Dissociating gait from static appearance: A virtual reality study of the role of dynamic identity signatures in person recognition

Noa Simhi[1] and Galit Yovel[1,2]

[1] The School of Psychological Sciences and [2] The Sagol School of Neuroscience, Tel-Aviv University, Tel-Aviv 69978, Israel

Correspondence regarding this manuscript should be addressed to:

Galit Yovel and Noa Simhi

School of Psychological Sciences & Sagol School of Neuroscience

Tel Aviv University

Tel Aviv, 69978, Israel

Email: gality@post.tau.ac.il, simhinoa@gmail.com

Tel: 972-3-640-5474

Fax: 972-3-640-9547

Abstract

Studies on person recognition have primarily examined recognition of static faces, presented on a computer screen at a close distance. Nevertheless, in naturalistic situations we typically see the whole dynamic person, often approaching from a distance. In such cases, facial information may be less clear, and the motion pattern of an individual, their dynamic identity signature (DIS), may be used for person recognition. Studies that examined the role of motion in person recognition, presented videos of people in motion. However, such stimuli do not allow for the dissociation of gait from face and body form, as different identities differ both in their gait and static appearance. To examine the contribution of gait in person recognition, independently from static appearance, we used a virtual environment, and presented across participants, the same face and body form with different gaits. The virtual environment also enabled us to assess the distance at which a person is recognized as a continuous variable. Using this setting, we assessed the accuracy and distance at which identities are recognized based on their gait, as a function of gait distinctiveness. We find that the accuracy and distance at which people were recognized increased with gait distinctiveness. Importantly, these effects were found when recognizing identities in motion but not from static displays, indicating that DIS rather than attention, enabled more accurate person recognition. Overall these findings highlight that gait contributes to person recognition beyond the face and body and stress an important role for gait in real-life person recognition.

1. *Introduction*

In daily life we typically recognize people based on the whole, moving person. When walking down the street we may spot a friend, even from a distance, or may recognize a professor walking up to the front of class while sitting at the back seats of a large auditorium. In many real-life situations, we see people from a certain distance, recognize them, and then may approach them to have a conversation. Nonetheless, most experiments on person recognition depict a very different setting, consisting of static faces, captured from a close distance, appearing and disappearing on a computer screen. While this situation is reminiscent of recognizing a friend on a social media website, for example, it is very different from the way we recognize people in real life (see Shamay-Tsoory & Mendelsohn, 2019 for a recent review on ecological research paradigms).

Studies have long investigated the role of motion in face recognition, showing contributions of motion to the perception of form and as a cue within itself under different conditions (Christie & Bruce, 1998; Knappmeyer, Thornton, & Bülthoff, 2003; Lander & Bruce, 2003; O'Toole & Roark, 2010; O'Toole, Roark, & Abdi, 2002; Xiao et al., 2014, see also for object recognition Newell, Wallraven, & Huber, 2004). It is only relatively recently that studies have begun to use dynamic, whole person stimuli to investigate the role of body and body motion in person recognition. In one of the pioneering studies, O'Toole et al., 2011 examined the contribution of the face and body to whole person recognition in static and dynamic displays, demonstrating that whole person recognition is better than recognition from the face alone, but only in dynamic person recognition. In a later study, Hahn, O'Toole, & Phillips, 2015 further showed that the dynamic body contributes to person recognition beyond the face, primarily when recognizing people from a distance (for review see Yovel & O'Toole, 2016). When examining the whole, dynamic person, however, it is important to take into account that motion can contribute to person recognition through two main sources of information: dynamic identity signatures or form-from-motion perception (see O'Toole, Roark, & Abdi, 2002 for a detailed description in the context of dynamic face recognition). Dynamic identity signatures are idiosyncratic motion patterns of an individual, which can be used to recognize them – a famous example is Charlie Chaplin's unique walking style. Similarly, a limp or a particular swinging of the arms while walking are possible examples of dynamic identity signatures. The second type of information is extracted from form-from-motion processes. Form-from-motion processes were extensively discussed in the object recognition literature (see for example Koenderink, 1986 and Ullman, 1979 on how these computations may take place in human perception). In the context of the whole person they refer to the additional information about body form that can be extracted from motion. To disentangle between the contribution of dynamic identity signatures and form-from-motion information to person recognition, Simhi & Yovel, (2016) asked participants to learn the identity of people from a video or a static image. Recognition was then performed from a static image to examine the role of form-from-motion perception, or from a video to examine the role of dynamic identity signatures. Results showed better recognition of a static whole person following exposure to a dynamic as compared to a static person. No such effect was found for recognition of dynamic people (Simhi & Yovel, 2016). These findings indicate that form-from motion perception rather than dynamic identity signatures contributed to dynamic person recognition (see also Robbins & Coltheart, 2015).

Nevertheless, previous studies that used point light displays (first introduced in Johansson, 1973) do indicate that dynamic identity signatures are used for person recognition. Point light displays are created by attaching LED lights to the major joints of a person's body and filming them while they perform varied actions. The resulting videos are then edited to include the points of light alone, which creates displays in which motion is the primary cue which is available in person recognition. Many studies using point light displays have demonstrated that person recognition from motion is possible when recognizing friends and relatives or familiarized individuals for example (Cutting & Kozlowski, 1977; Hill & Pollick, 2000; Jacobs, Pinto, & Shiffrar, 2004; Loula, Prasad, Harber, & Shiffrar, 2005; Troje, Westhoff, & Lavrov, 2005), even though the accuracy of person recognition varied greatly between these studies and was often quite low. Thus, the lack of contribution of dynamic identity signatures to person recognition in the aforementioned studies (Simhi & Yovel, 2016 and Robbins & Coltheart, 2015) may be due to the fact that these tasks examined unfamiliar person recognition, while dynamic identity signatures may take time to learn and may therefore be especially useful in familiar person recognition. Indeed, Simhi & Yovel, 2017 and Robbins & Coltheart, 2015 revealed that for full light videos, recognition was better for dynamic as compared to static stimuli following familiarization with the dynamic whole person, indicating that dynamic identity signatures contribute to familiarized person recognition. Familiarity is therefore one of the factors that determines whether or not dynamic identity signatures are used for person recognition.

Most previous studies that examined the specific role of dynamic identity signatures in person recognition have presented videos of people in motion (e.g.

Robbins & Coltheart, 2015; Simhi & Yovel, 2016, 2017). Whereas the usage of these stimuli is a step forward relative to the study of static images, there are several limitations to these video stimuli as well. One main limitation of these stimuli is that gait is inherent to the person identity and cannot be fully dissociated from static appearance (i.e. the face and body form); an identity will always appear with the same face, body form and gait. Thus, it is impossible to fully separate static appearance from gait when using real-life videos. A second limitation relates to the quantification of the distance of the moving person. As mentioned above, dynamic information may be particularly useful for person recognition from a distance (Hahn et al., 2015). To test this hypothesis, it is necessary to quantify the distance of the identities when they are recognized by participants. Such a task is non-trivial when using naturalistic videos – because different identities walk at different paces and therefore in a given amount of time a faster walker will pass a greater distance than a slower one. Thus, the response times of participants cannot be used as a measure of the distance at which the identities are recognized. Therefore, the actual distance in space should be quantified to measure such an effect. To manipulate distance in static face recognition, previous studies have employed several different methods, such as presenting faces on the screen and varying their size in pixels as well as the distance of the screen from the observer, or blurring the faces to simulate distance (see for example Jarudi & Sinha, 2003; Loftus & Harley, 2005; McKone, 2009). This is, however, still very different from naturalistic situations. Finally, a third limitation of using naturalistic videos relates to the difficulty in creating a proper control condition for examining the role of motion in these videos. To assess the role of motion in person recognition, recognition from dynamic videos is typically compared to recognition from static images, taken from the same videos. Such a control may leave apparent motion effects, due to the fact that the images are extracted from a display which was originally dynamic. It is therefore a challenge to create a control stimulus from these videos which eliminates motion effects.

