Assessing the Impact of Hand Motion on Virtual Character Personality

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Designing virtual characters that are capable of conveying a sense of personality is important for generating realistic experiences, and thus a key goal in computer animation research. Though the influence of gesture and body motion on personality perception has been studied, little is known about which attributes of hand pose and motion convey particular personality traits. Using the "Big Five" model as a framework for evaluating personality traits, this work examines how variations in hand pose and motion impact the perception of a character's personality. As has been done with facial motion, we first study hand motion in isolation as a requirement for running controlled experiments that avoid the combinatorial explosion of multimodal communication (all combinations of facial expressions, arm movements, body movements and hands) and allow us to understand the communicative content of hands. We determined a set of features likely to reflect personality, based on research in psychology and previous human motion perception work: shape, direction, amplitude, speed and manipulation. Then we captured realistic hand motion varying these attributes, and conducted three perceptual experiments to determine the contribution of these attributes to the character's personalities. Both hand poses and the amplitude of hand motion affected the perception of all five personality traits. Speed impacted all traits except openness. Direction impacted extraversion and openness. Manipulation was perceived as an indicator of introversion, disagreeableness, neuroticism and less openness to experience. From these results, we generalize guidelines for designing detailed hand motion that can add to the expressiveness and personality of characters. We performed an evaluation study that combined hand motion with gesture and body motion. Even in the presence of body motion, hand motion still significantly impacted the perception of a character's personality and could even be the dominant factor in certain situations.

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General Terms: Human Factors

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1. INTRODUCTION

Developing autonomous animated characters [Hartmann et al. 2002; 2006; Heloir and Kipp 2009; Kopp and Wachsmuth 2004; Neff et al. 2008; Thiebaux et al. 2008] is essential for many emerging applications, ranging from virtual worlds to interactive story systems. For agents to be natural, effective and believable, they must be able to simulate real human interlocutors and convey personality, mood and emotions [André et al. 2000; Mairesse and Walker 2007; Mcquiggan et al. 2008; Piwek 2003; Wang et al. 2005]. Constructing a computational framework for generating expressive agent performance remains an active research problem: modalities like language, gestures, body motion, eye movement and facial expression, as well as their coordinations, have been carefully studied for effective character design. However, little is known about how hand pose and motion can reveal a character's personality. Indeed, due to the difficulty of hand motion collection and generation, hand pose and finger motion of agents have long been neglected.

The "Big Five" model of personality provides a useful framework for synthesizing and evaluating the perception of personality: it has become a standard in psychology and, in recent years, increasingly applied in agent modeling [Badler et al. 2002; Mairesse and Walker 2010; 2011]. Over the last fifty years, researchers have observed correlations between a wide range of verbal and non-verbal behaviors and the “Big Five” traits of Extraversion, Emotional Stability (EMS), Agreeableness, Conscientiousness and Openness to Experience [Mehl et al. 2006; Norman 1963; Pennebaker and King 1999]. Non-verbal spatial attributes such as body attitude, gesture amplitude, motion direction, motion smoothness and fluency, and temporal attributes like gesture speed and response latency have been shown to be key indicators of particular personality traits like extraversion [Neff et al. 2010]. Non-signaling self-adaptors like scratching or rubbing can also reflect the emotional stability of the agent [Neff et al. 2011]. However, the whole picture of how motion variations impact the perception of the entire set of 5 personality traits in the “Big Five” model has never been fully studied. Even less is known about the perception of hand motion, though there is research about reconstructing plausible hand motion.

To our knowledge, this is the first study that examines the associations people make between virtual character hand motion and personality traits. We draw on insights from psychology to guide our research. Based on the relevant literature and previous motion perception work, we identify fundamental hand motion attributes: shape, direction, amplitude, speed, and the existence of manipulation. Shape is the dominant feature for static hand poses, and direction, amplitude and speed are the basic motion attributes that reflect the dynamics of hand motion. Direction corresponds to the two major planes in which the fingers move based on the underlying musculature: spreading movements caused by abduction, and flexion. Manipulation corresponds to self-adaptors (self touches) in [Neff et al. 2011], and for hands, mostly involves movements where fingertips contact each other. Studying hand motion in isolation avoids the combinatorial explosion inherent in the enormous sample space generated by combinations of arm movement, body movement and facial expressions. It thus makes practical controlled studies of hand motion.

We designed a series of perception experiments to understand the personality associations people make based on hand shape and motion. Hand motion data in the experiment was captured from real humans by varying the attributes, and then replayed on a mannequin hand with minimal motion loss. Our first experiment evaluates the five personality ratings for the selected hand poses: fist, flat, rest, spread and touching. Our second experiment investigates dynamic hand motion features. We compare the personality ratings between horizontal hand spreading motion and sagittal flexion motion (*direction*), large motion and small motion (*amplitude*), fast motion and slow motion (*speed*), and determine whether the corresponding motion attributes have an influence on personality perception. Our third experiment examines the effect of finger manipulation. We compare the personality ratings between closed-loop, manipulation motions and open-loop, general spread and flexion motions. The great majority of our tests yield significant results, indicating that people do reliably associate hand shape and motion with personality traits. We thus generalize guidelines for crafting hand poses and motions for characters with particular personalities. An evaluation study explored whether hand pose and motion can still significantly impact the perception of personality in the context of arm gestures and body movement. We generated two motion clips consisting of hand gestures and body motion that were edited to show more or less extraversion, based on [Neff et al. 2010]. To these, we added various combinations of hand movement based on our guidelines. Results consistently show that the hand motion impacted users’ perceptions of character personality, even when they were viewing these full body animations.

2. RELATED WORK

Over the last 50 years, the Big Five model of human personality has become widely accepted in psychology [Funder 1997; Goldberg 1990; Norman 1963], and is starting to serve as a framework for modeling

Table I. Example descriptions associated with the Big Five traits.

	High	Low
Extraversion	warm, gregarious, assertive, sociable, excitement seeking, active, spontaneous, optimistic, talkative	shy, quiet, reserved, passive, solitary, moody, joyless
Emotional Stability	calm, even-tempered, reliable, peaceful, confident	neurotic, anxious, depressed, self-conscious, oversensitive, vulnerable
Agreeableness	trustworthy, friendly, considerate, generous, helpful, altruistic	critical, selfish, judgemental, uncooperative, malicious
Conscientiousness	competent, disciplined, dutiful, achievement striving, deliberate, careful, orderly	disorganized, impulsive, unreliable, careless, forgetful
Openness	creative, intellectual, imaginative, curious, cultured, complex	narrow-minded, conservative, ignorant, simple

linguistic variations [Mairesse and Walker 2011; 2010; 2007; 2008], and gestural variations [Neff et al. 2010; Neff et al. 2011]. It consists of the personality traits: extraversion, emotional stability (EMS, also called by its opposite pole, neuroticism), agreeableness, conscientiousness and openness to experience, where adjectives associated with these traits are listed in Table I.

In the psychology literature, much attention has been paid to the relationship between personality and non-verbal behavior. For example, for the most studied trait, extraversion, the relevant literature shows that extraverts tend to move their upper body forward [Frank 2007; North 1972; Lippa 1998; Mehrabian 1969], have a broad posture [Lippa 1998; Knapp and Hall 1978], use a closer interaction distance rather than the turning away attitude of introverts [Argyle 1988; Mehrabian 1969], and take a free approach to others' space [Isbister and Nass 2000]. They have a higher gesture rate [Lippa 1998; Knapp and Hall 1978; Brebner 1985; Argyle 1988], quick response [Giles and Street 1994; Brebner 1985], faster motion velocity [Knapp and Hall 1978; Riggio and Friedman 1986; Lippa 1998; Brebner 1985], and more smooth and fluent movement [Takala 1953; Riggio and Friedman 1986; Lippa 1998]. Their gestures usually have an expansive style with wider-ranging movements [Argyle 1988; Brebner 1985], with less self-contact [Riggio and Friedman 1986] than introverts, and their gesture directions are outward [Argyle 1988; Takala 1953] and horizontal [North 1972]. Neurotic people, those with low EMS, show tension [Burgoon et al. 1978], reduced fluency [Takala 1953; North 1972], and rhythm disturbance [Takala 1953] in their motion. Their bodies are more distant from other's [Argyle 1988] and they have more self-contact movement [Riggio and Friedman 1986; Argyle 1988]. Compared to extraversion and EMS, less is known about movement correlates of the other 3 personality traits. Based on the psychology literature, there are 6 fundamental attributes for nonverbal behavior as it relates to personality: body pose, gesture direction, amplitude, smoothness, speed and response latency.

Several researchers have confirmed that variations in gesture performance described in the psychology literature also have a significant influence on the perception of agent's personality in the area of Intelligent Virtual Agents (IVAs). Nonverbal, especially gestural, behavior affected perception of agents' extraversion [Neff et al. 2010]. Variation in linguistic extraversion, however, made the largest contribution to perceived extraversion. [Neff et al. 2011] evaluated the impact of nonverbal behavior on agents' EMS by using varied gesture performance and non-signaling self-adaptors. They found that their model of gesture variation had no significant impact on either EMS or agreeableness, but the presence of self-adaptors, motions involving self-manipulation, caused agents to be perceived as more neurotic (less emotionally stable). Follow-up work [Liu et al. 2015] with exaggerated gesture variation did show that people perceive changes in EMS based on gestural performance. [Hu et al. 2015] has examined the effect of gestural and postural variation, and adaptation to the other agent, on perceptions of extraversion when two virtual agents are co-telling a story. This work shows that gestural and postural variation as well as adapation effect user perceptions of extraversion. Recent work [Ruhland et al. 2015] confirms that virtual agents' personality (extraversion, EMS and agreeableness) can be conveyed through eye gaze either using realistic or cartoon models. Other related work shows that characters' rendering style also affects its perceived agreeableness level [Zibrek and McDonnell 2014]. However, none of the perception work included any variation in finger movement, thus the effect of hand motion is still unknown.

