Evaluating the Distinctiveness and Attractiveness of Human Motions on Realistic Virtual Bodies

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Figure 1: *Example frames from distinctive (leftmost pairs) and non-distinctive walking, jogging and dancing motion clips.*

Abstract

Recent advances in rendering and data-driven animation have enabled the creation of compelling characters with impressive levels of realism. While data-driven techniques can produce animations that are extremely faithful to the original motion, many challenging problems remain because of the high complexity of human motion. A better understanding of the factors that make human motion recognizable and appealing would be of great value in industries where creating a variety of appealing virtual characters with realistic motion is required. To investigate these issues, we captured thirty actors walking, jogging and dancing, and applied their motions to the same virtual character (one each for the males and females). We then conducted a series of perceptual experiments to explore the distinctiveness and attractiveness of these human motions, and whether characteristic motion features transfer across an individual's different gaits. Average faces are perceived to be less distinctive but more attractive, so we explored whether this was also true for body motion. We found that dancing motions were most easily recognized and that distinctiveness in one gait does not predict how recognizable the same actor is when performing a different motion. As hypothesized, average motions were always amongst the least distinctive and most attractive. Furthermore, as 50% of participants in the experiment were Caucasian European and 50% were Asian Korean, we found that the latter were as good as or better at recognizing the motions of the Caucasian actors than their European counterparts, in particular for dancing males, whom they also rated more highly for attractiveness.

CR Categories: I.3.7 [Computer Graphics]: Three Dimensional Graphics and Realism—Animation;

Keywords: human animation, perception, motion capture

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1 Introduction

Animating realistic human motion is a challenging problem. The complex biomechanical and physiological processes that drive motion are very difficult to understand and replicate, so for many applications real human motion is captured and retargeted to a virtual human model. However, while such data-driven animation can produce extremely realistic animation, it also has several drawbacks in practice. One such disadvantage could be that the style of the captured person's motion could be quite distinctive, and therefore easily recognized when applied to one or more characters (e.g., in a group or crowd). It would also be undesirable to use motion that might be unappealing or unattractive to some or all of the target audience.

In order to create sufficient variety of motion in an environment given a limited repertoire of human motions, insights into the perception of distinctiveness of such movements would be very valuable. It has previously been found that humans find it difficult to distinguish between the motions of multiple walking people [McDonnell et al. 2008; Pražák and O'Sullivan 2011], but it is not clear if this is true for other gaits and actions apart from walking. Some questions that remain unanswered are: How many motions is it necessary to capture from one actor, or how many actors are needed to ensure that enough variety is present? Do distinctive features transfer across different actions, i.e., can you recognize a person from his/her walk, run, or more stylistic motions such as dancing. When synthesizing new motions, either by editing the original motion to satisfy certain constraints, or by procedurally modifying the motion to create new characters with their own individual styles, we also need to understand what the salient features of motion are, and how they influence a viewer's perception.

We draw on insights from the psychological literature to guide our research. Most of the research on the recognition of biological motion, however, has been done on very simple displays of dots, lines or silhouettes [Johansson 1973; Troje 2002]. While providing very useful insights for perception, it would also be valuable to know how human motion is perceived in more ecologically valid situations, such as on a realistic 3D character moving within a plausible scene. Furthermore, the stimuli used often contain information about body shape, as it is difficult to modify the body shape in a simple way without introducing disturbing motion artifacts.

Previous studies have demonstrated that distinctive faces can be perceived to be less attractive than average and/or symmetric faces [Rhodes 2006]. While there have been some studies with simple stimuli on the attractiveness of human motion, the perception of realistic virtual characters performing a variety of different human motions has not been performed. Furthermore, it is important to take cultural and gender issues into account when conducting a study of this kind. With the global reach of the games, movie and other industries that deploy virtual characters in their products, it is important that such characters be appealing and appear artifact free to all audiences. The main questions we ask are as follows:

- How distinctive are the motions of different actors when shown on exactly the same body?
- Is the average the least easy to recognize, as in faces?
- Are all gaits equally easy to recognize?
- Are there cultural or gender differences with respect to recognition?
- How attractive are the motions of different actors - are more distinctive actors less attractive? Is there a cultural influence?
- Is the average more attractive than the other motions?
- Is a person equally attractive when performing different gaits?

To understand these issues, we ran a set of experiments to explore the distinctiveness and attractiveness of virtual humans walking, jogging and dancing. Their motions were captured from 15 male and 15 female Caucasian European actors, and retargeted to one each of a realistic female and male model (Figure 1). All actors were retargeted to the corresponding male or female virtual model, thereby removing any cues as to body shape that could affect recognition and perceived attractiveness, while taking particular care to avoid introducing any motion artifacts and interfering with the original motion as little as possible (see Section 3). The experiments are described in Section 4. First, we explored the *distinctiveness* of the actors' three different gaits, by determining how well participants could remember whether each actor was present or absent from a group of three others; then we performed a *cross-gait analysis*, where participants rated the likelihood that two motions, either walk-jog, walk-dance or jog-dance, were from the same actor or not. Finally, we asked participants to rate the *attractiveness* of the actors for each of the different motions.

Answers to our questions are discussed in the corresponding sections, but some interesting results include: participants found Dancing motions easiest to recognize, and Female motions tended to be more distinctive than Male ones. However, distinctiveness in one gait does not necessarily imply that the same actor will be equally identifiable while performing a different gait or action. We found some evidence that an individual's motion characteristics can be transferred between walking and jogging, but only for certain combinations of gait distinctiveness. We also found an inverse relationship between attractiveness and distinctiveness, with average motions being amongst both the most attractive and the least distinctive. Regarding cultural effects, Asian participants were in general more accurate at recognizing actors and found Caucasian male dancers to be more attractive than was the case with the European participants.

2 Related Work

Several researchers have addressed the need to create greater variety in human motion, especially when simulating crowds of people. For realtime applications, only a certain number of different 3D human models can be animated and rendered, and therefore it is common to see the same characters many times in games and other interactive systems. McDonnell et al. [2008; 2009] considered the problem of disguising such "cloned" models, and focussed on changing face and body textures, as those are the areas of the body most attended to. It was found that cloned walking motions are much more difficult to detect, a result that Pražák and O'Sullivan [2011] explored further. They determined that only three unique walking motions were needed in order to create a crowd with replicated motions that was indistinguishable from a fully varied crowd where each character had its own motion. However, it is not clear how this work would extend to crowds of people performing more complex gaits and motions, such as jogging, dancing or conversing.

