies reported that dissimilar avatars can positively impact the user experience, in terms for example of interaction, perception or behaviour. However, given the sparsity and multi-disciplinary character of research related to dissimilar avatars, it tends to lack common understanding and methodology, hampering the establishment of novel knowledge on this topic. In this paper, we propose to address these limitations by discussing: (i) a methodology for dissimilar avatars characterization, (ii) their impacts on the user experience, (iii) their different fields of application, and finally, (iv) future research direction on this topic. Taken together, we believe that this paper can support future research related to dissimilar avatars, and help designers of VR applications to leverage dissimilar avatars appropriately.

**Index Terms**—Virtual Reality, HCI, Avatar

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## 1 INTRODUCTION

Virtual Reality (VR) can provide users with the unique experience of exploring and interacting through their avatar, i.e. their digital representation within the virtual environment (VE). While research has been striving for decades to match users and avatars’ appearance, VR also offers the possibility to go beyond merely replicating reality, and to experience embodying a “*dissimilar avatar*”, i.e. an avatar which differs from the user’s real body. A dissimilar avatar can either present subtle modifications which does not alter the anthropomorphic aspect of the avatar (e.g., another facial structure [6, 7], skin tone [12, 87], body proportion [80, 98] or outfit [69]), or more extreme body changes (resulting for example in a robot [66], animal [55, 85], avatar showing additional limbs [57, 99], or with an abstract appearance [5, 63]). Strictly speaking, any avatar is dissimilar, since even the most accurate 3D reconstruction technique does not perfectly reproduce the actual user appearance. Hence, rather than attempting to define an arbitrary threshold to determine whether an avatar would be considered dissimilar or not, our discussions focus on *dissimilarities*. We refer to a dissimilarity as a particular difference between the avatar and the real user appearance, whether they are concrete (e.g. a longer arm) or conceptual (e.g. lower realism). However, in order to simplify the discussion, we refer to a dissimilar avatar when dissimilarities are incorporated voluntarily to the avatar, and not due to technical limitations.

Numerous studies have shown that the broadness of appearances one can experience being embodied within VR, offers a large number of usages, in terms of user interaction [1, 93, 99], perceptual and behavioral alterations [71, 101, 122], mitigation of existing VR limitations [10, 66], or social interaction enhancement [7, 30]. However, because VR research on virtual embodiment was primarily focused on simulating reality as closely as possible, studies regarding dissimilar avatars are mostly sparse and disorganized among different research

fields, leading to a lack of common terminology and understanding. Hence, the purpose of this paper is to centralize and organize current knowledge regarding dissimilar avatars, with the aim of enhancing the understanding and promoting a standardized structure for future research on this topic.

As we mentioned, dissimilar avatars encompass a wide range of appearance options and are studied in diverse research fields, such as human-computer interaction (HCI) [72, 93, 99], but also social [87, 122] and cognitive psychology [54, 98], and medicine [22, 71]. This situation leads studies to characterize dissimilar avatars using terminologies and methodologies adapted specifically to their context, but which might be inconsistent with other studies. Regrettably, this inconsistency that can be found among studies hampers cross-studies discussions as well as the integration of small-scale research to wider-scale theories [81]. Thus, in order to facilitate future research on this topic, and hopefully push for the adoption of common definitions for dissimilar avatars discussions, we propose in Section 2 a characterization of dissimilar avatars. Specifically, we discuss in this section the challenges of characterizing avatars’ dissimilarities, and propose a characterization methodology, adapted to different requirements in terms of exhaustivity and concision. After proposing a common language to address the topic of dissimilar avatars, we aim to discuss how these avatars, and the inconsistencies that they create between the real and virtual body, may influence different factors of the user experience. Hence, in Section 3, we discuss the literature related to the distinct impacts of dissimilarities’ types, with a focus on interaction and sense of embodiment. Moreover, as aforementioned dissimilar avatars can find applications in various areas. Therefore, in Section 4 we attempt to centralize knowledge related to dissimilar avatars utilization, by surveying their different fields of applications. Finally, knowledge regarding dissimilar avatars is still limited as compared to the numerous questions that it raises. Hence, we capitalize and discuss in Section 5 different gaps existing in the literature that would benefit further research attention. This last section particularly aims at providing a better awareness of existing challenges regarding dissimilar avatars’ usages, as well as to anticipate their potential negative repercussions.

## 2 CHARACTERIZING DISSIMILAR AVATARS

In this section, we aim at providing a comprehensive methodology to characterize dissimilar avatars. The objective is to improve the clarity of dissimilar avatars descriptions, and to provide keys to classify a

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set of different avatars, as well as a common framework for dissimilar avatars studies reports, inter-studies discussions, and elaboration of new theories. Interestingly, it is worth noting that while we are discussing dissimilar avatars, our work also indirectly addresses the notion of similarity which is its direct counterpart.

While in some cases one might want to define an avatar in a detailed and unambiguous manner, in other circumstances it might be preferable to describe the overall avatar appearance and its variety of specificity concisely and comprehensively. Considering that these two objectives present conflicting requirements, they can not be tackled with a single common approach. In order to address these two distinct needs, we present two approaches to characterize dissimilar avatars, and discuss their distinct specificities. More specifically, we propose (i) an *atomic characterization* approach based on an original dissimilarity taxonomy, enabling unambiguous and exhaustive descriptions, along with (ii) a *holistic characterization* approach using conceptual notions to provide concise and comprehensive characterizations.

## 2.1 Atomic Characterization of Dissimilar Avatars

An atomic characterization of a dissimilar avatar can be seen as a comprehensive set of dissimilarities applied to the user's real body. This methodology allows to extract an objective, unambiguous and exhaustive dissimilar avatar characterization. Atomic characterizations can be useful for uncovering specific challenges that may arise from each avatar's dissimilarity independently, to recreate a dissimilar avatar unambiguously, and to generate an exhaustive set of design possibilities.

To support atomic characterization methodology, we present here an original and extensive taxonomy of such dissimilarities, illustrated in Figure 2.1. More specifically, we divide dissimilarities between three main atomic classes, whether they are modifying the avatar structure, volume or its superficial aspect.

### 2.1.1 Structural Dissimilarities

The structure refers to the kinematic chain's organization i.e., the counterpart of the user's bone structure. It defines limb organization, but also the range of postures that an avatar can take (which is different to the movement mapping, defining how a user's real body pose is translated into the avatar's pose). More specifically, we define the structure as a set of joints whose positions can be interconnected (but not necessarily) and which present predefined rotation limitations for each joint, via their degrees of freedom (DOF, the different directions in which a joint can be rotated) and maximum rotation amplitudes. To facilitate the discussion we will also employ the term "limb", referring here to a set of one or more inter-connected joints. Specifically, structural dissimilarities encompass:

- *Structural Reportion*: a modification wherein the distance between connected joints is modified. This dissimilarity can alter the avatar proportion uniformly [1, 11], or non-uniformly by impacting distinctly different body parts, for example by extending an arm only [51]).
- *Articulation Extension*: a dissimilarity where a joint rotation limitation is extended, either by increasing its DOF or maximum rotation amplitudes. Such dissimilarity allows impossible postures, such as directing arms backward [39], or spreading fingers in an unrealistic manner [82].
- *Limbs Reorganization*: the repositioning of a limb on the avatar structure. Specifically, it is achieved by breaking a connection between the set of joints and the rest of the structure, which is either reconnected to another joint (*reconnection* dissimilarity), or kept detached, creating a disconnected avatar structure (*disconnection* dissimilarity).
- *Limbs number alteration*: a modification of the limbs number. It encompasses two main categories, *limb addition* and *limb subtraction*. *Limb addition* consists in integrating a new limb to the structure [57], either by attaching it to a joint of the avatar structure [43] or by incorporating it inside a connected joints'

chain [109]. This dissimilarity is sometimes referred to in the literature as *supernumerary limbs*. The integrated set of joints can present a human body-part structure (e.g. an additional finger [43]) or a non-human one (e.g. a tail [107] or wings [85]). *Limb subtraction* symmetrically refers to dissimilarities where a limb is removed from the structure (e.g. by removing fingers [100]). If the limb was positioned in the middle of a joint's chain, the detached parts are reattached.