Much research has been dedicated to collecting or synthesizing accurate and realistic hand motion, ranging from normal hand poses and motions to dexterous manipulation such as musical instrument performance. Hand animation for virtual characters can be reconstructed from image based [Zhao et al. 2012; Wang et al. 2013], marker based [Kang et al. 2012; Wheatland et al. 2013], and glove based [Wang and Neff 2013; Huenerfauth and Lu 2010; Griffin et al. 2000; Hu et al. 2004; Menon et al. 2003; Steffen et al. 2011] motion capture techniques, or synthesized using physics knowledge [Zhao et al. 2013; Liu 2008; 2009; Ye and Liu 2012], data-driven [Jörg et al. 2012; ElKoura and Singh 2003] or rule-based methods [Zhu et al. 2012]. However, despite all the hand motion acquisition and generation research, little hand motion perception work has been conducted. [Samadani et al. 2011] examined human performance in recognizing affective expressions of hand-like structures, and their follow-up work [Samadani et al. 2013] developed a computational model for generating affective hand movements on anthropomorphic and non-anthropomorphic structures. In [Kessler et al. 1995; Hoyet et al. 2012], perceptual studies mainly examine the fidelity of the hand poses and motions, while [Wang and Neff 2013] added fingertip accuracy evaluation into their survey, but provide no answer to the question of which hand motions are best suited to a character's personality. This motivates our experiments on the impact of variations in hand poses and motions on the perception of personality.

3. STIMULI PREPARATION AND SETUP

3.1 Motion Capture

We use the CyberGlove II [Yazadi 2009] to record hand pose and motion for our experiments. Each glove has 18 sensors measuring rotation angles of the major hand joints, as illustrated in Figure 1. Motions were recorded in real time at 30 FPS.

The captured hand motion was mapped to a kinematic hand model which was previously proposed by [Kahlesz et al. 2004; Griffin et al. 2000; Hu et al. 2004; Turner 2001; Wang and Neff 2013], to minimize motion loss and include more flexible thumb pronation. The kinematic model contains 23 DOFs (Figure 1), which generally matches the real human hand. The glove sensor layout can be mapped to the kinematic hand model, thus most joint rotations are directly reconstructed from the sensor recordings. Some non-measured joint movements, e.g. finger distal interphalangeal (DIP) joint rotations are synthesized using $\theta_{DIP} = \frac{2}{3} * \theta_{PIP}$ [Chou et al. 2000; Kuch and Huang 1994; Lee and Kunii 1995; Pavlovic et al. 1997], and thumb pronation joint rotations, are synthesized from $\theta_{T\_PRON} = a * \theta_{T\_TMC} + b * \theta_{T\_ABD}$, where a and b are constant coefficients [Kahlesz et al. 2004; Griffin et al. 2000; Hu et al. 2004]. We ensure that the link length in the kinematic model is consistent with the size of the hand that performed the motion capture to reduce the retargetting error. Captured hand motions were calibrated through the method of [Wang and Neff 2013] to ensure plausible hand shape for open hand motion and exact fingertip positions for finger manipulation. The final motion clips were rendered on a neutral wooden mannequin hand, using Maya [Autodesk 2012].

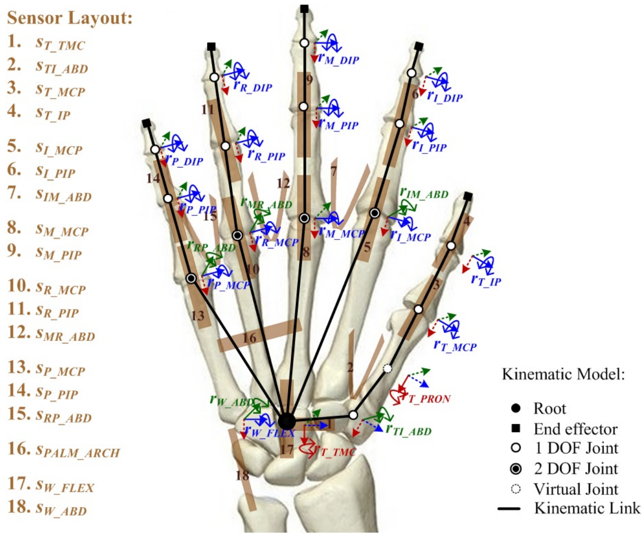


Fig. 1. Glove Sensor Layout and Kinematic Hand Model. 18 sensors are listed and kinematic joints are marked.

All clips were rendered from the same, single camera viewpoint with the camera aimed at the palm of the hand. This was selected to ensure that the hand pose and movement could be clearly seen in the videos. World space orientation was left undefined by not including a body. While we believe subjects made their judgments based on their resulting awareness of the shape of the hand, we have not investigated whether changing the viewing direction might impact their perceptions. This could benefit from further investigation.

3.2 Stimuli and Task

We recorded five hand poses and ten hand motions for our three experiments. While there has been limited specific research on hands, this set of variations corresponds to the types of body movements that have been correlated to personality in the psychology literature, as discussed above. For example, extraverts make larger movements than introverts, so we thought scale was an important mode. Extraverts also make faster movements, so speed was another important mode. Direction corresponds to the musculature of the hand, where most hand movements are dominated by either flexion or abduction, so we considered this was an important factor. The presence of self-adaptors (manipulations) has been reported as correlating with neuroticisim, so seemed like another important mode of variation.

Hand Poses: We select 5 poses for the hand shape experiment: flat - where all the DOF rotations are zeros, fist - where flexions are at maximum amount, spread - where abductions are at maximum

Table II. Quantitative Descriptions of Hand Poses.

Hand Pose	Joint Rotation	Dimension (w x l x d)
flat	appx. flexion = 0, abduction = 0	appx. 9cm x 16cm x 2cm
spread	appx. flexion = 0, abduction = 30	appx. 18cm x 16cm x 2cm
rest	appx. flexion = 30, abduction = 5	appx. 10cm x 12cm x 6cm
fist	appx. flexion = 90, abduction = 0	appx. 9cm x 7cm x 7cm
touching	appx. flexion = 60, abduction = 0	appx. 9cm x 10cm x 6cm

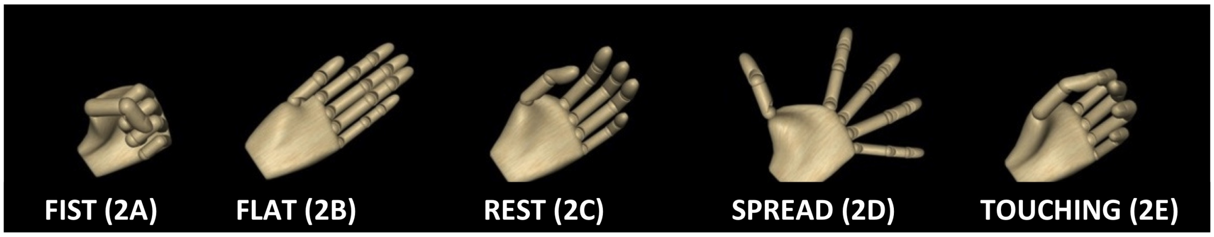


Fig. 2. Five hand poses in our experiments: Fist, Flat, Rest, Spread and Touching.

amount, rest - where the hand is in natural, relaxed state, and touching - where closed-loop contact is included, as illustrated in Figure 2. To be more natural and match a real speaker, we allow a small arm movement while maintaining the static hand pose, thus in the hand pose clip, a common neutral beat gesture in the wrist was imported for all the 5 static hand poses. We provide no context, and were careful to avoid any culturally specific emblematic content in the hand poses (e.g. thumbs up), thus the personality impression is conveyed through basic, low-level hand shapes, and is unlikely to be tied to any higher-level, culturally specific coding. An approximate quantitative description of the major hand joint angles and dimensions for the poses is given in Table II. Each pose clip lasts about 5 seconds.

Open-loop Hand Motions: We formulate three fundamental, dynamic attributes for the hand motion experiment: ***D***irection, ***A***mplitude and ***S***peed. Our notations are in $D_xA_yS_z$ format, where D, A and S indicate the attributes, and x, y and z represent the attribute settings. For each attribute, we explore two extreme cases: sagittal ***f***lexion vs. horizontal ***s***preading for D; ***s***mall vs. ***l***arge for A; and ***s***low vs. ***f***ast for S, totaling 8 motion settings. For each setting, the subject performs the hand motion three times in a row fluently. We do not provide any context information, and make sure that there are no semantic meanings associated with the motion, and thus personality is expressed through the motion itself. The quantitative descriptions of the spatial and temporal measurement of the hand motions are listed in Table III. These clips are about 6$\sim$12 seconds long, depending on the motion speed.

Closed-loop Hand Manipulation: Finger manipulation in hand motion (closed-loop motion) is a

Table III. Quantitative Descriptions of Open Hand Motions.

Motion	Joint Rotation	appx. Amplitude	appx. Speed
$D_fA_lS_f$ (*flexion, large, fast*)	Flexion at finger r_{F_MCP}, r_{F_PIP}, r_{F_DIP}, and thumb r_{T_MCP}, r_{T_IP}	flexion angle: $[10, 100]^\circ$	$70^\circ/s$
$D_fA_lS_s$ (*flexion, large, slow*)	Flexion at finger r_{F_MCP}, r_{F_PIP}, r_{F_DIP}, and thumb r_{T_MCP}, r_{T_IP}	flexion angle: $[10, 100]^\circ$	$20^\circ/s$
$D_fA_sS_f$ (*flexion, small, fast*)	Flexion at finger r_{F_MCP}, r_{F_PIP}, r_{F_DIP}, and thumb r_{T_MCP}, r_{T_IP}	flexion angle: $[10, 45]^\circ$	$40^\circ/s$
$D_fA_sS_s$ (*flexion, small, slow*)	Flexion at finger r_{F_MCP}, r_{F_PIP}, r_{F_DIP}, and thumb r_{T_MCP}, r_{T_IP}	flexion angle: $[10, 45]^\circ$	$10^\circ/s$
$D_sA_lS_f$ (*spread, large, fast*)	Abduction at finger r_{F_ABD} and thumb r_{TI_ABD}	r_{F_ABD}: $[0, 35]^\circ$ r_{TI_ABD}:$[0, 70]^\circ$	$40^\circ/s$ $80^\circ/s$
$D_sA_lS_s$ (*spread, large, slow*)	Abduction at finger r_{F_ABD} and thumb r_{TI_ABD}	r_{F_ABD}: $[0, 35]^\circ$ r_{TI_ABD}: $[0, 70]^\circ$	$10^\circ/s$ $20^\circ/s$
$D_sA_sS_f$ (*spread, small, fast*)	Abduction at finger r_{F_ABD} and thumb r_{TI_ABD}	r_{F_ABD}: $[0, 15]^\circ$ r_{TI_ABD}: $[0, 25]^\circ$	$20^\circ/s$ $35^\circ/s$
$D_sA_sS_s$ (*spread, small, slow*)	Abduction at finger r_{F_ABD} and thumb r_{TI_ABD}	r_{F_ABD}: $[0, 15]^\circ$ r_{TI_ABD}: $[0, 25]^\circ$	$5^\circ/s$ $8^\circ/s$

Table IV. Quantitative Descriptions of General Hand Motion (GNR) and Hand Manipulation (MNP) .