While much research has been carried out in the area of modelling the style of human motion, and using these generated models for motion synthesis, little is known about what makes the motion of an actor distinctive or attractive. Motion style can be defined as the differences between examples of the same behaviour (e.g. slow walk vs. fast walk) [Ma et al. 2010], and a variety of statistical and probabilistic models have been developed to address this problem. Motion models have been created for the interpolation and transfer of human motion style [Brand and Hertzmann 2000], for inverse kinematics [Grochow et al. 2004], and for motion synthesis and editing [Pullen and Bregler 2002]. More recently, motion variation has been added to this repertoire by modelling subtle differences in motion styles [Ma et al. 2010].

Being able to design metrics relevant for the automatic categorization of motions is also a challenging question explored by several researchers. Such metrics have been extensively used to automatically compute transitions between motion capture sequences [Lee et al. 2002; Kovar et al. 2002a; Arikan and Forsyth 2002], but they are also relevant to motion parameterization [Ma et al. 2010]. More importantly, metrics can also be perceptually evaluated, e.g., to determine visually optimal blending weights [Wang and Bodenheimer 2003] or durations [Wang and Bodenheimer 2004].

In the psychology literature, much attention has been paid to the perception of facial distinctiveness and attractiveness. A full review is beyond the scope of this paper, but Rhodes [2006] presents a review of research that has shown how certain features of a human face, especially averageness, symmetry and sexual dimorphism (i.e., very male or female features) are all positive factors in the perception of beauty. To explain such effects, an evolutionary theory has been proposed, in that hereditary features such as symmetry, averageness, and masculinity/femininity may be attractive as they are signs of good health [Rhodes 2006]. Another commonly found effect is that distinctiveness of faces correlates negatively with facial attractiveness, although this effect can be mitigated through familiarity [Peskin and Newell 2004].

The perception of biological body motion has also been a very active field of research. Johansson [1973] is an early pioneer of this research and he developed a special stimulus known as the "point-light walker", with most structural information about the body removed, leaving only motion cues visible. Subsequent research using these stimuli demonstrated, for example, that enough information was available in the motion signal for recognition of: gender [Pollick et al. 2005]; a particular person [Cutting and Kozlowski 1977]; or one's own walking pattern [Beardsworth and Buckner 1981]. Troje [2002] applied linear methods to analyze biological motion and build classifiers for human characteristics such as gender, which are then compared to human perceptual responses, and also created average walkers [Troje 2008]. Point-light walker displays, while removing a lot of form information, still do impart potentially confounding information about the structure of the body, (e.g., weight, hip to waist ratio, shoulder width, relative lengths of limbs), while conversely limiting the number of visual inputs (i.e., moving pixels on screen) that could impart important information used for motion recognition and the perception of attractiveness.

There has also been some work on the perception of attractiveness of body motion. For example, using degraded videos, Grammer et al. [2003] found that the overall body movement of dancing females was related to attractiveness. Pelvic sway in women and shoulder swing in men were also found to be strong cues [Johnson and Tassinary 2007], whereas it remains unclear whether symmetric bodies are indeed found to be more attractive [Brown et al. 2005; Reich 2013]. Johnson and Tassinary [2005; 2007] studied the effects of both shape and motion on the perception of attractiveness using silhouettes of human body shapes with varying waist to hip ratios.

Even if many of these perceptual effects are robust, cross-cultural differences still emerge when evaluating what is referred to in the literature as "other-race" effects. Such effects have been shown to influence face recognition [Meissner and Brigham 2001; Mondloch et al. 2010], where Asian and Caucasian observers attended to different regions of the face [Blais et al. 2008]. However, results have shown cross-cultural agreements when rating facial attractiveness [Perrett et al. 1994; Cunningham 1986], where faces that are judged to be very attractive in their own society are also rated as equally attractive in other societies, and when comparing biological motion perception using point-light humans and animals [Pica et al. 2011].

While this is by no means a comprehensive review of the literature, it motivates our study into the perception of human distinctiveness and appeal on virtual characters. We aim to study the distinctiveness and attractiveness of biological motion on realistic virtual human bodies for a variety of gaits. We take care to ensure that the motion is the only identification cue through careful retargeting and motion processing, while minimizing any changes made to the motion. Our results will therefore be relevant in the fields of both computer graphics and perception. We also compare distinctiveness and attractiveness of several different human motions and across two different cultural groups (Asian Koreans and European Caucasians).

3 Preparing the Stimuli

To conduct our studies, we recorded 15 male and 15 female Caucasian European actors. We recruited professionally trained actors to ensure that they would be at ease while being recorded, and they were specifically asked to act naturally without introducing any unusual or exaggerated motions. We took care to ensure that we selected actors who were reasonably similar in age and body shape, in order to minimize retargeting errors. Table 1 presents information related to our set of actors. For the experiments presented in this paper, we captured walking, jogging and dancing motions at 120Hz using a 19 camera Vicon optical system, with 67 markers positioned on each actor's body.

Figure 2: *Left: female actor walking; Center: female model jogging; Right: male model dancing.*

Actors	**Age**	**Height** (cm)	**Weight** (kg)
Females	25.1 ± 3.4	165.2 ± 6.4	60.3 ± 7.2
Males	23.3 ± 3.2	177.3 ± 5.2	77.4 ± 11.4

Table 1: *Information about the set of captured actors (mean and standard deviation).*

Walk and Jog: Actors were instructed to walk or jog in a straight line through the capture space. To prevent the frequency of the locomotion from influencing the distinctiveness of each actor, they were all instructed to walk or jog at the same frequency by following a metronome, thus ensuring that the resulting stimuli would vary based only on motion style. We used a frequency of 112 steps per minute for walking, and 138 steps per minute for jogging. These frequencies were derived from an existing database of 20 actors captured while walking and jogging at comfort speed. To avoid any unnatural alterations to the motion due to the distraction of the metronome, the actors trained with the beat until they were at ease with the step frequency. They were then captured without the metronome while maintaining the previous frequency as much as possible. To avoid excessive speed variations in captured clips, our motion capture space was set up to capture between three and four full locomotion cycles, always excluding the three first and last steps of the locomotion. In total, four walking and four jogging trials were captured per actor.

Dance: Actors were shown a 30s video clip from the game *Just Dance®* ("I Get Around", Beach Boys). They all saw the same video clip from the game and were asked to follow the motion of the character on screen while the music was playing. We thereby ensured that all actors were performing the same dance movements, with all variation coming from their individual dancing styles. Actors trained a minimum of three times on the video, or until confident enough with the choreography. Two dancing clips were then captured per actor.