To overcome these limitations, in the current study we used a virtual environment for the creation of our experimental setting. Recently, such technology has begun to emerge in the field of person recognition, both in the examination of facial motion and the examination of body motion (see for example Cook, Johnston, & Heyes, 2012; Pilz & Thornton, 2017; Pilz, Vuong, Bülthoff, & Thornton, 2011). In most cases this technology has been used to take different motion patterns and apply them to the same static appearance of an avatar, thus eliminating the possibility of using the face and body form for recognition, and examining if the actual motion pattern affects recognition. However, the development of virtual reality also allows us to create more naturalistic person recognition scenarios, which present several important advantages for this study in particular. One such advantage is that static appearances of different avatars can be paired with different gaits in a random fashion, which ensures a complete dissociation between the static elements of person identity (i.e. face and body form) and gait, and allows for the examination of the contribution of the gait beyond the face and body form. This can be done by pairing each avatar's static appearance with different gaits, and presenting these different pairings across participants, such that each participant sees a given static appearance with a given gait, as the case in real life. To examine the contribution of gait to person recognition independent of static appearance, performance is assessed per gait, across participants. A second important advantage is that one can accurately quantify the distance at which an identity is recognized in a virtual environment (in virtual units) as the entire setting is completely controlled. Finally, the virtual environment enables the control of naturalistic variability in factors such as the angle at which an identity appears, their clothes, the background scene etc., while varying these factors when filming naturalistic videos can be highly time consuming and difficult to achieve in a controlled fashion. This environment also allows for the creation of a highly matched control condition, which does not contain residual motion – identities can easily be presented in a standing position and made to appear and disappear at different distances from the observer. The identities can even be dynamic – moving and breathing slightly while still standing, without revealing any cues indicative of the gait motion pattern which is assessed. Thus, using a virtual environment also allows for better and more direct isolation of the role of motion, using carefully crafted controls.

To examine the pure contribution of gait in person recognition we varied gait distinctiveness. As mentioned above, previous studies have found that person recognition based on gait occurs only for familiar or familiarized individuals. Nevertheless, an important factor which may improve recognition of the dynamic whole person, even after a single exposure, is gait distinctiveness. The importance of distinctiveness to person recognition has been demonstrated for faces. Studies with static faces have shown that faces perceived as highly distinct are also recognized more accurately than faces of low distinctiveness (see for example: Cohen & Carr, 1975; Going & Read, 1974; Light, Kayra-Stuart, & Hollander, 1979 and also Valentine, 1991 for a framework examining the origin of this effect). Highly distinct voices have been shown to contribute to unfamiliar face recognition as well, while non-human sounds failed to do so (Bülthoff & Newell, 2015), suggesting that distinct information from different sources is integrated in perception. In addition, studies have examined the contribution of the distinctiveness of facial motion to familiar face recognition (Butcher & Lander, 2016; Lander & Chuang, 2005) and found that there was a greater benefit to recognition in motion when the facial motion was rated as highly distinct, and that familiarity correlated with motion benefit. Accordingly, here we hypothesized that distinctiveness may also contribute to recognition of people based on their gait. In particular, the more distinct a gait is, the more likely it will be used for person recognition – even when the identities are unfamiliar. Furthermore, as mentioned, gait is more likely to be used for recognition when seeing people from a distance, as is the case in many naturalistic situations, where information from the face is less clear (see Yovel & O'Toole, 2016 for a recent review), and this contribution to recognition from a distance may be mediated by distinctiveness as well.

In this study we therefore used a virtual environment set up to examine the independent contribution of gait to person recognition. Each avatar's static appearance (i.e. face and body form) was paired with a different gait across participants. This design was used so a given participant will see the face and body form of a given avatar with only one specific gait, as is the case in real-life settings, but gait can still be dissociated from face and body form by examination of performance per gait across participants. We created an old/new person recognition task in which participants studied identities with gaits of varying levels of distinctiveness, which were determined based on a pre-experiment rating task with an independent group of participants. Participants then recognized these identities in one of two test conditions: a dynamic setting, where dynamic identity signatures from the gait were available for person recognition, or a static, multi-view setting, which contained information about shape and form, but no dynamic identity signatures (see example videos of the stimuli used at: https://osf.io/fzmhy/?view_only=528775c8b3fd46a0878664fb46c03399). The face and body form of each avatar was presented with different gaits across participants. Analysis was performed across gaits according to their distinctiveness, and as a function of the accuracy at which they were recognized and their recognition distance. In this manner we examined if distinct dynamic identity signatures contribute to person recognition, by assessing if greater gait distinctiveness predicted greater accuracy in recognition, in the dynamic but not multi-static view condition. By comparing performance between dynamic and static test stimuli, we could also rule out the possibility that increased attention to the distinct gaits during the study phase improved recognition of identities with distinct gaits. Furthermore, this setup enabled us to quantify the distance at which the identities were recognized, in virtual units, and examine if the distance of person recognition could be predicted by gait distinctiveness. We hypothesized that accuracy in person recognition and the distance at which a person is recognized will vary as a function of gait distinctiveness.

2. Methods

2.1 Participants

Fifty-two participants took part in the study. Two participants were excluded from analysis: one due to a technical error during the experiment and one due to a misunderstanding of the experimental instructions. The final study group therefore included fifty participants (mean age = 22.78, SD = 2.84, 41 female) – 25 participants who participated in the dynamic test condition and 25 who participated in the static test condition. All participants were recruited at Tel Aviv University and took part in the experiment in exchange for course credit. All participants had normal or corrected-to-normal vision and gave their informed consent to participate in the study by signing the appropriate consent form approved by the Tel Aviv University ethics committee.

2.2 Stimuli

The stimuli in the experiment were created using Vizard (WorldViz). The stimuli consisted of virtual identities, which approached the participant, with different gaits and in different background scenes. Each participant viewed 20 identities – 10 'old' identities which appeared in both the study and test phase, with different sets of clothes, and 10 novel identities, which appeared in the test phase alone. For each participant, each avatar figure was paired with a unique gait. We use the term figure to refer to the static appearance (i.e. the face and body form) of the avatar. The term identity refers to a gait-figure pairing in the dynamic condition or to the figure alone in the static condition. The gait-figure pairings of each avatar varied on a between-participant level, with analysis conducted per gait, across participants, thus allowing for the dissociation between these two factors. Different background scenes were presented during the study and test phases. Example stimuli of the same avatar figure presented with 4 different gaits of different distinctiveness levels (each presented to a different participant) and examples of the same avatar in a dynamic and static test phase can be found in this link: https://osf.io/fzmhy/?view_only=528775c8b3fd46a0878664fb46c03399.