### 2.1.2 Volume Dissimilarities

The volume is the shape of the avatar (i.e. its mesh). The entire volume can be connected, or more rarely, be made of a set of disconnected sub-parts. The avatar volume is bounded to the structure through a "skinning", defining deformations applied to the volume to follow the avatar structure movements [60]. More specifically, volume dissimilarities encompass:

- *Distortion*: a shape alteration of a continuous part of the volume. A distortion can alter the volume proportions, in this case, we can speak about a *proportional distortion*, which can for example generate avatars with enlarged hips [98] or belly [80]). Furthermore, when the distortion goes beyond the simple proportion change giving it a completely new shape (e.g. the shape of a tool [88] or of an animal feature [76]), we call it a *remodeling distortion*.
- *Detachment*: separation of a continuous part of the volume into two noncontinuous parts [5, 41]. Note that this transformation does not imply an alteration of the joint connection within the avatar structure, i.e. the relation between two discontinuous parts through the kinematic chain is maintained.

### 2.1.3 Superficial Aspect Dissimilarities

The superficial aspect refers to features that are positioned on top of the avatar volume, either the visual material property or the attire. Hence, they encompass:

- *Material Change*: alteration of any aspect of the avatar material, i.e. colors, patterns, or transparency. Material changes can result in an avatar keeping a human appearance, for example by changing its skin tone [87], or alternatively to generate a non-human appearance, through for example an alien or a robotic texture [63]. Furthermore, it can also be used to display symbolic information, such as an interface [18].
- *Attire Change*: variation of the avatar clothes or accessories from what the user actually wears [69].

### 2.1.4 Atomic Dissimilarities Interdependence

To conclude this discussion regarding atomic characterization, we would like to mention that alterations of the three main atomic classes often come hand in hand, following a semi-dependent hierarchy. Indeed, an alteration of the avatar structure often induces a volume change, for example removing a finger's joints from the structure will most likely come along a removal of the corresponding volume. Similarly, a volume alteration generates a change in the superficial aspect, as for example the enlargement of the volume proportion requires assigning it a texture, and enlarging the attire accordingly. Hence, in order to simplify later discussions, when a given dissimilarity engenders other groups' dissimilarities, we refer to the overall change as belonging to the dissimilarity group with the deepest impact on the avatar, according to the following hierarchical order: structure, volume, and superficial aspect dissimilarities.

## 2.2 Holistic Characterization of Dissimilar Avatars

While an atomic characterization can provide an exhaustive and non-ambiguous description of an avatar, this approach might turn out to be arduous for complex avatars, and does not allow to hold comparisons between avatars presenting distinct atomic dissimilarities. Moreover, an atomic description might fail to capture subjective qualities elicited

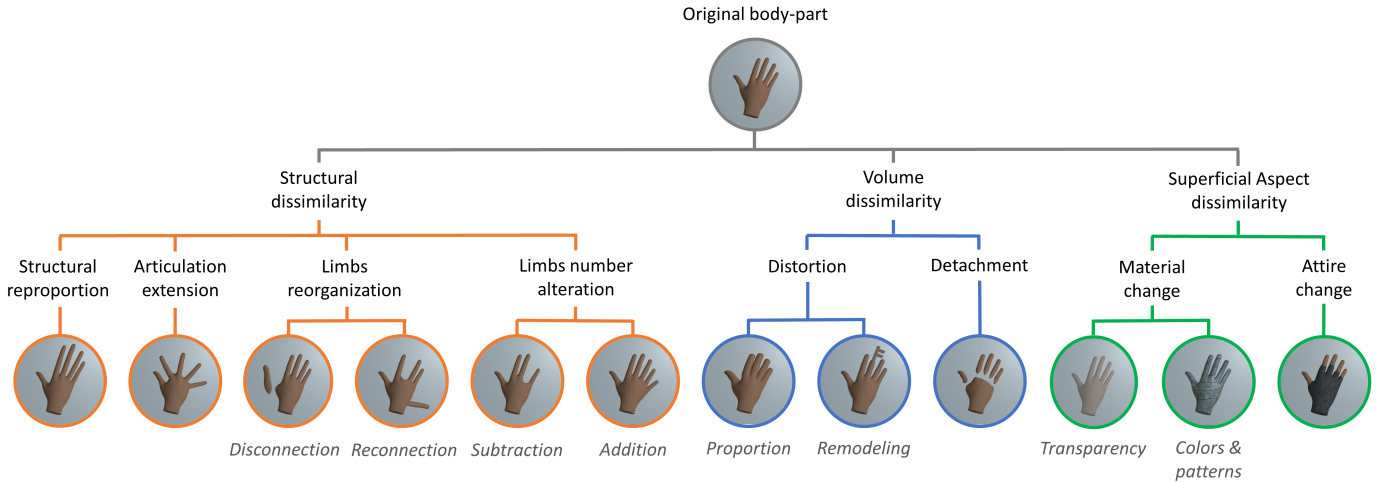


Fig. 1. Visual representation of the presented atomic taxonomy applied to a virtual hand.

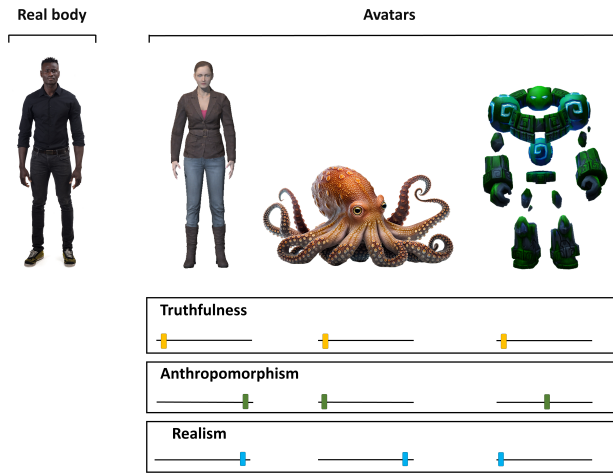


Fig. 2. Illustration of a real user body (left), and three different avatars (right), along with distinct subjective characterizations for each of the avatars, based on: “truthfulness”, “anthropomorphism” and “realism”.

by the avatar to the users, which can have a major impact on the user experience [69]. Therefore, we also need tools that can characterize avatars of any kind as a whole, putting any sets of atomic dissimilarities on the same subjective scale without extracting this set exhaustively. Such requirements can be fulfilled by using conceptual notions, e.g. “cartoonism”, “organicness” or “scariness”. For example, one can quickly provide a subjective ranking of avatars in Figure 3 based on their level of cartoonism, without considering individually each of their specific atomic dissimilarities. We refer to such characterization approach as a holistic characterization. Holistic characterizations are established from subjective criteria. Indeed, while we can often reach an overall shared sense of an avatar degree of organicness, there is no objective criteria to define for example the relative level of organicness generated by a metallic texture as compared to a cubic avatar volume. Moreover, an avatar’s holistic characterization can be altered by the context in which it is presented. For example, the sense of an avatar “self-similarity” (also named truthfulness) can be altered by how the user visually attend the avatar [120]. Hence, given its subjective nature a holistic description can be seen as a probability for a given avatar to be associated with the target concept, which is similar to some previous descriptions of subjective concepts in VR [105].