3.1 Motion Processing

The recorded body motion was mapped in Vicon IQ onto a skeleton calibrated specifically for each actor, where joint angles were computed and used to drive the bones of the skeleton. To create stimuli that were long enough for our experiments, we converted all walking and jogging motions to seamless looping animations using the cyclical property of locomotion. In order to interfere as little as possible with the original motion, we created looping animations using two full locomotion cycles, as one-cycle seamless locomotions are more likely to cause visible looping artifacts. We used an approach similar to that described in [Kovar et al. 2002a] to select from the original data the two most similar frames separated by two full locomotion cycles then linearly blended the difference between these two frames over the sequence. All the animations were carefully checked for any looping artifacts, and the visually best clip of the four was selected for each actor. We also selected from the dance video the 5s sequence with the most coordinated body movement, and reconstructed the corresponding 5s clip for each actor. We manually selected a static hand pose for each motion, which was used across all actors.

Although the actors were trained to walk and jog at a given step frequency during motion capture sessions, small differences still existed between the clips. As we did not wish to introduce the confounding variable of step frequency, which could influence the recognition of the actors, we timewarped all actors in each trial to the slowest step frequency of the actors presented simultaneously, as it was previously shown that slowing-down is less perceptible than speeding-up [Pražák et al. 2010]. In all cases the timewarping modification was extremely small, with a motion being slowed-down by approximately ten per cent in the worst case, far below the perceptibility thresholds found in previous studies [Pražák et al. 2010; Ryall et al. 2012].

As each actor has a different morphology, which usually does not match that of the virtual model, retargeting is almost always necessary to map motions onto virtual characters. We used the Autodesk 3ds Max Biped system to handle retargeting, which primarily processes lower body motion where disturbing footsliding artifacts can occur. Instead of representing legs as thigh or calf segments, a single segment independent of character proportions is used (hip to ankle, with an extension ratio), along with the half-plane containing hip, knee and ankle joints. Therefore, the knee is not explicitly defined, but is recomputed from these data and the anthropometric properties of a character [Kulpa et al. 2005; Hecker et al. 2008]. Also, the spine is represented with a spline, allowing for any number of vertebrae, and rotations from the motion capture data are used directly to animate the upper body. This efficient solution produces artifact-free animations, while keeping the original stride-length to leg-length ratio, thereby avoiding over-extended legs or unnaturally small steps. All actor skeletons, including that of the average actor (see Section 3.2), were thus retargeted to the skeleton of the corresponding male or female virtual model (Figure 2).

Because of the differences between actor and character morphologies, footsliding artifacts could become unacceptable when retargeting onto a virtual character. Such errors are directly proportional to the difference between actor and model of the thigh length to calf length ratio, which was on average extremely low (1.5±4.7% of the model's ratio). Therefore, we pre-processed all the locomotion animations to remove any residual foot motion from the original data by first detecting footstep constraints using a method similar to that of Le Callenec and Boulic [2006], then cleaning-up foot motion using the method of Kovar et al. [2002b].

3.2 Average Motion

Synchronizing motions is essential to obtain natural looking averaged motion. Because of the cyclical nature of locomotion, footsteps can be easily synchronized for walking and jogging motions. We used the method described in Section 3.1 to detect contact phases, then used Dynamic Time Warping to temporally align and average locomotion clips. We created an average male actor and an average female actor for walking and jogging using the corresponding 15 male and 15 female actors.

While the locomotion patterns and timings are similar for each actor, the amount of variability due to each individual's dancing style makes it very difficult to find similar synchronization patterns between actors. Furthermore, even though linear timewarping was an option, as all actors were performing the same dance sequence, the resulting average motion was not at all natural. Therefore, we focussed on exploring the distinctiveness and attractiveness of average human motions for walking and jogging only.

4 Experiments

For all the experiments presented in this paper, participants came from different disciplinary backgrounds and were naive to the purpose of the studies (mean age: 24.7±4). They were recruited via university email lists and were compensated for their time with cash or book vouchers. Furthermore, to test for cultural effects, all experiments were held in both Europe and Asia, so 50% of the participants were Caucasian European (EU) and 50% were Korean Asian. Virtual characters were rendered in real-time in our scriptable system, and participants gave their responses using the keyboard. The display covered a field of view of approximately 36 degrees of visual angle.

We performed Repeated Measures Analysis of Variance (ANOVA) on participant responses to test for statistically significant differences. We are interested in both Main Effects (i.e., when a variable has an overall effect) and Interaction Effects (i.e., when the effect of a variable differs depending on the level(s) of one or more of the other variables). When we found main or interaction effects, we further explored the cause of these effects using Neuman-Keuls post-hoc tests for pair-wise comparisons of means. We only consider effects to be significant at the 95% level ($p < 0.05$). In all experiments, we tested for participant sex and age and found no significant effects, so this is not discussed further. However, we did find significant effects for *Group* (EU or Asia) that will be presented along with the other results. The most interesting significant effects from the experiments are summarized in Table 2.

4.1 Distinctiveness

In this study, we wanted to explore how distinctive the motions of different actors are, when displayed on the same virtual body. Are some actors' motions more easily recognized than others, and if so, is this equally true for all their gaits? Are some gaits more easy to recognize than others? There is evidence that average faces are least distinctive (and most attractive) – will the average of our actors' motions also be the least easily recognized? And finally, is there a cultural effect to motion recognition, i.e., will the Asian participants have more trouble recognising the relatively unfamiliar Caucasian gaits?

We found that *Dancing motions were easiest to recognize*, followed by Jogging and finally Walking, and some (but not all) *Female motions were more distinctive than Male ones*. Some actors are more distinctive walkers, joggers or dancers than others, but *distinctiveness in one gait does not transfer* to being similarly recognizable in another. The exception to these results was that *the average actors were amongst the least distinctive in all cases*, i.e., for both female and male walking and jogging motions. Contrary to expectations, we also found that Asians were more accurate than Europeans at recognising certain actors' motions, especially for Dance.