The selection of the avatar figures, gait and background scenes, as well as the display mode is detailed below.

2.2.1 Avatar Figures

A pool of 24 (12 female) Caucasian avatar figures that differ in their face and body form were selected for the experiment from the WorldViz Vizard Complete Characters library. 20 of these figures were selected for each participant semi-randomly (ensuring a 10:10 female:male selection). Each figure was semi-randomly assigned to a gender congruent gait (as detailed below). Of the 20 figures selected per participant, 10 figures were selected to be included in the study phase. Each of the figures in the study phase was presented with the same gait in the test phase as well. Each studied figure was also fitted with two different sets of clothes – one which appeared during the study phase and one during the test phase.

2.2.2 Gait selection and presentation

To assess gait distinctiveness, 13 gaits were selected for each gender from the available Vizard avatar walking styles, and were rated in a preliminary experiment:

The experiment was conducted online for course credit, with 16 independent participants (mean age = 23.12, SD = 1.59, 14 female) with normal or corrected-to-normal vision who signed the appropriate consent form approved by the Tel Aviv University ethics committee. The participants viewed each identity approaching them from a distance in separate stimuli depicting each of the available gaits (312 trials in total). For each stimulus they rated the distinctiveness of the gait on a scale of 1-7 (1 being non-distinct and 7 being highly distinct).

Based on these ratings, we determined the mean distinctiveness of each of the gaits and included in the experiment gaits of varying distinctiveness ratings (see Supplemental Materials for the distinctiveness of the gaits in the experiment and the duration for which they were displayed). We selected 20 gaits, leaving out 6 gaits (3 per each gender), which could not be paired according to the criteria described below:

To create a similar distribution of gaits between the studied and novel identities in the experiment, we grouped the gaits by rating and gender into pairs and randomly allocated one gait in each pair to the study and the other to the test phase, to be presented as a novel gait. For example, a pair could be two male gaits with ratings of 6.35 and 6.59, in which case we would ensure that one of these gaits was used as the gait of an identity at study and one was used as the gait of a novel identity presented at test (see Supplemental Materials for the pairings of the gaits in the experiment).

In two cases where there were relatively large differences between the ratings within a pair of gaits (~0.8 points in rating), we first assigned the gaits to study/test randomly within one of the pairs. Then, if the gait with the higher rating was randomly selected for study in the first pair, we selected the gait with the lower rating for study in the second pair, and vice versa. In this way we ensured a similar distribution of gait distinctiveness in the study and novel stimuli in the experiment.

In both dynamic and multi-static view test conditions, gaits were selected and the identities were displayed in the study phase in the same manner, which depicted the dynamic identity approaching the participant at an angle (see Figure 1).

At test, identities approached the participant directly in the dynamic test condition (see Figure 1). In the multi-static view test condition, the identities appeared and disappeared at 8 different decreasing distances from the participant, every 1.54 virtual units. The identities remained for 1.2 seconds at each point, with 0.3 seconds between each appearance. At each point the identity stood, looked around, inhaled etc. but did not display the gait which was studied in the study phase (see an example of such a stimulus – test_multi_static.mp4 at: https://osf.io/fzmhy/?view_only=528775c8b3fd46a0878664fb46c03399).

All analyses in this experiment were conducted per gait, averaged across participants. Therefore, to determine if the 20 gaits included in this experiment were sufficient for analysis, we collected data from 8 participants (who did not take part in the main experiment), in the dynamic test condition. We predicted the accuracy of person recognition based on gait distinctiveness in the sample group (see the Data Analysis section for more details on how this model was created). This model was significant at $R^2_{adj} = .23$ $p = .02$, and therefore we used the same design with the set of 20 stimuli for the current study that did not include these 8 participants.

2.2.3 Background Scene

Two different background scenes were created for the experiment, using Vizard (WorldViz) and SketchUp (Trimble Inc.). The first scene was used during the study phase of the experiment and included identities approaching the participant at an angle in an outdoors, urban environment. The second scene was used during the test phase of the experiment and included approaching identities which faced the participant, and appeared in a different outdoors environment. Images of these two scenes can be seen in Figure 1.

Figure 1 ***Example frames from the study and test trials in the experiment***

Static frames from the dynamic study and test trials. The same identity is depicted in both images. As can be seen in the figure, a different background scene was used for the study and test trials, the identities appeared at a different angle, and with a different set of clothes.

2.3 Design

The experiment included a study and test phase in an old/new person recognition task. Two different groups of participants were presented with dynamic stimuli in the study phase, but were allocated to either dynamic or multi-static presentation during the test phase. During the study phase the participants in both of the groups were exposed to each one of the studied identities once. During the test phase that followed, the participants were exposed to the studied identities (with a different set of clothes, but the same face, body form and gait) along with novel identities. In the dynamic test condition these identities walked towards the participant; in the multi-static view test condition these identities appeared and disappeared at different distances from the participant. The participants were asked to determine for each identity whether he/she had appeared in the study phase or not. Each decision was followed by the display of a 1-7 confidence scale, on which the participants were asked to rate their confidence in the recognition decision they had made.

2.4 Apparatus and Procedure

The experiment was presented using Vizard (WorldViz) on a Samsung SyncMaster SA950, Full HD, LED monitor with a 1920 × 1080 screen resolution, in front of which the participants were seated at a comfortable distance of approximately 60 cm.

The old/new task in the experiment included a study and a test phase:

Study Phase – The design and procedure in the study phase were similar for both the static and dynamic test groups. During the study phase participants studied 10 identities (5 women) who appeared sequentially, each with a unique gait. Participants were instructed to study the identities which were presented in the study phase. They were informed that the identities would appear with a different set of clothes in the test phase and therefore they should not rely on clothes for recognition.

Each identity appeared at a distance and approached the participant at an angle before disappearing from sight. After the identity disappeared a new one appeared and approached in the same manner. Each identity was visible for a different amount of time depending on the gait (see Supplemental Materials for the display time of each of the gaits, according to distinctiveness).

Test Phase – During the test phase participants viewed 20 identities (10 women), half of which were presented during the study phase and half novel. The identities from the study phase appeared in the test phase with a different set of clothes, but had the same face, body form and gait as appeared in the study phase. The gaits of the novel identities in the test phase were matched in distinctiveness to those of the identities in the study phase, as described in the Stimulus section. In the multi-static test condition, the identities appeared and disappeared at 8 different distances from the participant (every 1.54 virtual units), and stood still at each point, hence no gait information was available for recognition.

The test phase was presented in a different scene from that in the study phase, and the identities approached the participants directly at test, and not at an angle (as depicted in Figure 1). In the dynamic condition the identities appeared at a distance from the participant and gradually approached. In the multi-static condition, they appeared and disappeared at decreasing distances from the participant. The closest point at which the identities appeared in the multi-static view condition was at the same distance as the closest viewing point in the dynamic condition. The participants could make a recognition decision anytime during the trial, which would cause the identity to disappear from the screen. If a decision was not made before the identity reached the participant (in virtual space), the identity would disappear and the experiment would pause until a decision was made.

