Vision, Video, and Graphics (2003)
P. Hall, P. Willis (Editors)

Studying the fidelity requirements for a virtual ballet dancer

R. J. Neagle[1,2], K. Ng[1,2] and R. A. Ruddle[1]

[1] Informatics Network, School of Computing, The University of Leeds, England
[2] Interdisciplinary Centre for Scientific Research in Music, The University of Leeds, England

Abstract

Teaching dance, especially ballet, usually involves the phrase: 'watch, copy and learn' and improvement is made by emulation. This involves not only how to achieve the steps but also the quality of the movement. In this paper, we present research into the fidelity that is required for a virtual ballet dancer driven by dance notation and its affect on the users ability to distinguish between expressive movement. The overall aim is to create a visualisation system that professionals could use to understand not only the choreography, but the expressive movement when resurrecting ballet scores and would be of benefit to teaching dance at all levels. Using Laban's effort theory to characterise the motion, this paper highlights the importance of the time factor to differentiate emotions. Two experiments are discussed that were designed to identify the accuracy of distinguishing emotions in ballet at lower levels of fidelity. The first experiment analyses the affect of the visual appearance on a 2D display and the second experiment looks into aspect of realism in the movement between keyframes defined by a dance notation. This paper explores understanding the quality of movement required for a virtual dancer, specifically, the expressivity encapsulated in the motion between key poses.

Categories and Subject Descriptors (according to ACM CCS): I.3.7, I.4.5, G.3 [Computing Graphics, Image Processing and Computer Vision, Probability and Statistics]: Three-Dimensional Graphics and Realism, Reconstruction, Correlation and Regression Analysis

1. Introduction

Like music, the choreographed movements that make up a dance performance can be written down, and the best known systems for doing so are Labanotation[1, 2], Eshkol-Wachman[3] and Benesh notation[1, 4]. Choreography is primarily written down for archival purposes and to promote its dissemination to a wider audience. Unlike music, dance notation is not widely understood by dancers. There are few professional performers who can read written choreography, and this represents a considerable barrier to the utility of choreography in its written form (see Figure 1).

Real-time computer graphics are ideally suited to bridging the gap between written choreography and performance, via the creation of a virtual dancer. Such a dancer can be driven from machine readable versions of dance notations[5] to produce, in theory, a realistic performance. However, as with any virtual environment (VE) application, it is important to analyse the fidelity that is required.

The overall goal of our research is to develop a virtual ballet dancer (VBD) that helps professional performers to learn the choreography required for a certain performance including the poses, movements, and nuances that are described by

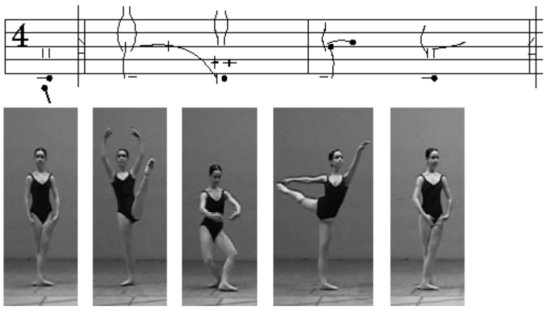

Figure 1: *Example of Benesh notation, defining five poses ("keyframes") and the movement (arc-lines) the dancer should make. The corresponding physical poses are shown in the photographs.*

the written choreography. To achieve this, two broad categories of fidelity need to be considered. The first category is the visual appearance of the VBD, i.e. the physical characteristics of the VBD on a given computer display (size, resolution and (non)stereo viewing) and the realism of the avatar's body and clothing, ranging from texture mapped 3D geometry to a stick figure.

The second category is the realism with which the dancer moves, i.e. the level of fidelity required for the model used to animate the VBD's movement. This model includes the method used to interpolate between the keyframes that are defined by the dance notation and the body parts (especially legs, arms, back, hands and head) that are animated as part of the movement.

This paper describes two experiments that manipulated digital videos of ballet performances to ascertain some of the fidelity requirements for a virtual dancer. Experiment 1 investigated whether participants could discriminate between ballet exercises performed with different emotions when those exercises were displayed as small videos on a computer screen (a reduction in size and resolution compared with the real-world). Experiment 2 investigated the effect of the video frame rate, which has implications for the fidelity required of the movement model. Section 2 presents the background to the study.