4.1.1 Method

We first ran a within-group experiment to compare walking and jogging motions, where 26 participants (10F, 16M) viewed both types of motion. The experiment consisted of two *Motion* blocks (Walk

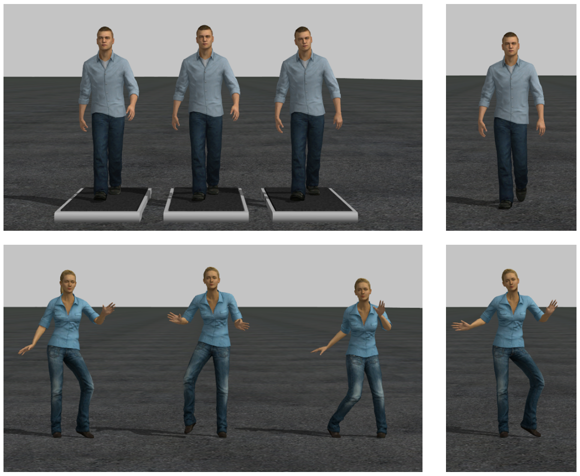

Figure 3: *Examples of the distinctiveness stimuli where three different actors are presented on screen first (left). A single actor is then presented (right) and participants indicate whether the single actor was present or absent in the group of three.*

and Jog), the order of which was counterbalanced across participants. Each block lasted about 40 minutes, with a break between blocks. To follow up on our interesting results (discussed below), we ran a second experiment with 26 new participants (11F, 15M) who viewed only one block of dancing motions. In both experiments, we displayed each *Sex* in separate blocks: 15 Male (M1-M15) and 15 Female (F1-F15) *Actors*, with additional male and female average actors (Mavg, Favg) in the Walk and Jog blocks (see Section 3). The order of display for the male and female blocks was counterbalanced, and the stimuli were presented in random order in each block.

In order to evaluate the distinctiveness of each motion clip, we used a 2-Alternative Forced Choice (2AFC) design. Participants first watched a five-second clip of three different actors walking, jogging or dancing. The three actors were displayed side by side on the same virtual character model and randomly distributed between the left, center or right positions. Because of the difference in speed between actors in the Walk and Jog blocks, the three actors were each positioned on a treadmill (not present in the capture session) on which the surface texture moved at the same speed as the respective actors (Figure 3, left). They then viewed a single actor performing the same gait for up to ten seconds (Figure 3, right). The latter was presented without a treadmill in order to remove any potentially confounding cues, such as the speed at which the treadmill was moving. The Dance block was similar, except that no treadmill was displayed in either case.

The participants' task was to indicate whether the single actor was present or absent in the previous group of three, by pressing a key as soon as they made their decision. The actor was present or absent in an equal number of trials and there were three repetitions of all combinations of factors. When the actor was present, the other two actors were randomly selected from the full set of actors, over all repetitions of that actor per participant and over all participants. Therefore, each participant viewed 384 trials in the first experiment: 2 *Motion* (Walk/Jog) $\times$ 2 *Sex* (Female/Male) $\times$ 16 *Actor* $\times$ 2 (for present or absent) $\times$ 3 (repetitions); and 180 trials in the second experiment (with one Dance motion and 15 actors).

The "present or absent" task helps us to answer the question: "is the person distinctive enough to be remembered?". Similar experimental designs are common in the field of shape recognition [Fugard et al. 2011], and we chose this task in order to avoid simple matching between motions, preferring instead to pose a true signal detection/recognition challenge. Three actors were presented (rather than more or fewer) as during pilot tests we found this to be the most effective number to allow participants to distinguish between the more or less distinctive actors (presenting only one or two actors became a simple matching task, whereas presenting more than three proved to be too difficult).

Music was never played when presenting the dance motions, as we wished to compare the results with those for walking and jogging, for which there was no accompanying audio. Furthermore, it would have been difficult to exactly synchronize the motion with the music that the actor was dancing to for that particular dance segment. Thereby we could have given an impression, erroneous or otherwise, as to their ability to keep time to music, which might affect recognition and attractiveness.

4.1.2 Results

In this experiment, we were interested in evaluating the sensitivity of each participant to the presence or absence of each actor performing each gait. Using Signal Detection Theory, we computed the d-prime (d') metric, which is commonly used in psychophysical studies to reliably measure sensitivity to a signal. This metric takes response bias into account (the tendency to be over-conservative or over-discriminative) by considering both the Hit Rate (HR), i.e., the percentage of time an actor is correctly reported to be present; and the False Alarm Rate (FAR), i.e., the percentage of time the actor is incorrectly reported to be present when absent. A d' value is computed for each actor and each participant using: $d' = z(HR) - z(FAR)$, where $z(p) \in [0, 1]$ is the z-score (a.k.a. normal score) of p. High d' values indicate that participants are very sensitive to the presence or absence of a specific actor, thereby providing a good measure of the distinctiveness of the motion being performed.

As we had two different sets of participants for this study, one for the Walk and Jog motion blocks, and the other for the Dance block, we could not compare all three factors in a single within-group ANOVA. Instead we performed three between-groups pairwise analyses of gait. For each block, we also had two groups of participants: Asians and Europeans. The three ANOVAS we performed were thus:

Walk vs. Jog: 2$\times$2$\times$16 Repeated Measures ANOVA with within-subjects variables Motion (Walk/Jog), Sex (M/F) and Actor, and within-groups categorical predictor Group (Asia/EU);

Walk vs. Dance: 2$\times$15 Repeated Measures ANOVA with within-subjects variables Sex (M/F) and Actor, and within-groups categorical predictors Motion (Walk/Dance) and Group (Asia/EU);

Jog vs. Dance: 2$\times$15 Repeated Measures ANOVA with within-subjects variables Sex (M/F) and Actor, and within-groups categorical predictors Motion (Jog/Dance) and Group (Asia/EU).

Significant effects are listed in Table 2. It should be noted that we do not report any main or two-way effects of Actor. This is because an effect of Actor is only meaningful when considered in interaction with the Sex of the actor, as the Male and Female actors are different. So we would always expect a main effect of Actor and an Actor$\times$Sex interaction (which we found indeed to be the case). Therefore, only three-way interactions of other variables with Actor and Sex are reported for this, and the following, experiments.

The results are summarized in Figure 4 (left) (though it is important to note that this graph is for clarity purposes, and represents both within- and between-groups effects). We can see that Female walks and jogs were more easily recognized than their cor-

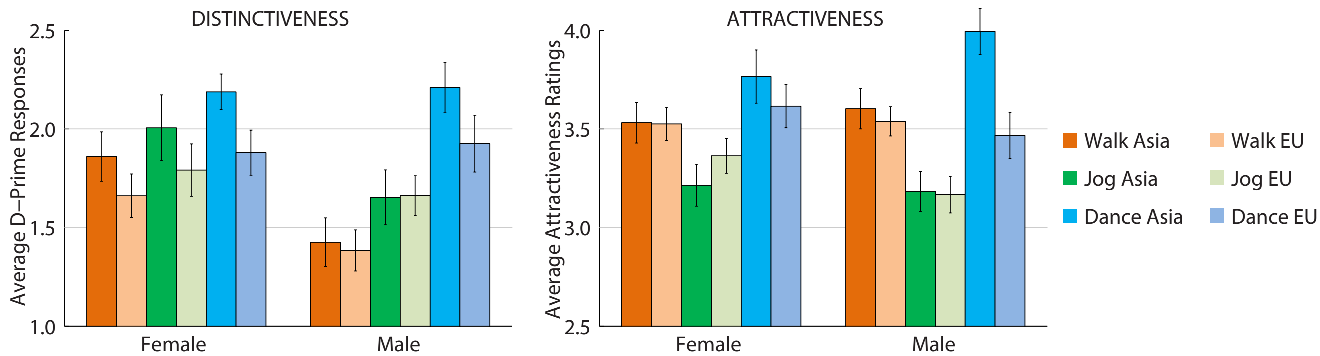

Figure 4: *(Left: d' distinctiveness values, and Right: attractiveness ratings, averaged over Group (Asia/EU), Actor Sex (Male/Female) and Motion (Walk/Jog/Dance).*

