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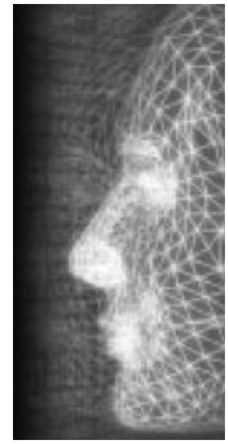
Real-time expression of affect through respiration



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Affect has been shown to influence respiration in people. This paper takes this insight and proposes a real-time model to express affect through respiration in virtual humans. Fourteen affective states are explored: excitement, relaxation, focus, pain, relief, boredom, anger, fear, panic, disgust, surprise, startle, sadness, and joy. Specific respiratory patterns are described from the literature for each of these affective states. Then, a real-time model of respiration is proposed that uses morphing to animate breathing and provides parameters to control respiration rate, respiration depth and the respiration cycle curve. These parameters are used to implement the respiratory patterns. Finally, a within-subjects study is described where subjects are asked to classify videos of the virtual human expressing each affective state with or without the specific respiratory patterns. The study was presented to 41 subjects and the results show that the model improved perception of excitement, pain, relief, boredom, anger, fear, panic, disgust, and startle. Copyright © 2010 John Wiley & Sons, Ltd.

KEY WORDS: respiration; affect; virtual humans; real-time

Introduction

There is growing evidence that respiration reflects affect [1]. Breathing becomes faster and deeper in states of excitement such as when one is experiencing anger [2]. Breathing becomes faster and shallower when one hyperventilates such as in panic [3]. Breathing becomes slower and deeper when one is experiencing a relaxed resting state [4]. Aside from changes in depth and respiration rate, emotions can also cause breathing to be momentarily suspended such as in startle or surprise [5,6]. Finally, several different non-respiratory air movements accompany emotional displays such as laughing, sighing, or yawning [7].

This paper explores a model for expression of affect through respiration in virtual humans. Virtual humans are agents that have virtual bodies and are capable of expressing themselves through their bodies [8]. Typical expression modalities are gesture, face, and voice. However, aside from these modalities, there is a vast literature that reports occurrence of specific autonomic signals when people experience various affective states [9,10]. One challenge then becomes to simulate these signals so as to improve perception of affective states in virtual humans. This challenge is important as it has been argued that expression of emotions increases agent believability [11] and improves efficiency and naturalness in human-agent interactions [8]. This challenge has already begun to be addressed by several researchers. For instance, it has been shown that simulation of autonomic signals such as blushing, wrinkles, sweating and tears can influence the perception of emotions in virtual humans [12]. This paper, in turn, simulates the kinds of respiratory phenomena that co-occur with affective states in people, so as to influence the perception of affect in virtual humans.

The paper proposes a real-time model to simulate respiration. Real-time constraints are particularly important in virtual humans as, following the paradigm of human face-to-face interaction, it is necessary to integrate several verbal and non-verbal modalities and, moreover, these modalities need to synchronize at the sub-second level [8]. The challenge is, thus, to strike the right balance between visual realism and behavioral realism. The idea is that, if the behavior is simulated properly, the virtual human need not be photorealistic in order to promote the audience's suspension of disbelief and, therefore, provide the illusion of life [13]. Thus, our approach steers away from expensive physically based

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models of respiration [14,15] and, instead, uses morphing to simulate respiration. Morphing is an inexpensive technique that, instead of animating the mesh through the skeleton, deforms the vertices directly [16]. Morphing has been used regularly to simulate breathing, for instance, in games. The contribution of this paper is, therefore, not in using this technique to simulate respiration, but in using it to simulate typical respiration patterns we see in people to convey affect. Fourteen affective states which are described as having specific respiratory patterns in the literature are explored: excitement, relaxation, focus, pain, relief, boredom, anger, fear, panic, disgust, surprise, startle, sadness, and joy. In order to simulate these patterns, the model defines several parameters that control respiration including: *respiration rate*, the number of breaths per minute; *respiration depth*, the maximum amplitude of breathing; and *respiration curve*, a function that defines how depth varies with time in a respiration cycle.

