The Effect of Dynamic Facial Asymmetries on the Perceived Believability, Appeal, and Naturalness of Animated Agents

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ABSTRACT

An animated agent's believability, often defined as "the illusion of life," has many facets, including the agent's appearance, movements, and user interactions. Considering that human facial expressions are often not symmetrical, evaluating how facial expression asymmetries affect believability in animated agents would provide valuable insights for researchers and artists. Our research focused on facial movements and examined the impact of three dynamic facial asymmetries on users' perception of the agent's believability, appeal, and naturalness. Our research involved three studies: 1) a preliminary study in which we determined the maximum values to base asymmetry levels, 2) a study in which we identified what level of asymmetry yields the most perceived believability for each asymmetry location, and 3) a study in which we determined what effects different combinations of asymmetries have on perceived believability, appeal, and naturalness. The findings confirmed the effect of dynamic facial asymmetry on the agents' perceived believability, appeal, and naturalness. Furthermore, our research suggests that including one or a combination of asymmetric eyebrow, mouth, or eyelid motions increases the agents' perceived believability, appeal, and naturalness.

CCS CONCEPTS

• **Computing methodologies** → *Procedural animation.*

KEYWORDS

virtual agent, asymmetry, facial expression, naturalness, believability, appeal

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1 INTRODUCTION

Embodied animated agents have become ubiquitous in human-computer interactions. Utilizing embodied animated agents as an interface metaphor offers a significant advantage by enabling users to engage with computers in a way that closely resembles face-to-face conversation, maximizing the interaction's naturalness.

However, animated agents must be believable in their appearance, movements, and interactions with the users to connect with them effectively. A believable agent "...allows the audience to suspend their disbelief" and provides a convincing representation of the appearance, movements, gestures, and personality they expect from the agent [Loyall 1997]. While more aspects of animation exist, believability, appeal, and naturalness pertain to how people perceive virtual characters. In this paper, we define appeal as "a design or an action that the audience enjoys watching" [Lasseter 1998] and naturalness as "the degree to which the character's facial movements are similar to the facial articulations seen in a real human" [Kiran 2017]. Since asymmetric facial expressions are a natural occurrence in humans, it is essential to investigate how such asymmetrical expressions could affect viewers' perception of the agents. Our research contributes knowledge in this area by examining the extent to which three distinct dynamic facial asymmetries (eyebrow, mouth, and eyelids) occurring during speech with varying levels of displacement affect the perceived believability, appeal, and naturalness of two animated agents: one male and one female.

Based on our results, we argue that dynamic facial asymmetry influences the perceived believability of animated agents. These findings have significant implications for researchers using animated agents and practitioners using animated characters for other purposes. Based on the results, we provide guidelines for enhancing the believability, appeal, and naturalness of animated agents using dynamic asymmetry and provide a base for future research to examine the effects of dynamic facial asymmetries about other areas of the face and for agents that show different visual styles (from stylized to realistic).

We organized this paper as follows. In Section 2, we discuss prior studies related to animated agents' facial asymmetry, believability, appeal, and naturalness. We describe the three studies in Sections 3, 4, and 5. In Section 6, we discuss the findings, and in Section 7, we report conclusions and future work.

2 RELATED WORK

2.1 Facial Asymmetry in Animated Agents

Facial asymmetry may be structural (static) or dynamic (occurring during facial expression). Most human faces present mild structural asymmetry, and many facial expressions are asymmetrical [Thiesen et al. 2015]. Static and dynamic facial asymmetry is fundamental in character animation. According to the old Disney masters, an appealing and believable animated character should not display any symmetrical movements, including facial movements, because this "creates an unnatural look" [Thomas and Johnston 1995].