Considering the abstract nature of holistic characterization, they are also more subject to be associated with diverging definitions among

studies. Definition divergences might be due to a same notion being perceived in different ways, or to an extensively broad notion being used to refer to solely one of its specific features. For example *anthropomorphism* might often be used to refer to either *appearance anthropomorphism* or *animation anthropomorphism*, which are two distinct characteristics that when confounded, can lead to readers’ wrong interpretations and over-generalization. Hence, we would recommend to precisely define conceptual notions when using them, and especially to avoid using exaggeratedly wide notions. In that sense, in order to clarify notions that will be used in the rest of the paper, and hopefully push for the adoption of common definitions among studies, we gather and specify here the definition of three widely used notions, previously presented by Garau [34] (also showcased on specific examples in 2.2):

- *Anthropomorphism* is the perception or assignment of human traits or qualities [81]. Specifically, in this paper we will use the notion of *appearance anthropomorphism*, which is the extent of human traits that are found in the avatar appearance [81].
- *Realism* is the perception that something could realistically or possibly exist in a non-mediated context [17]. Furthermore, we mostly refer in this paper to *appearance realism*, i.e. how much an object’s appearance is perceived to be plausible in the real world.
- *Truthfulness* is the extend to which an avatar is perceived to resemble the user [34]. Again, it can be further specified to *appearance truthfulness*, referring to the extent of visual features shared between the user and the avatar.

Naturally, similarly to how each of these notions can be specifically centered on the avatar’s appearance, they can be further specified by centering them on either the structure, volume or superficial aspect of the avatar.

### 3 AVATAR DISSIMILARITIES IMPACT ON THE USER EXPERIENCE

Mismatches generated by dissimilar avatars between real and virtual appearance may directly influence the user experience at diverse levels. In this section we propose a review of previous research exploring the impact of dissimilar avatars on the user experience, supported by the characterization methodologies presented in Section 2. In particular, we focus here on the impact of two fundamental aspects of user experience, (i) the user’s capacity to interact with the VE, and (ii) the sense of embodiment (i.e. the perception of being embodied in the avatar).

### 3.1 Impact of Dissimilar Avatars on Interactions with the Virtual Environment

Most VR interactions require at some point the user to move and to enter in contact with other elements of the VE. However, avatar dissimilarities may impact the quality of these two “elementary” interactions, and consequently, all interactions build upon them. Hence, in this section we discuss the impact of dissimilarities on motor control, and visuo-haptic contact coherence.

#### 3.1.1 Impact of Dissimilar Avatars On Motor Control

Structural dissimilarities involving either an articulation extension or an alteration of limb number, necessitate to re-design the virtual movement mapping, as they prevent a direct mapping between real and virtual joint rotations and position. The remapping options depend on the type of atomic dissimilarity. To begin with, after a limb subtraction the remapping can be simply addressed by keeping unmatched the real joints whose virtual counterparts have been removed [100]. Furthermore, an articulation range extension can be addressed by redefining the transfer function between the real and the virtual joint rotations [39, 82]. However, in the case of DOF extensions or limb additions, the overall DOF is higher in the avatar structure as compared to the real body, preventing the possibility to implement an injective mapping between real and virtual movements. We can extract at least three different strategies to control the additional DOFs, based on analogous reflections in the field of robotic [24]. First, a *transfer control* maps the additional DOFs to other real limbs DOFs [32, 43, 57], the remapping can lead one DOF of the real body to control several virtual DOFs (e.g., the movement of one single real hand is mapped to several virtual hands’ movement [99]). The second strategy, *augmentation control*, consists in mapping additional DOFs to user’s inputs other than their movements, such as their voice [116], or neural signals [89]. Finally, *autonomous controls* consists in mapping additional DOFs to externally-generated inputs e.g., algorithms [32], or other users’ actions [109]

#### 3.1.2 Impact of Dissimilar Avatars on Visuo-haptic Contact Coherence

The incorporation of a volume or structural dissimilarity generates a risk of visuo-haptic mismatch (i.e., a misalignment between the visual information and the tactile sensation), which can hinder interaction performance [56] or virtual body perception [14]. This issue can be addressed using movement retargeting algorithms, consisting in dynamically repositioning the virtual body in order to align real and virtual points of contact [19]. However, to the best of our knowledge, no algorithm have been proposed to satisfy complex interactions involving multiple contact points. Moreover, previous results indicate that the quality of the tactile interaction engendered by this technique might depend on the type of avatar dissimilarity [19]. As a result, most studies proposing visuo-tactile stimulation towards avatars whose volume varies sharply from the user’s body, require constrained setups (e.g., by asking the user to keep the stimulated limb still [51, 80] and/or by generating the contacts externally following a controlled pattern [43, 51]).

Another solution is to artificially provide tactile contact information, dynamically adapting to the virtual contact. The tactile contact information can be either provided through a haptic device [21, 25], or communicated through other sensory channels (i.e. pseudo-haptic), for example via visual information [94]. However, to this day these techniques are still far from providing levels of realism, details and variety of tactile information comparable to a real-world tactile interaction.

### 3.2 Impact of Dissimilar Avatars on the Sense of Embodiment

When users embody an avatar in VR, it raises questions regarding how it is perceived, and especially how much it is felt to be one’s own body. Such sensation has been broadly studied in the literature, and is referred to as the *sense of embodiment* [50]. The sense of embodiment is usually subdivided in to three sub-components, the senses of self-location, agency and ownership. These perceptual elements have been found to impact the user experience in diverse ways, such as the feeling of being present in the VE [100], the perception of the

environment [11], behaviors inside and outside the VE [23, 98], task performances [5, 25] or cognitive load [73]. Hence, we present here a discussion based on previous results reported in the literature for different avatar’s dissimilarity types, regarding the sense of embodiment. While we intend to discuss impacts of specific dissimilarity types, this section does not provide a strict systematic per-type comparison, due to the lack of detailed systematic comparison in the literature, and in order to avoid over-generalizing results that might also depend on other factors (e.g. task [31], control mapping [32, 57], or dissimilarity scale [51]). Furthermore, it is worth mentioning that the different sub-components of the sense of embodiment are often tightly interconnected [38], i.e. any factor impacting one sub-component will often indirectly impact other sub-components. Hence, in this section we focus on findings presenting rationales that a given factor could impact a perceptual component (i.e. stronger quantitative impact or fitting to theoretical models), even if we understand that some findings might be subject to different interpretation s.