Motion	Dimension (w x l x d)	appx. Amplitude	appx. Speed
GNR	appx. 10cm x 12cm x 6cm	finger flex: $[30, 60]^\circ$ finger abd: $[5, 20]^\circ$	$6^\circ \sim 20^\circ/s$
MNP	appx. 10cm x 12cm x 6cm	thumb flex: $[0, 30]^\circ$ thumb abd: $[30, 45]^\circ$ thumb roll: $[65, 85]^\circ$	$7^\circ \sim 22^\circ/s$

type of self-manipulation designed to correspond to self-adaptors in previous gesture research [Neff et al. 2011]. We hypothesize that finger manipulation should have a similar effect on personality perception, appearing more neurotic. We used a medium motion amplitude and speed to better reflect a normal, general movement. The closed-loop manipulation was captured from a subject when she was in a natural conversational interaction. It is about 8 seconds long, with the thumb tip contacting the index tip, continuously performing the rubbing, scratching motion. To understand the effect of hand manipulation, we designed another control motion, an open-loop general hand motion that includes a combination of flexion and abduction, but no finger contact. We ensured that the two motion clips used similar hand shape, amplitude and speed and their quantitative descriptions are listed in Table IV.

4. EXPERIMENTS

For all the experiments presented in this paper, participants were recruited from Mechanical Turk, and paid for their time. The survey form started with “I see the character who performs the hand pose/motion as...”, followed by each of the terms from the Ten Item Personality Inventory (TIPI) [Gosling et al. 2003]. Subjects provided ratings on a 7-point Likert scale with options ranging from *disagree strongly* (1) to *agree strongly* (7) and personality scores were calculated from these responses. We ran an Analysis of Variance (ANOVA) on the personality ratings, and only consider results to be significant at the 95% leval ($p < 0.05$). Post-hoc analyses were conducted using Tukey tests for comparison of means.

4.1 Hand Pose Experiment

In the hand pose experiment, we explore the effect of hand shape on character’s perceived personality. We made five hand pose clips, as described in Sec 3.2. Each clip displays the whole hand in the center, accounting for about $25\% \sim 50\%$ of the screen, with the palm facing forward, in 640×480. All the clips are rendered using the same view, texture, lighting and other settings, so that the rendering conditions will not influence personality judgements. Our primary hypothesis is that different hand shapes will be perceived as conveying significantly different personalities. We also expect the experimental results to reveal which hand poses are the most/least highly rated for a specific personality trait.

Thirty participants took part in this experiment, [male] 46.1%, [nonnative speaker] 10.3%, [age above 50] 11.5%, [age 40-50] 18%, [age 30-40] 24%, [age 20-30] 44.2%, [age under 20] 2%. First, they were shown the video clip, and then they answered the TIPI questions based on the observed video. The video clips were shown in random order.

4.1.1 *Results.* The detailed results for the hand pose experiment are listed in Table V. Figure 3 illustrates the five personality ratings for all the five hand poses, e.g. it is easy to see that Spread is perceived as strongly indicating both openness and extraversion, and that Fist is strongly associated with disagreeableness (low values on the agreeableness scale).

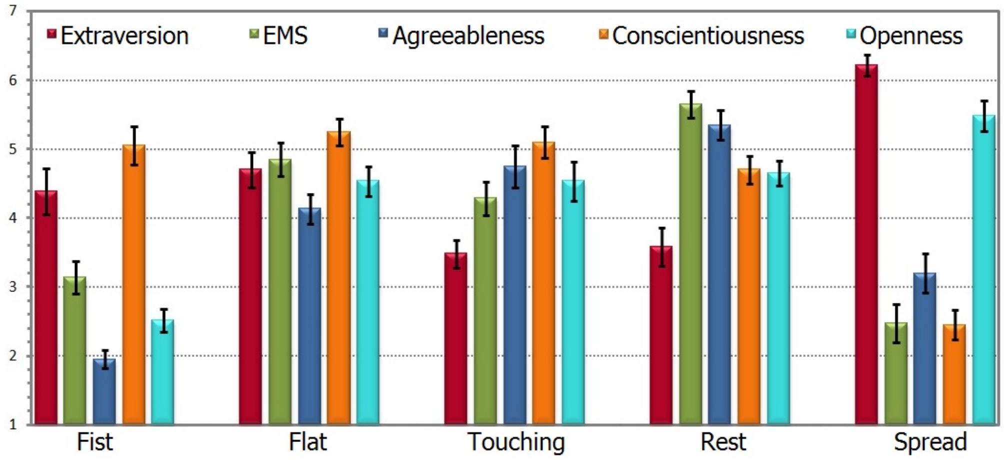


Fig. 3. Personality ratings of the five hand pose clips (horizontal offset within groups provided for readability).

Extraversion

The ratings for extraversion show a significant difference on perceived extraversion among the five hand poses. Based on a 1-way ANOVA, the most extraverted hand pose is Spread, and the least extraverted poses are Touching and Rest. Fist and Flat yield more neutral ratings. The detailed ranking of the extraversion ratings are listed in Table V. These findings are generally consistent with previous research on posture and extraversion: broad posture [Lippa 1998; Knapp and Hall 1978] with less self-contact [Riggio and Friedman 1986] is perceived as more extraverted, which is consistent with the high ratings for spread and the low ratings for the touching pose. The rest pose is also rated low in extraversion, and we think this may be because it is a passively relaxed pose, and the scrunching of fingers adds a sense of shyness, as in the adjectives associated with introversion in Table I.

Emotional Stability

An ANOVA on the five hand poses indicates significant differences in perceived EMS. The most emotionally stable hand pose is Rest, and the least stable poses are Fist and Spread. Flat and Touching have a neutral level of EMS. Rest is the most relaxed hand pose among the 5 poses, which is consistent with the perception of rest as indicating a calm state; both the fist and spread poses express arousal, and are consistent with being anxious or neurotic as expressed by the adjectives associated with low EMS in Table I. The shape of the touching pose resembles the rest pose, but previous research suggests that self-contact expresses neuroticism [Riggio and Friedman 1986; Argyle 1988], consistent with our finding that touching expresses a lower EMS than the rest pose, with a neutral level of EMS.

Agreeableness

An ANOVA on the effect of the five hand poses on perceived agreeableness indicates significant differences. There are several levels of agreeableness: the most agreeable pose is Rest; Touching and Flat are next; Spread is even less agreeable; and the least agreeable pose is Fist. This can be explained as Rest is a relatively more relaxed, comforting pose and thus has the highest ratings. Compared to Rest, Touching expresses more arousal (uneasiness), which lowers its agreeableness. The expansion and aggressiveness of spread could indicate the ability to be critical or judgmental. The fist pose is regarded as uncooperative and quarrelsome, thus the least agreeable. See the adjectives associated with low agreeableness in Table I.

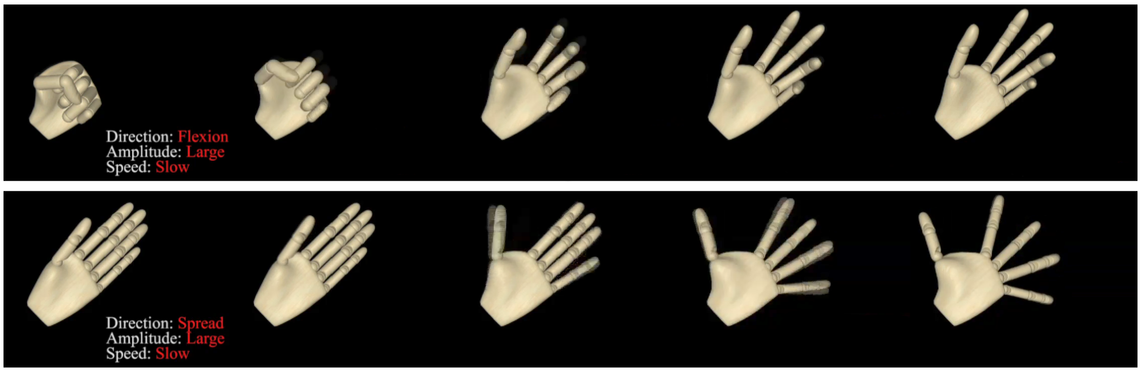


Fig. 4. Ordered left to right, the above figure shows evenly spaced frames from two of the movement animations. The top row shows a large flexion and the bottom a large spread. The movements are repeated several times, in and out, in each clip.

Conscientiousness
The five poses also produce significant differences in perceived conscientiousness. There are only two levels for the five poses: Spread is the least conscientious pose, while Flat, Touching, Fist, and Rest are all significantly more conscientious than Spread. An ANOVA among Flat, Touching, Fist and Rest indicates no significant difference. An interpretation of this is that the spread pose may lead to the perception of impulsiveness or lack of control, while the others can all be seen as disciplined, deliberate and careful, as specified by adjectives associated with conscientiousness in Table I.