Researchers have examined facial asymmetry's effects on animated characters' perception. Delor et al. [Delor et al. 2021] investigated the perceived genuineness of emotions expressed with facial asymmetry. They showed that asymmetry significantly impacted the perception of virtual characters' genuineness, but further research was needed to evaluate precisely what aspects of asymmetry affect people's perceptions. Ahn et al. [Ahn et al. 2013] developed an asymmetric facial expression synthesis tool. They performed a study using static images generated by their tool to assess the effectiveness of symmetric and asymmetric facial expressions in conveying eight basic and complex emotions. The findings highlighted the importance of facial asymmetries and the significant enhancement achieved through asymmetry in expressing ambivalent feelings.

2.2 Believability in Animated Agents

According to Loyal [Loyall 1997], "a character is considered believable if it allows the audience to suspend their disbelief and if it provides a convincing portrayal of the personality they expect or come to expect." As Gomes et al. [Gomes et al. 2013] pointed out, believability has many distinct components, including the agent's behavior coherence, change with experience, awareness, behavior understandability, personality, emotional and social expressiveness, visual impact, and predictability. Facial asymmetry is closely related to two believability components proposed by Gomes et al. [Gomes et al. 2013]: emotional expressiveness and visual impact. Emotional expressiveness is "the extent to which the character expresses its emotions." Two established findings in cognitive neuroscience indicate that basic emotions typically exhibit slight asymmetry in their expression. Moreover, complex emotions, like ambivalent feelings, may partially display distinct and potentially opposing emotions on each side of the face [Wang et al. 2017]. Hence, asymmetric facial movements are fundamental in conveying natural, believable emotions. Visual impact is "the amount by which an agent draws our attention" [Gomes et al. 2013]. As mentioned in the previous section, an appealing animated character that draws the viewer's attention should not display symmetrical movements. [Thomas and Johnston 1995].

Other components, such as social expressiveness, play a significant role in the believability of an animated agent. Work by Afonso and Prada [Afonso and Prada 2009] suggests that virtual agents with richer social behaviors are more believable. Predictability is also an essential facet of an agent's believability. ElSayed and King [ElSayed and King 2017] argue that human players prefer engaging with other human players over artificial intelligent (AI) agents. This inclination is rooted in the unpredictability inherent in human behavior. Hence, there is a need for agents that show a certain degree of unpredictability in their behavior to avoid the pitfall of repetitive behavior.

2.3 Appeal in Animated Agents

Lasseter [Lasseter 1998] defines appeal as "a design or an action that the audience enjoys watching." A study by Kokkinara and McDonnell [Kokkinara and McDonnell 2015] showed that the realism of the virtual agents' animation contributes to the agent's appeal. The authors employed face-tracking technology to capture real-time data on participants' head and eye movements and facial expressions. They mapped the data on virtual faces with varying degrees of realism and various levels of animation realism. Their findings indicated that virtual faces with higher levels of animation realism were perceived as more appealing.

Lighting is another crucial aspect of a virtual agent's perceived appeal. Wisessing et al. [Wisessing et al. 2020] conducted a series of perceptual experiments to examine the impact of critical light brightness levels and various key-to-fill light ratios applied to the two sides of a character's face. They showed that lighting is an effective tool in modifying the emotional intensity of a character, with brighter conditions consistently enhancing the character's appeal. Fleming et al. [Fleming et al. 2016] examined the effect of stylization on perceived character appeal. They investigated whether stylized body shapes versus realistic body shapes increase perceived appeal. They showed that the most appealing character was a partially stylized one. Another interesting result was that characters with high or no stylization were rated as the least appealing.

2.4 Naturalness in Animated Agents

Kiran et al. [Kiran 2017] define naturalness as "the degree to which the character's facial movements are similar to the facial articulations seen in a real human." As facial asymmetries are a natural occurrence in human facial expressions, an animated agent that displays facial asymmetries is likely to be perceived as more natural than an agent that displays symmetrical facial motions.

Characters can convey emotions by precisely replicating the facial expressions and vocal cues observed in human behavior or by tempering or amplifying the intensity of these emotional expressions. Hyde et al. [Hyde et al. 2014] conducted a study in which participants evaluated animations of a character whose facial motions matched an actress' and animations in which the facial motions had been exaggerated. They showed that the exaggeration of the facial motions increased perceived emotional intensity but was negatively related to naturalness ratings. Based on their findings, they suggested that accurately emulating human facial motions might have the most significant effect on perceived naturalness.