#### 3.2.1 Impact of Dissimilar Avatars on the Sense of Self-location

The sense of self-location can be defined as the space in which one perceives to be located [5]. Self-location can be measured subjectively via questionnaires, or objectively by measuring the adaptation of users’ movements to where they feel to be located [83, 98], referred to as “*proprioceptive drift*”. Eliciting a strong sense of self-location facilitate the capability to interact within a VE, as it results in colocalizing the virtual and perceived body position. To begin with, previous studies reported comparable levels of subjective self-location elicited by non-anthropomorphic and anthropomorphic avatar materials [63], which is coherent with the fact that these dissimilarities preserve the alignment between the real and virtual body-volumes in space. However, even when this alignment is preserved, it was found that the appearance truthfulness might improve the subjective sense of self-location [28]. In addition, when a position-mismatch exists between the virtual and real bodies, it was reported that material realism could improve the sense of self-location measured by proprioceptive drift [83]. Furthermore, the sense of self-location might decrease when an avatar presents dissimilarities in terms of volume [80] or structure [103, 126], which can be explained by the misalignment generated between the real and virtual bodies’ volumes. However, in these cases it was found that the sense of self-location could be improved by providing congruent visuo-tactile stimulation. For example, different studies reported an improvement of the sense of self-location using this technique on avatars presenting volume dissimilarities such as a larger belly [80], or structural proportion changes, for example a three times extended arm [51]. A study conducted in augmented reality even reported that congruent visuo-tactile stimulation of an additional hand could increase the participants’ sensation that one of their hand was located at two different positions [96]).

#### 3.2.2 Impact of Dissimilar Avatars on the Sense of Agency

The sense of agency can be described as “the subjective feeling of controlling one’s own actions, and through them, external events” [118] (page 1). Agency can improve motor learning, action preference, and visual attention [118]. To begin with, several studies reported comparable levels of agency between avatars with and without external aspects dissimilarities [16, 63, 69, 83], which is understandable considering that such dissimilarities do not alter the movement mapping. Regarding volume dissimilarities, studies also reported comparable levels of agency when no tactile feedback is involved [63, 126]. On the other hand, when a volume dissimilarity disrupts the visuo-haptic coherence as described in Section 3.1.2, it was found to decrease the sense of agency [14]. However, while to our knowledge no study has tested the sense of agency generated by retargeting algorithms in a dissimilar avatar embodiment context, in a non-dissimilar embodiment context, it has been shown that such algorithm can be implemented and support tactile sensations without significantly altering the sense of agency [27]. Finally, structural dissimilarities, which disrupt the mapping between users’ motor control and avatars’ movements, have

been reported to decrease the level of agency [63, 126]. In contrast, several studies also reported that diverse structural dissimilarities could elicit levels of agency comparable to avatars without structural dissimilarities [5, 43, 55]. Such results were obtained with avatars either presenting dissimilarities in terms of: structural proportions (e.g. a longer fingers [19]), limbs addition (e.g. an additional finger [43] or a robotic arm [32]), or limbs reduction (e.g. a hand reduced to a sphere [5], or virtual hands only without a virtual body [103]). It was even found that presenting a drastically dissimilar avatar structure reduced to a sphere-shape hand could increase the level of agency [5], which was hypothesized to result from a lower expectation of fine correlation between real movements and virtual animations. Together, these last results are in line with the *homonculus flexibility theory* [121], stating that one is “capable of adapting to novel bodies, in particular bodies that have extra appendages or appendages capable of atypical movements” [121](page 1).

However, beyond dissimilarities, the agency elicited towards a dissimilar avatar is affected by other factors that are equally worth considering. First, different control mappings applied to an identical structurally dissimilar avatars can significantly impact the sense of agency [32, 57]. Moreover, it was found that disrupting body movements in a way that leverage s task performance could improve the level of agency [44]. Hence, we can hypothesize that the dissimilarity’s appropriateness to a task positively impacts the level of agency. This might explain the aforementioned result reporting a higher level of agency elicited by a sphere-shape hand avatar as compared to a highly anthropomorphic hand with finer controls, in a context where the sphere-shape enables and possibly even simplifies the task completion [5].

### 3.2.3 Impact of Dissimilar Avatars on the Sense of Body Ownership

The sense of body ownership can be described as the sensation of appropriation one tends to feel towards its own body [51], which can be transmitted to an avatars [124]. The elicitation of a sense of body ownership towards an avatar generally requires the application of congruent sensory information towards the real and the virtual bodies, commonly visual and tactile (visuo-tactile correlation [51, 108]), or visual and motor (visuo-motor correlation [64, 103]). The application of such sensory correlation can elicit a sense of body ownership towards avatars showing different types of dissimilarities: superficial aspect (material [16, 83, 87] or attire [69]), volume [80], or structure (whether it is structural proportion [51], limb addition [43] or limb subtraction [65]). However, several studies also report that the type of dissimilarity remains an important factor impacting the sense of body ownership [5, 19, 63, 126]. Specifically, it was reported that structural dissimilarities have a stronger negative impact on the sense of body ownership than volume dissimilarities [5, 19, 63, 126], and that volume dissimilarities have a stronger negative impact than material dissimilarities [5, 63, 126]. Furthermore, it was found that an increased appearance truthfulness tends to improve the sense of body ownership [28, 46]. However, surprisingly several studies reported that a decreased level of volume and material anthropomorphism could positively impact the sense of body ownership [46, 66]. This latter finding was hypothesized to be due to the *uncanny valley effect* [75], a phenomenon wherein a robot or an avatar reaching a high level of anthropomorphism without perfectly reaching it creates a feeling of rejection and eeriness.

## 4 APPLICATIONS OF DISSIMILAR AVATARS

This section proposes an overview of diverse fields of application of dissimilar avatars in VR. To begin with, we discuss how dissimilar avatars can be employed as an user interface, either as an input through augmented interactions, or as an output by utilizing it as a display. Then, we discuss indirect outcomes that can result from dissimilar avatars embodiment, either by inducing perceptual and behavioral changes, or by solving stimuli incoherence in the VE. Finally, we expand our discussion to social VR applications and present different motives for using dissimilar avatars to create a virtual identity.

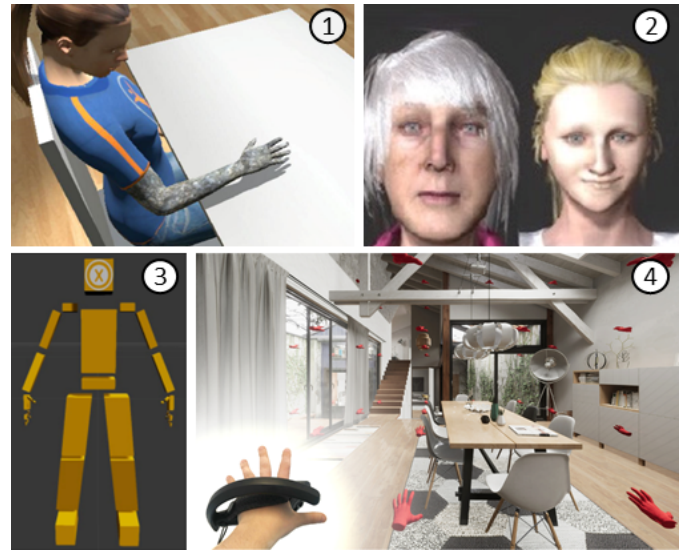


Fig. 3. Examples of dissimilarities applications for (1) altering user’s perception and behavior [16], (2) displaying a younger version of the user’s self (the altered version in on the right side) [7], (3) reducing the expectation of realistic behaviors by reducing appearance realism [66], (4) increasing users grasping speed, by increasing the user hands number [99].