2. Background

2.1. Benesh notation

Benesh notation is particularly prominent in ballet. It was designed by Rudolf and Joan Benesh in 1947 to represent classical ballet and gives a rich vocabulary for describing human positions and movement. The notation captures structural and positional aspects of the performer at specific times.

Benesh notation is written from left to right on a five-line stave, mapping to a person's feet, knees, waist, shoulders and top of the head. To record a position or pose, the Benesh notation notes the exact locations occupied by the four extremities (the hands and feet). In addition, the position of a bend, such as the knee or elbow, may also be required to describe the posture of the dancer. Given these points and the body and head positions, it is possible to reconstruct and visualise the whole pose. To capture the wide range of poses that are adopted in ballet, the Benesh notation uses symbols like ⸍ and ┼ (see Figure 2) and written annotations used to indicate types of movement, rhythm and phrasing.

2.2. Laban's Effort-Shape Theory

Laban's theory is used to characterise the way in which people move and it can be applied to many of the notations for movement. We are concerned with three particular factors: space, weight, and time (see below). In EMOTE[6], Chi gives excellent descriptions:

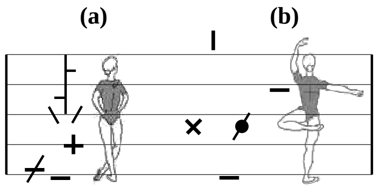

Figure 2: *(a) demonstrates glyphs for rotations of the head and body, positions in front of the body (right knee), crossed to the opposite side of the body (right foot), and contact glyphs (hands on the hips). (b) shows glyphs positioning the extremities in front and above the body (left hand), at the extremes of the dancers reach (right hand), behind the body (left knee), and behind and crossed to the other side of the body (left foot). Both examples have the suporting foot planted flat on the ground.*[4]

Weight: is the sense of impact of the movement and exertion required ranging from *light* (buoyant and delicate) to *heavy* (powerful with impact e.g. pushing or punching).

Time: describes the qualities of sustainment and quickness of movement as opposed to speed measured by the clock or tempo marked by a metronome. Time ranges from *sustained* (lingering and indulging in time) to *sudden* (agitated, jerky movements).

Space: is spatial focus and attention to surroundings, overlapping shifts in the body among a number of foci ranging from *indirect* (multi-focused) to *direct* (pinpointed and single focused).

2.3. Virtual Ballet

Professional dance performers and choreographers are not required to read dance notation and very few can visualise its meaning. In classical ballet, most dancers learn by emulating observed movement from others and live demonstrations are paramount. The transformation from notation to performance is a large step with few tools to aide the process and this is where visualisation, using the concept of a VBD fits in. Current work in this area can be split into two sections: (a) virtual dance applications, and (b) computer tools that allow notations to be written down or stored.

Virtual dance has developed over the last few years with two main approaches: (a) motion capture, and (b) animations driven from machine readable versions of dance notations. Motion capture has mainly been used with contemporary dance with some development towards classical ballet. 'Shaped Time' led by Stevens[7] uses mathematical tools to analyse and quantify the dynamics of human movement in contemporary dance. Li et al.[8] describe a statistical model similar to the original motion capture data of complex human-figure motion. The learnt motion texture from the captured dance motion is used to generate new animations automatically and can be manipulated at different levels. In 'Style Machines'[9] Brand and Hertzmann approach the problem of stylistic motion synthesis by learning motion patterns from a highly varied set of motion capture sequences identifying common choreographic elements and included classical ballet.