To assess how successful our model is in conveying affect through respiration, a study is described where people are asked to compare videos of the virtual human expressing affective states with or without the typical respiration patterns. All respiration patterns are simulated using the proposed real-time model of respiration.

In summary, this paper contributes the following: (a) A review of the literature on affect and respiration, including specific respiration patterns that correlate with affect; (b) A real-time model that implements those patterns; (c) A study that assesses how successful the model is in conveying affect through respiration and that demonstrates the relevance of respiration for perception of affect in virtual humans.

The rest of the paper is organized as follows: first, background on respiration anatomy and mechanics, respiration simulation in computer graphics and the literature on the correlation between respiration and affect in people are described; then, a real-time model of respiration is proposed; next, a study that was conducted to assess how successful the model is in conveying the 14 affective states is presented; finally, the results are discussed and future work is suggested.

Background

Respiration Anatomy and Mechanics

The anatomy and mechanics of respiration have been widely documented [7,17,18]. Breathing consists of two phases: *inspiration* and *expiration*. Inspiration (inhaling) and expiration (exhaling) are accomplished by alternately increasing and decreasing the volume of the thorax. A relaxed adult breathes an average of 15 times per minute. In normal quiet breathing, volume ranges from 2500 to 3000 cc. Volume can be as low as 1500 cc in forced expiration and as high as 6000 cc in forced inhalation. The model proposed in this paper supports parameters for respiration rate and respiration depth (or volume).

Air movements through the respiratory system that are not associated with breathing are termed *non-respiratory movements* [7]. Such movements accompany emotional displays such as in laughing, sighing, and yawning. Laughing consists of a deep inspiration followed by a rapid convulsive expiration. Sighing consists of a deep prolonged inspiration followed by a rapid, forceful expiration. Yawning consists of a deep inspiration through a widely opened mouth. The inspired air is usually held for a short period before sudden expiration. This work also explores a simple simulation of all these movements.

Respiration Simulation

Several computational models of the mechanics of breathing for clinical applications have been explored [15,19–22]. In contrast to the medical focus in these systems, Zordan *et al.* [14] explore a model for the visual simulation of breathing. This is accomplished by a physical model of the torso which uses deformable surfaces for the diaphragm and abdomen and articulated rigid-body bones for the spine and ribs. External and internal intercostal muscles are simulated using mass-spring simulation and animation of the gut relies on volume preserving functions. Using this model they simulate various breathing styles—calm breath, slow deep breath, panting breath, and forced exhale—in a visually similar way to humans. However, this system does not run in real-time. DiLorenzo *et al.* [23] have also explored a physically based simulation of laughter. The approach presented in this paper avoids physically based models of respiration which are very expensive computationally and, instead, explores mesh morphing [16] to animate respiration. Several parameters are defined to control respiration such as respiration rate, respiration depth, and respiration curve. These parameters are then manipulated to simulate respiration patterns for excitement, relaxation, focus, pain, relief, boredom, anger, fear, panic, disgust, surprise, startle, sadness, and joy.

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Respiration and Affect

Several affective states have been argued to associate with specific respiration patterns. Excitement has been shown to correlate with faster and deeper breathing [1,24–27]. Enhanced respiration in this case is argued to reflect readiness for action such as in preparation for flight or fight and, therefore serves an adaptive purpose [28]. In contrast, relaxation is usually associated with slow and deep breathing [1,4,29,30]. Fast and shallow breathing tends to associate with behavioral demands that may require restrained and goal-directed attention [1,3,4,29,31]. Emotionally, this pattern is usually associated with focus or concentration. Pain has been associated to an increase in respiratory volume (i.e., faster and/or deeper breathing), a lengthening of post-inspiratory pauses and breath-to-breath variability [27,32–34]. If the increase in respiratory volume can be explained by the aversive nature of a painful task, breath-holding is seen as instrumental in reducing the aversive stimulation [27].