After the recognition decision, a confidence scale of 1-7 appeared on the screen and participants were asked to rate their confidence in the recognition decision, 1 being not confident at all and 7 fully confident. After the confidence response, the scale disappeared and the next trial began.

2.5 Data Analysis

We performed several analyses for assessing the contribution of distinct dynamic identity signatures from gait to person recognition. First, we examined the relation between the accuracy of person recognition and gait distinctiveness. To do so, for each gait, we calculated the proportion of correct responses for that gait, across the different participants. For example, if in the dynamic condition only 5 out of 25 participants responded correctly (e.g. ‘yes’ if the identity was studied and ‘no’ if the identity was novel) when viewing a certain gait – the accuracy of recognition of that gait would be 5/25 = 0.2. In this manner we computed a measure for the accuracy of person recognition, per gait. It is important to note that in multi-static trials, all identities were presented without any gait during the test phase, as described above. To calculate accuracy in person recognition per gait in multi-static trials we used the following strategy: for studied identities the gait distinctiveness in multi-static test trials was determined based on the gait distinctiveness in the study phase. For novel identities, each of the avatar figures in the multi-static test condition was pre-assigned to a particular gait, in the same manner as the dynamic trials (as detailed in the Stimulus section), even though this gait was not shown in practice. These pre-assigned novel trials were then used to calculate accuracy of recognition per gait in the multi-static test condition.

To assess if gait distinctiveness predicts person recognition in dynamic but not static recognition, the accuracy of person recognition was computed across participants per gait, and a linear regression model was used to predict the accuracy of person recognition according to the gait distinctiveness, in dynamic and multi-static test conditions. Such an effect would indicate that dynamic identity signatures contribute to person recognition, and that their contribution increases with distinctiveness. In addition, a contribution of distinctiveness to the accuracy of person recognition in dynamic but not static recognition conditions would indicate that the contribution of distinctiveness to person recognition does not result from an increase of attention to distinct stimuli in the study phase, but is rather due to their use during the recognition phase.

We also assessed whether gait distinctiveness would predict the distance of person recognition, and in particular, if higher gait distinctiveness would also enable recognition at a greater distance. We used linear regression to predict the distance from the participant (in virtual units) at which the identities were recognized according to gait distinctiveness. The scale for the measure of the distance of person recognition was 0 (the point closest to the participant) to 12.62 (the distance from the participants at which the identity appeared, in virtual units). Responses which were made after the identity reached the closest point and disappeared from the screen were considered 0 virtual units. The mean distance at which identities were correctly recognized was calculated separately for each of the gaits in the experiment, across participants; i.e. the distance of recognition was averaged across participants, per gait. We again created separate linear regression models for recognition in the different test conditions (dynamic vs. multi-static views).

In addition to examining the relationship between gait distinctiveness and the proportion of correct responses and distance of recognition, we also directly examined whether identities with gaits that are recognized more accurately, are also recognized at greater distances. In other words, we assessed the efficiency of recognition, that is the relationship between the distance and accuracy of the response. To examine this, we assessed the proportion of correct responses per gait, as detailed above, and assessed, using linear regression, whether accuracy predicted the distance of recognition. Distance of recognition was assessed in the same manner as described above, per gait, across participants by averaging the distance on correct recognition trials. Importantly, we assessed whether this effect was fully mediated by gait distinctiveness by examining if accuracy had an independent contribution to the prediction of the distance of recognition, beyond gait distinctiveness. We did so by comparing the model predicting distance of recognition based on gait distinctiveness alone with a multiple linear regression model predicting distance of recognition using both gait distinctiveness and accuracy.

Another measure we used was response times (RTs). It is important to note that even though RTs and the distance of person recognition are related, walking speed is a critical mediator between these measures. If, therefore, distance is a critical factor in person recognition, then two identities with different walking speeds would be expected to be recognized at similar distances, but with very different RTs (since identities with slow gaits will take longer to pass the same distance as identities with fast gaits). Overall therefore, if the main contribution of gait distinctiveness to person recognition is enabling person recognition at a distance, we would expect distinctiveness to predict the distance of person recognition but not the RTs. To assess this, we measured the average RT for each gait, across participants, on correct trials. We then used linear regression to examine if gait distinctiveness was predictive of RTs, in dynamic and multi-static recognition conditions.

Finally, we examined the confidence ratings when recognizing identities with different gait distinctiveness. Confidence ratings were scaled to a scale of 1-7 per each participant. We used linear regression to assess if the confidence ratings, on correct trials, were predicted by gait distinctiveness in dynamic and multi-static recognition conditions. In this case as well, confidence ratings were calculated per gait, across participants.

Due to the high correlation between study display time and gait distinctiveness (.46), in cases where significant effects of gait distinctiveness were found we assessed if gait distinctiveness was the source of the effect regardless of study display time. We did so by comparing a model in which study display time is the only predictor with a model in which both study display time and gait distinctiveness were used for prediction. This enabled us to assess whether gait distinctiveness has an independent contribution, beyond study display time to person recognition. We report these results within each of the relevant sections.

P-values were corrected for multiple comparisons using the Holm method (Holm, 1979).

Trials with RTs more than three standard deviations from the mean were excluded from all analyses, per each participant.

Statistical analysis was performed in RStudio and JASP (Version 0.10.0).

3. Results

3.1 Accuracy

To examine if the accuracy of person recognition was influenced by gait distinctiveness, we calculated the proportion of correct responses for each gait, averaged across participants, as detailed in section *2.5 Data Analysis*. Next, to assess if gait distinctiveness affects the accuracy of person recognition, we used linear regression to model the proportion of correct responses based on gait distinctiveness in the different test conditions. We found that gait distinctiveness was a significant predictor of the proportion of correct responses in the dynamic test condition ($F(1,18) = 15.34$, $p = .002$, $R^2_{adj}=.43$), and recognition improved as a function of gait distinctiveness. There was no such relation in the multi-static test condition ($F(1,18) < 1$, $p = .93$, $R^2_{adj}=-.05$). These results can be seen in Figure 2. P-values are reported after Holm correction for two comparisons.