### 4.1 Augmenting Users Interaction Abilities

Interaction techniques are at the core of most of VR applications, they define the influence that a user can have on the VE and impact both objective (e.g., performance [5, 72] or cognitive load [99]) and subjective (i.e., embodiment [1] or hedonic qualities [55, 88]) aspects of the user experience. *Gesture based direct manipulation* is a class of interaction allowing users to interact with the VE in a similar way that they would do in the real-world, for example using hand gestures to grasp objects [5, 94], or walking [1] in order to navigate in the VE. This type of interaction takes advantage of different real-world based knowledge [45], improving their discoverability and learnability, as well as the subjective experience (e.g. embodiment [1] or hedonic qualities [88]). However, the alignment with real world interaction also limits such interaction to go beyond human capabilities and to improve other qualities, such as expressive power, efficiency, versatility, ergonomics, accessibility or practicality [45].

Here, we present the applications of avatar dissimilarities as an alternative to tackle real-world interaction limitations, while preserving most of the advantages of gesture-based direct manipulations. Indeed, dissimilar avatars naturally open the possibility to go beyond the user’s body limitations. For example, the GoGo interaction technique allows users to expend their arm’s length, allowing them to reach far objects [93]). On another hand, compared to abstract interaction techniques (e.g. arbitrary controller inputs), using dissimilar avatars allows to preserve a relative level of behavior fidelity (defined by Bowman et al., as “the degree with which the actions [...] used for a task in the UI correspond to the actions used for that task in the real world” [15]). For example, regarding the aforementioned GoGo technique, despite the control of the arm elongation, actions used to grab an object or press a distant button with this technique, correspond to actions used for these tasks in the real world. This relative preservation of the behavior fidelity may allow to preserve, at least partly, the aforementioned advantages of real-world-based interactions.

Beyond improving interactions’ performance inside the VE, other benefits of dissimilar avatars’ based interactions can be considered. For example, offering users novel interaction abilities that they can not experience in the real world (e.g., supernatural, or animal-specific interaction) can be a source of entertainment by itself and lead to enjoyment and interest [55]. In addition, altering interactive abilities

may also be utilized to explicitly experience specific body conditions. This usage can be useful to reveal accessibility issues, for example child reachability limitations in a given room setup [11]. They might also be employed to support movie acting, by permitting actors to be embodied as the character or creature that they have to play [49].

To illustrate the different ways dissimilar avatars can be used to enrich user interactions, we provide examples divided between two categories: dissimilarities *enhancing natural interactions*, and dissimilarities *offering novel interaction means*.

#### 4.1.1 Dissimilarities Enhancing Natural Interactions

In this section we describe avatar dissimilarities aiming at enhancing interaction capabilities that are already naturally available to the user (i.e.: walking, reaching and manipulating objects, observing the environment, etc.) by overcoming their inherent limitations (i.e., walking speed, reaching range, blind spots, etc.). To this day, the major body of research related to dissimilar avatars applications for enhancing natural interactions focuses on improving users' natural reaching capabilities, by focusing on on hands and arm dissimilarities. For example, expanding the user's reach in the VE can be achieved by increasing the avatar's arm length [72, 93]. Other studies proposed to increase the number of virtual objects one can reach at the same time by incorporating an additional arm to the avatar structure [57], or by increasing fingers articulations' range [82]. Furthermore, providing users with a large number of hands covering a large portion of the environment (illustrated in Figure 3.4) decreases the distance to any targets and hence the reaching movement duration [99]. Apart from improving the reaching capability, dissimilar avatars can also increase one's displacement speed and provide different viewpoints by altering the avatar's height [1]. Furthermore, changing the avatar's texture by making it partially transparent, gives visibility to objects behind them, and can improve manipulation tasks' performance [115]. Finally, past research explored the possibility to incorporate two additional arms to the user's body to improve gestural communication [113].

#### 4.1.2 Dissimilarities Providing Novel Interaction Means

We refer here to dissimilar avatars providing users with interaction means different from what their original body can provide. For example, the incorporation of tools to the avatar [88] confers to the user novel interaction means that can not be carried with a bare non-altered avatar, such as cutting paper or playing a musical instrument. This later example is an alternative to hand holding virtual tools in VR, which, while being more realistic, may not provide the real-world fine controls due to the absence of haptic feedback [88]. Another option for increasing interaction means is to directly augment the avatar with graphical user interface elements, such as buttons [26], or color palette and canvas [128]. Furthermore, the mental models one owns of animal capabilities offers a set of intuitive controls that can be provided to the users [55], for example flying by flapping incorporated wings [123] or cutting objects with claws [55]. Previous research also explored the possibility to collaborate on the same task from the same body perspective [109], by embodying an avatar presenting a supernumerary arm and providing shared control between two users.

Finally, while we mostly considered here the novel interaction means in terms of non-human abilities, dissimilar avatars can also be employed to virtually restore a missing limb. Such virtual limb restoration can be utilized to improve the efficiency of prosthesis control training [95].

## 4.2 Using the Avatar as an Information Display

Many works have explored the use of the real body as an information display in non-immersive contexts using projection systems [42]. Displaying information on-body makes it easily accessible, and allows to draw clear connections between an information and the specific body part on which it is displayed [42, 94]. VR offers an opportunity to further exploit this concept as it can reliably display 2D information on the avatar texture, or display 3D information through volume modification. For example, the avatar can be used to visually display the user's biosignals, which usually can not be perceived, such as heart rate [13, 59], skin conductance response [13, 59], or brain signals [74]).

These signals can be useful to augment self and inter-users' awareness, regarding their emotions or physical state (e.g. tiredness or attention). Furthermore, dissimilar avatars can be used to increase inter-user communication by leveraging information conveyed through facial expressions. For example, it was shown that giving a cartoon shape aspect to a virtual character could increase the intensity of its expression [125]. Also, allowing users to select non-isomorphic facial expressions opens the possibility to communicate a rich set of non-realistic facial expressions [9], similarly to emojis. Visual information displayed on dissimilar avatars can also be used to replace sensory information that cannot be generated. For example, fingers' color can change to inform about a contact with a virtual object when the setup cannot simulate the appropriate contact forces [94]. Finally, displayed information can even turn the avatar into a deformable screen (via body movements) displaying games or videos [18].

## 4.3 Altering Users' Perception and Behavior

In the real world, one's appearance can be an essential vector of implicit information, influencing perception and behaviors [2]. Likewise, in VR various research has shown that altering users' avatars could affect their perception and behaviors at various levels [16, 87, 122]. Hence, in this section we discuss such behavioral and perceptive impacts, through the *Proteus effect* and *virtual reality perspective taking* phenomena, along with the alteration of *stimuli*, and *affordance* perception.