More than serving a respiratory need, non-respiratory movements are generally viewed as the expression of emotional states [7]. Specifically, laughter has been associated with joy [27,35], sighing with relief, boredom and anxiety [1,36,37] and yawning with drowsiness and boredom [1,38].

Finally, even though there is some evidence that respiration correlates to dimensions rather than categories of emotions [1], several researchers have attempted to find respiration patterns specific to basic emotions [39] such as anger, fear, disgust, surprise, sadness, and joy. Anger and fear are usually associated with increased arousal and, therefore, tend to be associated with the same respiratory pattern of excitement, i.e., faster and deeper breathing. This has been confirmed in many studies [1,2,32,40]. Anxiety seems to be associated with a different pattern: fast and shallow breathing [41–43]. Anxiety, in turn, is well known to relate to panic [44]. Disgust was found to correlate with inspiratory pauses [27]. The reason for this was suggested to be that cessation of ventilation is a respiratory response to exclude inhalation of noxious gases or suppression of nausea [27]. Surprise correlates with the typical phasic interruption of breathing which occurs upon presentation of unexpected or novel stimuli [6,45]. A variation of surprise is startle which has a more intricate but similar effect on respiration. When the event that causes startle occurs, if the person is inspiring, inspiration is accelerated and prolonged; but, if the person is expiring, expiration ceases to give way to a quick inspiration [5,46–48]. Sadness and joy seem to have a similar respiratory manifestation of slow and deep breathing [1,32,43]. A special case of joy, as was described above, involves laughter and this has the typical respiration pattern of laughing [27,35]. Table 1 summarizes the respiration patterns discussed here.

State	Respiration pattern
Excitement	Fast and deep breathing [1,24–27]
Relaxation	Slow and deep breathing [1,4,29,30]
Focus	Fast and shallow breathing [1,3,4,29,31]
Pain	Fast and deep breathing with occasional post-inspiratory pauses [27,32–34]
Relief/boredom	Sighing [1,36,37]
Boredom	Yawning [1,38]
Anger	Fast and deep breathing [1,2,32,40]
Fear	Fast and deep breathing [1,2,32,40]
Panic/anxiety	Fast and shallow breathing [41–43]
Disgust	Post-inspiration pauses/Breathing suspension [27]
Surprise	Breathing suspension [6,45]
Startle	Expiration cessation and quick inspiration [5,46–48]
Sadness	Slow and deep breathing [1,32,43]
Joy	Slow and deep breathing [1,32,43] or laughter [27,35]

Table 1. Affective respiration patterns.

Model

Morphing is used to animate respiration. Morphing is a real-time technique where the virtual human's mesh is deformed by displacing its vertices locally [16]. The idea is to create several deformed poses of the mesh, called *morph targets*, and then animate by interpolating between the neutral mesh and these targets. Moreover, mixed deformations can be created by blending several targets. In our case, the *neutral target* corresponds to maximum expiration. This should correspond to minimum volume in the lungs, i.e., the residual volume. A morph target, named the *breathing target*, is then defined for maximum inspiration. This should correspond to maximum volume of the lungs, i.e., the total lung capacity. Finally, morphing supports interpolation between these two targets.

Respiration is visually characterized by the respiration rate and a respiration cycle. The *respiration rate* defines how often the respiration cycle repeats itself each minute. The *respiration cycle* defines how the

