Expression of Emotions using Wrinkles, Blushing, Sweating and Tears

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Abstract. Wrinkles, blushing, sweating and tears are physiological manifestations of emotions in humans. Therefore, the simulation of these phenomena is important for the goal of building believable virtual humans which interact naturally and effectively with humans. This paper describes a real-time model for the simulation of wrinkles, blushing, sweating and tears. A study is also conducted to assess the influence of the model on the perception of surprise, sadness, anger, shame, pride and fear. The study follows a repeated-measures design where subjects compare how well is each emotion expressed by virtual humans with or without these phenomena. The results reveal a significant positive effect on the perception of surprise, sadness, anger, shame and fear. The relevance of these results is discussed for the fields of virtual humans and expression of emotions.

Keywords: Expression of Emotions, Wrinkles, Blushing, Sweating, Tears

1 Introduction

Communicating one's emotions serves an adaptive purpose [1, 2, 3, 4]. A person might express anger to signal another to cease some action which might be hindering his goals. A person might express shame to convey regret for breaking some accepted social rule. In fact, emotions play a significant role in social interaction where participants continuously monitor and respond to each other's emotions while pursing their own goals. As to the manner emotions are expressed, besides facial expression, vocalization and appropriate gestures, several other autonomically mediated signals accompany emotions such as changes in coloration that result in local blood flow (e.g., flushing, blushing, blanching and bulging of arteries), whereas others involve additional detectable changes such as piloerection, sweating (and accompanying odors), tearing and crying [5]. As we try to build embodied virtual agents, or virtual humans, which communicate emotions effectively and naturally with humans [6], we should also simulate these autonomically mediated signals.

This paper describes a model to express emotions in virtual humans using wrinkles, blushing, sweating and tears. Regarding wrinkles, two kinds can be distinguished [7]: (a) *permanent wrinkles*, which are caused by aging and habitual facial expressions as the skin looses elasticity; (b) *temporary wrinkles*, which are caused by deformations of the skin layers as a result of muscle contraction. In this work we are interested in the subset of the latter which is associated with emotional facial expressions. The argument here is that wrinkles can be an important, if not crucial, clue to the perception of the emotion the agent is trying to convey. In particular, the work focuses on simulation of wrinkles in the forehead caused by the expression of surprise, sadness and anger.

Blushing manifests physiologically as a spontaneous reddening of the face, ears, neck and upper chest as the small blood vessels in the blush region dilate, increasing blood volume in the area [7]. Blushing, aside from being associated with self-consciousness, can be accompanied by social anxiety, uneasiness, embarrassment, shame or happiness (e.g., when someone receives an undeserved praise) [8]. Several theories of blushing have been proposed: (a) the *interpersonal appraisal theory* argues that blushing arises from being self-aware and thinking about what others are thinking of us [9]; (b) the *communicative and remedial theory* argues that blushing is a save-face action which acknowledges and apologizes for breaking an accepted social rule [10]; the *social blushing theory* expands on the previous one (e.g., explaining cases where blushing occurs with positive emotions) and argues that blushing will occur when undesired social attention is given to someone [8]. In this work we are interested in the fact that blushing serves an important communicative function and is associated with certain characteristic emotions. In particular, the work focuses on simulation of blushing associated with two self-conscious emotions - shame (with negative valence) and pride (with positive valence).

Sweating is primarily a means of thermoregulation but can also be caused by emotional stress [7]. This latter form is referred to as *emotional sweating* and manifests physiologically in the palms of the hands, soles of the feet, axillae and head [11, 12]. This form of sweating may occur in situations where an individual is subjected to fearful situations or the scrutiny of others (e.g., talking in public or to a superior) and is particularly evident in shy and social phobic individuals [13]. This work focuses on the simulation of sweating in the forehead associated with fear.

Crying is usually associated with the experience of intense emotions in situations of personal suffering, separation, loss, failure, anger, guilt or joy [14]. Crying manifests physiologically through the shedding of tears and a characteristic noise (which might become concealed with age). Several explanations have been advanced for crying: (a) in one view, crying is seen as being cathartic and a release after an intense experience [15]; (b) in another view, attachment theory explains crying as an appeal for the protective presence of a parent [16]. For the infant, crying is used to call the attention of its care-takers in face of some urgent need (e.g. danger). Later in adulthood, crying continues to be a reaction to a loss and to carry an attachment message which seeks to trigger a response from its "care-takers" (e.g., spouse or friends). Thus, two factors motivate the simulation of tearing in our work: first, the important communicative function it serves; and second, its association with the expression of strong emotions. The focus of the work is in the simulation of tearing which occurs when experiencing intense sadness.