### 4.3.1 The Proteus Effect

The utilization of dissimilar avatars to alter the user's perception and behavior is well illustrated by the *Proteus effect* [122], "*a phenomenon whereby a user of a virtual environment temporarily adopts attitudes and behaviours that are consistent with stereotypes associated with the appearance of their avatar*" [21](page 1). For example, Yee and Bailenson found that being embodied in a taller avatar can alter the user's confidence in a negotiation task, and that the avatar attractiveness could alter intimate behaviors [122]. Among others, it was also shown that being embodied inside an avatar seen as creative improved ideas' fluency and originality inside and outside the VE [37]; that an opposite gender's avatar could alter gender-stereotypical beliefs about one's own personality [108], and that being presented with a more muscular avatar could increase the number of repetitions in a weightlifting exercise [23]. Peck et al. also found that the Proteus effect could be used to alleviate *stereotype threats* [86], a phenomenon wherein one feels at risk to confirm a stereotype about her/his social group, which might lead to cognitive underperformance [106]. Indeed, results showed that the negative effect of a woman being presented to the stereotype threat "*women show less performance than male in maths*", would be eliminated when embodied in a male avatar [86].

Nevertheless, it is worth mentioning that applications of the Proteus effect should be considered with caution. Indeed, Clark noted that VR designers willing to avoid the negative impacts of the Proteus effect might be tempted to reduce customization options of certain groups suffering stereotype biases. This well-meant decision would however reduce the user's capability to represent and express themselves in the VE [21]. Instead, Clark promotes to use Proteus effect as a measurement of stereotype bias, in order to evaluate methods aiming at reducing or eliminating them [21].

### 4.3.2 Virtual Reality Perspective Taking

To answer the aforementioned need to eliminate stereotype bias, Virtual Reality Perspective Taking (VRPT) embodies participants inside an avatar belonging to a group different than their own, which has been proved to reduce stereotypes and lead to altruistic behaviors towards the embodied group. Perspective taking phenomena (whether it takes place in VR or not) was introduced by Galinsky and Moskowitz, and explained by the overlap between the representation of the self and of the out-group [33]. In VR, it was for example found that being embodied in a dark-skinned avatar decreases implicit racial bias carried by light-skin caucasian people [87], which effect was later proved to still be present one week after experiencing the embodiment [12]. It was also found that a group of domestic violence offenders experiencing a

harassment scenario in VR from the point of view of the victim would show a decrease of stereotypical gender bias in fear recognition [101]. Moreover, taking the perspective of a person becoming homeless in VR, can increase empathy and positive attitudes towards homeless people, and increase the willingness to sign a petition supporting them [40]. These effects were reported to be present even eight weeks after the exposure [40]. Beyond altering attitudes towards a group of people, Ahn et al. also found that being embodied into an animal increases the feeling of interconnection between the self and nature, as well as the perception of environmental risks [3]. These effects were still present one week after the immersion [3].

However, it has to be mentioned that VRPT-based manipulations should be considered carefully, as they also can lead to negative outcomes. For example, previous research found that implicit gender bias would be increased when users are presented with a scenario where the outer-group is negatively stereotyped [64].

### 4.3.3 Altering the Perception of Stimuli

Beyond attitudinal and behavioral alterations, avatars' dissimilarities can also impact how users perceive stimuli whether they originate from the VE or the self. Regarding VE-originated stimuli, it was shown for example that the fear of height in a VE could be altered when presented to an avatar which seems to be less subject to suffer a fall, such as a bird [85] or a tough robot avatar [67]. Lowering threat perception through avatar dissimilarities can also alter biological responses accordingly. For example, lowering an avatar appearance anthropomorphism and realism can reduce skin galvanic responses when presented with a threat [5]. In addition to the perception of physical threats, it was shown that the anxiety engendered by a public speaking task in VR could be alleviated by decreasing the avatar's appearance truthfulness [6].

Avatar dissimilarities can also be employed to alter internally generated stimuli. For example, it was reported that pain sensations could be alleviated by altering the skin color [70], transparency [71], and body size [71]. Furthermore, restoring a missing limb was reported to alleviate phantom limb pains, a pain emerging from a limb which has been lost [22]. Beyond pain alteration, it was shown that being presented in an athletic body during a cycling task could decrease the perception of exertion and heart rate [52], and being presented with longer legs could increase the user speed perception during a displacement, as well as the perceived time needed to reach an object [112]. Moreover, it was found that modifying the avatar material could accordingly impact various internal sensations, and accordingly behavioral and biological responses. For example, being embodied with a magma-texture's hand was shown to increase the perceived temperature and decrease the actual hand temperature as compared to an ice texture's hand [53]. Furthermore, a stone-texture (illustrated in Figure 3.1) was reported to increase the sensation of arm heaviness, coldness and stiffness, and accordingly to elicit faster movement initiations as an adaptation to the heaviness sensation [16]. On another note, dissimilar avatars were also shown to alter the perception of the self at different levels. For example, embodying an avatar showing a different body size can alter users' weight or body size estimation [80, 90], and accordingly eating behaviors [110]. These later effects are promising as a treatment for eating disorders [91]. In another vein, it was shown that being presented with a low-realism avatar represented as an energetic essence merging with other users' avatars, would elicit sensations of ego dissolution and connectedness with others, at a level comparable to psychedelic drugs [35].

### 4.3.4 Altering the Perception of Affordances

*Affordances* describe action possibilities offered by any object [78], which can be communicated to the user via perceptual cues called signifiers [79]. Seinfeld et al. proposed that the avatar appearance could be used as a signifier of the interaction afforded by the avatar [102]. We discuss here examples where avatar's dissimilarities alter the user's perception of avatar affordances. For example, it was reported that when presented with an avatar whose hands were replaced by different tools, participants would rely exclusively on the objects self-revealing

affordances to remember the associated interaction [88]. Moreover, such signifiers can implicitly alter how users choose to interact in the VE. For example, it was found that in an object-picking task, directional cues displayed on the avatar would impact objects grabbing position [48]. Furthermore, a study reported that in a scenario where avatar hands afford blocking virtual cannons' projectiles, this capability was significantly more utilized when participants were embodied in a tough alien-looking avatar, as compared to a bare-handed anthropomorphic avatar [20]. This finding can be hypothesized to result from the tougher non-anthropomorphic hand, implicitly conveying more affordances to resist a cannon's projectile as compared to a bare anthropomorphic hand. Beyond signifying an avatar's affordances that the real body does not afford, dissimilar avatars can also be employed to signify the absence of an avatar's affordance that the real body would actually afford. Indeed, as stated by Alkemade et al., "*a model of a physical hand can [...] be confusing if it does not support the perceived affordance*" [4] (page 14). Hence, when a given real-world interaction cannot be afforded in the VE, presenting users with a dissimilar avatar that does not seem to afford the given interaction can help reducing the user expectation of such affordance [5]. Furthermore, it was found that in a picking task, the action planning duration of the picking action was reduced when embodied with a capsule-shaped hand, as compared to an anthropomorphic hand. This result was hypothesized to result from a reduction of the available actions' panel [47].

## 4.4 Solving Stimuli Incoherence

The concept of *coherence* in VR was defined by Skarbez as "*the degree to which the virtual scenario behaves in a reasonable or predictable way*" [104]. Coherence is considered to increase various qualia of the VR experience [58, 104]. For example, Latoschick and Wienrich [58] recently proposed a theoretical model where coherence (renamed congruence in their model) is the crucial component to the elicitation of plausibility, in turn contributing to various other qualia, including presence, copresence or virtual body ownership.