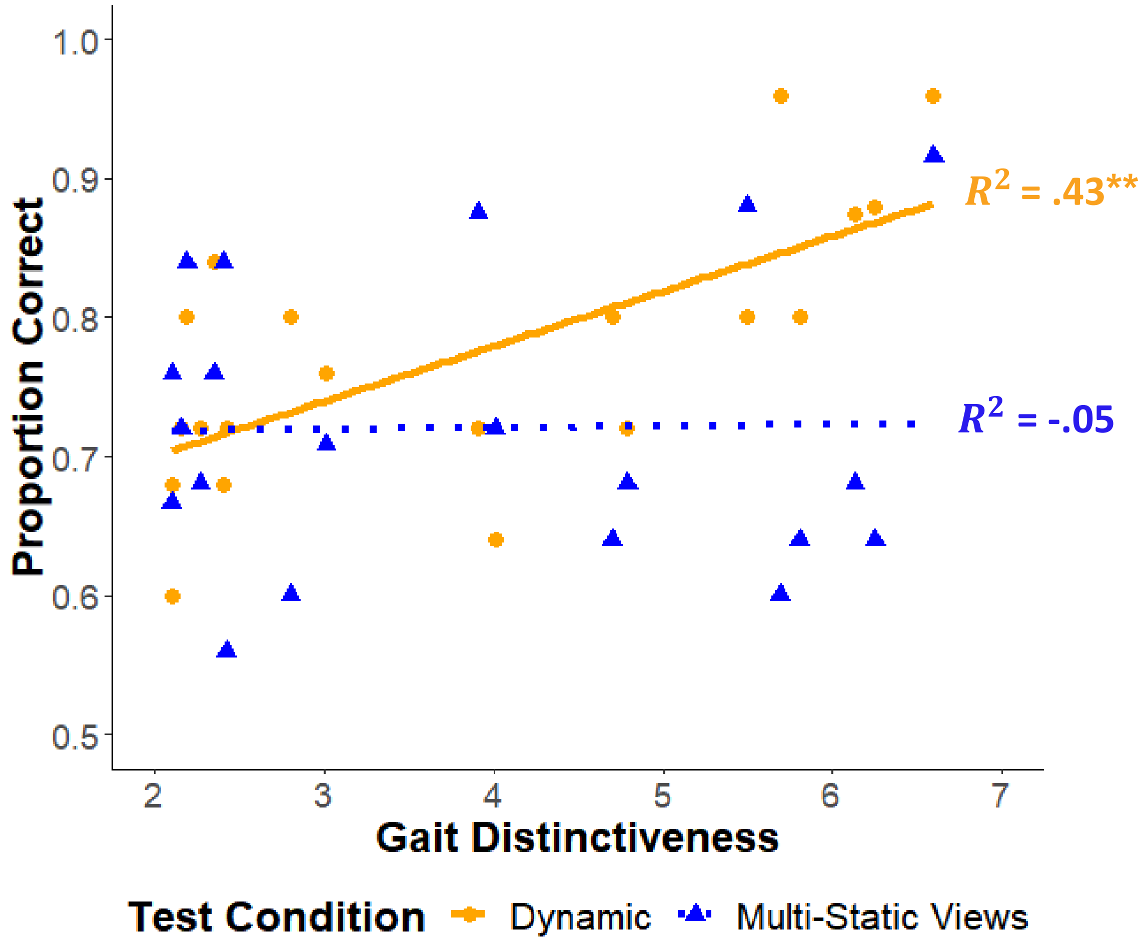

Figure 2 ***The relationship between the proportion of correct responses and gait distinctiveness***

*Gait distinctiveness was used to predict the proportion of correct responses in the dynamic and multi-static view test conditions. Each dot represents the proportion of correct responses per gait, averaged across participants (participants were presented with different static appearances per gait). Gait distinctiveness predicted the proportion of correct responses in the dynamic, but not multi-static view conditions with the proportion of correct responses increasing with gait distinctiveness. ** - p < .01*

Correlation analysis showed that study display time was associated with gait distinctiveness (r = 0.46). To assess whether gait distinctiveness contributed significantly beyond study display time, we conducted model comparison between a linear model for prediction of the proportion of correct responses based on both study display time and gait distinctiveness (F(2,17) = 8.75, p < .01, R^2_{adj}=.45), and a linear model performing the same prediction based on study display time alone (F(1,18) = 6.15, p = .02, R^2_{adj}=.21). Model comparison revealed that gait distinctiveness contributed to the prediction of the proportion of correct responses beyond study display time (F(1,17)=8.71, p<.01). This indicates that even though study display time is predictive of the proportion of correct responses, gait distinctiveness contributes independently to dynamic person recognition.

A complementary analysis of *d′* revealed the same pattern of results: gait distinctiveness was a significant predictor of *d′* in the dynamic test condition (F(1,18) = 10.4, p = .009, R^2_{adj}=.33), but not in the multi-static test condition (F(1,18) < 1, p = .66, R^2_{adj}= -.04). A comparison between a model predicting *d′* based on study display time and gait distinctiveness (F(2,17) = 5.63, p = .01, R^2_{adj}=.33) and a linear model predicting *d′* based on study display time alone in the dynamic test condition (F(1,18) = 4.28, p = .05, R^2_{adj}=.15) also revealed that gait distinctiveness contributed to the prediction of *d′* beyond study display time (F(1,17)=5.84, p = .03).

3.2 Distance

We next assessed if the distance of person recognition was predicted by gait distinctiveness. The distance of person recognition was averaged across correct recognition trials, separately for each gait, across participants. Separate models were created for recognition in dynamic and multi-static test conditions. These results can be seen in Figure 3. P-values are reported after Holm correction for two comparisons. We found that distance of recognition was predicted by gait distinctiveness in the dynamic test condition (F(1,18) = 19.4, p < .001, R^2_{adj}= .49) but not in the static test condition (F(1,18) = .1.96, p = .18, R^2_{adj}=.05).

To ascertain that the effect of gait distinctiveness on distance of recognition in dynamic trials was not driven by differences in study display times, we examined whether gait distinctiveness significantly contributed to the prediction of distance of recognition, beyond study display time. We created a model predicting distance of recognition, in dynamic trials, based on both study display time and gait distinctiveness ($F(2,17) = 16.32$, $p < .001$, R^2_{adj}=.62). We then compared it to a linear model predicting distance of recognition based on study display time alone ($F(1,18) = 14.06$, $p = .001$, R^2_{adj}=.41). Model comparison between these two models, revealed that gait distinctiveness significantly contributed to the prediction of distance of recognition in dynamic trials, beyond study display time ($F(1,17) = 10.87$, $p = .004$).