Openness
The 1-way ANOVA shows that there is a significant difference in the perceived openness among the five hand poses. Spread is rated as the most open hand pose, and Fist is the least open pose. Rest, Touching and Flat are relatively neutral for their openness. From the perspective of hand shape, spread pose is visually the most open pose among all the poses. Fist gets the lowest openness rating, maybe because visually it is the most closed pose, and it looks relatively stiff and inflexible.

Summary
Along with the detailed results, we can identify three notable hand poses based on this study: Spread, which achieves the most extraversion, the most openness, the least EMS and the least conscientiousness; Rest, which is rated as the least extraverted, the most EMS, the most agreeable and the most conscientious; Fist, which is rated as the least EMS, the least agreeable and the most conscientious. We also find a neutral hand pose: Flat, where the means of its five personality ratings are all around neutral, within range [4.1, 5.3], and based on the ANOVA, the five personality ratings for Flat have no significant difference. Touching is similar to Flat, with the exception of low extraversion ratings, the other ratings are around neutral, within range [4.3, 5.1], with no significant difference detected by ANOVA.

4.2 Hand Motion Experiment

In the hand motion experiment, we examine how the dynamic attributes of hand motion impact perception of a character's personality. Eight video clips were shown to the participants, including two motion directions (abduction vs. flexion) x 2 amplitudes (large vs. small) x 2 speeds (fast vs. slow), as described in Table III. Fig. 4 illustrates the different directional movements used as experimental

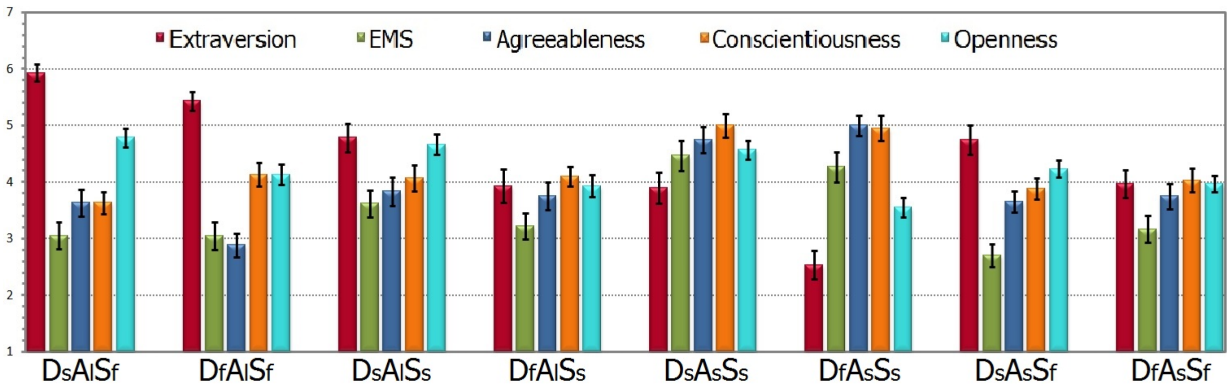


Fig. 5. Ratings for all Big Five personality traits of the eight hand motion clips.

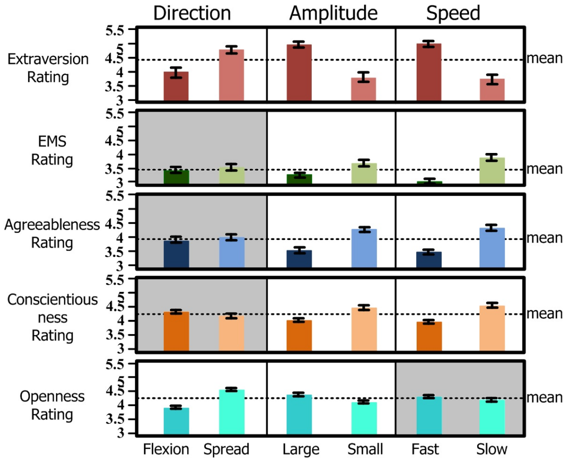
stimuli, flexion and spreading. All the clips were rendered in Maya on a wooden mannequin hand using the same rendering settings, so that the only difference is the motion the virtual hand performs.

Thirty participants were recruited for this experiment, [male] 57.1%, [nonnative speaker] 5.7%, [age above 50] 5.7%, [age 40-50] 20%, [age 30-40] 37%, [age 20-30] 31.4%, [age under 20] 6%. They first watched the hand video clip and then were asked to answer the TIPI questions to rate the personality. To analyze the experiment results, we conducted a 3-way ANOVA, with direction, amplitude and speed as the factors. We are interested in both Main Effects and Interaction Effects for each personality trait.

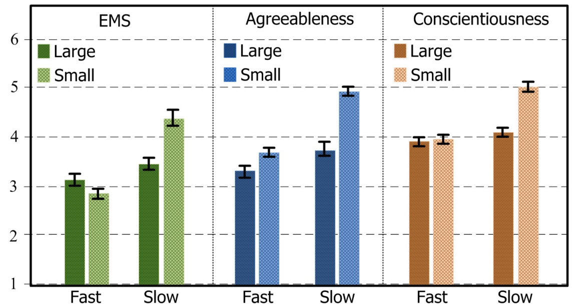
4.2.1 *Results.* The detailed results for personality perceptions of the hand motion stimuli are listed in Table V. Fig. 5 illustrates the five personality ratings for all the eight clips. The main effects are plotted in Fig. 6(a).

Extraversion
There are significant differences in perceived extraversion among the eight hand motion clips. The most extraverted hand motions are: $D_sA_lS_f$ (*spread, large, fast*), $D_fA_lS_f$ (*flexion, large, fast*); and the least extraverted motion is: $D_fA_sS_s$ (*flexion, small, slow*). We analyze the three motion attributes using a 3-way ANOVA, and find that all the attributes– direction, amplitude and speed– have significant impacts on extraversion perception, which corroborates previous findings about gesture and body motion in psychology [Knapp and Hall 1978; Riggio and Friedman 1986; Lippa 1998; Brebner 1985; Argyle 1988; North 1972; Takala 1953] and virtual agent [Neff et al. 2010] research. Spreading motions are regarded as more extraverted than flexion, large more extraverted than small, and fast more extraverted than slow.

Emotional Stability
A 1-way ANOVA on the effect of the eight hand motion clips on perceived EMS indicates significant differences. The most emotionally stable hand motions are $D_sA_sS_s$ and $D_fA_sS_s$, and the most neurotic motions are $D_fA_lS_s$, $D_fA_sS_f$, $D_fA_lS_f$, $D_sA_lS_f$ and $D_sA_sS_f$. We then analyze the three factors: direction, amplitude and speed, and our 3-way ANOVA shows that hand motion direction does not contribute to perceived EMS. In our experiment, hand motion amplitude and speed have significant impact on EMS: small motions are more emotionally stable than large motions; slow motions are more emotionally stable than fast motions. Large and fast motions may be perceived as neurotic, anxious behaviors, as in the adjectives associated with low EMS in Table I. The Amplitude*Speed interaction



(a) Main Effects of *Direction*, *Amplitude* and *Speed*



(b) *Amplitude*Speed* Interaction Effects

Fig. 6. Main and Interaction Effects

effect is illustrated in Fig. 6(b). When the hand motion is large, performing it slowly does not increase the perception of EMS, however when hand motion is small, performing it slowly does significantly increase the perceived EMS. Previous research [Burgoon et al. 1978; Takala 1953; North 1972; Takala 1953] provides general descriptions of neurotic people: they display disturbed motion rhythms, reduced fluency and more suddenness. Our experiments now provide more specific and detailed guidelines of how to manipulate hand motion to increase or decrease EMS perceptions.

Agreeableness

The eight motion clips yield significant differences in perceived agreeableness. Among them, the most agreeable motions are $D_f A_s S_s$ and $D_s A_s S_s$, and the least agreeable motions are $D_f A_l S_s$, $D_f A_s S_f$, $D_s A_s S_f$, $D_s A_l S_f$ and $D_f A_l S_f$. The analysis of the three motion factors shows that motion direction does not make a significant difference, only amplitude and speed impact perceived agreeableness. Small motions are more agreeable than large motions and slow motions are more agreeable than fast motions. There is one Amplitude*Speed interaction effect, see Fig. 6(b): slowing down hand motion can greatly increase the perceived agreeableness when the motion is small, but for large motion, lowering the speed has less effect.

Conscientiousness

The eight motion clips also lead to significant differences in perceived conscientiousness. The most conscientious hand motions are $D_s A_s S_s$ and $D_f A_s S_s$, and the least conscientious motions are $D_f A_s S_f$, $D_s A_s S_f$ and $D_s A_l S_f$. Similar to EMS and agreeableness, the 3-factor analysis shows that motion direction does not influence perceived conscientiousness, only amplitude and speed affect it. Small motions are perceived as more conscientious than large, and slow motions are perceived as more conscientious than fast. This could be explained as large and fast motions are perceived as relatively more impulsive and careless, while small and slow motions are more disciplined and deliberate. See the adjectives for conscientiousness in Table I. There is one Amplitude*Speed interaction illustrated in Fig. 6(b): perceived conscientiousness is similar for fast motion, whether it is large or small, but for slow motions, making it small can significantly increase its conscientiousness level.

Openness
The eight motion clips also yield significant differences in perceived openness. The ANOVA shows that $D_sA_lS_f$ is the most open hand motion, and $D_fA_sS_f$, $D_fA_lS_s$ and $D_fA_sS_s$ are regarded as the least open hand motions. The 3-factor analysis shows that perceived openness is only influenced by hand motion direction and amplitude; whether the hand motion is performed at high or low speed has no effect on openness. Hand spread motion is rated as more open than flexion motion; large motion is more open than small motion. Large and spread motions are more outward than small and flexed motions and may be perceived as more creative, imaginative and curious as specified by the adjectives associated with openness in Table I.