Krejsa et al. [Krejsa et al. 2018] developed a model for generating high-fidelity head and eye movements during gaze shifts for animated characters. Because the eye and head animation stimuli were high-fidelity, participants rated them as highly natural. This shows how the accurate replication of facial movements may contribute to high ratings of perceived naturalness.

3 PILOT STUDY: PREFERENCE OF ASYMMETRY LEVELS

Our pilot study aimed to determine the maximum acceptable level of displacement of three distinct dynamic facial asymmetries for two animated agents: a male and a female. The study considered dynamic asymmetries in the eyebrow, eyelid, and mouth with five displacement levels for each facial asymmetry, namely low (50% of the maximum displacement value determined by the character animation rigging software), medium-low (75%), medium (100%), medium-high (125%) and high (150%). The study focused on three action units (AUs) of the Facial Action Coding System (FACS) [Ekman and Friesen 1978]: Outer Brow Raiser, Lip Corner Puller, and Squint. We illustrate in Figure 1 the minimum, middle, and maximum values of the five total facial asymmetry displacement levels for the Outer Brow Raiser and Lip Corner Puller, respectively.

3.1 Participants

Our sample consisted of seven 3D animation professionals (years of experience: $M = 6.42, SD = 3.58$). Six graduate students specializing in computer graphics technology and animation and one professor whose research includes virtual humans (age: $M = 24.90, SD = 4.85$). Participants were recruited through word of mouth.

3.2 Stimuli

We used the Character Creator 4 software to create the models and rigs for the virtual agents. We exported to Autodesk Maya, where the characters were posed with different levels of asymmetry in the eyebrows, mouth, and eyelids. The levels of asymmetry were based on the Character Creator 4 Blend Shape values, where a value of zero means that there is no displacement applied to the asymmetric component, and one is what Character Creator 4 determined should be the maximum range of displacement for the mesh component. We captured five images for each asymmetric component at 50%, 75%, 100%, 125%, and 150% of the Character Creator 4 Blend Shape value of 1.00, resulting in 30 images (five asymmetry levels × five facial components × two agents).

3.3 Procedure

We developed and used a survey to collect the data using the Qualtrics system. Participants were shown five images side by side with increasing levels of asymmetry for each asymmetric facial feature for each agent. We then asked them to identify the image representing the maximum acceptable displacement value for each asymmetric location and character.

3.4 Results

For the female Eyebrow level, the average maximum acceptable asymmetry was 110% ($SD = 21\%$) of the Character Creator 4 Blend Shape value; for the Female Eyelid Level, the average maximum acceptable asymmetry was 130% ($SD = 15\%$); and for the Female Mouth Level, the average maximum acceptable asymmetry was 140% ($SD = 20\%$). For the Male Eyebrow level, the average for maximum acceptable asymmetry was 130% ($SD = 22\%$); for the Male Eyelid Level, the average for maximum acceptable asymmetry was 135% ($SD = 19\%$); and for the Male Mouth Level, the average for maximum acceptable asymmetry was 130% ($SD = 33\%$).

4 STUDY 2: IDENTIFYING THE LEVELS OF ASYMMETRY

Our goal was to determine the most believable level of asymmetry for each of the three AUs as perceived by the participants. The experiment focused on dynamic facial asymmetries during speech. For the study, we used a within-group design; the independent variables were the asymmetry level, asymmetry location, and the agent gender, and the dependent variable was the participant believability rating on a Likert scale from 1 (unbelievable) to 5 (believable).

4.1 Participants

We recruited participants via email and word of mouth. Thirty-four participants (age: $M = 21.60$, $SD = 5.00$) completed the survey; 18 identified as male, 15 identified as female, and one preferred not to say. We asked participants about their experience with computer animation. Two responded that they were very experienced with computer animation, 21 were moderately experienced with computer animation, 10 had little experience, and one had no experience with computer animation.