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respiratory volume changes with time. Thus, a convenient way of modeling a respiration cycle is as a function which defines the respiratory volume (image) at each instant of time (domain). The image can be constrained to lie in the range [0.0, 1.0], where 0.0 corresponds to minimum lung volume (i.e., the neutral morph target) and 1.0 to the total lung capacity (i.e., the breathing target). Regarding the domain, if the values are interpreted as absolute, then the respiratory rate is defined by the total length of the cycle; if the values are interpreted as relative, then the cycle is time-warped to match an intended respiratory rate. Using this abstraction several kinds of respiration cycle functions are supported: *linear*, defines simple linear interpolation back and forth between minimum and maximum values; *keyframe*, supports definition of an arbitrary shape for the cycle by interpolating <time, volume> pairs; and, *spline*, supports definition of arbitrary shapes for the cycles according to one-dimensional spline curves [16]. Figure 1 exemplifies two different respiration cycles. Transition between cycles can occur at the end of the current cycle, so as to avoid a discontinuity in the animation, or immediately. In summary, three parameters are provided to control respiration: (a) respiration rate; (b) a function defining the respiration cycle; and (c) a boolean value defining whether the cycle time values are absolute or relative.

Finally, in order to build complex respiration cycles and facilitate transitions between cycles, a *stack* of *respiration layers* is defined. A respiration layer defines a respiration cycle and the number of repetitions the cycle is to execute (which can be infinite). The respiration animation is defined by the topmost layer. Once the cycle has executed all the repetitions, the layer is popped and the next layer executes its respiration cycle. For instance, default quiet respiration could be set to run forever in the bottommost layer and a temporary respiration cycle, such as deep and fast breathing for excitement, could be loaded into the topmost layer to run for a finite number of repetitions.

Study

Overview

A study was conducted to assess how successful is the model in conveying affect through respiration. All 14

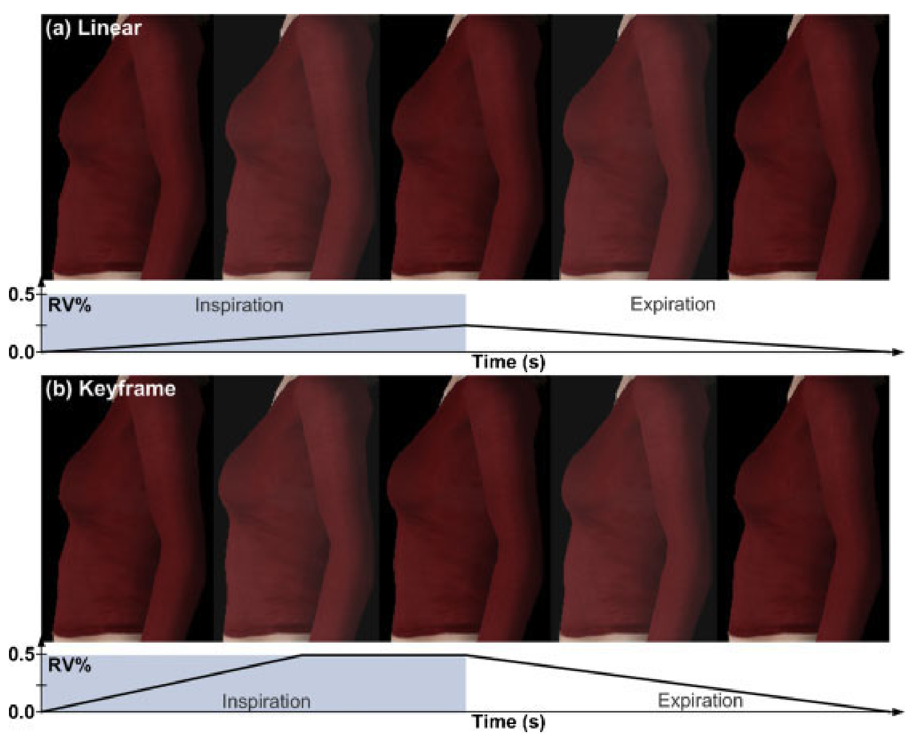

Figure 1. Two different respiration cycles: (a) linear (e.g., neutral) and (b) keyframe with inspiratory pause (e.g., startle). "RV%" stands for respiratory volume percentage.