The second approach is based more in virtual ballet and designed to aide in the visualisation of a dance notation. Most research involves editors and is linked to animation applications such as NUDES[10] and Life Forms[11]. Several programs now exist to create, store, modify and print scores and are mostly still works in progress using Benesh and Laban notation. These include: Benesh Notation Editor; MacBenesh; Calaban; LabanPad PDA (currently: Apple Newton); LabanWriter; and LED[12]. Related to these are are editors and to animation libraries for classical ballet. LINTER is an API, which takes a file of a Labanotation score from LED, and generates from it an animation script to manipulate a set of ellipsoids forming the figure in the NUDES animation system[13]. BALLONES ('Ballet Animation Language Linked Over Nudes Ellipsoid System'), is a proposal by Hall and Herbison-Evans[14] for a classical ballet interpreter using a lexical analyser comprising a YACC parser and a set of NUDES procedures. Associated with LabanPad, Christian Griesbeck proposes Limelight, a modular program which integrates components necessary for professional computer aided choreographing. An interface between Laban Writer and Life Forms is currently being researched and developed. It will enable the user to type in the movement notation and have the computer play it back in animation. Life Forms Dance 4.0 already includes a package called Rhonda Ryman's Ballet Moves with over 100 ballet positions and transitions[11].

These systems animate generalised positions and transitions requiring an amount of interpretation to transform the animations to artistic dancing[15]. Unnatural looking dance animations leave the visualising of artistic quality to be filled in by the imagination of the user. In this respect, the literature on synthetic characters and animations such as *The Illusion of Life*[16] explains the art of creating believable characters. Animation software can be used to apply these techniques, but the software does not generate dance and is limited to the capabilities of the animator. Motion capture on the other hand, creates natural movement (all the detail and nuance of live motion for all the degrees of freedom) but had disadvantages in not providing full control over the motion plus being labour intensive and costly.

To summarise, a VBD is required to not only animate a sequence of poses with transitions to visualise dance steps and combinations but also to provide nuances that reveal the inner thoughts of the synthetic character. Most research focusing on understanding expressive movement, particularly dance movement, has focused on Laban's theory of Effort-Shape including research led by Cummurri[17] and EMOTE[6].

3. General methodology

To investigate the fidelity requirements, we designed a study that involved video taping dancers performing certain exercises with different emotions and then used those videos in two experiments to measure whether professional dancers could distinguish between the emotions when they were presented at reduced visual detail compared with the real-world (experiment 1) and a variety of frame rates (experiment 2).

The factors investigated for experiment 1 were ten different pairs of emotions performed with three different levels of complexity. Participants with a foundation in professional ballet were required to distinguish whether the ten pairs of emotions (combinations of happy, sad, angry and afraid) were the same or different for two exercises carried out at three different levels of complexity.

For experiment 2, the factors were six pairs of emotions performed with two levels of complexity at four different frame rates. Participants were required to distinguish between the emotions (combination of happy, sad and angry) from four two dance exercises at each of the lowest and highest level of complexity, which were displayed at four different frame rates.

The movements had three levels of complexity (*easy*, *medium*, and *hard*) with each level having two exercises. Easy movements were choreographed to involve movement of the head, upper torso and upper limbs. Medium movements extended the easy movements by including lower limb movements which added travel and one leg balances increasing the technical requirements. The hard movements involved jumping as well as upper and lower limb movements. The dancers were required to land on one foot and in one instance perform half a turn requiring even greater technique and were choreographed extending the medium movements. The four motive themes (*happy, sad, afraid* and *angry*) generated different movement in relation to Laban's time, weight and space descriptors[18]. The four emotions were chosen because of their combined effects in Laban categorisation. When combined, it can create significantly different and contrasting nuances for each emotion in the performance of the exercise.

4. Capturing Video Data

4.1. Location, Personnel and Layout

The data was recorded in the University of Leeds Clothworkers' Centenary Concert Hall as shown in Figure 3. This allowed unrestricted movement by two classically trained ballet students who were separated by a partition to avoid being influenced visually by the movements of each other.

4.2. Procedure

The recording of the exercises were split into two sessions during a day lasting a total of 5 hours. Prior to the start

Figure 3: *The experiment setup in the Concert Hall*

of the first session, the dancers were given an explanation of the level of choreography required and the motives they would be given for each exercise. Each session involved the recording of an easy, medium and hard exercise, and used the following procedure.

1. Explain choreography to dancers
2. Allow a practise run through for the dancers
3. Give motive description
4. Start recording on all three cameras
5. Use labelled clapper board sheets on camera to mark video position of exercise and motive
6. Count the dancers in so they start at the same time
7. Stop cameras
8. Repeat 3. to 7. for all motives in a different order
9. Repeat 1. to 8. for second exercise at the same complexity level
10. Repeat 1. to 9. for medium exercise
11. Repeat 1. to 9. for hard exercise

5. Extracting the Dancers and Application Construction

The original movies that were filmed contained both dancers. An application was developed to extract each dancer as a separate movie with a selection of frame rates (see below).