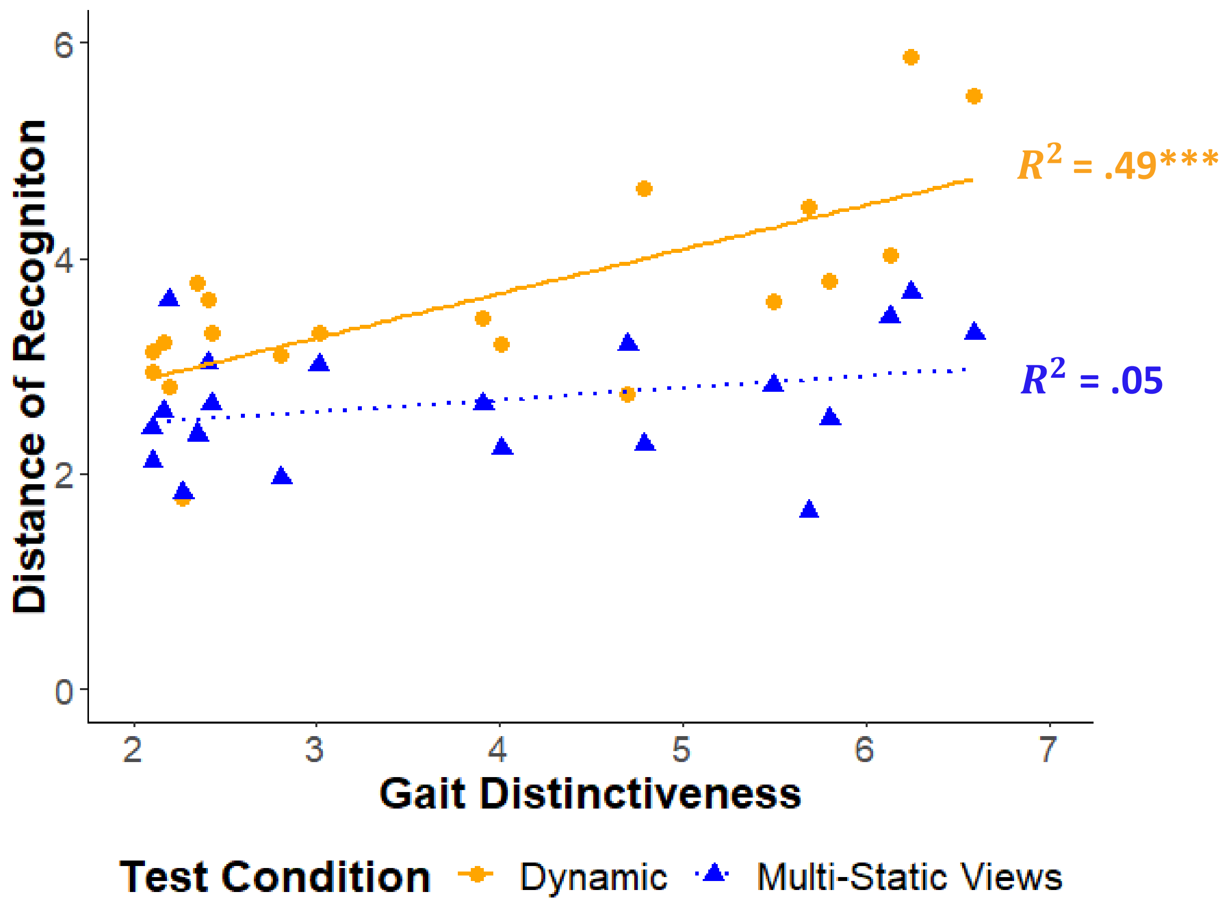

Figure 3 ***The relationship between the distance of person recognition and gait distinctiveness***

*Gait distinctiveness was used to predict the distance at which recognition was performed. Each dot represents a different gait, averaged across participants (participants were presented with different static appearances per gait). The distance of person recognition is measured in virtual units, (see Methods section 2). *** - p < .001*

Taken together, these findings indicate that identities with distinct gaits were recognized from a greater distance. Furthermore, this relation was present only in the dynamic test condition, and cannot be explained by differences in display time during the study phase. This shows that identities with highly distinct gaits are recognized at greater distances than identities with low distinctiveness gaits and that this decision is based on the use of the motion information – that is the dynamic identity signature.

3.3 *Efficiency of Recognition*

The findings presented so far indicate that distinctiveness predicted both the accuracy as well as the distance of recognition. A relationship between distance and accuracy, provides a measure of recognition efficiency (similar to a relationship between accuracy and reaction time). Indeed, accuracy predicts the distance of recognition in the dynamic test condition (F(1,18) = 10.06, p = .01, R^2_{adj}=.32) but not in the multi-static view test condition (F(1,18) = 2.40, p = .14, R^2_{adj}=.07) (P-values are reported after Holm correction for two comparisons). We asked however, whether this relationship exists beyond gait distinctiveness or is fully mediated by it. To that effect, we created linear models for the prediction of the distance of recognition based on both accuracy and gait distinctiveness for dynamic (F(2,17) = 10.03, p = .001, R^2_{adj}=.49) and multi-static recognition conditions (F(2,17) = 2.28, p = .13, R^2_{adj}=.12). We compared these models to the models predicting the distance of recognition based on gait distinctiveness alone, which were presented in Section 3.2. Model comparison revealed that accuracy did not contribute to distance of recognition beyond gait distinctiveness, in the dynamic (F(1,17) < 1) or multi-static conditions (F(1,17) = 2.44, p = .14). **Error! Reference source not found.** shows the relationship between accuracy, distance of recognition and gait distinctiveness (indicated by the size of the dots), showing that more distinct gaits are associated with higher accuracy and larger recognition distance in the dynamic but not the static condition.

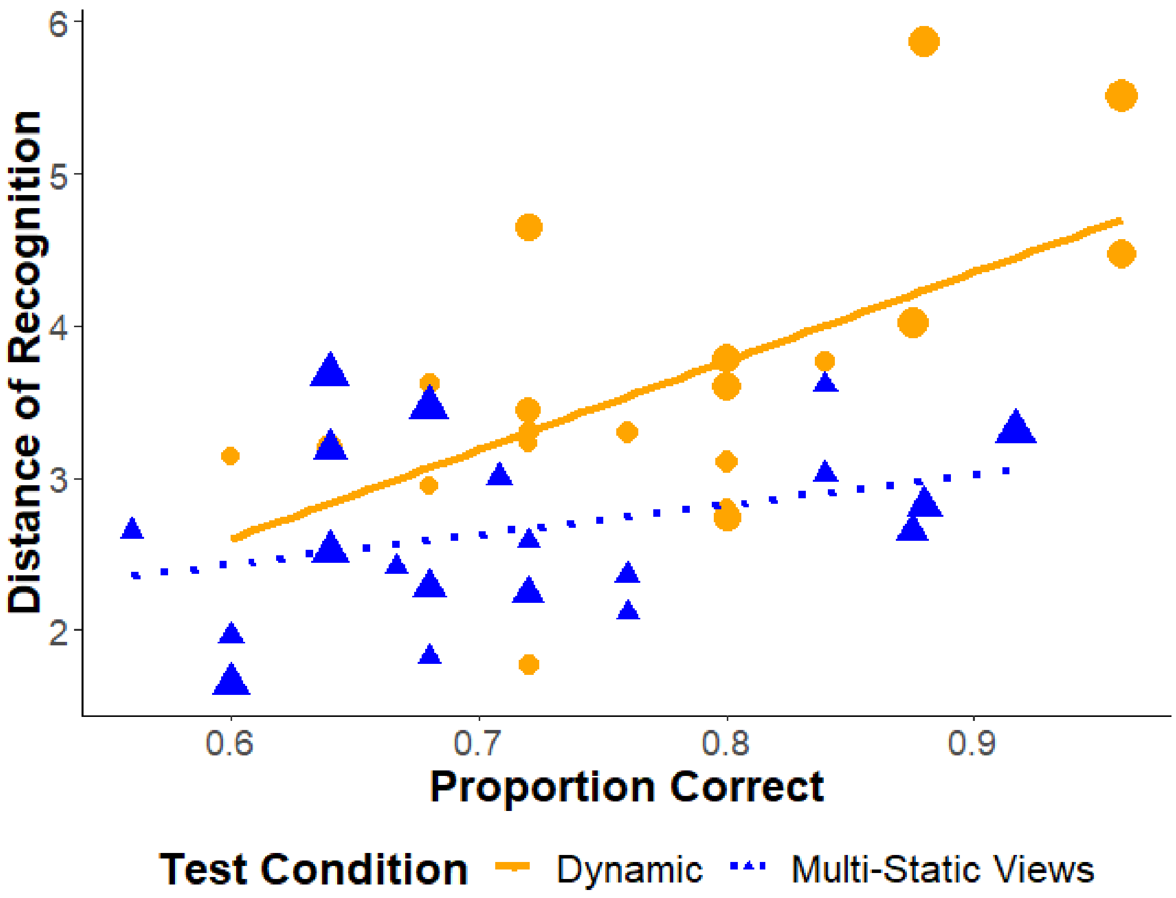

Figure 4 ***The relationship between distance of recognition, accuracy and gait distinctiveness***

The scatterplot shows that gaits that were more distinct, as indicated by the size of the dots, with larger sizes indicating greater distinctiveness, were recognized more accurately and at a larger distance for the dynamic but not multi-static condition.