affective states described in the ''Respiration and Affect'' Subsection are explored: excitement, relaxation, focus, pain, relief, boredom, anger, fear, panic, disgust, surprise, startle, sadness and joy. The study follows a within-subjects design where subjects compare videos of the agent expressing the affective states with or without specific respiration patterns. Thus, for each affective state, there are two conditions: (a) *control*, the agent expresses the affective state using neutral respiration and appropriate postures and facial displays; (b) *expressive*, the agent expresses the affective state using the same postures and facial displays as in the control condition, plus specific respiration patterns. Subjects are asked to classify, for each condition, how well does the agent appear to be experiencing the affective state from 1 (meaning ''not experiencing the affective state at all'') to 10 (meaning ''perfectly experiencing the affective state''). The hypotheses are that subjects will perceive, for each affective state, the agent to be experiencing the affective state more intensely in the expressive than in the control condition.

Conditions

In the control condition, the agent expresses the affective state using postures, facial displays and neutral respiration (see ''Respiration Anatomy and Mechanics'' Subsection): 15 breaths per minute and respiration depth ranges from 5 to ~25% of the maximum respiratory depth. In the expressive condition the agent expresses the affective state using the same postures and facial displays as in the control condition, plus the specific respiration patterns described in the ''Respiration and Affect'' Subsection. The actual values for the parameters in the respiration model where defined according to our interpretation of the literature on the respiration patterns. In both conditions the agent is standing up with the arms hanging to the sides. Idle motion is applied consisting of blinking and very subtle movement of the neck, spine, arms and fingers. The camera is focused on the chest framing the upper body at a 45° angle to the right with respect to the vertical axis. Finally, the agent is illuminated using a strong white light from the front and a dim white light from the right.

The details for the conditions in each affective state follow:

- *Excitement*: The agent has a neutral face and posture. In the expressive condition, respiration is set to be fast (40 breaths per minute) and deep (depth ranges from 5 to 40% of maximum volume). Videos in both conditions last 7 seconds.
- *Relaxation*: The agent has a slight smile and neutral posture. In the expressive condition, respiration is set to be slow (10 breaths per minute) and deep (depth ranges from 5 to 40% of maximum volume). The videos last 14 seconds.
- *Focus*: The agent has a slightly frowned forehead and a neutral posture. In the expressive condition, respiration is set to be fast (35 breaths per minute) and shallow (depth ranges from 5 to 17% of maximum volume). The videos last 6 seconds.
- *Pain*: The agent has a typical facial expression of pain (left upper lip raised and squinted eyes) and a neutral posture. In the expressive condition, the agent displays a post-inspiratory pause of 1 second before expiring and then proceeds to breathe fast (40 breaths per minute) and deeply (depth ranges from 5 to 40% of maximum volume). The videos last 7 seconds.
- *Relief*: The agent displays the characteristic movement of the mouth and nose for a sigh and has a neutral posture. In the expressive condition, the agent synchronizes the facial movements with a deep inspiration in the chest followed by a quick expiration. The videos last 7 seconds.
- *Boredom*: The agent displays the characteristic opening of the mouth in a yawn and has a neutral posture. In the expressive condition, the agent synchronizes the facial movements with a deep inspiration in the chest followed by a quick expiration. The videos last 7 seconds.
- *Anger*: The agent has a typical face of anger [39] and a neutral posture. In the expressive condition, respiration is set to be fast (40 breaths per minute) and deep (depth ranges from 5 to 40% of maximum volume). The videos last 5 seconds.
- *Fear*: The agent has a typical face of fear [39] and a neutral posture. In the expressive condition, respiration is set to be fast (40 breaths per minute) and deep (depth ranges from 5 to 40% of maximum volume). The videos last 6 seconds.
- *Panic*: The agent displays the same face as in fear and a neutral posture. In the expressive condition, respiration is set to be very fast (60 breaths per minute) and shallow (depth ranges from 5 to 20% of maximum volume). The videos last 6 seconds.
- *Disgust*: The agent has a typical face of disgust [39] and a neutral posture. In the expressive condition, when the disgusting event occurs, the agent suspends breathing for 1 second and then proceeds with the expiration and normal breathing. The videos last 9 seconds.