A study was also conducted to evaluate the influence of our model of wrinkles, blushing, sweating and tears on the perception of surprise, sadness, anger, shame, pride and fear. The study follows a repeated-measures design where subjects compare images of a virtual human expressing each of the aforementioned emotions with or without wrinkles, blushing, sweating and tears.

The rest of the paper is organized as follows: Section 2 describes related work; Section 3 describes the model for simulation of wrinkles, blushing, sweating and tears; Section 4 describes the experiment conducted to assess the influence of the model on the expression of sadness, anger, surprise, fear, shame and pride; finally, Section 5 discusses the results and future work.

2 Related Work

Three kinds of methods have been explored to simulate wrinkles: *texture mapping*, *physically-based* and *geometric* methods. Texture mapping methods rely on the *bump mapping* technique [17] to simulate wrinkles. Bump mapping simulates small details in an object's surface by locally changing the vertices' normals and, thus, affect the lighting calculation without deforming the object's geometry. Normal deformation can be defined using a texture, called a *normal map*, or calculated on-the-fly. Physically-based methods [18, 19] approximate the biomechanical properties of skin and, dynamic wrinkles emerge naturally as a consequence of skin deformation under the influence of muscle contraction. These methods tend to produce very realistic visual results and dynamic behavior for the wrinkles but, are very expensive computationally. Geometric methods avoid the computational cost of physical models by deforming the geometry, so as to simulate dynamic wrinkles, based on geometrical properties [20, 21]. This work uses bump mapping to render the wrinkles and normal map interpolation to simulate wrinkle dynamics.

There have been fewer systems developed for the simulation of blushing. Kalra et al. [22] define several textures with appropriate coloration of the face which are then interpolated appropriately according to the prevailing emotion. Jung et al. [23] also rely on predefined textures to simulate coloration of the face. The model presented here does not rely on textures and applies color to user-defined regions in the face.

Regarding tearing and sweating, several researchers [24, 25] have simulated the physical properties of water drops as well as its interactions with other water drops and solid surfaces. These systems, even though producing very realistic visual results, are far from being real-time. Jung et al. [23] propose a rare implementation of real-time tearing. Their system simulates refraction of light and strong highlights in tear drops. Tearing dynamics rely on 3D textures, which define a sequence of keyframe normal maps with a gloss map in the alpha channel, to animate the tears in real-time. This work also uses 3D textures to simulate dynamics but also explores another simpler technique. Furthermore, besides simulating strong highlights in the tears, highlights in the eyes are also simulated. Finally, sweating is easily implemented with the tears model by using appropriate normal and dynamic textures.

3 The Model

The model for wrinkles, blushing, sweating and tears has strict real-time requirements. First, following the paradigm of human face-to-face conversation, virtual humans need to integrate several verbal and nonverbal modalities [6].

Therefore, these new forms of expression need to integrate with the usual facial, bodily and vocal expression channels. Effectively, in this work the proposed model is integrated with an existent platform for virtual humans [26]. Second, virtual humans' behavior unfolds in time subject to various sub-second temporal constraints [6]. For instance, gestures which accompany speech must closely follow voice cadence. If these timing requirements are not met, the effectiveness of the communication breaks down. Therefore, the challenge is not to simply integrate the state-of-the-art in the techniques for simulation of each expression modality but to strike a balance between *visual realism* and *behavioral realism*. The idea of a believable character, which need not be visually realistic, but whose behavior provides the illusion of life and thus permits the audience's suspension of disbelief, applies here [27]. Therefore, this work steers away from physical models of wrinkles, blushing, sweating and tears which, even though creating visually realistic results, are very expensive computationally. Furthermore, our model makes extensive use of the *graphics processing unit* or *GPU*. The GPU implements a hardware-supported programmable graphics rendering pipeline where certain stages can be set to run user-defined programs, called *shaders*, written in a special language [28]. The advantage of using the GPU over pure software solutions is the considerable increase in speed we gain from hardware acceleration. This factor is likely to play a significant role in virtual human research as the models for expression modalities become more and more complex and new modalities are integrated.