4.2 Stimuli

For this study, we used the same characters as the pilot study. As the study focused on dynamic facial asymmetries during speech, we applied a lip sync animation of an emotion-neutral sentence to each agent. The sentence was, *"Everyone was busy, so I went to the movie alone."* We generated text-to-speech audio using Microsoft Azure. We layered the asymmetric facial motions about the agent's eyebrow, mouth, and eyelids on top of the speech animation with 33%, 66%, and 100% of the maximum perceived asymmetry value identified from the pilot study. This resulted in 20 stimuli videos (three asymmetry levels × three facial components × two agents + two baseline videos with no asymmetry). We illustrate in Figure 2 frames extracted from the stimuli animations.

4.3 Procedure

We developed a survey using the Qualtrics survey tool to collect participants' ratings. The survey included 20 videos presented randomly, each featuring an animated agent speaking a sentence while an asymmetric expression is applied to various locations on their face. After watching each video, participants rated the believability of the stimulus on a Likert scale from 1 (unbelievable) to 5 (believable).

4.4 Results

Findings showed that for the male character, the asymmetry in the mouth with a displacement of 33% was preferred, the asymmetry in the eyelid squint with a displacement of 33% was preferred, and the asymmetry in the brow with a displacement of 66% was preferred. For the female character, the mouth at 33% was preferred, the eye

Figure 1: Female character eyebrow asymmetry levels for the pilot study (left) and male character mouth asymmetry levels for the pilot study (right).

Figure 2: Frames extracted from the female (left) and male (right) agents' animations featuring the three levels of asymmetry in the Squint.

at 66%, and the brow at 33% was preferred. We illustrate in Figure 3 the average responses for each asymmetry component and level.

5 STUDY 3: EFFECTS OF FACIAL ASYMMETRY ON PERCEIVED AGENT'S BELIEVABILITY, APPEAL, AND NATURALNESS

Based on our findings in Study 2, which revealed what levels of asymmetric facial displacements were perceived as the most believable, we created combinations of asymmetric facial motions. Our goal in this study was to examine which specific combinations of dynamic facial asymmetries would yield the highest perceived agent's believability, appeal, and naturalness. We followed a within-group design and collected quantitative data through questionnaire responses. For this study, the independent variables were the asymmetry level, asymmetry location, and their combinations and the agent gender, and the dependent variables were the participant believability, appeal, and naturalness ratings.

5.1 Participants

To recruit participants for this study, we forwarded emails to students' listservs and through word of mouth. Thirty-nine participants (age: $M = 21.70$, $SD = 4.60$) completed the survey. Fourteen identified as male, 19 as female, and six preferred not to say. Two responded that they were very experienced in animation, 18 were moderately experienced, 15 had little experience, and 14 had no experience.

5.2 Stimuli

We used the characters and lip-synch animations created for Study 2. Based on the results from Study 2, we produced 16 stimuli videos: (three videos with one asymmetry location + three videos with two asymmetry locations + one video with all three asymmetry locations + one baseline video without asymmetry) × two characters. In the videos, we included combinations of the three facial asymmetries with optimal displacement levels. Figure 4 shows frames extracted from the video stimuli used in Study 3.

5.3 Procedure

We developed a survey in Qualtrics to collect data for Study 3. In the survey, we presented the video stimuli in random order. After watching each video, we asked the participants to rate the agent's believability, appeal, and naturalness on a Likert scale ranging from 1 to 5, with one being not believable, appealing, and natural and five being believable, appealing, and natural.