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- *Surprise*: The agent displays a typical face of surprise [39] and a neutral posture. In the expressive condition, when the surprising event occurs, the agent suspends breathing for 1 second and then proceeds with the expiration and also increases the respiration rate to 27 breaths per minute. The videos last 10 seconds.
- *Startle*: An unexpected event is suggested to occur (not visible) which causes the agent to quickly pull the neck backwards and opening the eyes widely. In the expressive condition, breathing is suspended when the event occurs and then the agent proceeds to breathe fast (35 breaths per minute) and deeply (depth ranges from 5 to 35% of the maximum respiratory volume). The videos last 6 seconds.
- *Sadness*: The agent has a typical face of sadness [39] and a neutral posture. In the expressive condition, respiration is set to be slow (11 breaths per minute) and deep (depth ranges from 5 to 40% of maximum volume). The videos last 15 seconds.
- *Joy*: The agent displays a neutral posture and laughs. In the expressive condition, the agent inspires before the laugh and then convulses the chest with each chuckle. The videos last 3 seconds.

Finally, since the best way to understand these conditions is to visualize them, a video is sent with the supplemental materials and is also available in this location: http://www.youtube.com/watch?v=pAVND3GPKA4.

Participants

The survey was anonymous and implemented as an online survey. Subjects were allowed to save their session and continue at a later session. Average duration from start to the end of the survey was: for subjects that did *not* save their sessions (92.68%), ~22.3 minutes; for subjects that saved their sessions (7.32%), ~18.83 hours. Forty-one (41) participants were recruited with the following age distribution: 11–20 years, 4.88%; 21–30 years, 56.10%; 31–40 years, 26.83%; 41–50 years, 4.88%; 51–60 years, 4.88%; and, *more than* 70, 2.44%. Gender distribution was as follows: *female*, 46.34%; *male*, 53.66%. The expected or awarded education degree distribution was as follows: *basic*, 4.88%; *college*, 24.39%; *Masters*, 36.59%; and, *PhD or above*, 34.15%. Education majors were in diverse areas. Participants also had diverse origins: *America*, 46.34%; *Europe*, 29.27%; *Asia*, 9.76%; and, *Africa*, 9.76%.

Results

The *Kolmogorov-Smirnov* test was applied to assess the normality of the data in each condition for each affective state. The results of this test indicate that at least one of the conditions in the relaxation and fear states differed significantly ($p < 0.05$) from the normal distribution. Therefore, the *dependent t*-test was used to compare means between the expressive and control conditions in excitement, focus, pain, relief, boredom, anger, panic, disgust, surprise, startle, sadness and joy; and, the *Wilcoxon Signed Ranks* test was used to compare ranks between the expressive and control conditions in relaxation and fear. Table 2 summarizes the descriptive statistics, statistical significance and effect sizes for each affective state. Effect sizes for the *dependent t*-test and *Wilcoxon Signed Ranks* test are calculated as suggested by Rosenthal [49]. The guidelines for interpretation are [50]: $r = 0.10$ (small effect), the effect explains 1% of the total variance; $r = 0.30$ (medium effect), the effect explains 9% of the total variance; $r = 0.50$ (large effect): the effect explains 25% of the total variance.

Variables	Control	Expressive	Sig. 2-sd (*r*)
	Mean (SD)	Mean (SD)	
Excitement*a	2.51 (1.69)	4.37 (2.21)	0.000 (0.657)
Relaxation b	5.71 (2.25)	5.76 (2.50)	0.850 (0.034)
Focus*a	5.85 (2.01)	5.05 (1.99)	0.003 (0.444)
Pain*a	4.88 (1.98)	6.24 (2.49)	0.000 (0.696)
Relief*a	4.27 (2.12)	5.46 (2.12)	0.000 (0.537)
Boredom*a	4.98 (2.06)	5.76 (2.52)	0.009 (0.398)
Anger*a	5.90 (2.14)	7.07 (2.31)	0.000 (0.550)
Fear*b	5.59 (2.21)	7.17 (2.13)	0.000 (0.602)
Panic*a	4.90 (2.15)	7.17 (2.26)	0.000 (0.738)
Disgust a	6.46 (2.23)	6.46 (2.35)	1.000 (0.000)
Surprise a	6.34 (2.33)	6.15 (2.37)	0.587 (0.086)
Startle*a	6.56 (1.83)	7.32 (1.78)	0.002 (0.468)
Sadness a	6.46 (2.37)	6.71 (2.27)	0.230 (0.189)
Joy a	6.15 (2.19)	6.29 (2.40)	0.635 (0.076)