3.1 Wrinkles

Wrinkles are simulated using bump mapping with normal maps. One normal map represents a typical temporary wrinkle pattern associated with a certain emotion. Wrinkle dynamics are then synchronized with the underlying pseudo-muscular model for facial expressions [26]. To implement this, three steps are taken. First, the vertex structure is augmented to contain binormal and tangent vectors which, together with the normals in the normal map, define a frame of reference on which lighting calculations, accounting for bump mapping, are performed [28]. Second normal maps for the wrinkle patterns are created. For each, the following procedure is realized, Fig.1: (a) a picture is taken with a person doing the respective wrinkle configuration; (b) the picture is cropped and converted to grayscale; (c) the picture is composited onto the virtual human texture; (d) the composited picture is edited to remove color information everywhere but in the wrinkle region, a Gaussian filter is applied to blur the image and the side borders are faded into the background color; (f) finally, the NVIDIA's normal map tool[1] is used to create the normal map. The third and final step is to create a shader program to run in the GPU which, given the data from the previous steps, actually applies the bump mapping technique while at the same time providing the following expression parameters: (a) one or more normal maps to apply; (b) the interpolation level between the images with and without bump mapping applied. The first parameter supports composition of wrinkle patterns, whereas the second implements wrinkle dynamics by synchronizing it with changes in the pseudo-

[1] Available at: http://developer.nvidia.com/object/nv_texture_tools

muscular model of the face [26]. The results for the emotions of surprise, anger and sadness are shown in Fig.2-(a) to (c). Fig.2-(d) shows how this effect can also be applied to simulate bulging of arteries in anger.

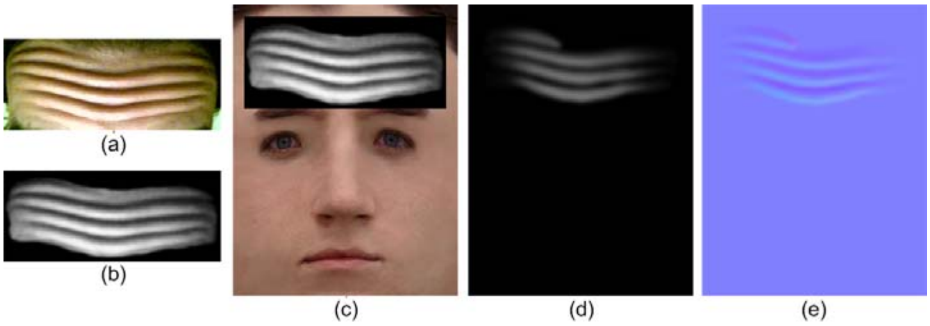

Fig. 1. Methodology to get normal maps for wrinkle patterns.

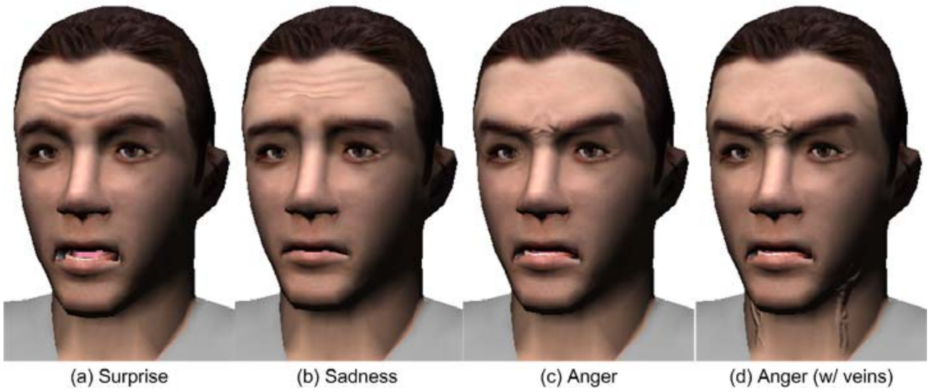

Fig. 2. Expression of surprise, sadness and anger using wrinkles.