The video movies recorded at 25Hz were downloaded using Firewire into a format compatible with 'Quicktime 4 Linux' (found at http://openquicktime.sourceforge.net/) and an application has been developed to load and manipulate the movies on a frame by frame basis. The application had two main functional components. The first function allowed the movie to be cropped and each dancer to be displayed and stored separately as Quicktime encoded movies. The second function reconstructs the movie at different frame rates as specified. It would be simple to down sample the movie at a given frame rate. However, keyframes can not be guaranteed using such a direct approach. Therefore, we implemented an alternative solution that preserved the keyframes at the expense of introducing jitter.

The frame rates selected for analysis ranged from 5Hz (jerky movements) to 25Hz (smooth with the usual video flicker). Preserving key poses required two stages: (1) manually identify keyframes in every video and store frame rate numbers where the frame selected mapped the dancers position to the Benesh notation (see Figure 4); (2) to determine

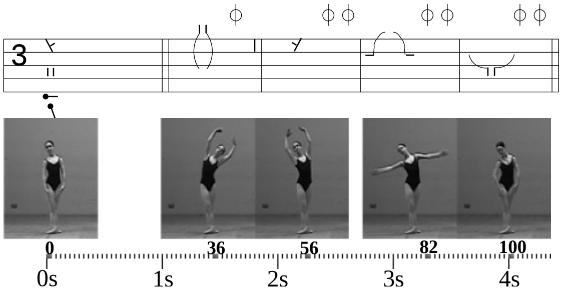

Figure 4: *The top row of this figure shows a 'port de bras' in Benesh notation, the middle section illustrates the key poses with the bottom section presenting the elapsed time and frame numbers (0, 36 etc.) for the keyframes.*

which frames should be displayed in-between keyframes (IBK) to approximate a given frame rate. The number of frames (n) between each pair of key frames was calculated using Equation 1 where (N) is the original number of frames, (r) the new frame rate and (R) the original frame rate.

$$n = \frac{N \times r}{R} \tag{1}$$

The value of n was rounded up to the nearest integer, and IBK frames chosen so they were approximately equally spaced. The following two examples illustrate how this works.

Example 1: Keyframes at frame number 36 and 56. From Equation 1 for 5Hz frame rate, $n = 4$ therefore the IBK frames are 41, 46, and 51.

Example 2: Keyframes at frame number 0 and 36. From Equation 1 for 5Hz frame rate, $n = 7.2$ (rounded up to 8) therefore the IBK frames are 5, 9, 14, 18, 23, 27 and 32.

Example 1 is a perfect fit. Example 2 introduced some jitter to the frame rate, but the most jitter in any of the videos was 0.02*sec* and this was accepted to be negligible to the human eye.

6. Experiment 1

Experiment 1 investigated the users' ability to distinguish emotions performed by a trained classical dancer. All the videos used a constant frame rate (25Hz). The fidelity level was lowered from the real-world to: a 3D representation displayed on a 2D LCD display; a slight degradation in resolution (some artifacts from re-compressing the videos as MOVs); and a small image size (220×175 pixels). Participants viewed pairs of videos and judged whether each pair was danced with the same or different motive theme. Three sets of analyses are presented: (1) percentage correct judgements for same versus different emotions at the three levels of complexity; (2) the accuracy of participants judgements between pairs of the same emotions; and (3) the judgements between emotions that were different and had either similar or different properties in Laban's space, weight and time dimensions.

6.1. Method

Participants

Six adults, three males and three females, participated in this experiment. The ages ranged between 28 to 40 years of age with a minimum of 8 years current or past professional experience in ballet and/or teaching dance at a professional level.

Materials and procedure

For the real world experiments, a bespoke VB application was developed to present pairs of video's was run on a Dell Latitude C600 Intel Pentium III 600MHz with 256M RAM and an ATI Rage Mobility 128 video card (8M). The 14.1" XGA Color TFT display had a resolution set at 1024 x 768 x 16.7 million colours. The system ran the Windows 2000 operating system using Windows MCI for playing embedded multimedia.