responding Male motions, but both male and female dancing motions were equally recognizable. The Motion effects demonstrate that the Dance was the most distinctive gait, followed by Jog and then Walk. The Asian participants were more accurate at recognizing the actors, in particular for the females, but for males only when they were dancing.

We were particularly interested in whether averaged motions were more or less distinctive than the original captured motions, and whether distinctiveness of motion transferred across different gaits. We can find answers to these questions by examining the three-way *Motion*Sex*Actor* interaction effects in Figure 5 (left). For the comparison between Walk and Jog, and Walk and Dance, we sorted the results based on the distinctiveness of each actor's walking gait, and sorted them by jogging distinctiveness for Jog and Dance. We can see from the graphs that there is no evidence that distinctiveness in one gait transfers to another. In fact, the evidence points to the contrary, as the d-prime values for the other gait do not follow the same trendline. In the case of the female dance, there is even a slightly negative correlation. One notable exception, however, is for the average walking and jogging motions (there is no average dance), between which there is no significant difference. In both cases we can also see that the d-prime values are amongst the lowest.

Finally, we classified each gait for each actor as being distinctive (D), medium (M) or non-distinctive (ND), using the results of the post-hoc analyses for each gait. This gave us three significantly different homogeneous groups to be used in the following experiment.

4.2 Cross-gait analysis

Our previous study demonstrated that an actor's distinctiveness varies depending on the gait performed, but how does this affect the perceived similarity of their different gaits? Does an individual have certain motion characteristics or a style that transfers across his or her gaits, irrespective of how distinctive or otherwise they are? We therefore explored whether it was possible to recognize when the same actor was performing pairs of side-by-side gaits, either walk and jog, jog and dance, or walk and dance.

We found that it was very difficult to tell whether the same actor was performing or not, suggesting that *style characteristics do not transfer well across gait*. For walking vs. jogging motions, performance was slightly less poor, and there was limited evidence that *some motion characteristics may transfer between walking and jogging*, depending on the relative distinctiveness levels of both gaits.

4.2.1 Method

We tested three combinations (*Combo*) of gaits (Walk-Jog, Walk-Dance, Jog-Dance), each on a different group of participants. In order to evaluate whether cross-gait recognition is affected by how distinctive actors are for each gait, we created four groups of actors for each gait combination as follows: distinctive in both gaits (D-D); distinctive in one gait, non-distinctive in the other (D-ND); vice-versa (ND-D); and non-distinctive in both gaits (ND-ND). For each group, four actors (2 Male, 2 Female) were selected based on the results of the Distinctiveness experiment.

Fifty volunteers took part in these experiments: 16 (8F, 8M) in the Walk-Jog group, 16 (8F, 8M) for Walk-Dance, and 18 (10F, 8M) for Jog-Dance. Participants saw two characters on screen, one of whom was walking and the other one jogging (Walk-Jog), or one walking and one dancing (Walk-Dance), or jogging vs. dancing (Jog-Dance). Walking and jogging characters were positioned on a treadmill where the surface texture moved at the speed of the character. Dancing characters were positioned on a stage with similar appearance to ensure that they were presented at the same height (see Figure 6). The two characters were randomly positioned on the left or right side, and were either performing motions from the same actor or from different actors. When presenting motions from different actors, the second actor (second gait) was randomly selected from the other distinctive actors half of the time, and otherwise from the non-distinctive ones.

In total, 64 trials were shown in each group condition: 2 *Sex* (Female/Male) $\times$ 8 *Actor* $\times$ 2 (same or different actor) $\times$ 4 repetitions. Each actor pair was presented for a maximum of 10s, and participants were asked to rate how likely it was that the motions were from the same actor, using a Likert scale ranging from 1 (very unlikely) to 7 (very likely). The order of Male or Female motion blocks was counterbalanced across participants, and the stimuli were presented in random order within each block.

4.2.2 Results

To determine whether cross-gait recognition is affected by actors being perceived as distinctive in neither, one, or both of their gaits, we calculated sensitivity measures by parsing the responses to the Likert scale into hit rates and false alarms, thus allowing us to compute d' values as before.

We ran a 2$\times$8 Repeated Measures ANOVA on these values, with within-subjects variables *Sex* (M/F) and *Actor*, and within-groups categorical predictors *Combo* (Walk-Jog/Walk-Dance/Jog-Dance) and *Group* (Asia/EU).