3.2 Blushing

The basic idea for simulating blushing is having a way to selectively apply a color tint over certain vertices in the virtual human mesh (e.g. the vertices in the cheek). To accomplish this, four steps are taken. First, a floating-point value, called *mask*, is added to the virtual human vertex structure (which already has position, normal, skinning blend weights and texture coordinates). This value provides the foundation for defining custom subsets of the virtual human mesh, which we call *mesh masks*. A coding scheme, not described in the paper, is adopted which supports the association of up to 8 masks with each vertex. Thus, mesh masks can be overlapping. Second, a tool is developed to support the interactive creation of mesh masks. Once the mask is finished, the tool allows saving the mask in XML format. Having developed the tool, the third step is to use it to define masks for the areas of the face where blushing is to occur. Two masks are created: one for the cheeks; and one for the cheeks, forehead, nose and ears. The fourth and final step is to create a shader program to run in the GPU which tints the vertices in the specified mask. An important detail is that the tint is multiplied with the diffuse light component and, thus, the portion of the mask in the dark does not get painted. Several expression parameters are defined for this shader: (a) color of the tint (e.g., reddish for blushing); (b) mask to apply the tint; (c) fadeoff at the boundary, which defines how far the pixels in the (outside of the) mask boundary get affected by the color tint. Blushing of the cheeks and the full face, which can be associated with shame or pride, are shown in Fig.3-(b) and (c).

Fig. 3. Expression of shame and pride using blushing.

3.3 Tearing and Sweating

Simulation of tearing consists of modeling the properties of water and its dynamics. Regarding the former, the material properties of water were defined to have a very high specular component, a low diffuse component (e.g. RGB color of [10, 10, 10]) and a null ambient component. The water is, then, rendered using bump mapping with a normal map of a typical pattern of tears. The normal map's alpha channel is set to a nonzero value in the tearing (sweating) zone and to zero elsewhere. This channel is then used to composite the tears (or sweat) on top of the virtual human image. Moreover, the specular component of the eyes is increased to simulate accumulation of water in the eyes in the case of tearing. Regarding dynamics, two approaches are explored: (a) *volume textures*, which consist of a sequence of normal maps defining keyframes which are then interpolated to animate the tears (or sweat); (b) *definition of a dynamics texture*, which consists of a unique grayscale texture which defines how tears (or sweat) evolve in time being black the earliest and white the latest. This texture can then be used to interpolate a value which defines how much of the normal map is rendered at each instant. Each one of these mechanisms has its advantages and disadvantages. The first allows greater expressive control but at the cost of higher memory requirements and artistic effort. The second has lower memory requirements and requires less artistic effort but is less flexible than the former. Finally, both the properties of water and its dynamics are defined in a shader program to run in the GPU which defines parameters to set which animation mechanism to use and the current time in the animation. Results for the expression of sadness using tears are shown in Fig.4-(a) to (c). Fig.4-(d) shows simulation of sweating in fear.

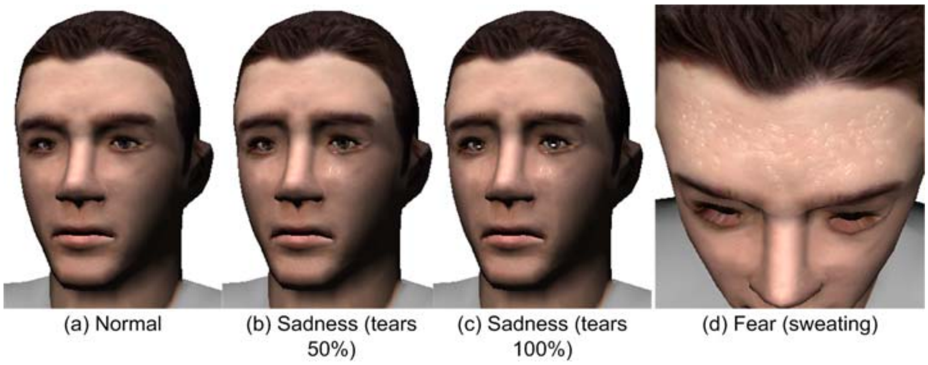

Fig. 4. Expression of sadness using tears and fear using sweating.

4 Evaluation

4.1 Design

A study was conducted to evaluate the influence of the wrinkles, blushing, sweating and tears model on the perception of surprise, sadness, anger, shame, pride and fear. The experiment followed a repeated-measures design with two conditions per emotion: the *control virtual human*, which uses only facial expression to convey the emotion; the *expressive virtual human*, which uses facial expression and wrinkles, blushing, sweating and tears to convey the emotion. Subjects are asked to classify, for each condition, whether the virtual human expresses the emotion on a scale from *1* (meaning 'doesn't express the emotion at all') to *10* (meaning 'perfectly expresses the emotion'). The order of presentation of the emotions is randomized. The order of presentation of the conditions, given an emotion, is also randomized.