With the four emotions, the software generated ten pairs of combinations. Of the ten paired combinations, four had the same emotion {*(happy, happy) (sad, sad) (angry, angry) (afraid, afraid)*} and six had different emotions {*(happy, sad) (happy, angry) (happy, afraid) (sad, angry) (sad, afraid) (angry, afraid)*}. To equalise the number of trials for the same and different pairs, there were three trials for each of the same emotional pairs and two trials for each of the pairs making 24 trials for each level of complexity. In total there were 72 trials (24 for each level of compexity). The trials were presented in three blocks of 24 and the order of presentation for the emotional pairings and complexities were randomised. Each trial featured two videos of one of the dancers chosen at random.

For each trial, the application played the pair of video's sequentially followed by two questions for the participants to answer by selections with the mouse (see Figure 5). The procedure was:

1. Subject selects button "Start Experiment"/"Next Trial"
2. Two pairs of video's are played sequentially
3. The question *"The films express emotions that are the"* will pop up with 'Same' or 'Different' selection boxes
4. After the selection a second question pops up. *"How confident of your selection are you?"*. There is a radio selection box from 1 to 5 where 1 is the least confident.
5. The participant selects button "Next Trial"/"End Experiment" button to start the next trial or end the experiment.

During the running of the experiment, the "Next/End Experiments" button, concatenated the results for each trial to a text file.

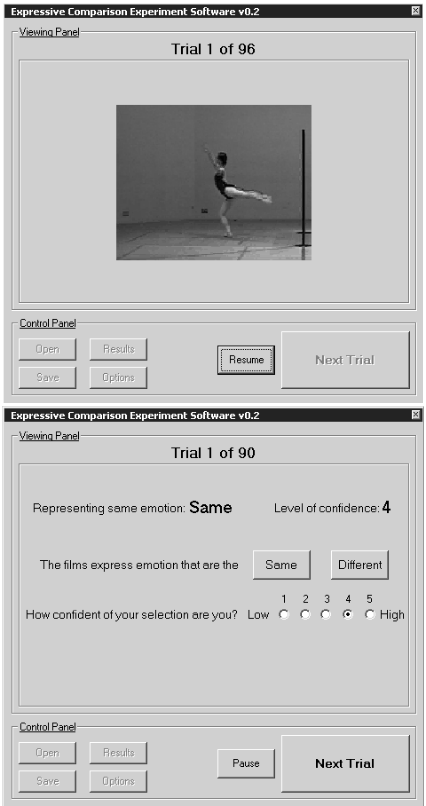

Figure 5: *Screenshots of the experiments video display window (top). Questions and selections interface (bottom).*

6.2. Results

Three types of analysis were performed. First, the percentage of trials that participants answered correctly with the three complexities of exercise, each divided into trials with same versus different pairs, were compared. Second, the percentage correct for the four emotions was analysed (using only trials that contained pairs of the same emotion). Third, the effect of Laban's time, space and weight dimensions was compared by analysing the percentage correct for trials in which different pairs of emotion were presented to participants. All of the analyses were performed using repeated measures analyses of variance (ANOVAs) and none of the interactions were significant.

Participants gave fewer correct answers as the exercises became more complex, but the difference was only marginally significant ($F(1,5) = 3.91, p = .06$). There was no significant difference between pairs of same exercises and different exercises ($F(1,5) = 0.52, p = .50$). See Figure 6.

For trials in which pairs of the same emotion were presented, there was a significant difference between the percentage of trials that participants answered correctly for the four emotions ($F(1,5) = 3.43, p = .04$), but not for the three

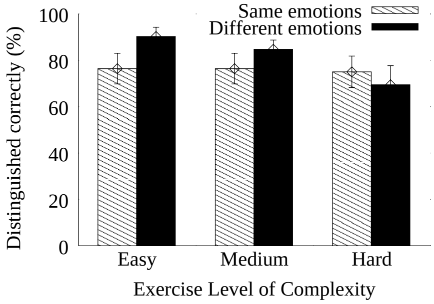

Figure 6: *Mean number of correctly distinguished pairs of emotions for each exercise level of complexity. Error bars indicate standard error of the mean.*

complexities of exercise ($F(1,5) = 0.52, p = .98$). See Figure 7. Participants made most errors for sad-sad and afraid-afraid trials, and a common factor for these emotions is that they are both slow in Laban's time dimension.