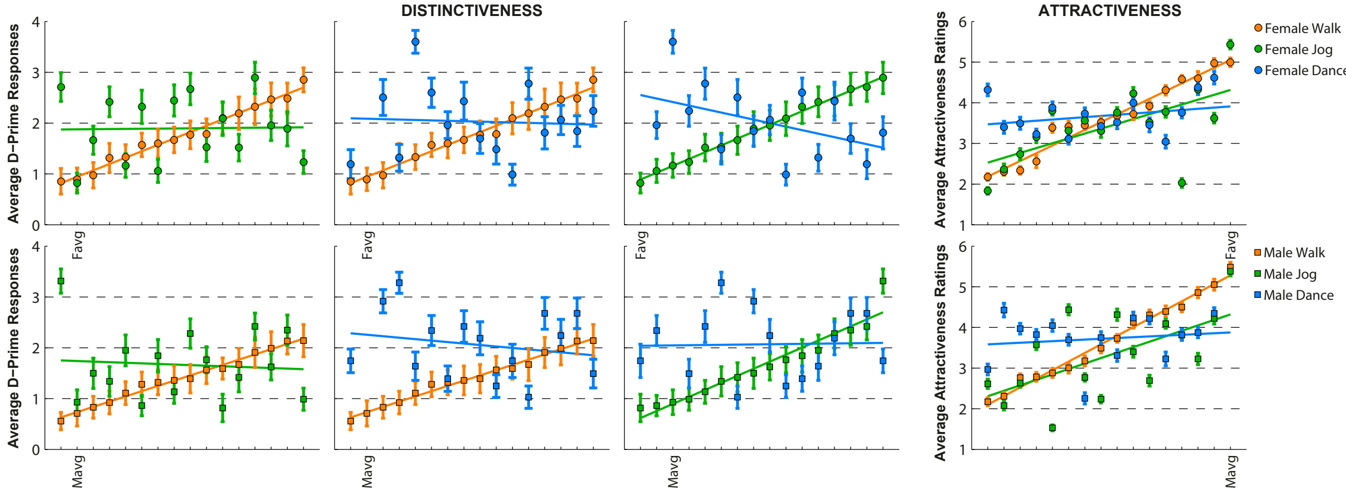

Figure 5: *Three-way Motion*Sex*Actor Interaction Effects; Top: Females, and Bottom: Males; Left: d′ responses, and Right: attractiveness ratings for all Actors, averaged over Actor Sex (Male/Female) and Motion (Walk/Jog/Dance); The actors are sorted (along the horizontal axis) from least to most distinctive/attractive Walk averages for all comparisons with walking, and by Jog values otherwise.*

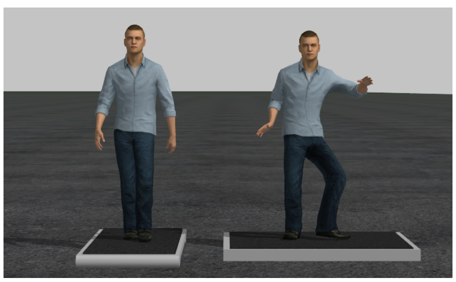

Figure 6: *Example of the Cross-gait stimuli. Participants were asked to rate how likely it was that the motions were from the same actor.*

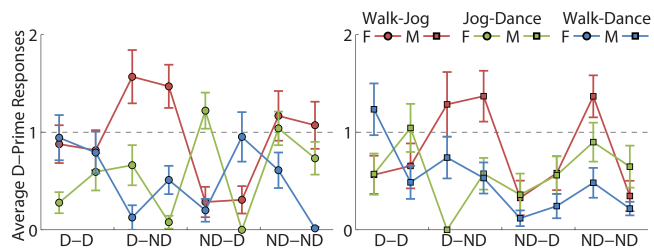

Figure 7: *Average d′ responses for all Actors in the Cross-Gait experiment, by Actor Sex (Female left, Male right) and gait Combo (Walk-Jog/Walk-Dance/Jog-Dance).*

Significant effects are given in Table 2. The main effect of Combo shows that, while the Jog-Dance and Walk-Dance gait combinations were equally difficult to identify, performance was better for the Walk-Jog pairs. There was an interaction effect of Group×Sex, where Asian participants were more accurate at matching the gaits of Male actors. Figure 7 sheds some light on the three-way *Sex*Actor*Combo* interaction effect. It appears that the most information was transferred between walking and jogging when the walk was distinctive but the jog non-distinctive. This result was true for all four actors in this category: two females and two males. Further investigation is needed to understand what features might be transferred, and why they occur in these D-ND pairs, which is an interesting direction for future research.

4.3 Attractiveness

It has been shown in previous attractiveness research that average and non-distinctive faces are considered to be attractive. Therefore, we wished to determine the perceived attractiveness of the motions of our thirty actors and their averages, and to explore how these ratings related to their distinctiveness. Are the actors' motions perceived to be equally attractive, irrespective of which gait they are performing? Is an actor's attractiveness in a gait related to how distinctive they are? The average motions were found to be non-distinctive, but will they be perceived to be highly attractive, as previous face perception research would suggest? Is there a cultural effect, whereby Asians perceive attractiveness differently from Europeans?

We found that, as predicted, *average motions were perceived to be most attractive*, and there was a *negative correlation between attractiveness and distinctiveness for walking and jogging*, but not for dancing. Dancing motions were considered overall to be more attractive, and *Asian participants found the dancing males to be more attractive* than the Europeans did.

4.3.1 Method

Sixty-eight volunteers took part in this experiment: 34 (17F, 17M) in the European group and 34 (17F, 17M) in the Asian group. All participants viewed three Motion blocks (an actor walking, jogging or dancing) for both actor sexes, presented in counterbalanced order, and stimuli were presented randomly within each block. Participants viewed 2 *Sex* (M/F) × 16 *Actors* (15 + average) in the Walk and Jog blocks and 2 *Sex* × 15 *Actors* in the Dance block, with 3 repetitions of each stimulus. Participants viewed each stimulus for 5s, and were instructed to rate the attractiveness of the motion on a Likert scale from 1 (very unattractive) to 7 (very attractive).

4.3.2 Results

We ran a 3×2×15 Repeated Measures ANOVA with within-group variables *Motion* (Walk/Jog/Dance), *Sex* (M/F) and *Actor*, and between-groups categorical predictor *Group* (Asia/EU).

Distinctiveness

Comparison	Effect	F-Test	Post-hoc
Walk vs. Jog	SEX	$F_{1,24} = 16.2, p < 0.0005$	Male < Female
Walk vs. Jog	MOTION	$F_{1,24} = 6.1, p < 0.05$	Walk < Jog
Walk vs. Jog	MOTION×SEX×ACTOR	$F_{15,360} = 1.9, p < 0.05$	See Figure 5 (left)
Walk vs. Dance	SEX	$F_{1,48} = 5.1, p < 0.05$	Male < Female
Walk vs. Dance	MOTION	$F_{1,48} = 20.0, p < 0.00005$	Walk < Dance
Walk vs. Dance	MOTION×SEX	$F_{1,48} = 7.4, p < 0.05$	Male < Female only for Walk
Walk vs. Dance	GROUP	$F_{1,48} = 4.9, p < 0.05$	EU < Asia
Walk v Dance	MOTION×SEX×ACTOR	$F_{14,672} = 3.6, p < 0.0005$	See Figure 5 (left)
Jog vs. Dance	MOTION	$F_{1,48} = 4.1, p < 0.05$	Jog < Dance
Jog vs. Dance	MOTION×SEX	$F_{1,48} = 7.4, p < 0.05$	Male < Female only for Jog
Jog vs. Dance	MOTION×SEX×ACTOR	$F_{14,672} = 3.6, p < 0.0005$	See Figure 5 (left)

Cross-gait

Effect	F-Test	Post-hoc
COMBO	$F_{2,44} = 7.9213, p \approx 0.005$	WD = JD < WJ
SEX×GROUP	$F_{1,44} = 5.3462, p \approx 0.05$	EU < Asia only for Male
SEX×ACTOR×COMBO	$F_{14,308} = 3.8022, p < 0.00001$	See Figure 7