The control and expressive conditions for each emotion are shown in Fig.5. The virtual human, in both conditions, assumes a typical muscular configuration of the face [29]. The virtual human in the expressive condition rely, additionally, on wrinkles, blushing, sweating and tears as follows: surprise, sadness and anger are given typical wrinkle patterns in the forehead; sadness is also associated with tears and shiny eyes; anger is also associated with bulging of arteries in the neck region and a light reddening of the face; pride and shame are associated with blushing of the cheeks; and, fear is associated with sweating of the forehead.

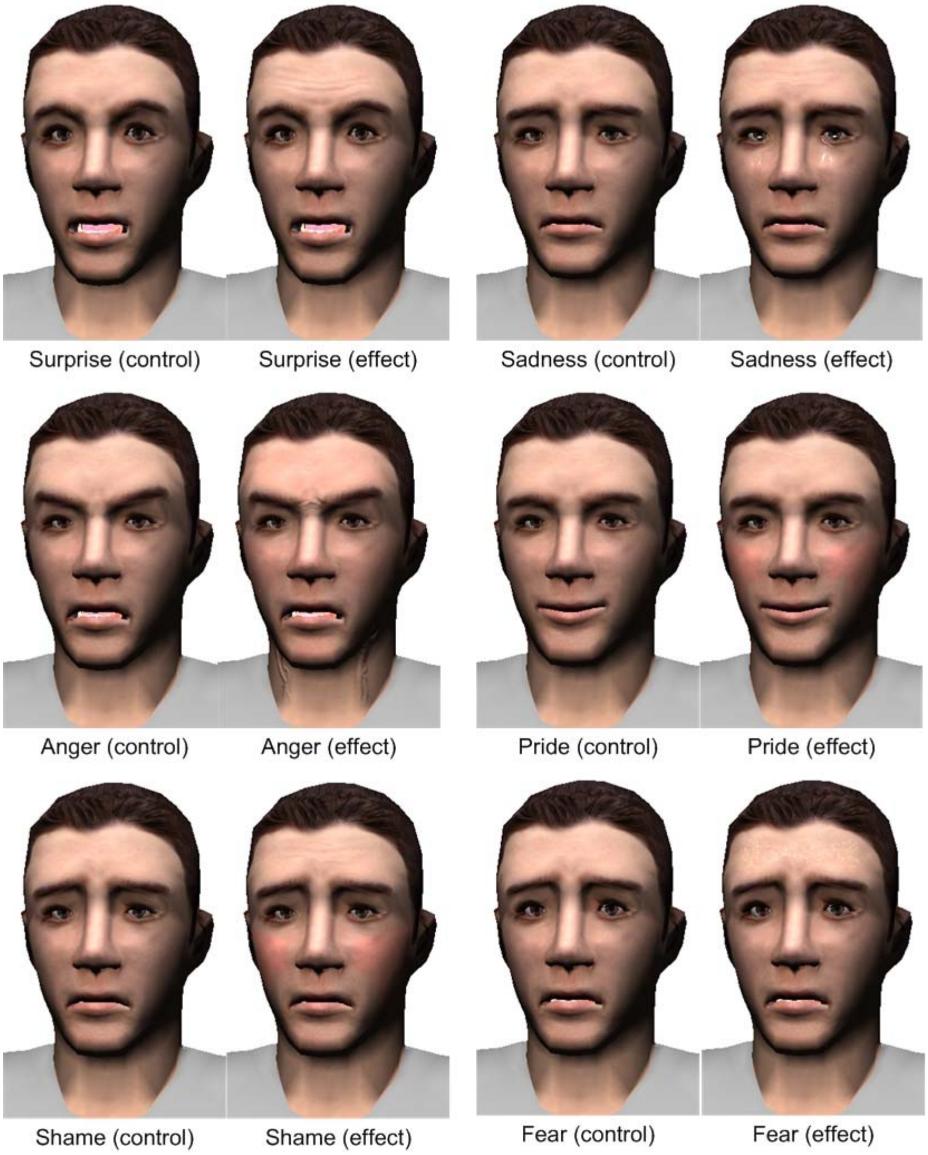

Fig. 5. Control and expressive conditions for surprise, sadness, anger, pride, shame and fear.