Summary
The hand motion experiment tests combinations of settings for three motion attributes, which makes the results more complicated than the hand pose experiment. As with the extreme hand poses, there are also two extreme hand motions among the eight clips that produce a particularly large set of associations: $D_sA_lS_f$ achieves the most extraversion, the least EMS, the least agreeableness, the least conscientiousness and the most openness; and $D_fA_sS_s$ achieves the least extraversion, the most EMS, the most agreeableness, the most conscientiousness and the least openness.

4.3 Manipulation Experiment

In this experiment, we examine the influence of finger-manipulation on a character's perceived personality by comparing closed-loop hand manipulation (i.e. motions with self-touch between the thumb and fingers) with open-loop, general hand motion. Two video clips were shown to the participants. The open-loop general hand motion clip serves as a control and the hand only performs general flexion and abduction motion with no contact between the fingers. In the closed-loop hand manipulation clip, the thumb keeps scratching and rubbing the index finger. We use a medium level of hand shape, amplitude and speed for the open-loop hand motion, to provide a relatively neutral comparison point. We also try to maintain a similar hand shape, motion amplitude and speed for the hand manipulation clip so that the major difference between the two motion clips is the existence of manipulation (details described in Table IV).

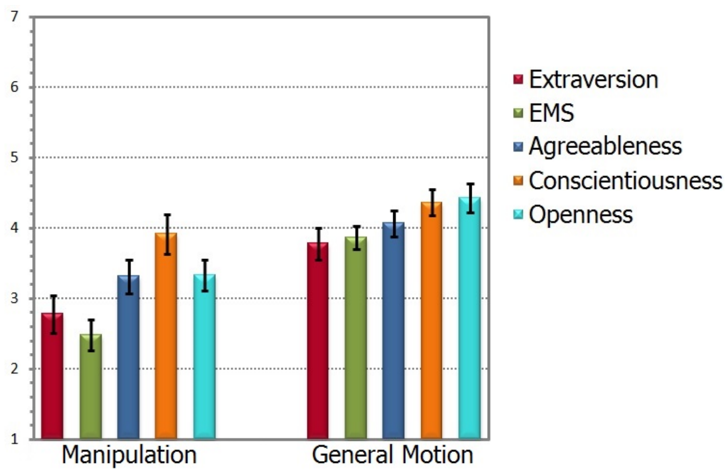


Fig. 7. Personality ratings between the closed-loop manipulation and the open-loop general hand motion.

Thirty participants took part in this experiment, [male] 65.9%, [nonnative speaker] 11.4%, [age above 50] 3.4%, [age 40-50] 17%, [age 30-40] 25%, [age 20-30] 46.6%, [age under 20] 8%. They were requested to answer the TIPI questions after watching each video clip. For EMS, based on the findings on body motion and gesture in previous work [Riggio and Friedman 1986; Argyle 1988; Neff et al. 2011], we hypothesized that closed-loop manipulation would be perceived as emotionally less stable (more neurotic), than general hand motion. For the other four personality traits, there is no prior knowledge available. Thus this experiment aims to establish for the first time how the perceptions of extraversion, agreeableness, conscientiousness and openness are influenced by finger manipulation.

4.3.1 *Results.* The detailed results for finger-manipulation on a character's perceived personality are listed in Table V. Fig. 7 illustrates the five personality ratings for the close-loop manipulation motion and the open-loop general motion. As expected, the open-loop general hand motion yields five personality average ratings all around the medium level (the midpoint 4 of each scale).

Extraversion
The Extraversion ratings show that there is a significant difference in perceived extraversion among the two motion clips. Though both clips have average extraversion ratings lower than the midpoint four, the ANOVA indicates that closed-loop manipulation motion is perceived as significantly more introverted than open-loop hand motion. This finding is consistent with the previous observations on body motion [Riggio and Friedman 1986]: gestures from extraverts should have less self-contact than introverts.

Emotional Stability
For the EMS trait, hand manipulation is perceived as significantly different from the general hand motion. As predicted, the ANOVA indicates that hand manipulation is emotionally less stable and more neurotic than the open-loop general motion. This corroborates previous findings about body motion [Riggio and Friedman 1986; Argyle 1988; Neff et al. 2011], suggesting that people with low emotional stability display more self-contact movement.

Agreeableness
The 1-way ANOVA indicates there are also significant differences in perceived agreeableness between the two motion clips. Hand manipulation is rated as less agreeable than the general hand motion. It could be that the open-loop general hand motion is perceived as more warm and generous, and the hand manipulation more suspicious and unfriendly, as per the adjectives associated with agreeableness in Table I.

Conscientiousness
For the conscientiousness trait, the ANOVA shows no significant differences between the two motion clips.

Openness
The two motion clips lead to significant differences in perceived openness. Hand manipulation is significantly less open than the general hand motion, apparently leading to perceptions of being narrow-minded or ignorant, as per the adjectives in Table I.

4.4 Cross-experiment Analysis

In Secs. 4.1 to 4.3, we presented three experiments aimed at testing the influence of hand pose, motion direction, amplitude, speed and hand manipulation on a character's perceived personality. However, the three experiments are not entirely independent. Hand motions in Exp.2 and Exp.3 are composed of a sequence of hand poses which inevitably may include poses in Exp.1. For example, flexion motions in Exp.2 contain the fist and rest poses in Exp.1. We can also easily relate the spread hand pose in

Table V. Significant results for hand pose, hand motion and manipulation experiments.

Experiment	Traits	Effect	F-Test	Post-hoc
Hand Pose	Extraversion	Hand Pose	$F_{4,145} = 19.42, p < 0.001$	$Spread > Flat > \{Rest, Touching\}; Spread > Fist$
	EMS	Hand Pose	$F_{4,145} = 28.83, p < 0.001$	$Rest > Touching > \{Fist, Spread\}; Flat > \{Fist, Spread\}$
	Agreeableness	Hand Pose	$F_{4,145} = 32.03, p < 0.001$	$Rest > Flat > Spread > Fist; Touching > Spread > Fist$
	Conscientiousness	Hand Pose	$F_{4,145} = 27.00, p < 0.001$	$\{Flat, Touching, Fist, Rest\} > Spread$
	Openness	Hand Pose	$F_{4,145} = 25.42, p < 0.001$	$Spread > \{Touching, Flat\} > Fist; Rest > Fist$
Open Hand Motion	Extraversion	Motion	$F_{7,232} = 19.46, p < 0.001$	Most extraverted: $D_sA_lS_f$, $D_fA_lS_f$
				Least extraverted: $D_fA_sS_s$
		Direction	$F_{1,232} = 26.65, p < 0.001$	Spread > Flex
		Amplitude	$F_{1,232} = 52.94, p < 0.001$	Large > Small
		Speed	$F_{1,232} = 52.94, p < 0.001$	Fast > Slow
	EMS	Motion	$F_{7,232} = 6.68, p < 0.001$	Most stable: $D_sA_sS_s$, $D_fA_sS_s$
				Least stable: $D_fA_lS_s$, $D_fA_sS_f$, $D_fA_lS_f$, $D_sA_lS_f$, $D_sA_sS_f$
		Amplitude	$F_{1,232} = 5.91, p = 0.016$	Small > Large
		Speed	$F_{1,232} = 27.58, p < 0.001$	Slow > Fast
		Amplitude * Speed	$F_{1,232} = 9.68, p = 0.002$	Large motion has higher EMS than small motion when it is fast
				Small motion has higher EMS than large motion when it is slow
	Agreeableness	Motion	$F_{7,232} = 9.08, p < 0.001$	Most agreeable: $D_fA_sS_s$, $D_sA_sS_s$
				Least agreeable: $D_fA_lS_s$, $D_fA_sS_f$, $D_sA_sS_f$, $D_sA_lS_f$, $D_fA_lS_f$
		Amplitude	$F_{1,232} = 23.48, p < 0.001$	Small > Large
		Speed	$F_{1,232} = 29.47, p < 0.001$	Slow > Fast
		Amplitude * Speed	$F_{1,232} = 4.16, p = 0.043$	Small motion has much higher agreeableness than large motion when it is slow
	Conscientiousness	Motion	$F_{7,232} = 5.73, p < 0.001$	Most conscientious: $D_sA_sS_s$, $D_fA_sS_s$
				Least conscientious: $D_fA_sS_f$, $D_sA_sS_f$, $D_sA_lS_f$
		Amplitude	$F_{1,232} = 11.16, p = 0.001$	Small > Large
		Speed	$F_{1,232} = 17.67, p < 0.001$	Slow > Fast
		Amplitude * Speed	$F_{1,232} = 7.96, p = 0.005$	Small motion is much more conscientious than large motion when it is slow
	Openness	Motion	$F_{7,232} = 6.14, p < 0.001$	Most open: $D_sA_lS_f$
				Least open: $D_fA_sS_f$, $D_fA_lS_s$, $D_fA_sS_s$
		Direction	$F_{1,232} = 30.82, p < 0.001$	Spread > Flex
		Amplitude	$F_{1,232} = 6.24, p = 0.013$	Large > Small
Manipulation	Extraversion	Manipulation	$F_{1,58} = 8.19, p = 0.006$	Hand manipulation is less extraverted than the general hand motion.
	EMS	Manipulation	$F_{1,58} = 25.73, p < 0.001$	Hand manipulation is less emotionally stable than the general hand motion.
	Agreeableness	Manipulation	$F_{1,58} = 6.00, p = 0.017$	Hand manipulation is less agreeable than the general hand motion.
	Conscientiousness	Manipulation	$F_{1,58} = 1.76, p = 0.190$	No significant difference for Conscientiousness.
	Openness	Manipulation	$F_{1,58} = 13.15, p = 0.001$	Hand manipulation is less open than the general hand motion.

Exp.1 to spread motion in Exp.2 and the touching pose in Exp.1 to manipulation motion in Exp.3. The open-loop general hand motion in Exp.3 is based on the rest hand pose in Exp.1, with extra finger flexion and abduction. On the other hand, a single hand pose can also have amplitude variation, e.g. spread is a hand pose with large amplitude, fist is a small pose. We now examine findings across the three experiments in order to produce more useful generalizations and IVA design guidelines.