Attractiveness

Effect	F-Test	Post-hoc
MOTION	$F_{2,132} = 37.253, p \approx 0$	Jog < Walk < Dance
MOTION×GROUP	$F_{2,132} = 6.9863, p < 0.005$	EU < Asia only for Dance
SEX×GROUP	$F_{1,66} = 5.4185, p < 0.05$	EU < Asia only for Male
MOTION×SEX×ACTOR	$F_{28,1848} = 24.416, p \approx 0$	See Figure 5 (right)
MOTION×SEX×ACTOR×GROUP	$F_{28,1848} = 2.0194, p < 0.005$	See Figure 8

Table 2: *Main significant results for the experiments presented in this paper.*

Significant effects are given in Table 2 and overall results are summarized in Figure 4(b). There was a main effect of Motion, where the Dance was considered to be the most attractive motion overall, followed by Walk, with Jog considered to be least appealing. Interactions between Motion and Group, and Sex and Group, were caused by Asians finding the Male actors, and the Dance motions, to be more attractive than the Europeans did. Further examination of a four-way interaction (Motion*Sex*Actor*Group) revealed that the Asian and European ratings were mostly similar for walking and jogging motions and for Female dancing, where in some cases one or other group occasionally preferred specific actors. However, in the case of the Male Dance motions, the Asian ratings were higher for the majority of actors. In order to demonstrate this effect more clearly, we sorted the Male dancing ratings, averaged over Actor and Group, from least to most attractive. Figure 8 clearly shows how consistent the Asian preferences were. While the Europeans found the top 50% of actors to be similarly attractive, the Asian participants continued to rate them increasingly more highly. Perhaps this is related to the fact that Asians were also found to be more accurate at recognizing male dancers, which would be an interesting direction for further investigation, as would possible cultural influences.

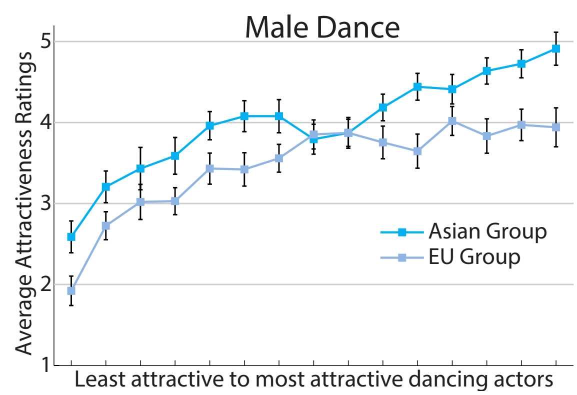

Figure 8: *Attractiveness ratings for Male dancing motions by Actor and Group (Asia/EU). Asian participants consistently rated the male dancers as more attractive.*

We explore the Motion×Sex×Actor interaction further by examining Figure 5 (right). This interaction effect tells us that attractiveness varied depending on the gait that an actor performed. We can see that the scatter of results compared to the Walk ratings (by which the graph is ordered) is relatively random, especially for walking vs. dancing. However, there does appear to be some level of similarity between the rankings of walking and jogging motions, although this is more true for the female motions. This result could be related to the fact that we found some evidence in the cross-gait experiment that some motion characteristics may transfer between these two gaits. Perhaps these potentially translatable characteristics are related to attractiveness?

Finally, regarding the attractiveness ratings of the Average walking and jogging motions, we can see that the Male and Female average actors were rated most attractive for both gaits. This result can be seen from the two right uppermost markers on both graphs (top and bottom). We also found negative correlations between the distinctiveness values (i.e., d-primes) and attractiveness ratings for Walk and Jog, but no correlation for Dance.

5 Discussion

Predicting how diverse users will perceive different gaits across a variety of actors is a useful contribution for creating realistic and engaging virtual scenarios. Sometimes, it may be desirable to create distinctive motions, e.g., for a hero or villain character in a game or movie. In other cases, motions that are too easily recognized will detract from the perceived realism, e.g., when displaying an animated crowd. Similarly, attractive characters could facilitate the engagement of a user with a movie, game or interactive experience.

While previous research has demonstrated that cloned walking motions can be difficult to detect in group or crowd simulations, we found that this was not the case for jogging or dancing motions, which appear to be more distinctive and therefore easier to recognize. Female motions tended to be more distinctive than the male ones, and our Asian participants were more accurate at identifying actors, which could suggest that cultural and/or familiarity effects are at play. However, our sample size is not large enough to generalize these, or indeed any of our results, to a wider group of actors. Nevertheless, they do provide some interesting insights into factors that should be considered and explored further. For example, a rigorous analysis of the motion features of the actors' gaits will be performed, in order to identify the motion properties that contributed most to the attractiveness and/or distinctiveness effects.

Our results also showed that distinctiveness in one gait does not generally transfer to another. The only evidence that an individual's motion characteristics might possibly be transferred has been found between walking and jogging, but only for certain combinations of gait distinctiveness, and even then, recognition accuracy was low. Therefore, future studies are needed to further investigate what features (if any) of a gait might be reliably transferred. The implications of these results for industry could be useful, in that it may not be necessary to capture the motion of as many actors for group or crowd scenes, as long as multiple different gaits of the same actor are being simultaneously displayed. It would also be interesting to study how the distinctiveness of the gaits of a single actor vary across different conditions, e.g., with different types of shoes, walking like a super-model, or talking on a phone while strolling.

The relationship we found between distinctiveness and attractiveness of average body motions mirrors previous results observed on the perception of average faces, as our average motions were always amongst the least distinctive and the most attractive motions for each gait. This finding is encouraging for application areas where the time for capturing and processing motions is severely limited, but yet where appealing characters are very important for user engagement. An average motion could potentially be used far more frequently, especially if it could be parameterized in some way to create style variations. The developer could then be assured that such motions would be more appealing to the target audience.

In CG, captured motions are almost always retargeted to a different body shape than their own, and frequently mapped to significantly different morphologies, e.g., fantasy characters. Only in specialized scenarios, e.g., a hero character model depicting a famous athlete for a sports game, might a bespoke character model be used with the same dimensions as the actor. Therefore, understanding the distinctiveness and perceived attractiveness of captured motions, independently of body shape, could be very useful in practice. Of course, how body shape and motion interact to affect perception is also an extremely important question and worthy of further investigation, especially as visual motion and form information are inextricably linked in the brain [Mather et al. 2013], and as body shape is a highly significant cue to attractiveness [Johnson and Tassinary 2007]. However, the goal of this paper is to explore the space of natural body motions only and how this varies across different gaits and by sex. Introducing the confounding factor of body shape would have either invalidated our conclusions, or involved capturing and processing the motion of a much larger database of actors to find similar morphologies to compare. We therefore chose to use realistic virtual characters to display the motions, as this represents the most common scenario in data-driven applications. Point-light walkers are too impoverished for results to be generalizable to realistic scenes, while conversely imparting confounding body-shape details that could still be inferred by the viewer. Using 3D models allowed us to more easily normalize for body shape than would be possible using real videos, for example, while the challenge of recruiting the number of actors needed to exactly match the morphologies of real actors in videos would be prohibitive.