4.2 Procedure

The survey was implemented as an online survey. Forty-four participants were recruited with the following age distribution: *11-20* years, 6.8%; *21-30* years, 47.7%; *31-40* years, 31.8%; *41-50* years, 6.8%; and, *51-60* years, 6.8%. Gender distribution was as follows: *female*, 54.6%; *male*, 45.4%. Most had college education or above

(90.9%) from diverse fields. Participants had diverse origins: *North America*, 38.6%; *Europe*, 36.4%; *Asia*, 13.6%; and, *Africa*, 11.4%.

4.3 Results

The Kolmogorov-Smirnov test was applied to assess the normality of the data in each condition in each emotion. The results show that the control conditions for surprise (D(44)=0.12, p>.05), sadness (D(44)=0.13, p>.05) and shame (D(44)=0.10, p>.05) are significantly non-normal. Therefore, the dependent t test was used to compare means between the expressive and control conditions in pride, anger and fear as shown in Table 1; and, the *Wilcoxon* signed-rank test was used to compare ranks between the expressive and control conditions in surprise, sadness and shame as shown in Table 2.

Table 1. Dependent t test statistics for difference in means between the expressive and control conditions for the following emotions: PRIDE; ANGER; and, FEAR (df = 43).

Variables	*Mean*	*Std. Dev.*	*Std. Error Mean*	*95% CI* Lower	Upper	*t*	*Sig. 2-sd*
PRIDE	-0.182	1.369	0.206	-0.598	0.234	-0.881	0.383
ANGER*	1.886	1.186	0.179	1.526	2.247	10.555	0.000
FEAR*	0.523	1.338	0.202	0.116	0.930	2.592	0.013

* Significant difference, p < 0.05

Table 2. *Wilcoxon* signed-rank test statistics for difference in mean ranks between the expressive and control conditions for the following emotions: SURPRISE; SADNESS; and, SHAME (N = 44).

Variables	*N*			*Mean Rank*		*Z*	*Sig.*
	Neg.	Pos.	Ties	Neg.	Pos.		*2-sd*
SURPRISE*	19	8	17	14.39	13.06	-2.069	0.039
SADNESS*	34	2	8	19.32	4.50	-5.152	0.000
SHAME*	29	6	9	19.02	12.69	-3.952	0.000

* Significant difference, p < 0.05

The results in Table 1 show that, on average:

- Subjects perceived the virtual human with blushing (M=5.73, SE=0.33) to be less expressive of pride than the control virtual human (M=5.91, SE=0.34). However, this result was not significant: t(43)=-0.881, p>.05, r=0.133[2];
- Subjects perceived the virtual human with wrinkles, veins and blushing (M=7.91, SE=0.28) to be significantly more expressive of anger than the control virtual human (M=6.02, SE=0.314, t(43)=10.555, p<.05, r=0.849);

[2] Effect size for the dependent t test statistic is calculated as suggested by Rosenthal [30].

- Subjects perceived the virtual human with sweating (*M*=6.89, *SE*=0.31) to be significantly more expressive of fear than the control virtual human (*M*=6.36, *SE*=0.32, *t*(43)= 2.592, *p*<.05, *r*=0.368).

The results in Table 2 show that, on average:

- Subjects perceived the virtual human with wrinkles (*M*=5.84, *SE*=0.31) to be significantly more expressive of surprise than the control virtual human (*M*=5.36, *SE*=0.32, *Z*=-2.069, *p*<.05, *r*=-0.312[3]);
- Subjects perceived the virtual human with wrinkles and tears (*M*=7.93, *SE*=0.27) to be significantly more expressive of sadness than the control virtual human (*M*=6.18, *SE*=0.27, *Z*=-5.152, *p*<.05, *r*=-0.777);
- Subjects perceived the virtual human with blushing (*M*=6.55, *SE*=0.31) to be significantly more expressive of shame than the control virtual human (*M*=5.52, *SE*=0.31, *Z*=-3.952, *p*<.05, *r*=-0.596).

5 Discussion

This paper presents a real-time model for the expression of emotions in virtual humans using wrinkles, blushing, sweating and tears. Wrinkles are rendered using bump mapping with normal maps representing typical wrinkle patterns and its dynamics simulated using normal map interpolation synchronized with the underlying pseudo-muscular facial model. Simulation of blushing relies on application of color to selected subsets of the virtual human's mesh and interpolation of color at the pixel-level. Tears and sweating are rendered using bump mapping with a normal map for typical patterns and by simulating some of the properties of water. The dynamics of tearing and sweating are simulated using either volume textures or a special dynamics texture which maps time into grayscale values. The model is also integrated with a virtual humans platform which supports bodily, facial and vocal expression and, moreover, is implemented making extensive use of the GPU.