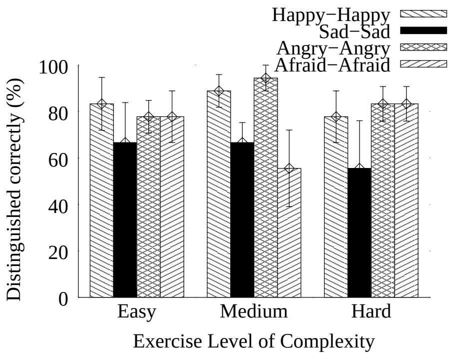

Figure 7: *Mean number of correctly distinguished pairs of the same emotions for each exercise level of complexity. Error bars indicate standard error of the mean.*

For trials in which pairs of different emotions were presented, there was a significant difference between the six combinations of emotion ($F(1,5) = 9.51, p = .00$). When Laban's time parameter was fast for both emotions in a pair (happy–angry), the participants results were equivalent to chance as shown in Figure 8. Participants were still able to distinguish different emotions where both emotions of the pair were characterised as slow in Laban's time parameter (sad–afraid) though there is a marked drop off when compared to pairs with different time parameters.

6.3. Discussion

Despite the reduction in the resolution, size, and display aspects of fidelity, the overall mean percentage correct was high ($M = 78.70\%$). The analysis undertaken to examine the accuracy for distinguish emotions at the three levels of

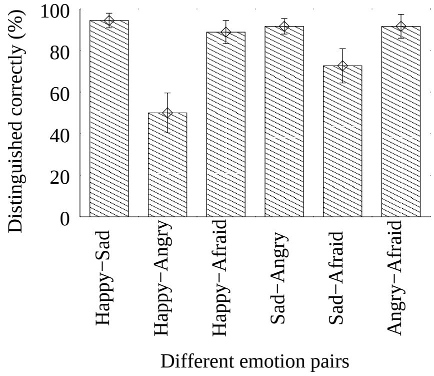

Figure 8: *Mean number of correctly distinguished pairs of different emotions. Error bars indicate standard error of the mean.*

complexity showed a greater accuracy at the easier level for different pairs of emotions. The accuracy for the same emotional pairs was similar for all three complexity levels. One possibly solution is the professionally trained dancers ability to accurately reproduce positions[19] provides less variation between the same emotions compared to different pairs of emotions showing greater movement variation. As movements become more complex for the dancers to perform, the amount of variation in the performance decreases and appears to the participants to have similar emotions.

The results for pairs of the same emotions establish the participants had generally less accuracy for emotions with a slow time factor. One possible hypothesis is: the slower time for the movies to complete the exercises gave more time for the participants to over analyse the movement and see more nuances, i.e. any extra deviation in the movement interpreted as differences between two emotions rather than variation in making movements. This result highlights that the participants found it significantly more difficult to distinguish certain emotions.

For different pairs of emotions, the common factor between pairs that were accurately distinguished over pairs that were not was Laban's time parameter. Different pairs with the same time characteristics were less accurately recognised, probably due to the participants finding it easier to differentiate using time. Pairs with the same time requires interpretation of other nuances in the performance of the movement by using the other Laban dimensions to distinguish the emotions. The greater the speed of movement, the more difficult the participants found it to read the visual clues. These results highlight that a key indication to distinguish different emotions is the time factor. Other visual clues such as Laban's space and weight dimensions were used to confirm their decision while emotions with similar times relied on the other dimensions highlighting the other dimensions aid the distinguishing process.

In conclusion, Experiment 1 has shown that on a small 2D visual display: (1) there was a high percentage correct overall despite the fidelity reduction; and (2) Laban's time dimension is a major clue when comparing different emotions.

7. Experiment 2

Experiment 2 investigated the ability of participants to distinguish emotions when presented at four different frame rates (5, 8.33, 12.5 and 25Hz). To limit the number of trials, it was decided to use only the extreme levels of complexity (easy and hard) and three emotions (happy, sad and angry). As in Experiment 1, each trial display either the same or different emotions and used the same dancer, exercise and frame rate for both emotions.