In this section, we discuss cases where a dissimilar avatar can be employed to "resolve" incoherence, by establishing consistency between the avatar and other elements, whether they are real or virtual. To begin with, dissimilar avatars can be powerful tools to resolve *sensory incoherence* between the visual information and other senses. For example, visuo-tactile incoherence often results from a lack of technical solutions to generate tactile feedback at the appropriate position. In order to maintain coherence between virtual and real contact, it was proposed to provide the user with an arm that would disconnect and reach distant areas through a portal. This dissimilar avatar allows to match the visual contact of a far object, with the tactile contact sensation provided by a close real object [10]. Another issue commonly encountered in VR, is the position and movements incoherence between the avatar's and actual limbs. This incoherence mostly arises when a standard VR system, with tracking commonly restricted to the user's head and hands positions, is used with a full body avatar, resulting in displaying many non-tracked body-parts. To tackle the limited motion tracking, one common strategy is to subtract non-tracked limbs from the avatar structure, such as legs, elbows or facial expressions [41, 117]. Such strategy has been proved to increase the sense of presence [41], performance [117] and workload [117]. Beyond sensory incoherence, dissimilar avatars can play a role in mitigating *semantic incoherence*, for example by presenting an avatar's appearance matching with the VE [68]. Indeed, it was reported that avatars wearing clothes matching the VE, i.e. a suit in an office environment, or sports outfits in a gym environment, would increase the perceived avatar plausibility as compared to an incoherent avatar/environment association [69]. Moreover, as mentioned in Section 3.2.2, simplifying the avatar's structure may enable it to hide incoherence arising from real detailed movements that can not be tracked, hence increasing the sense of agency [5]. In addition, as mentioned in Section 3.2.3 decreasing the avatar realism can increase the sense of body ownership [46, 66] (illustrated in Figure 3.3), as it permits to avoid falling into the *uncanny valley* [75]. This result can be attributed to the resolution of incoherence between the expectation of real-world-like appearance and behaviors, elicited by



a quasi-realistic avatar, and the actual avatar which does not present these realistic characteristics.

As a final note, it is important to notice that the user perception of coherence is not necessarily based on pragmatic rules. This might even more be the case when embodying a low-realism avatar, where expectations can not be based on prior real-world experiences. This was illustrated by a study presenting users with either nine times smaller or nine times taller avatars. In this situation, as participants' expectations of objects' behavior when interacting with them could not be based on their previous experiences, participants' perception of coherence deviated from the actual physical laws and was inconsistent between smaller and taller avatars' conditions [92]. This last remark warns on the non-triviality of generating a sensation of coherence in non-realistic scenarios, and on the necessity to validate design by users' feedback.

## 4.5 Creating a Virtual Identity

In the real world, people tend to adapt their displayed identity to social settings, arising from concerns of how they will be perceived by others [36]. In VR, the malleability of users' virtual appearance gives them increased flexibility regarding how they can create and craft their virtual identity [30]. While the available options are different, the reason one might want to modify his displayed identity can be very similar to real world motives [30]. For example, interviews conducted with users of social virtual environments reported that the choice of avatar's appearance might be motivated by: aestheticism, giving a positive image of themselves, showing visually a facet of their identity, adapting to a social context, standing out, or reversely indicating their affiliation with a group [7, 30, 61]. Moreover, dissimilar avatars offer users the possibility to hide aspects of themselves that they do not want to disclose, such as their genders [30], disabilities [127] or age [7]. Users can take advantage of it to avoid harassment or being subject to stereotype bias [7, 30, 127]. Moreover, using dissimilar avatars to mislead others regarding one own identity can be a way to draw attention to oneself and to ease social interaction [7, 30]. Regarding usages specific mostly to non-virtual contexts, changing one's virtual appearance can be used as an opportunity to explore a different identity from one's own. For example, dissimilar avatars offer the possibility to embody and socially interact with: another gender [30], a younger self [7] (illustrated in Figure 3.2), an ideal version of the self [61] or a non-anthropomorphic avatar [76]).

## 5 RESEARCH AGENDA REGARDING DISSIMILAR AVATARS

As mentioned in the introduction, since most VR research focuses on simulating reality, studies investigating specifically dissimilar avatars utilization in VR are still rare. Hence, a variety of important questions and promising applications remain to be explored. To begin with, we discuss the remaining challenges and perspectives to leverage the user experience, first in terms of interaction and then regarding the sense of embodiment. Thereafter, we discuss applications focusing on using dissimilar avatars for entertainment purposes. Finally, we discuss potential risks engendered by different dissimilar avatars applications.

### 5.1 Interaction Challenges

We discuss here limitations related to dissimilar avatars and interaction. In particular, we mention (i) the necessity to provide tactile stimulation in out-of-the-lab contexts, and (ii) the potential of implementing specific adaptations of the avatar to the context.

#### 5.1.1 Providing Tactile Stimulation in Out-of-the-lab Contexts

As mentioned in Section 3.1.2, dissimilar volumes and structures can disrupt tactile interaction with other objects or one's own body by generating visuo-tactile mismatches [14]. While different techniques exist to provide congruent visuo-tactile stimulation to dissimilar avatars [19, 43, 108], most of them were validated with heavily constrained setups and protocols, and are hardly replicable to unconstrained, out-of-the-lab contexts. To tackle this issue, future research should focus on developing solutions that provide coherent visuo-tactile stimulation in a wide range of interaction contexts, not only in specific use cases. To the best of our knowledge, except tactile stimulation

involving an experimenter's action [43, 51, 108], which is highly unpractical, previous studies only provided solutions to simple congruent self-tactile stimulation, using retargeting algorithms [19, 80]. However, techniques used in these studies do not provide solutions to replicate diverse specific tactile stimulation, and seem limited to certain types of dissimilarities [19]. Hence, it seems necessary in future research to work on algorithms which do not limit tactile stimulation to a unique point of contact, and that can support a wider range of dissimilarities. Furthermore, to foster interaction with the VE, it seems also important to study how these algorithms can be applied to tactile interaction with external objects, in particular in the case of complex manipulations.

#### 5.1.2 Towards Dynamic Appearance Adaptation

In Section 4.1, we showcased a wide range of dissimilar avatars' applications that meet various needs in terms of interaction (e.g. changing viewpoint, reaching far objects, using tools capacities). However, these desired interaction means are often time-varying and might alternate throughout the same VR experience. Hence, it would be interesting to study avatars showing an appearance dynamically adapting to the interaction needs. Such dynamic adaptation could for example take advantage of previous findings, reporting that a reduction of the avatar structure complexity that does not reduce the capacity to carry out the desired task, might improve agency and task performance [5, 46]. Hence, it would be interesting to observe the impact of an avatar adapting the complexity of its structure to the task's requirement. Furthermore, as mentioned in Section 4.3.4, the avatar's dissimilarity can be employed as a tool to communicate its affordances. In that sense, future research could study people's response to an adaptive avatar's appearance, visually representing the modification of its affordances. For instance, the avatar could present a stone-material when movements are slowed down for precision purposes, or a non-anthropomorphic material when affording wrist rotations beyond the human maximum rotation.

However, the potential use of dynamically altered avatars raises new questions. In particular, one might wonder what level of control users should have over the avatar's adaptations, and how it might impact performance and perceived experiences, including the sense of embodiment. Hence, it seems important to investigate whether users would accept to embody an avatar adapting automatically to the context, or on the contrary if they would favor being provided more control towards their body's transformation. Parallels might be made with similar discussions regarding non-immersive user interfaces [8], and it would be interesting to study if the specific relationship one has with one's own body as compared to another object, might produce different results and acceptance from the user.