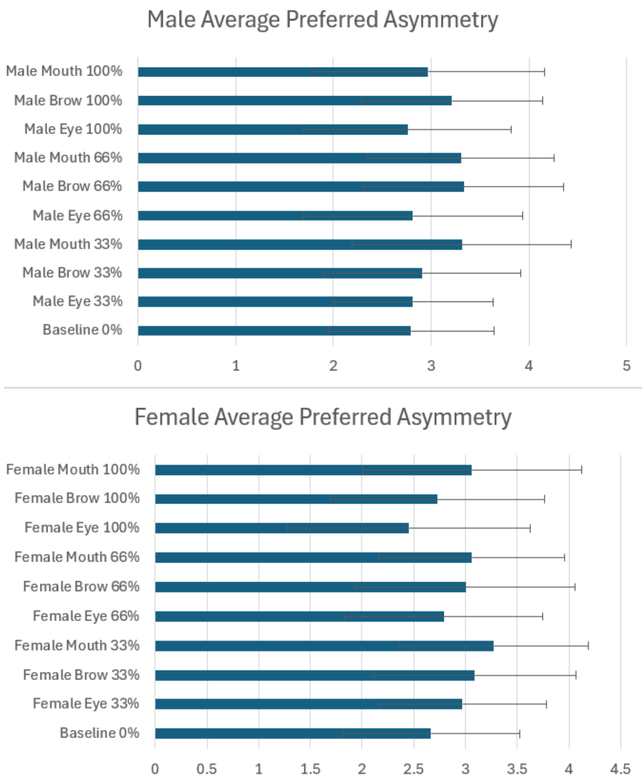

Figure 3: Average of preferred percentages of asymmetry for male (Top) and female (Bottom) agent.

6 RESULTS

6.1 Male Agents Perceived Appeal

We used one-way within-group analysis of variance (ANOVA) to compare facial expression asymmetry's effect on the appeal of the male virtual agent in combinations of eye, brow, and mouth asymmetries (i.e., Default, Eye, Brow, Mouth, EyeBrow, EyeMouth, BrowMouth, EyeBrowMouth). We found a significant effect of facial asymmetries, Wilks' $\Lambda = .458$, $F(7, 28) = 4.556$, $\eta_p^2 = .532$, $p = .002$. We used Bonferroni-corrected estimates for pairwise comparisons to assess the statistically significant ($p < .05$) results. The pairwise comparison indicated that there was a significant difference in the scores between the Default ($M = 2.57$, $SD = 1.11$) and EyeBrow ($M = 2.82$, $SD = 1.01$) conditions at $p = .045$, Default and EyeBrow-Mouth ($M = 3.11$, $SD = .86$) conditions at $p = .003$, between Eye ($M = 2.62$, $SD = 1.03$) and BrowMouth ($M = 3.00$, $SD = .93$) conditions at $p = .009$, and between Eye and EyeBrowMouth conditions at $p = .003$. These results suggest that animated facial symmetries influence virtual agents' appeal. Specifically, our results indicated that virtual agents are significantly more appealing when eyebrow asymmetry is combined with eye asymmetry. However, there is no significant difference in appeal when a single asymmetric feature is used.

6.2 Male Agent Perceived Naturalness

The one-way within-group ANOVA indicated a significant effect of facial asymmetries, Wilks' $\Lambda = .603$, $F(7, 28) = 2.629$, $\eta_p^2 = .397$, $p = .032$. The pairwise comparisons indicated that there was a significant difference in the scores for the Default ($M = 2.45$, $SD = 1.01$) and EyeMouth stimuli ($M = 2.91$, $SD = .78$) conditions at $p = .040$, Default and BrowMouth ($M = 3.05$, $SD = .93$) conditions at $p = .013$, and between Default and EyeBrowMouth ($M = 3.11$, $SD = .83$) conditions at $p = .009$. These results suggest that animated facial asymmetries influence the naturalness of virtual agents. Specifically, our results indicate that virtual agents are perceived as significantly more natural when mouth asymmetry is combined with other asymmetries.

6.3 Male Agent Perceived Believability

The one-way within-group ANOVA indicated a significant effect of facial asymmetries, Wilks' $\Lambda = .571$, $F(7, 28) = 3.003$, $\eta_p^2 = .429$, $p = .018$. Pairwise comparisons indicated a significant difference in the scores for the EyeBrow ($M = 2.77$, $SD = 1.00$) and EyeBrowMouth stimuli ($M = 3.17$, $SD = .95$) conditions at $p = .025$. These results suggest that animated facial influence the believability of virtual agents. While these results do not show a significant difference from the baseline, there is a significant difference between EyeBrow and EyeBrowMouth stimuli, suggesting that specific combinations of asymmetric features can significantly affect believability.