Table 2. Descriptive statistics, statistical significance and effect sizes for all the affective states in the study ($N = 41$).
***Significant difference, $p < 0.05$.**
a *Dependent t*-test used to calculate significance.
b *Wilcoxon Signed Ranks* test used to calculate significance.

Discussion

This paper proposes a real-time model for expression of affect through respiration in virtual humans. First, the literature is surveyed for typical respiration patterns of excitement, relaxation, focus, pain, relief, boredom, anger, fear, panic, disgust, surprise, startle, sadness, and joy. Then, a real-time model of respiration is proposed that uses morphing to animate breathing and defines several parameters to control respiration including respiration rate, respiration depth and respiration cycle curve. The model also defines a stack of respiration cycles to help create complex respiration patterns and facilitate transition between different respiration curves. This model is used to implement the aforementioned respiration patterns. Finally, a study is conducted that assesses the success of the model in conveying affect through respiration. The study follows a within-subjects design where subjects are asked to compare, for each affective state, videos of a virtual human expressing the affect with or without the typical respiration patterns.

The results of the study show: (a) a large effect of the model on perception of excitement, pain, relief, anger, fear, and panic; (b) a medium effect on perception of boredom and startle; (c) no effect on perception of relaxation, disgust, surprise, sadness, and joy; (d) a medium effect against the experimental hypothesis for the perception of focus. The positive results in (a) and (b) suggest that the model is, in fact, helping people perceive more clearly these affective states. The results also suggest that respiration is effective in conveying *intensity* of affect. Effectively, even though the control conditions got relatively high scores, respiration managed to improve even further these scores. Being able to control intensity of affect is, of course, important in regulating human-agent interaction.[8] The fact, that only a medium effect was achieved with boredom or startle might reflect that facial displays and postures dominate in these cases (yawning in the former and a typical startle motion in the latter) and, thus, respiration is overshadowed by them. However, it might also be the case that respiration is just not that relevant for perception of boredom or startle.

That no effect was achieved for certain affective states can have multiple explanations. First, the videos might have been too short to perceive the influence of respiration for some affective states. This seems to be the case for relaxation and sadness, both of which are expressed by a slow and deep respiration pattern. If people managed to perceive an increase in respiration rate in other cases (e.g., anger or fear), there are no positive results associated with perception of slow respiration. It might be the case that to perceive a reduction in respiration rate simply takes a longer time of interaction. This is something designers should be aware of when developing agents for short interactions. Second, the absence of effect in boredom and surprise might be explained by imperfections in the experimental setup. In fact, in both cases, a crucial aspect of the associated respiration pattern is breathing suspension. However, in the videos, even though a post-inspiratory pause is simulated, idle motion of the spine and arms is still being animated. Therefore, subjects might have failed to perceive breathing suspension due to this secondary motion. Alternatively, these results could be interpreted as suggesting that respiration is simply not that relevant for the perception of these affective states. Further research is necessary to distinguish between these two possible explanations. A further explanation can be advanced regarding disgust. Effectively, the literature is particularly ambiguous regarding this affective state. One of the few studies suggesting a clear effect of disgust [27] reports that subjects suspended breathing during a movie scene where a man vomits. What our results suggest is that this respiration pattern does not seem to generalize to all forms of disgust. Respiration in laughter also failed to have an effect on perception of joy. Two explanations could be advanced in this case: (1) the facial display predominates in this state, as can be seen by the high average scores in both conditions (control, 6.15; expressive, 6.29); (2) our simulation of laughter was imperfect. In fact, we simulated laughter by a deep inspiration followed by synchronized convulsions of the chest. However, an in-depth look at the mechanics of laughing [51] clarifies that convulsions actually occur in the abdominal area. This can be supported in our model by using another morph target that emphasizes motion of the abdomen. Finally, not only did our results fail to support the expressive condition for focus, they actually supported the control condition. This might suggest that our simulation of the typical ''fast and shallow'' respiration pattern for focus or concentration [1,3,4,29,31] was incorrect. In fact, the literature is not very clear about how much faster and shallower should respiration be and our assumptions on that regard might have been incorrect.