Extraversion

The spread pose in Exp.1 is the most extraverted pose, which is consistent with the findings in Exp.2 that horizontal spreading motion is more extraverted than flexion motion. Rest and touching poses are of the same extraversion level in Exp.1. However, in Exp.3, the general hand motion based on rest pose is rated as more extraverted than the manipulation motion that is related to touching pose. This helps to confirm the contribution of the dynamics of the manipulation motion, rather than the contact status of finger tips, to perceived low extraversion.

Emotional Stability

Exp.2 shows that hand motion direction does not contribute to perceived EMS. This finding can explain why both fist and spread are the least stable poses in Exp.1. Rest pose is the most emotionally stable pose in Exp.1, and the touching pose is less stable than the rest. Though the general hand motion is based on the rest pose, its EMS ratings is not as high ($F_{1,58} = 31.29, p < 0.001$), which means extra finger flexion and abduction added to the rest pose could lower perceived EMS. The manipulation motion has even lower EMS ratings than the general hand motion in Exp.3, which corroborates the finding that the touching pose is emotionally less stable than the rest pose in Exp.1.

Agreeableness
Findings in Exp.2 show that small motions are perceived as agreeable, which corresponds to the result from Exp.1 that rest is the most agreeable pose. The widest pose spread has relatively low ratings for its agreeableness. However spread is not the least agreeable pose, fist is, which is another small hand pose. This suggests that the low ratings of fist are not from the amplitude of the pose, but mostly come from the impression of violence associated with the pose. The touching pose is less agreeable than the rest pose in Exp.1, which is consistent with the finding in Exp.3 that hand manipulation is less agreeable than the general hand motion.

Conscientiousness
Results from Exp.1 show that the spread pose is perceived as the least conscientious hand pose. However in Exp.2, motion direction has no contribution to perceived conscientiousness, thus the low ratings of the spread hand pose are not likely from its horizontal direction, but more likely from the wideness or amplitude of the pose. Rest and touching poses show the same level of conscientiousness in Exp.1, which is consistent with the findings from Exp.3: the general hand motion and hand manipulation have no significant difference in perceived conscientiousness.

Openness
Results from the three experiments coincide with each other. The spread pose is the most open hand pose in Exp.1, and spreading motion is more open than flexion motion in Exp.2. The fist pose is the least open hand pose in Exp.1, and the least open motion clips in Exp.2 are all flexion motions. The touching pose is less open than the rest pose in Exp.1, and the hand manipulation is less open than the general hand motion in Exp.3.

5. GUIDELINES AND EVALUATIONS

5.1 Guidelines

Based on our experiments, we propose guidelines for designing virtual characters with particular personalities, see Table VI. For conversing characters, the ideal hand pose can be selected according to their personality traits. During conversation, characters will have periods when they are actively gesturing and periods when they are “idle”. Motion can be adjusted appropriately in both of these phases. For example, a disagreeable character might hold his hands in closed fists while idle and choose gestures that use the fist and which can be rendered large and fast. Adding finger manipulation can increase the perception of one end of the personality scales. For instance, a neurotic character might

Table VI. Guidelines for designing virtual characters with particular personalities.

	High	Low
Extraversion	Wide, abducted hand poses like spread are preferable. Large, fast spread hand motion can add extraversion. Avoid finger manipulation.	Small poses like rest, touching and fist are preferable. Small, slow flexion motion can add to introversion. Finger manipulation can be added.
EMS	A relaxed rest pose is preferred. Hand motion is better if it is slow and small. Avoid finger manipulation.	The fist and spread poses are preferable. Large fast motion can be added. Finger manipulation can increase neuroticism.
Agreeableness	The rest pose is preferred. Hand motion is better if it is slow and small. Avoid finger manipulation.	The fist pose is preferred. Large and fast hand motion is preferable. Finger manipulation can be added.
Conscientiousness	Avoid the spread pose. Slow and small hand motion is preferable.	The spread pose is preferred. Large and fast hand motion is preferable.
Openness	The spread pose is preferred. Large spreading motion is preferable. Avoid finger manipulation.	The fist pose is preferred. Small flexion motions are preferable. Finger manipulation can be added.

Table VII. Gesture Performance and Body Posture Parameter Settings

Parameters	B_0	B_1
Stroke Scale	Narrow Gesture (x*.5, y*.6, z*.8)	Wide Gesture (x * 1.4, y*1.2, z*1.1)
Stroke Position	Low Gesture (x-12cm, y-5cm)	High Gesture (x+12cm, y+ 10cm)
Duration	Slow Motion (100%)	Fast Motion (80%)
Arm Swivel	Narrow Posture	Wide Posture (33+ deg)
Spine Rotation Forward	Posture Leaning Backward (-6 deg)	Posture Leaning Forward (6 deg)
COM Shift Forward	Posture Leaning Backward (-5 cm)	Posture Leaning Forward (6 cm)
Body Motion Scale	Small Body Movement ($10\% \sim 60\%$)	Large Body Movement (100%)

perform hand manipulation motions, even when idle. See our applied guidelines in the attached video.

5.2 Evaluation Studies

To check the applicability of our hand motion guidelines in Table VI, we designed and conducted an evaluation study, which combined whole body posture and movement with hand pose, finger motion, and gesture performance. This allows us to test the relative contribution of hand motions to the perception of personality given the presence of body movements.

Body Posture and Gesture Performance: As the broad picture of how body motion influences the perception of all five personality traits is unclear from previous research, we selected two clips designed to vary in extraversion. B_0 has a narrow posture, small and slow gestures and reduced body movement. B_1 has broader posture, wider and faster gesture and larger scale of body movement. The detailed parameters are listed in Table VII. The gesture frequency in B_0 is also half that of B_1. These clips were shown to be perceived with higher (B_1) and lower (B_0) extraversion in [Neff et al. 2010], but not tested on other traits.

Hand Pose and Finger Motion: For each personality trait, we made two sets of hand motions based on the guidelines in Table VI and summarized in Table VIII, one corresponding to high rating and the other low rating of the personality trait. We use notions in H_y^x format, where H indicates **H**and motion, x indicates personality traits (**e**, **s**, **a**, **c**, **o** for **E**xtraversion, Emotional **S**tability, **A**greeableness, **C**onscientiousness and **O**penness) and y indicates expected low (0) or high (1) levels of specified personality based on the guidelines. We listed the hand poses and motions used in Table VIII.

For each personality trait, we integrate the two body motions with the two high/low hand motions and demonstrate four video clips to our subjects. A front viewpoint was chosen which displayed the character from the knee to head. The clips are generated at size 640 x 480. Figure 8 illustrates 4 video examples of different personality settings. We test each personality trait separately, with thirty

Table VIII. Hand variations used in the experiment with full body motion.

	Hand Pose	Hand Motions
H_0^e - Low Extraversion	rest	small slow flexion, manipulation
H_1^e - High Extraversion	spread	large fast spread
H_0^s - Low EMS	spread	large fast flexion, spread and manipulation
H_1^s - High EMS	rest	
H_0^a - Low Agreeableness	fist	large fast spread
H_1^a - High Agreeableness	rest	
H_0^c - Low Conscientiousness	spread	large fast spread, flexion
H_1^c - High Conscientiousness	fist	
H_0^o - Low Openness	rest	small slow flexion, manipulation
H_1^o - High Openness	spread	large fast spread

Fig. 8. Video Examples: Sample frames from clips used to study the impact of hand motion when combined with body motion.

subjects. The four clips in a set were shown to subjects in random order. Then subjects were asked to answer the TIPI questions using 7-point likert ratings.

5.2.1 *Results.* The detailed ratings of individual video clips for the five personality traits and the main effects of body motion and hand motion are illustrated in Figure 9. A 2-way ANOVA testing the effect of the two factors: body motion vs. hand motion shows that hand motion makes a significant difference to character's perceived personality, even with the body motion present.

Extraversion
The 2-way ANOVA indicates that both body and hand motions contribute to perceived extraversion: B_1 is rated as more extraverted than B_0 ($F_{1,116} = 237.25, p < 0.001$) and H_1^e more extraverted than H_0^e ($F_{1,116} = 12.55, p = 0.001$). This result is consistent with the findings in [Neff et al. 2010] and it also shows that congruent body motion and hand motion can add to the general perceived extraversion. There was an interaction between body and hand for the extraversion ratings ($F_{1,116} = 4.21, p = 0.042$). See Figure 10 for a graph of the interaction. When the body was introverted, the extraverted hand movements had a greater effect on the perception of extraversion than when the body was extraverted.

Emotional Stability
The 2-way ANOVA shows that both body and hand motions affect character's perceived EMS: B_0 is rated as more emotionally stable than B_1 ($F_{1,116} = 5.77, p = 0.018$), and H_1^s is rated as significantly more stable than H_0^s ($F_{1,116} = 137.26, p < 0.001$). Hand movements dominated the perception of EMS. There was also an interaction between body and hand for the EMS ratings ($F_{1,116} = 5.42, p = 0.022$). See Figure 10 for a graph of the interaction. When the body was introverted, the stable EMS hand movements had a greater effect on the perception of stability than when the body was extraverted. Said another way, the body didn't matter for the low EMS (neurotic) hand movements, but it did for the stable movements, with the extraverted body plus stable hand movements being judged as more neurotic than the introverted body with stable hand movements.