Overall these results indicate that while there is a relationship between accuracy and distance in the dynamic test condition, this relationship is mediated by gait distinctiveness. Thus, identities with more distinct gaits are recognized more accurately and at a greater distance.

3.4 RT

To complement the analysis of distance above, we also analyzed the measure of RTs, in correct trials, and examined if RTs were predicted by gait distinctiveness. As mentioned in the introduction, because distance and walking speed are confounded, RT is not expected to predict person recognition. We found that gait distinctiveness did not predict RTs in both dynamic (F(1,18) < 1, *p* = .57, R^2_{adj}=-.04) and multi-static view test conditions (F(1,18) = 2.64, *p* = .24, R^2_{adj}=.08). P-values are reported after Holm correction for two comparisons.

3.5 Confidence

Finally, we examined whether confidence in correct trials was predicted by gait distinctiveness. We created linear regression models of confidence ratings using gait distinctiveness, for dynamic and multi-static view conditions. We found that gait distinctiveness predicted confidence ratings for both dynamic (F(1,18) = 4.32, *p* = .05, R^2_{adj}=.15) and multi-static view (F(1,18) = 5.78, *p* = .05, R^2_{adj}=.20) test conditions. P-values are reported after Holm correction for two comparisons.

To examine if the effect of gait distinctiveness on confidence was driven by differences in study display times, we examined whether gait distinctiveness significantly contributed to the prediction of confidence ratings, beyond study display time. We did so separately for dynamic and multi-static conditions.

We created a model predicting confidence ratings, in dynamic trials, based on both study display time and gait distinctiveness (F(2,17) = 2.06, *p* = .16, R^2_{adj}=.10) and compared it to a linear model predicting confidence ratings based on study display time alone (F(1,18) < 1, *p* = .47, R^2_{adj}=-.02). This comparison revealed that gait distinctiveness did not significantly contribute to the prediction of confidence ratings in dynamic trials, beyond study display time (F(1,17) = 3.50, *p* = .08).

Next we created a model predicting confidence ratings, in multi-static trials, based on both study display time and gait distinctiveness (F(2,17) = 3.02, *p* = .07, R^2_{adj}=.18) and compared it to a linear model predicting confidence ratings based on study display time alone (F(1,18) = 2.52, *p* = .13, R^2_{adj}=.07). This comparison revealed that gait distinctiveness did not significantly contribute to the prediction of confidence ratings in multi-static trials, beyond study display time (F(1,17) = 3.22, *p* = .09). Taken together, these results indicate that confidence ratings were associated with study display time rather than with gait distinctiveness.

4. Discussion

In this study, we used a virtual environment setting to examine the contribution of gait to person recognition independent of static appearance. We found that gait significantly contributed to person recognition, beyond static information, following a single exposure to the dynamic whole person. In particular, we found that gait distinctiveness predicts the accuracy of person recognition – such that the more distinct the gait, the more likely it is that the identity will be correctly recognized. In addition, we found that gait distinctiveness predicted the distance of person recognition. The more distinct the gait, the greater the distance they could be recognized from. Importantly, gait distinctiveness was predictive of the accuracy and distance of recognition in dynamic but not multi-static recognition conditions. This indicates that the motion pattern itself, that is the dynamic identity signature, was used for person recognition and contributed beyond the static information that was available. Therefore, a highly distinct dynamic identity signature both increases the likelihood of an identity to be recognized, and allows us to recognize that identity from farther away. The fact that no such effects were found in the multi-static test condition further indicates that these results are not due to increased attention to identities with distinct dynamic identity signatures during the study phase, but rather they point to recognition of the dynamic identity signature itself.

It is important to note that these results do not indicate that static information, available in the face and body form, does not contribute to person recognition. As can be seen in Figure 4, the accuracy of person recognition in the multi-static condition was above chance, indicating that a person's static appearance also contributes to person recognition. The distance of recognition did not vary, however, in relation to accuracy when recognition was performed from static images alone. Recognition in the static condition is likely to be based only on static information from faces, since previous studies have shown that recognition is based more on the face rather than the body as distance decreases (Hahn et al., 2015). Furthermore, experiments regarding face recognition suggest that there is an optimal range in which this recognition takes place (see for example McKone, 2009). Overall, these findings indicate that in dynamic conditions gait distinctiveness contributes to person recognition, beyond static appearance, in particular at a greater distance.

A critical novel feature of the current study is the use of a virtual environment to reveal the pure contribution of dynamic identity signatures to person recognition. The use of VR in such studies and in experimental psychology in general is still relatively uncommon (see a recent review on the subject of using virtual reality to study social interactions, for example, which addresses some of the advantages and challenges of this approach: Pan & Hamilton, 2018). The more common method to study the role of dynamic information is real-life videos. These videos are much more realistic than most of the current VR technologies. Virtual reality still does not compare to real-life videos in the realism of the avatars which are available, and in the variability of the motion patterns. This is relevant to this study, in which the same exact gait was used in both study and test, while in real life there is likely to be some variability in motion patterns of the same individual across viewing occasions.

Nonetheless, using VR has some critical advantages as compared to real-life videos: first, a virtual environment enables the control of manipulated variables in a way which cannot be accomplished with dynamic stimuli of filmed individuals. For the purpose of the current study, using a virtual environment allows for the dissociation between the gait and the static appearance of a person, while in real life the form and gait of an identity are two inseparable variables and cannot be fully dissociated to examine the pure contribution of motion to person recognition. A second advantage of using a virtual environment is that new variables, which are highly difficult to explore in naturalistic settings, can be accurately measured. Measuring the distance at which a person is recognized, in the current study, is an example of such a case. To estimate distance in a video one has to apply sophisticated measures, and slight variability, for example in the position of the camera between videos, can strongly affect this calculation. Using VR on the other hand, almost any stimulus related measure can be easily obtained and accurately measured. Finally, using a virtual environment allows for the creation of a highly controlled setting where the experimenter can make sure that any variability inserted into the study is indeed desired. For example – presenting identities in different scenes, different lighting conditions, angles, clothing sets etc. is something which is highly time consuming and difficult to create when relying on real life videos, but is relatively trivial when using a virtual setting. Another advantage of the VR setting is that it enables the creation of a highly precise control, static condition. We created a multi-static control condition in which identities could appear and disappear in a standing position, while performing naturalistic breathing and slight motion characteristic of standing still. The most common control condition for naturalistic dynamic videos is a static image display, which consists of images which are typically taken from the same video and may contain apparent motion effects that are highly difficult to avoid (see for example O'Toole et al., 2011; Simhi & Yovel, 2016, 2017). In this case as well, using a virtual environment offers an efficient solution for this limitation and allows for the creation of more effective and precise control conditions. We therefore suggest that using virtual environments for person recognition studies has many advantages, and we hope that the use of this tool will increase in the near future.