6.4 Female Agent Perceived Appeal

A one-way within-group ANOVA was conducted to compare the effect of facial asymmetries on the appeal of the female virtual agent in combinations of eye, brow, and mouth asymmetries. We found a significant effect of facial asymmetries, Wilks' $\Lambda = .611$, $F(7, 28) = 2.549$, $\eta_p^2 = .389$, $p = .037$. Pairwise comparisons indicated that there was a significant difference in the scores for the Default ($M = 2.28$, $SD = 1.20$) and Brow ($M = 2.65$, $SD = 1.13$) conditions at $p = .009$, and Default and BrowMouth ($M = 2.82$, $SD = 1.12$) conditions at $p = .026$, and Default and EyeBrowMouth ($M = 2.80$, $SD = 1.07$) conditions at $p = .031$. These results suggest that animated facial asymmetries affect the appeal of virtual agents. Specifically, our results indicate that virtual agents are perceived as significantly more appealing when eyebrow asymmetry is combined with other asymmetries.

6.5 Female Agent Perceived Naturalness

The one-way within-group ANOVA indicated a significant effect of facial asymmetries, Wilks' $\Lambda = .488$, $F(7, 27) = 4.039$, $\eta_p^2 = .512$, $p = .004$. Pairwise comparisons indicated that there was a significant difference in the scores for the Default ($M = 2.35$, $SD = 1.12$) and BrowMouth ($M = 2.94$, $SD = .98$) conditions at $p = .041$, Default and Mouth ($M = 2.82$, $SD = 1.15$) conditions at $p = .047$, and EyeMouth stimuli ($M = 2.47$, $SD = 1.13$) and BrowMouth conditions at $p = .040$. These results suggest that animated facial asymmetries influence the perceived naturalness of virtual agents. Specifically, our results indicate that virtual agents are perceived as significantly more natural when mouth asymmetry is combined with other asymmetries.

Figure 4: Frames extracted from the female (left) and male (right) agents' stimuli for Study 3.

Table 1: Estimated marginal means for all characters and factors. The factors are abbreviated as follows: E=Eye asymmetry, B=Brow asymmetry, and M=Mouth asymmetry.

Means	No Asymmetry	E	B	M	EB	EM	BM	EBM
M Believability	2.77 (SD=1.17)	2.77 (SD=1.09)	2.94 (SD=1.06)	3.06 (SD=1.06)	2.77 (SD=1.00)	2.89 (SD=.93)	3.11 (SD=1.16)	3.17 (SD=.95)
M Appeal	2.57 (SD=1.12)	2.63 (SD=1.03)	2.91 (SD=.85)	2.77 (SD=1.09)	2.83 (SD=1.01)	2.80 (SD=.96)	3.00 (SD=.94)	3.11 (SD=.87)
M Naturalness	2.46 (SD=1.01)	2.74 (SD=.92)	2.94 (SD=.94)	2.89 (SD=.96)	2.71 (SD=.99)	2.91 (SD=.78)	3.06 (SD=.94)	3.11 (SD=.83)
F Believability	2.51 (SD=1.09)	2.66 (SD=1.11)	2.86 (SD=1.06)	2.77 (SD=1.14)	2.97 (SD=1.15)	2.60 (SD=1.19)	3.00 (SD=1.00)	3.03 (SD=1.12)
F Appeal	2.29 (SD=1.20)	2.46 (SD=1.12)	2.66 (SD=1.14)	2.57 (SD=1.09)	2.71 (SD=1.10)	2.49 (SD=1.17)	2.83 (SD=1.12)	2.80 (SD=1.08)
F Naturalness	2.35 (SD=1.12)	2.47 (SD=1.02)	2.68 (SD=.94)	2.77 (SD=1.16)	2.82 (SD=.97)	2.47 (SD=1.13)	2.94 (SD=.98)	2.85 (SD=1.08)