Agreeableness
The 2-way ANOVA indicates that both body and hand motions contribute to character's agreeableness level: B_0 is rated as more agreeable than B_1 ($F_{1,116} = 12.17, p = 0.001$), and H_1^a more agreeable than H_0^a ($F_{1,116} = 139.25, p < 0.001$). Hand motion dominated the perception of agreeableness. There was no

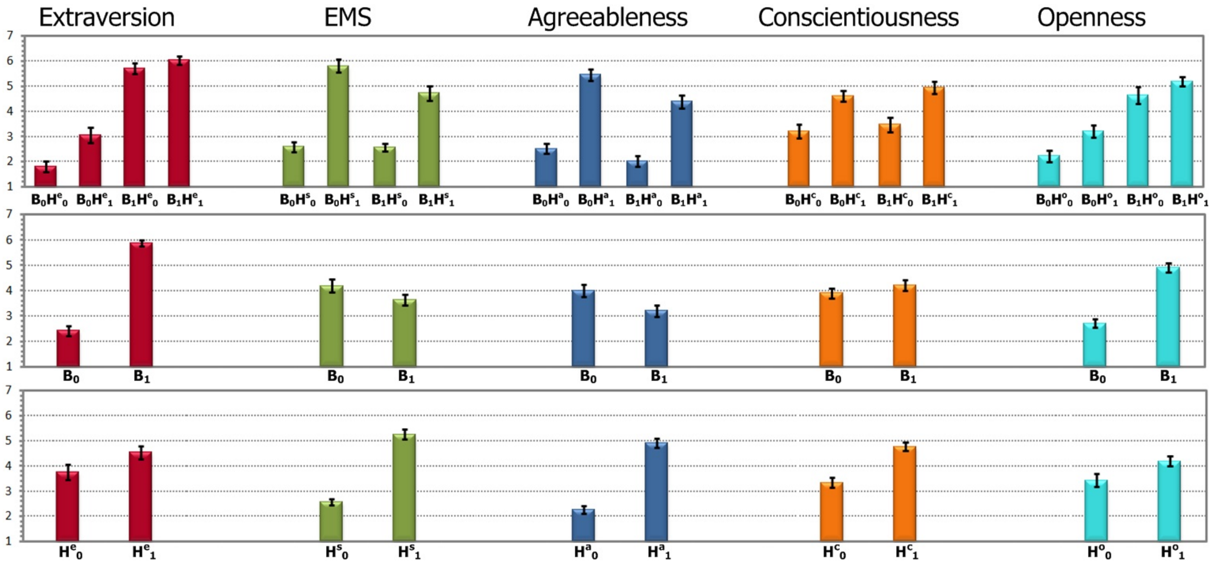


Fig. 9. Personality Ratings and Main Effects

interaction between body and hand for agreeableness ($F_{1,116} = 1.59, p = 0.21$).

Conscientiousness
For conscientiousness, a 2-way ANOVA shows that body motion does not make a difference in the ratings ($F_{1,116} = 1.37, p = 0.245$). Hand motion dominates perceptions of conscientiousness: $H_1^c > H_0^c$ ($F_{1,116} = 31.17, p < 0.001$). There was no interaction between body and hand for conscientiousness ($F_{1,116} = 0.02, p = 0.897$).

Openness
From a 2-way ANOVA, both body and hand motions contribute significantly to perceived openness: B_1 is rated as more open than B_0 ($F_{1,116} = 77.32, p < 0.001$), and H_1^o more open than H_0^o ($F_{1,116} = 9.39, p = 0.003$). There was no interaction between body and hand for openness ($F_{1,116} = 0.75, p = 0.388$).

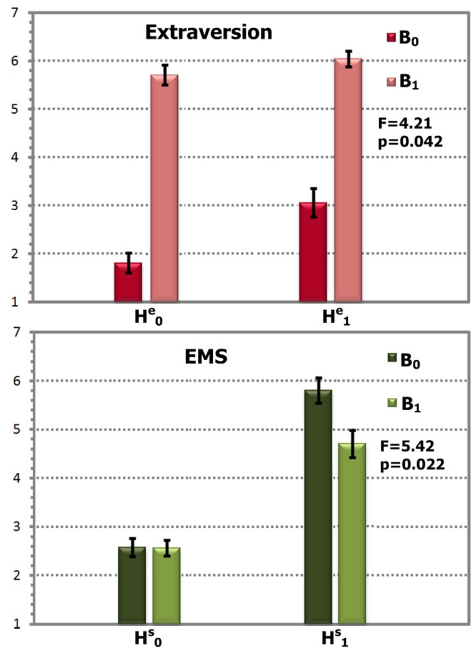


Fig. 10. Interaction Effects of Hand Motion combined with Body Motion.

This evaluation study confirms that hand pose and motion make a significant difference in a character's perceived personality given the presence of body posture, body movement and gesture performance. For EMS, agreeableness and conscientiousness, when personality cues from body motion were not strong, hand motion dominated perception of the trait. For extraversion and openness, when personality cues from body and hand were both strong, body motion plays a more dominant role, while congruent hand motion still significantly enhances perceived personality.

6. CONCLUSION AND FUTURE WORK

Understanding the personality traits associated with hand poses and motions is a useful contribution for designing diversified and believable characters. More fundamentally, this research helps us to understand the role that hand shape may play in the perception of personality. While previous research has suggested rules for generating personalized verbal behavior and non-verbal behavior such as gesture and body motion, little was previously known about detailed hand motion. The experiments reported here provide fundamental insights into how hand pose and motion impact the perception of personality, the role of motion vs. pose in this effect, and the impact of finger manipulation. However, hand perception work is by no means complete, and it can be improved in the following ways:

—We have explored five commonly-used hand poses, three types of variation in hand motion (direction, amplitude and speed), and compared manipulation movement to general hand movement. While a good sampling, in the future, we will introduce more stylistic hand motion examples from different actors. Another limitation of current work is that all the hand motions are performed with one hand. Two-handed motions like clapping hands or twiddling thumbs are not included and should be added to future research. It is also likely that some hand poses or motions are culturally-specific. It would be worthwhile to study the cultural differences in the perception of hand motion by recruiting subjects from various cultural backgrounds.

—To allow for controlled experiments that avoid a combinatorial explosion, we first explored hand motion in isolation and then evaluated our findings in combination with body movement and gesture performance in a follow-up study. From previous work, we know the effect of various verbal and non-verbal behaviors on personality perception, including the linguistic form of utterances and the effect of facial expressions. In the future, we plan to include more factors, both verbal and non-verbal, in studying personality perception.

—Finally, it would be interesting to conduct studies with a more detailed hand model that supports skin deformation to see if this detail is perceptually important. Our wooden mannequin hand model does not support skin deformation, so the force and pressure of the scratching and rubbing in the manipulation clip of Exp.3 cannot be fully reflected in clips rendered with this model. Physically realistic models may require recording additional information during the motion capture or using simulation to generate the results. Such models would allow investigation of a range of self-manipulation behaviors - from a soft stroke to a forceful pinch - to see if these convey different personality information. Such subtle variations are beyond the scope of our current apparatus.

We hope that our work can provide fundamental guidelines on the personality perception of hand poses and motion, while also encouraging more experiments on hand motion perception in the future.

7. ACKNOWLEDGMENT

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REFERENCES

ANDRÉ, E., RIST, T., VAN MULKEN, S., KLESEN, M., AND BALDES, S. 2000. The automated design of believable dialogues for animated presentation teams. *Embodied conversational agents*, 220–255.

ARGYLE, M. 1988. *Bodily communication*. Taylor & Francis.

AUTODESK. 2012. Maya, 3d computer graphics software.

BADLER, N., ALLBECK, J., ZHAO, L., AND BYUN, M. 2002. Representing and parameterizing agent behaviors. In *Computer Animation, 2002. Proceedings of*. IEEE, 133–143.

BREBNER, J. 1985. Personality theory and movement. *Individual differences in movement*, 27–41.

BURGOON, J. K., SAINE, T., ET AL. 1978. *The unspoken dialogue: An introduction to nonverbal communication*. Houghton Mifflin Boston.

CHOU, T., GADD, A., AND KNOTT, D. 2000. Hand-eye: A vision based approach to data glove calibration. *Proceedings of Human Interface Technologies 2000*.

ELKOURA, G. AND SINGH, K. 2003. Handrix: animating the human hand. In *Proceedings of the 2003 ACM SIGGRAPH/Eurographics symposium on Computer animation*. Eurographics Association, 110–119.

FRANK, K. 2007. Posture & Perception in the Context of the Tonic Function Model of Structural Integration: an Introduction. *IASI Yearbook 2007*, 27–35.

FUNDER, D. C. 1997. *The personality puzzle.* WW Norton & Co.

GILES, H. AND STREET, R. 1994. Communicator characteristics and behavior. *Handbook of interpersonal communication 2*, 103–161.

GOLDBERG, L. R. 1990. An alternative" description of personality": the big-five factor structure. *Journal of personality and social psychology 59,* 6, 1216.

GOSLING, S. D., RENTFROW, P. J., AND SWANN, W. B. 2003. A very brief measure of the big-five personality domains. *Journal of Research in personality 37,* 6, 504–528.

GRIFFIN, W., FINDLEY, R., TURNER, M., AND CUTKOSKY, M. 2000. Calibration and mapping of a human hand for dexterous telemanipulation. In *ASME IMECE 2000 Symposium on Haptic Interfaces for Virtual Environments and Teleoperator Systems*. 1–8.

HARTMANN, B., MANCINI, M., AND PELACHAUD, C. 2002. Formational parameters and adaptive prototype instantiation for mpeg-4 compliant gesture synthesis. *Computer Animation, 2002. Proceedings of*, 111–119.

HARTMANN, B., MANCINI, M., AND PELACHAUD, C. 2006. Implementing expressive gesture synthesis for embodied conversational agents. In *gesture in human-Computer Interaction and Simulation*. Springer, 188–199.

HELOIR, A. AND KIPP, M. 2009. Embr–a realtime animation engine for interactive embodied agents. In *Intelligent Virtual Agents*. Springer, 393–404.

HOYET, L., RYALL, K., MCDONNELL, R., AND O'SULLIVAN, C. 2012. Sleight of hand: perception of finger motion from reduced marker sets. In *Proceedings of the ACM SIGGRAPH Symposium on Interactive 3D Graphics and Games*. ACM, 79–86.

HU, H., GAO, X., LI, J., WANG, J., AND LIU, H. 2004. Calibrating human hand for teleoperating the hit/dlr hand. In *Robotics and Automation, 2004. Proceedings. ICRA'04. 2004 IEEE International Conference on*. Vol. 5. IEEE, 4571–4576.