One possible limitation of this research is that, while we took special care to avoid any motion artifacts and interfered as little as possible with the original motion, it may still have been possible that the characters fell into some kind of uncanny valley, or that subtle glitches could have influenced the distinctiveness or attractiveness ratings. To address these concerns insofar as was possible, we very carefully checked each motion clip for any residual artifacts, discarding any unsuitable motions (and actors) from our database. To ensure that high distinctiveness ratings of our motions were actually caused by an actor's distinctive style and not any motion artifacts, we ran a pilot experiment where we carefully cross-checked all the results with videos of the actors' motions. Furthermore, even though we took care to choose actors who were reasonably similar in age and body morphology, it could still have been possible that motions might have been perceived as distinctive or unattractive due to retargeting errors. To check whether this was the case, we computed correlations between the attractiveness/distinctiveness results and several physical parameters specific to each actor (weight, height, overall RMS error between the actor's and the model's segment lengths) and found no evidence of any statistically significant correlation between retargeting error and attractiveness or distinctiveness (Figure 9) for walking or jogging. In the case of attractiveness of female dancing motions only, perceived attractiveness actually slightly increased with higher retargeting errors, a result worthy of further investigation.

Finally, while we had to limit the number of variables to make this experiment tractable, several interesting questions could be further explored. For instance, the original music track was never included when presenting dancing motions in order to avoid introducing a confounding factor when comparing with walking or jogging motions, which could possibly affect attractiveness perception. There is already evidence that sound and vision interact in facial attractiveness perception [Borkowska and Pawlowski 2011], and that both musical and body information convey information about tension and emotion in dance performances [Krumhansl and Schenck 1997]. It is also important to note that the results presented in this paper might depend on the particular frontal view chosen to present the characters. While this was a reasonable choice for this first set of experiments, future studies could explore how results might differ for other viewpoints (e.g., jogging motions might be more attractive from a side view, where the similarities between walks and jogs might also become more obvious).

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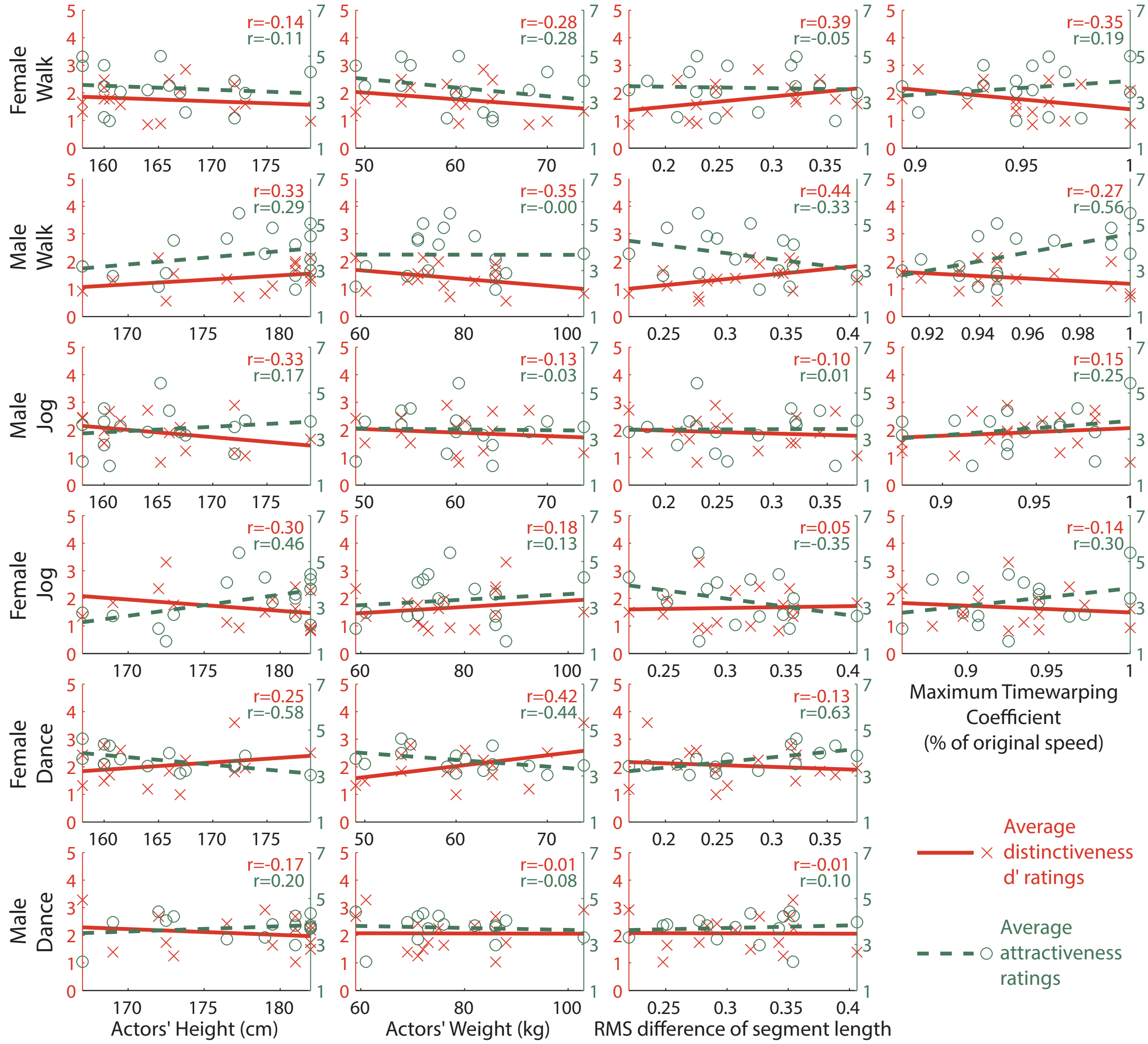

Figure 9: *Distinctiveness d' (red) and Attractiveness ratings (green) versus physical parameters (height, weight, overall RMS error with model's segment lengths) of the different actors used in these experiments. Weight and height for average actors are averages of the corresponding male/female actors. Correlation r values are indicated with each graph.*

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