6.6 Female Character Believability

The one-way within-group ANOVA indicated a significant effect of facial asymmetries, Wilks' $\Lambda = .604$, $F(7, 28) = 2.618$, $\eta_p^2 = .396$, $p = .033$. Pairwise comparisons indicated a significant difference in the scores for the Default ($M = 2.51$, $SD = 1.09$) and BrowMouth ($M = 3.00$, $SD = 1.00$) conditions at $p = .036$. These results suggest that animated facial asymmetries affect the believability of virtual agents. Specifically, our results indicate that believability increases with Eyebrow and Mouth asymmetries. These results also reveal that combinations, including the asymmetric squint, are not perceived to be significantly different from baseline.

6.7 Comparison of Appeal

Paired-sample t-tests were conducted for all the stimuli combinations between male and female virtual characters. We found a significant difference in the scores for the Male EyeMouth ($M = 2.48$, $SD = 1.17$) and the Female EyeMouth ($M = 2.80$, $SD = .96$) conditions; $t(4) = -2.234$, $p = .032$. These results suggest that the female model is significantly more appealing only in the EyeMouth stimuli condition.

6.8 Comparison of Naturalness

Paired-sample t-tests were conducted for all the stimuli combinations between male and female virtual characters. We found a significant difference in the scores for the Male Brow ($M = 2.65$, $SD = .93$) and the Female Brow ($M = 2.94$, $SD = .93$) conditions; $t(4) = -2.049$, $p = .048$. There was a significant difference in the scores for the Male EyeMouth ($M = 2.48$, $SD = 1.12$) and the Female EyeMouth ($M = 2.91$, $SD = .78$) conditions; $t(4) = -2.674$, $p = .011$. These results suggest that the female model is perceived as significantly more believable in the Brow and EyeMouth stimuli conditions.

6.9 Comparison of Believability

Paired-sample t-tests were conducted to compare the Male Default and Female Default stimuli. We found a significant difference in the scores for the Male Default ($M = 2.51$, $SD = 1.09$) and the Female Default ($M = 2.77$, $SD = 1.16$) conditions; $t(4) = -2.052$, $p = .048$. These results suggest that the female model is more believable than the male model. Additional paired-sample t-tests were conducted for all the other combinations. We found a statistically significant difference in the scores for the Male Mouth ($M = 2.77$, $SD = 1.13$) and the Female Mouth ($M = 3.05$, $SD = 1.05$) conditions; $t(4) = -2.144$, $p = .039$. We found a significant difference in the scores for the Male EyeMouth stimuli ($M = 2.60$, $SD = 1.19$) and the Female EyeMouth stimuli ($M = 2.88$, $SD = .93$) conditions; $t(4) = -2.253$, $p = .031$. These results suggest that the female model is significantly more believable in the Mouth and EyeMouth stimuli conditions.

7 DISCUSSION

Based on our findings, certain combinations of asymmetric facial movements could affect animated characters' believability, appeal, and naturalness. Not all asymmetric facial movements may increase animated agents' perceived believability, appeal, and naturalness. Asymmetric motions in the eyebrow and mouth may impact believability, appeal, and naturalness more than the eyelids. This is possibly due to the eyelid motion (squint) being more difficult to

Table 2: Paired-sample t-tests comparing male and female characters for all factors and combinations. The factors are abbreviated as follows: E=Eye asymmetry, B=Brow asymmetry, and M=Mouth asymmetry.