Regarding future work, it is certainly possible to improve the efficacy of our respiration model in conveying affect. Whereas this work focuses on respiration patterns as characterized by respiration rate, respiration depth, respiration curve and non-respiratory movements, there is also evidence that, in people, affect

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influences more respiration parameters. For instance, it has been argued that thoracic-abdominal balance reflects affect in that thoracic dominance appears to correlate with positive emotions, whereas abdominal dominance correlates with pleasant emotions [33,51]; irregularity of breathing was also found to correlate with several affective states [52,53]; and, as the inspiration time can differ from the expiration time in meaningful ways [54], variation of the inspiration time to expiration time ratio has also been found to correlate with different affective states [32,55].

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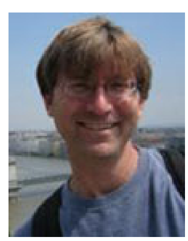
Celso M. de Melo is a PhD student at the University of Southern California (USC). He is developing his Thesis at the Institute for Creative Technologies, under the supervision of Professor Jonathan Gratch. He completed his Master's Degree at IST-Technical Universtity of Lisbon on expression through gesticulation in virtual humans. His recent work focuses on: cooperation and negotiation between embodied agents and humans; expression of emotions using autonomically mediated signals such as wrinkles, blushing, tearing, and breathing; and the manipulation of the formal elements of art, such as color, to influence perception of emotion in virtual humans.



Patrick Kenny has been researching and developing in the Artificial Intelligence field for the past 15 years. He is currently the principal investigator creating virtual human patients for research and training in medical applications at The Institute for Creative Technologies, a world known research lab part of The University of Southern California. He previously was the virtual human group lead integrating the virtual human architecture with cognitive and simulation systems. Mr Kenny previously worked at The University of Michigan AI Lab researching and developing cognitive robotics for unmanned ground vehicles. While in Michigan Mr Kenny founded a spin-off company, Soar Technology, from the AI Lab to support and develop cognitive agents

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Jonathan Gratch is an Associate Director for Virtual Humans Research at the University of Southern California's (USC) Institute for Creative Technologies, Research Associate Professor in the Department of Computer Science and co-director of USC's Computational Emotion Group. He completed his PhD in Computer Science at the University of Illinois in Urban-Champaign in 1995. Dr Gratch's research focuses on virtual humans (artificially intelligent agents embodied in a human-like graphical body), and computational models of emotion. He studies the relationship between cognition and emotion, the cognitive processes underlying emotional responses, and the influence of emotion on decision making and physical behavior. A recent emphasis of this work is on social emotions, emphasizing the role of contingent nonverbal behavior in the co-construction of emotional trajectories between interaction partners. His research has been supported by the National Science Foundation, DARPA, AFOSR and RDECOM. He is on the editorial board of the journal *Emotion Review* and is the President-Elect of the HUMAINE association, the international association on emotion and human-computer interaction. He is sitting member of the organizing committee for the International Conference on Intelligent Virtual Agents (IVA) and frequent organizer of conferences and workshops on emotion and virtual humans. He belongs to the American Association for Artificial Intelligence (AAAI) and the International Society for Research on Emotion. Dr Gratch is the author of over 100 technical articles.

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