7.1. Method

Participants

The same six participants were used for this experiment that were used for Experiment 1.

Procedure

There were six combinations of the three emotions. Three involved pairs of the same emotion {*(happy, happy) (sad, sad) (angry, angry)*} and the other three were pairs of different emotions {*(happy, sad) (happy, angry) (sad, angry)*}. Participants performed two trials of each combination of emotion, exercise and frame rate, resulting in 96 trials overall, that were presented in three blocks of 32. The procedure was the same as Experiment 1 and as before, the order of presentation of the trials was randomised (see §6.1)

7.2. Results

The data were analysed using similar types of ANOVA to Experiment 1. Participants answered significantly more trials correctly when different pairs of emotions were presented than same pairs ($F(1,5) = 8.29, p = .03$), but the difference was almost entire due to the percentage participants answered correctly for different emotions in the easy exercise (see Figure 9). The effect of frame rate was marginal ($F(1,5) = 3.01, p = .06$), with participants answering fewer trials correctly at the fastest frame rate (25 Hz.).

For trials in which pairs of the same emotion were presented, there was a significant difference between the three emotions ($F(1,5) = 4.47, p = .04$). Participants answered more trials correctly with the angry emotion ($M = 86.46\%$) than with the happy ($M = 71.88\%$) or sad emotion ($M = 61.46\%$). There was no significant difference between the frame rates.

For trials in which pairs of the different emotions were presented, there was a significant difference between the three combination of emotions ($F(1,5) = 13.63, p = .01$). Participants answered fewer trials correctly with happy–angry pairs ($M = 66.67\%$) than with the happy–sad ($M = 93.75\%$) or angry–sad pairs ($M = 93.75\%$). There was no significant difference between the frame rates.

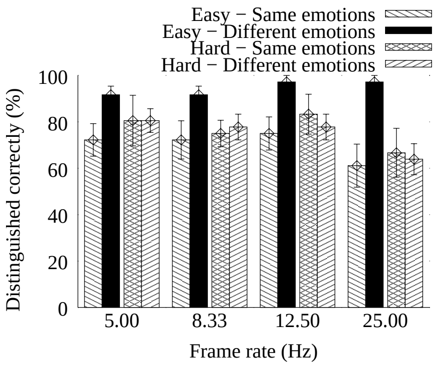

Figure 9: *Mean number of correctly distinguished pairs of emotions for the easy and hard exercise level of complexity using four different frame rates. Error bars indicate standard error of the mean.*

7.3. Discussion

Experiment 2 provides some understanding on the amount of visual detail required between keyframes for users to differentiate emotions on a VBD. The overall mean percentage correct was high ($M = 78.99\%$) despite using the different frame rate aspect of fidelity and produced similar results to Experiment 1. This result highlights the possibilities interpolating between keyframes approximating 5 to 25Hz and achieve an expressive animation.

An unexpected result was that participants were less accurate with the normal frame rate than the lower frame rates. A possible hypothesis is after making judgements with less visual clues at lower frame rates, the extra detail obtained from the higher frame rate made the distinction between pairs more confusing. Participants over compensated for the amount of detail provided at the normal frame rate and found it difficult to determine whether the observed differences in the expressive nuances were caused by different emotions, or variations of the same emotion. However, it should be emphasised the frame rates had only a marginal effect to distinguish emotions. More significantly, participants were more accurate on different pairs of emotions performed at an easy level of complexity matching Experiment 1.

The results for pairs of the same emotions and pairs of different emotions were similar to Experiment 1, and in both analyses, frame rate had no effect on accuracy of participants judgement. This second experiment also highlighted the importance of the time dimensions in judging the motive themes underpinning ballet movement.

8. General discussion

This study analysed the different fidelities requirements to develop a VBD and looks into how these issues of fidelity affect the users judgement to distinguish emotions. Two aspects were considered in relation to the visual appearance of the VBD and the realism of the movement required. Using videos of real dancers provided the best possible 3D dancer model and movement algorithm to assess the different aspects of fidelity. The high percentage accuracy overall for Experiment 1 where the fidelity was lowered from the real-world to a 3D representation displayed on a 2D display highlighted that expressive motion can be distinguished by a user. The fidelity on the 2D display assessed included degradation in resolution and a small image size.