T-test Sig	No Asymmetry	E	B	M	EB	EM	BM	EBM
Believability	.048	.458	.499	.039	.281	.031	.501	.304
Appeal	.058	.138	.071	.198	.458	.032	.295	.062
Naturalness	.609	.107	.048	.487	.571	.011	.545	.071

notice. Additionally, certain combinations like BrowMouth and EyeBrowMouth often produce higher scores as seen in Table 1. Another interesting result of these findings was the discovery that facial asymmetries had more significant increases than believability in appeal and naturalness. This implies that while asymmetric facial movements affect believability, they have an even greater effect on how appeal and naturalness are perceived. When comparing male and female agents, results revealed that female characters receive higher ratings for believability, appeal, and naturalness (Table 2). This comparison was included to illustrate the need for further research on how different characters influence believability, appeal, and naturalness with facial asymmetries. The concepts of believability that Gomes et al. [Gomes et al. 2013] have proven to apply to facial expression asymmetry, as there is a clear distinction in our results between the three concepts we chose: believability, appeal, and naturalness. With our study, we could also answer many questions left by Delor et al. [Delor et al. 2021] in their study on facial asymmetry. While they focused on the perception of emotions conveyed by asymmetry, we have answered how asymmetry affects the perception of believability. Kiran et al. [Kiran 2017] showed us that replicating other human motions onto virtual agents yields more naturalness. Since facial expression asymmetries are a natural phenomenon, we have shown that their prior research was correct; replicating them onto virtual characters yields changes in appeal, naturalness, and believability.

7.1 Limitations

First, our study considered only the agent's gender and did not examine the extent to which other factors such as the agent's age, ethnicity, and stylization might affect the perception of facial asymmetries and hence the perception of the agent's perceived believability, appeal, and naturalness. Second, our study focused solely on three facial AUs. It is possible that asymmetries pertaining to other AUs may yield different results. Third, the study considered only two agents; hence, the findings may have been affected by the intrinsic design characteristics of the characters. Fourth, we focused solely on one emotional expression (neutral) and did not examine the relationship between dynamic facial asymmetries and other emotional expressions.

7.2 Implications for Future Research and Practice

Our study provides valuable information for future researchers and animators. Similar experiments can be replicated to create optimal levels of facial asymmetries for any animated character. For use with other characters, a short perception study would be necessary to determine the maximum acceptable levels of asymmetry. Since most characters differ in design in some way from the characters used in this study, conducting a perception study to find the proper values is essential. However, these findings can be generalized by having an artist determine the maximum level for facial asymmetries and using a value between 33% and 66% of the maximum value.

This research also provides essential considerations for practical uses. First, results confirm the principle of asymmetry in animation, which states that there should be no symmetry in a facial expression because this creates an unnatural look. Second, findings reveal that to influence the believability of a character, asymmetries should be particularly prominent in certain areas of the character's face versus other areas. Third, animators and character designers should consider that asymmetries impact female characters' believability more than male characters. While these findings can be applied to practical use, we recommend using the results of this research as a guideline, as artists should consider the further effects of asymmetries beyond believability, appeal, and naturalness. Asymmetries should be carefully blended into animations, and care should be taken to ensure that whatever is intended to be conveyed with the character is maintained by including or lacking dynamic asymmetries.

8 CONCLUSION AND FUTURE WORK

In future work, factors like age, ethnicity, and levels of stylization need to be explored, and their effect on asymmetry and its perception need to be evaluated. Additionally, more facial asymmetries and their combinations could affect perception differently. Research with a greater variety of characters and emotions must also be conducted to assess their effect on the perception of asymmetries. Most importantly, future work needs to be conducted to evaluate how facial proportions relate to these levels of asymmetry. This future work would allow us to provide guidelines for asymmetric facial movements based on the characters' proportions. Despite its limitations, the study reported in the paper yielded interesting results suggesting that facial asymmetry may change or improve animated virtual agents' believability, appeal, and naturalness. Asymmetry movements in the eyebrow and mouth regions may produce the greatest change in believability compared to the lesser effect of asymmetry in the eyelid area. These findings have significant implications as they contribute to our understanding of dynamic facial asymmetries' impact on animated agents' believability and establish a foundation for future investigations in this field. Moreover, the results offer valuable guidance for professionals in various domains, including artists, animators, and instructional content developers. They provide guidelines for enhancing the believability and overall appeal of animated agents, potentially influencing the educational effectiveness of pedagogical agents.

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