### 5.2 Dissimilar-Avatar-Oriented Approaches for Sense of Embodiment Elicitation

Most of the research aiming at eliciting a sense of embodiment towards a dissimilar avatar tends to use similar elicitation techniques as those used for non-dissimilar avatars. However, the specific avatar dissimilarities may cause different technical and perceptual implications that might be worth considering and adapting to. Hence, in this section, we discuss (i) how to provide a specific sensation of body change, and (ii) the benefit of a smooth appearance transition.

#### 5.2.1 Providing a Sensation of Body Change

The specificity of eliciting a sense of embodiment towards a dissimilar avatar is that it should provide users with the sensation that their body has changed [97]. Hence, to foster the illusion of embodiment towards dissimilar avatars it would be interesting to investigate novel stimulation techniques, not only providing users with an *ownership illusion* (i.e. "this body is mine"), but also to a *body-change illusion* (i.e. "this body is different from my real world experience"). Such illusion might have stronger chances to arise if users are presented with stimulation specific to the avatar dissimilarity. For example, previous research has shown that a sensation of embodiment could be transferred towards a slime, by providing the illusion that one body can extensively stretch through a congruent visuo-tactile stretching stimulation [54].

Furthermore, the addition of auditory cues fitting the dissimilar avatar seems promising to infer a body change. For example, a previous study displayed a stone contact sound when visually and haptically hitting an avatar presenting a stone textures [16]. It would be interesting to build on these previous encouraging results, by comparing them to classical ownership illusion techniques (i.e. the classical congruent stroke stimulation), and to investigate whether they can be expanded to different types of dissimilarities and interactions.

### 5.2.2 Providing a Smooth Appearance Transition

In most cases, the dissimilar avatar is presented to the users at the outset of the immersion. This sharp transition might challenge the virtual body acceptance. Hence, it could be interesting to investigate methodologies providing coherent and smooth transitions from a relatively similar avatar to the targeted dissimilar avatar. In that sense, previous research proposed to display continuous body transformations and to provide semantic explanations to it, for example by pulling a finger to elongate it [77], or flexing muscles to become bigger [84]. While these studies showed promising results, they are still rare and might require further exploration regarding the specific modalities providing a sensation of coherent and plausible transformation (e.g., semantic, tactile, sound). However, rapid body transformation is a concept that one doesn't ever generally experience in real life. Hence, it would be interesting to try replicating transformations borrowed from fictional works, as they probably represent the main mental models one has of what a body transformation should feel and look like.

### 5.3 Use of Dissimilar Avatars for Entertainment

While many research presented in Section 4 focused on the functional benefits of utilizing dissimilar avatar's embodiment, almost none of them studied the potential of dissimilar avatars for entertainment purposes. This lack of attention for entertainment applications contrasts with the prominence of VR entertainment applications in the VR industry, and the great potential dissimilar avatars show in that perspective. Indeed, dissimilar avatars offer user the unique opportunity of experiencing being and interacting beyond their real body experience (e.g., becoming one's favorite superhero, or any kind of curious and unusual experience of being and moving like an animal or a supernatural creature). Hence, it would be interesting for more research to follow an approach similar to Krekov et al. [55] focusing on the entertainment and hedonic potential of dissimilar embodiment experiences. In particular, future research could further study solutions to provide compelling interactions fitting the dissimilar avatar (e.g. flying like Superman, or climbing like a monkey). Furthermore, it would be also interesting to explore novel dissimilar avatars' based interactions from a playful perspective. Indeed, such novel interactions focused on enjoyment rather than efficiency could open new possibilities for game design, be enjoyable to perform, challenging to master, or enable novel asymmetric gameplay mechanics.

### 5.4 Ethical Concerns

Throughout this paper, we focused mainly on the positive outcomes dissimilar avatars could engender. However, it is also important to examine the negative consequences that their inappropriate utilization might provoke. In order to better anticipate these risks, we discuss here different concerns related to dissimilar avatars divided between (i) tangible risks and (ii) long-lasting negative impacts.

#### 5.4.1 Tangible Risks

To begin with, the potential of dissimilar avatars to alter the perception of diverse stimuli mentioned in Section 4.3.3 raises concerns regarding how they might hide stimuli that are critical to users' safety. For example, reducing body exertion's awareness [52] might lead to injuries in exergames, changing temperature perception [16,53] might lead users to get sick or burn themselves, and a decreased pain sensation [70,71] might cause users to undermine a physical damage. In addition, the alteration of proprioceptive senses that may provoke avatars presenting a dissimilar volume or structure might present risks. Indeed, reducing the awareness towards one's own body position and volume in space

might lead users to put themselves or others in danger, for example by hitting surrounding objects or people [114].

In addition to risks of physical injuries, the perspective of social VR platforms where anyone's appearance can be modified at will entails risks related to identity deception [62]. For example, pretending to be someone else by taking her/his virtual appearance (identity theft), might cause risks of self-disclosure to unintended individuals or falsely attributing responsibility for inappropriate actions to the wrong person [62]. Moreover, appearance alterations also provide individuals with the possibility to hide different aspects of themselves. While we mentioned in Section 4.5 the benefit of such use to avoid group-based discrimination, it does not come without potential misuses. For example, one might provoke exaggerated trustworthiness, by leading others to believe one is younger or belong to the same social group. This exaggerated trustworthiness could be dangerously exploited in order to provoke self-disclosure of personal or sensitive information.

#### 5.4.2 Long Lasting Risks

While previous studies related to Proteus effect [21,29] and VRPT [3,101] mentioned in Section 4.5, focused mainly on the positive outcomes that they can engender, it is important to recognize that they can equally provoke negative outcomes depending on the scenario [29,64]. These negative outcomes might arise from a deliberate desire to harm a specific group or to provoke irrational positive attitudes towards a dangerous group. Alternatively, they might unintentionally be generated by a VR designer unaware of these risks. For example, VR applications often provide avatar's appearance options defined by holistic characterizations such as gender or race. In this case, particular caution should be provided as to how such conceptual notions are mapped to a set of specific atomic features. Indeed, the VR designers' subjectivity might lead to stereotypical associations, such as over-sexualized features for female's avatar, or exaggerated racist features for a specific avatar race. These stereotypical associations might in turn induce stereotypical biases in the embodied user [29]. Generally speaking, it seems important to investigate in future research the Proteus effect and VRST in terms of their potential negative outcomes, in order to understand their mechanism, learn to detect misuses and provide guidelines directed to VR designers.

In another vein, presenting users to the visceral experience of embodying an idealized version of the self [7,30] raises concerns regarding lasting impacts on the real-body satisfaction. Indeed, one can worry that the adverse effects found when presenting an idealized self on social networking services (SNS), such as body dissatisfaction [111] and eating disorders [119], may also arise when embodying an idealized avatar in VR.

## 6 CONCLUSION

In this paper, we attempted to survey and provide a frame to current knowledge regarding dissimilar avatars. In particular, we proposed a characterization methodology, surveyed the state of the art regarding the main impacts to consider as well as the benefits derived from dissimilar avatar embodiment, and discussed different interesting future directions for research related to dissimilar avatars. We believe that this paper contributes to future research, especially by providing tools to study the distinct characteristics of different types of dissimilarities, helping to the elaboration of large scale theories, and a better understanding of the unique opportunity offered by VR to go beyond our real body limitations.

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