Experiment 2 assessed aspects of movement fidelity using different frame rates to assess levels of interpolation required for a VBD. The high percentage accuracy overall and the results showed different frame rates had only a marginal effect on the participants. This highlighted that interpolation between keyframes equivalent to 5-25Hz is capable of providing enough visual clues for the user to distinguish differences in emotions from the animated movement of a VBD.

Future research is to create a VBD driven by dance notation and develop the emotive model and algorithm for expressive movement. The full development of a software animation system to represent and simulate dance would be beneficial to historians, choreographers and choreologists to: (a) evaluate ballet choreography with expressive styles, and (b) aide professionals to visualise the movement required for resurrecting ballet scores. In classical ballet, the main mode of knowledge transfer is the live demonstration process. The final system hopes to fill a gap in the learning process of choreography and dance using VE technologies.

References

1. A.K. Brown and M. Parker. *Dance Notation for Beginners*. Dance Books Ltd, 1984.
2. R. Laban. *Choreutics*. MacDonald and Evans Ltd, second edition, 1966.
3. N. Eshkol and A. Wachmann. *Movement Notation*. Weidenfeld and Nicolson, 1958.
4. R. Benesh and J. Benesh. *Reading Dance: The Birth of Choreology*. McGraw-Hill Book Company Ltd, 1983.
5. R. Neagle and K. Ng and R.A. Ruddle. Notation and 3D Animation of Dance Movement. *Proceedings of the International Computer Music Conference (ICMC2002)*, 459–462 , 2002.
6. D.M. Chi, M. Costa, L. Zhao and N.I. Badler. The EMOTE Model for Effort and Shape. *Siggraph 2000, Computer Graphics Proceedings*, 173–182, 2000.
7. C. Stevens, S. Mallock, R. Haszard-Morris and S. McKechnie. Shaped Time: A Dynamical Systems Analysis of Contemporary Dance. *Proceedings of the 7th International Conference on Music Perception and Cognition*, 161–164, 2002.
8. Y. Li, T. Wang and H. Shum. Motion Texture: A Two-Level Statistical Model. *Siggraph 2000, Computer Graphics Proceedings*, 2002.
9. M. Brand and A. Hertzmann Style Machines. *Siggraph 2000, Computer Graphics Proceedings*:183–192, 2000.
10. D. Herbison-Evans, R.D. Green and A. Butt. Computer Animation with NUDES in Dance and Physical Education. *Australian Computer Science Communications*, **4**(1):324–331, 1982.
11. Credo Interactive Inc. Life Forms. http://www.credo-interactive.com/products/index.html, last accessed in October 2002.
12. R. Neagle A survey on application for editing and animating dance notations. http://comp.leeds.ac.uk/royce/, last accessed March 2003.
13. D. Herbison-Evans, F. Edward, S. Hunt and G. Politis LED and LINTER: An X-WINDOWS Mini-Editor and Interpreter for LABANOTATION. http://linus.socs.uts.edu.au/ don/pubs/led.html, last accessed January 2003.
14. N.L. Hall and D. Herbison-Evans. BALLONES: A Ballet Animation Language. *Proceedings of Australian Computer Graphics Association (AUSGRAPH90)*, 1990.
15. J. Lansdown Computer-Generated Choreography Revisited. *Proceedings of 4D Dynamics Conference*, 89–99, 1995.
16. F. Thomas and O. Johnson. *Disney Animation: The Illusion of Life*, Abbeville Press, New York, 1981.
17. A. Camurri, S. Hashimoto, M. Ricchetti, A. Ricci, K. Suzuki, R. Trocca and G. Volpe. EyesWeb - Toward Gesture and Affect Recognition in Dance/Music Interactive Systems. *Computer Music Journal*, **24**:57–69, 2000.
18. C. Dell. *A Primer for Movement Description*. Dance Notation Bureau, Inc, forth edition, 1977.
19. J.R.E. Ramsay and M.J. Riddoch. Position-matching in the upper limb: professional ballet dancers perform with outstanding accuracy. *Clinical Rehabilitation*, **15**(3):324–331, 2001.