HU, Z., WALKER, M. A., NEFF, M., AND "FOX TREE", JEAN E. ND WALKER, M. A. 2015. Storytelling agents with personality and adaptivity. In *Proc. of Intelligent Virtual Agents Conf., IVA 2015*. 181–191.

HUENERFAUTH, M. AND LU, P. 2010. Accurate and accessible motion-capture glove calibration for sign language data collection. *ACM Transactions on Accessible Computing (TACCESS) 3,* 1, 2.

ISBISTER, K. AND NASS, C. 2000. Consistency of personality in interactive characters: Verbal cues, non-verbal cues, and user characteristics. *International Journal of Human Computer Studies 53,* 2, 251–268.

JÖRG, S., HODGINS, J., AND SAFONOVA, A. 2012. Data-driven finger motion synthesis for gesturing characters. *ACM Transactions on Graphics (TOG) 31,* 6, 189.

KAHLESZ, F., ZACHMANN, G., AND KLEIN, R. 2004. 'visual-fidelity'dataglove calibration. In *Computer Graphics International, 2004. Proceedings*. IEEE, 403–410.

KANG, C., WHEATLAND, N., NEFF, M., AND ZORDAN, V. 2012. Automatic hand-over animation for free-hand motions from low resolution input. In *Motion in Games*. Springer, 244–253.

KESSLER, G., WALKER, N., AND HODGES, L. 1995. Evaluation of the cyberglove as a whole hand input device.

KNAPP, M. AND HALL, J. 1978. *Nonverbal communication in human interaction*. Holt, Rinehart and Winston New York.

KOPP, S. AND WACHSMUTH, I. 2004. Synthesizing multimodal utterances for conversational agents. *Computer animation and virtual worlds 15,* 1, 39–52.

KUCH, J. AND HUANG, T. 1994. Human computer interaction via the human hand: a hand model. In *Signals, Systems and Computers, 1994. 1994 Conference Record of the Twenty-Eighth Asilomar Conference on*. Vol. 2. IEEE, 1252–1256.

LEE, J. AND KUNII, T. 1995. Model-based analysis of hand posture. *Computer Graphics and Applications, IEEE 15,* 5, 77–86.

LIPPA, R. 1998. The nonverbal display and judgment of extraversion, masculinity, femininity, and gender diagnosticity: A lens model analysis. *Journal of Research in Personality 32,* 1, 80–107.

LIU, C. K. 2008. Synthesis of interactive hand manipulation. In *Proceedings of the 2008 ACM SIGGRAPH/Eurographics Symposium on Computer Animation*. Eurographics Association, 163–171.

LIU, C. K. 2009. Dextrous manipulation from a grasping pose. In *ACM Transactions on Graphics (TOG)*. Vol. 28. ACM, 59.

LIU, K., TOLINS, J., TREE, J. E. F., NEFF, M., AND WALKER, M. 2015. Two techniques for assessing virtual agent personality. *Transactions on Affective Computing*.

MAIRESSE, F. AND WALKER, M. 2007. Personage: Personality generation for dialogue. In *Annual Meeting-Association For Computational Linguistics*. Vol. 45. 496.

MAIRESSE, F. AND WALKER, M. A. 2008. Trainable generation of big-five personality styles through data-driven parameter estimation. In *ACL*. 165–173.

MAIRESSE, F. AND WALKER, M. A. 2010. Towards personality-based user adaptation: psychologically informed stylistic language generation. *User Modeling and User-Adapted Interaction 20,* 3, 227–278.

MAIRESSE, F. AND WALKER, M. A. 2011. Controlling user perceptions of linguistic style: Trainable generation of personality traits. *Computational Linguistics 37,* 3, 455–488.

MCQUIGGAN, S. W., MOTT, B. W., AND LESTER, J. C. 2008. Modeling self-efficacy in intelligent tutoring systems: An inductive approach. *User Modeling and User-Adapted Interaction 18,* 1-2, 81–123.

MEHL, M. R., GOSLING, S. D., AND PENNEBAKER, J. W. 2006. Personality in its natural habitat: manifestations and implicit folk theories of personality in daily life. *Journal of personality and social psychology 90,* 5, 862.

MEHRABIAN, A. 1969. Significance of posture and position in the communication of attitude and status relationships. *Psychological Bulletin 71,* 5, 359–372.

MENON, A., BARNES, B., MILLS, R., BRUYNS, C., TWOMBLY, A., SMITH, J., MONTGOMERY, K., AND BOYLE, R. 2003. Using registration, calibration, and robotics to build a more accurate virtual reality simulation for astronaut training and telemedicine. In *Proceedings of the 11th International Conference in Central Europe on Computer Graphics, Visualization, and Computer (WSCG03)*.

NEFF, M., KIPP, M., ALBRECHT, I., AND SEIDEL, H.-P. 2008. Gesture modeling and animation based on a probabilistic recreation of speaker style. *ACM Transactions on Graphics (TOG) 27,* 1, 5.

NEFF, M., TOOTHMAN, N., BOWMANI, R., TREE, J. E. F., AND WALKER, M. A. 2011. Dont scratch! self-adaptors reflect emotional stability. In *Intelligent Virtual Agents*. Springer, 398–411.

NEFF, M., WANG, Y., ABBOTT, R., AND WALKER, M. 2010. Evaluating the effect of gesture and language on personality perception in conversational agents. In *Intelligent Virtual Agents*. Springer, 222–235.

NORMAN, W. T. 1963. Toward an adequate taxonomy of personality attributes: Replicated factor structure in peer nomination personality ratings. *The Journal of Abnormal and Social Psychology 66,* 6, 574.

NORTH, M. 1972. *Personality assessment through movement*. Macdonald and Evans.

PAVLOVIC, V., SHARMA, R., AND HUANG, T. 1997. Visual interpretation of hand gestures for human-computer interaction: A review. *Pattern Analysis and Machine Intelligence, IEEE Transactions on 19,* 7, 677–695.

PENNEBAKER, J. W. AND KING, L. A. 1999. Linguistic styles: language use as an individual difference. *Journal of personality and social psychology 77,* 6, 1296.

PIWEK, P. 2003. A flexible pragmatics-driven language generator for animated agents. In *Proceedings of the tenth conference on European chapter of the Association for Computational Linguistics-Volume 2*. Association for Computational Linguistics, 151–154.

RIGGIO, R. AND FRIEDMAN, H. 1986. Impression formation: The role of expressive behavior. *Journal of Personality and Social Psychology 50,* 2, 421–427.

RUHLAND, K., ZIBREK, K., AND MCDONNELL, R. 2015. Perception of personality through eye gaze of realistic and cartoon models. In *Proceedings of the ACM SIGGRAPH Symposium on Applied Perception*. ACM, 19–23.

SAMADANI, A.-A., DEHART, B. J., ROBINSON, K., KULIC, D., KUBICA, E., AND GORBET, R. 2011. A study of human performance in recognizing expressive hand movements. In *RO-MAN, 2011 IEEE*. IEEE, 93–100.

SAMADANI, A.-A., KUBICA, E., GORBET, R., AND KULIĆ, D. 2013. Perception and generation of affective hand movements. *International Journal of Social Robotics 5,* 1, 35–51.

STEFFEN, J., MAYCOCK, J., AND RITTER, H. 2011. Robust dataglove mapping for recording human hand postures. *Intelligent Robotics and Applications*, 34–45.

TAKALA, M. 1953. *Studies of psychomotor personality tests, 1-.* Suomalainen Tiedeakatemia.

THIEBAUX, M., MARSELLA, S., MARSHALL, A. N., AND KALLMANN, M. 2008. Smartbody: Behavior realization for embodied conversational agents. In *Proceedings of the 7th international joint conference on Autonomous agents and multiagent systems-Volume 1*. International Foundation for Autonomous Agents and Multiagent Systems, 151–158.

TURNER, M. 2001. Programming dexterous manipulation by demonstration. Ph.D. thesis, Citeseer.

WANG, N., JOHNSON, W. L., MAYER, R. E., RIZZO, P., SHAW, E., AND COLLINS, H. 2005. The politeness effect: Pedagogical agents and learning gains. *Frontiers in Artificial Intelligence and Applications 125*, 686–693.

WANG, Y., MIN, J., ZHANG, J., LIU, Y., XU, F., DAI, Q., AND CHAI, J. 2013. Video-based hand manipulation capture through composite motion control. *ACM Transactions on Graphics (TOG) 32,* 4, 43.

WANG, Y. AND NEFF, M. 2013. Data-driven glove calibration for hand motion capture. In *Proceedings of the 12th ACM SIGGRAPH/Eurographics Symposium on Computer Animation*. ACM, 15–24.

WHEATLAND, N., JÖRG, S., AND ZORDAN, V. 2013. Automatic hand-over animation using principle component analysis. In *Proceedings of the Motion on Games*. ACM, 175–180.

YAZADI, F. 2009. Cyberglove systems cyberglove ii wireless data glove user guide. CyberGlove Systems LLC.

YE, Y. AND LIU, C. K. 2012. Synthesis of detailed hand manipulations using contact sampling. *ACM Transactions on Graphics (TOG) 31,* 4, 41.

ZHAO, W., CHAI, J., AND XU, Y.-Q. 2012. Combining marker-based mocap and rgb-d camera for acquiring high-fidelity hand motion data. In *Proceedings of the ACM SIGGRAPH/Eurographics Symposium on Computer Animation*. Eurographics Association, 33–42.

ZHAO, W., ZHANG, J., MIN, J., AND CHAI, J. 2013. Robust realtime physics-based motion control for human grasping. *ACM Transactions on Graphics (TOG) 32,* 6, 207.

ZHU, Y., RAMAKRISHNAN, A. S., HAMANN, B., AND NEFF, M. 2012. A system for automatic animation of piano performances. *Computer Animation and Virtual Worlds*.

ZIBREK, K. AND MCDONNELL, R. 2014. Does render style affect perception of personality in virtual humans? In *Proceedings of the ACM Symposium on Applied Perception*. ACM, 111–115.

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