A study is also described to assess the influence of the model on the perception of surprise, sadness, anger, shame, pride and fear. The results show a large effect on the perception of anger, sadness and shame; a medium effect on the perception of fear and surprise; and, no effect on the perception of pride. This suggests that the model can improve the perception of anger, sadness, shame, fear and surprise. One explanation for this might be that the communicative functions wrinkles, blushing, sweating and tears serve in human-human interactions [5, 8, 12, 14] can also carry to human-virtual human interactions. The fact that no effect is achieved with blushing in pride could be explained for three reasons: (a) the physiological manifestation of pride is not successfully simulated by our model; (b) the facial expression of pride is not universal [29]; (c) further contextual cues are necessary for the association of blushing with pride (e.g., the knowledge that an individual's accomplishments could have been easily missed in virtue of the quality of the work of others) [8].

The results also suggest that wrinkles, blushing, sweating and tears can be used to convey *intensity* of emotion. Effectively, even in the control condition, where the

[3] Effect size for the *Wilcoxon* signed-rank test is calculated as suggested by Rosenthal [30].

virtual human relied only on proper configuration of the muscles in the face to convey emotion, subjects, on average, were already giving relatively high classifications (surprise: 5.36; sadness: 6.18; anger: 6.02; shame: 5.52; pride: 5.91; fear: 6.36). Still, the expressive conditions managed to increase the average classification for all emotions (surprise: 5.84; sadness: 7.93; anger: 7.91; shame: 6.55; fear: 6.87) but pride (5.73). Being able to control the intensity of the expressed emotion is, of course, useful in regulating human-virtual human interactions [6]. However, display of strong emotions should be used with care. For instance, it would be unreasonable to always use bulging of arteries to express anger or tearing to express sadness as these occur only in specific cases in human-human interactions [5, 16].

Future work consists of developing computational cognitive models for blushing, sweating and tears. Notice wrinkles occur naturally with the deformation of the underlying muscles and, therefore, can be considered to be a physical, rather than cognitive, phenomenon. Regarding the other phenomena, the cognitive models need to define clearly the respective eliciting conditions. In this work we assumed a simple association between emotions and blushing, sweating and tears. However, this association is not that simple and there are several factors influencing the magnitude and whether these physiological manifestations occur when experiencing the corresponding emotions [5, 8, 12, 14]. For instance, individual factors are known to influence the display of blushing [8], sweating [11] and tears [14].

Furthermore, a study needs to be conducted to evaluate the dynamics of emotion expression using the proposed model. The way emotion expression unfolds in time is known to influence its perception. For instance, it has been shown that subtle variations in facial dynamics can have an impact on how much people are willing to trust and cooperate with a person [31]. Subjects in our study compared only static images of the virtual human. What is required is a second study which asks subjects to compare videos of the virtual human in a control and expressive conditions.

The proposed model can also be used to display more autonomically mediated signals. The wrinkles model is used to display bulging of arteries in the neck but, this effect can also be used to simulate bulging of arteries in other regions of the body and, thus, possibly support the display of more emotions. The blushing model can be used to simulate blanching, pallor and flushing of the face which are known to be associated with the occurrence of emotions [32]. The sweat model can be used to simulate perspiration in other regions from the body, aside from the forehead. In fact, emotional sweating is believed to occur significantly in the palms of the hands, soles of the feet and axillae [11]. This might also explain why perspiration of the forehead only caused a medium effect on perception of fear in our study.

Finally, the proposed model can be used to influence the perception of more emotions. This work focuses on the display of surprise, sadness, anger, shame, pride and fear. These are emotions commonly associated with the phenomena being simulated [5, 8, 12, 14]. However, looking at the eliciting conditions suggested by Ortony, Clore and Collins' emotion appraisal theory [33], it seems likely that resentment, reproach, disappointment, disgust and remorse can benefit from display of wrinkles, blushing and sweating. Furthermore, the display of autonomically mediated signals has also been argued to play a major role on the display of moral emotions such as reproach, anger, shame, remorse, admiration, gratitude and sympathy [34, 35, 36].

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