The current study revealed several novel findings. To our knowledge, this is the first time that dynamic identity signatures were shown to contribute to person recognition after a single exposure, as a function of gait distinctiveness. Studies which examined the contribution of motion to unfamiliar person recognition did not reveal a contribution of dynamic identity signatures to the accuracy of whole person recognition in the past (Robbins & Coltheart, 2015; Simhi & Yovel, 2016, 2017). They did not, however, assess the distinctiveness of motion. In addition, even though it has been suggested that the whole body and gait might be particularly important for person recognition at a distance (see Yovel & O'Toole, 2016 for a review), the role of distance has not yet been assessed in a continuous manner. The most extensive study on the subject of whole person recognition at a distance, Hahn et al., 2015, examined dynamic videos of familiarized individuals alone. The current study is the first to directly compare the distance at which recognition is made for dynamic and static stimuli, which enables us to demonstrate the specific contribution of motion to person recognition. Furthermore, to examine the importance of distance in dynamic whole person recognition from naturalistic videos, Hahn et al., 2015 divided the videos into segments and examined person recognition from these segments individually or sequentially. The current study is the first study to directly examine the distance of person recognition as a continuous variable. This effect of distance cannot be assessed using reaction times alone, since identities with different walking speeds will take different amounts of time to pass the same distance. Indeed, studies examining the contribution of motion to person recognition did not reveal RT effects in the past (as was the case in Simhi & Yovel, 2017 for example) and such an effect was not found in the current study as well. Distance of recognition in the current study provides an alternative measure to speed of recognition. Furthermore, the relationship between accuracy and distance of recognition indicates recognition efficiency. Here we found that recognition efficiency was mediated by gait distinctiveness. Thus, identities with more distinct gaits were recognized more efficiently (i.e. – more accurately and at a greater distance).

This study also presents interesting questions regarding the role of distinctiveness and of dynamic identity signatures, which should be examined in the future to fully clarify their contribution to person recognition. For example, as discussed in the introduction, studies have previously examined the contribution of the distinctiveness of different face related measures to person recognition, such as the distinctiveness of the static face, or facial motion pattern (e.g. Butcher & Lander, 2016; Cohen & Carr, 1975; Going & Read, 1974; Light et al., 1979). It would be interesting to examine if the contribution of the distinctiveness of these different sources of information to person recognition is additive, or if the most dominant source takes precedence. For example, would an identity with a highly distinct dynamic identity signature and a highly distinct face be recognized more accurately than an identity with the same dynamic identity signature but a less distinct face? How do these features interact, and how may distance mediate their contributions?

Another question for future research is how consistent are dynamic identity signatures from gait in real life. In the current study, each identity had the exact same gait in the study and test session. In real life however, it is likely that a gait is not exactly the same in all cases, but rather varies slightly on different occasions. Indeed, we recently examined this question using real life videos and found significant correlations between the distinctiveness ratings of the gait of the same identities across videos filmed on different days (Simhi & Yovel, 2020). A third direction for future research, which could easily be enabled by the VR technology used to design this study, is to examine how immersion affects person recognition and in particular the contribution of gait to person recognition. Presenting a similar study to this one in a VR headset, thus creating an immersive environment, could reveal important insights into how person recognition might improve when identities are perceived as more relevant to the observer. The contribution of gait in particular might be greater in an immersive setting. Recent studies have shown that having the observer play an active role in a virtual setting improved face recognition (Bülthoff, Mohler, & Thornton, 2019), which suggests that greater immersion with the scene influences performance. These directions should also be examined in the future, even though technological limitations present challenges for performing a direct comparison in the same conditions between the VR headset display and the computer screen display (which does not suffer, for example, from the mesh-like appearance, known as the "screen door effect", which VR headsets are prone to under certain viewing conditions).

Finally, using a virtual environment one can easily manipulate the same factors in many additional ways, to further validate the findings presented here. For example, the contribution of gait to person recognition can be examined using recognition under ambiguous conditions, similarly to the task in Pilz & Thornton, 2017. In this study, identities were studied with identical bodies, unique faces and unique motion patterns. At recognition, the faces were morphed, and the unique motion patterns were presented. Under these ambiguous conditions, participants were asked to recognize the identities from the study phase. This paradigm can be used to examine the interaction between form and motion by assessing if, for example, more distinct gaits have a greater influence on the recognition decision (i.e. the identity will be recognized based on the gait even when the ambiguous face morph is highly dissimilar to the face with which the gait was studied). While the current study examined recognition under conditions mimicking real life (with each identity appearing with the same face, body form and gait on the within participant level), manipulations such as the one described above will help clarify how static identity and gait perception interact.

In conclusion, in this study we have shown that distinct dynamic identity signatures from gait contribute to person recognition, beyond static information, after a single exposure in two important ways – they allow identities to be recognized more accurately, and at a greater distance. While most studies on person recognition examine conditions which mimic recognition at a short distance, in real life, recognition of the whole person from a large distance may be more common, and therefore the role of dynamic identity signatures in real life may be especially important. Finally, we stress the advantages of using VR in person recognition studies and the many new possibilities it opens up for the field, which has been dominated by stimuli consisting of static images of faces for several decades.

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Supplemental Materials

Gait Pairings:

The table below reports the average and SEM (in parentheses) of distinctiveness rating of each of the gaits used in this study, as well as the study display time of each gait. Each gait is presented alongside with the gait it was paired with in the experiment – as described in section *2.2 Stimuli*. In each pair, one gait was selected to be used as the gait of a studied identity and the remaining gait was used as the gait of a novel identity. In the case of the two pairs highlighted in the table, where there were relatively big differences in the ratings of the gaits in the pair (~.8 points), if the gait with the higher rating was selected for study in the first pair, the gait with the lower rating was selected for study in the second pair. This ensured a similar distribution of gait distinctiveness in study and test stimuli.

Gender	**Gait 1 Rating**	**Gait 1 Display Time**	**Gait 2 Rating**	**Gait 2 Display Time**
Female	2.16 (.19)	9.717	2.1 (.21)	9.67
Male	2.19 (.14)	12.369	2.1 (.17)	8.293
Male	2.35 (.16)	14.373	2.27 (.17)	9.668
Male	2.42 (.21)	9.407	2.41 (.18)	9.288
Female	3.01 (.19)	14.382	2.8 (.19)	14.377
Male	3.91 (.21)	12.445	4.7 (.2)	9.695
Female	4.01 (.21)	14.328	4.79 (.25)	17.157
Female	5.69 (.18)	15.161	5.49 (.22)	8.746
Female	5.8 (.21)	9.656	6.13 (.14)	14.345
Male	6.25 (.18)	17.234	6.59 (.12)	15.235