Understanding Movement for Interaction Design: Frameworks and Approaches

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Abstract The results of a study of two computer games, that use human movement as direct input, were analysed using four existing frameworks and approaches, drawn from different disciplines that relate to interaction and movement. This enabled the exploration of the relationships between bodily actions and the corresponding responses from technology. Interaction analysis, two design frameworks and Laban movement analysis were chosen for their ability to provide different perspectives on human movement in interaction design. Each framework and approach provided a different, yet still useful, perspective to inform the design of movement-based interaction. Each allowed us to examine the interaction between the player and the game technology in quite distinctive ways. Each contributed insights that the others did not.

Keywords: Body, Embodied, Framework, Interaction, Movement

1 Introduction

The emergence of interactive spaces and computer-mediated environments has been made possible by the development and availability of a variety of sensing technologies. Now human movement can act as a direct means of input to these systems. Interaction design for movement-based input raises new questions about the potential use, and consequences of use, of the active, moving body in human-computer interaction. These questions stem from the recognition that, as with any interaction design, systematic and predictable relationships need to be articulated between specific human actions and specific machine responses.

This research is motivated by the premise that movement is constituent of perception, and thus movements cannot be considered incidental to action [1]. We seek to incorporate the embodied nature of human cognition into our understandings of the roles and places of moving bodies in interaction design. In this paper we present our findings from a study of the use of two Sony® Eyetoy™ games [2] that rely on movement as direct input. The results have been analysed using four existing frameworks and approaches drawn from different disciplinary sources that relate to interaction and movement. Interaction analysis [3], two design frameworks [4], [5] and movement analysis [6] were used to investigate the relationships between bodily actions and the corresponding responses from technology. This investigation contributes to developing understandings of human movement in interaction design that can, in turn, inform the design of movement-based interaction.

The paper is structured as follows. We begin with a brief discussion of embodied perspectives in interaction design, and an overview of research endeavours and design approaches/solutions directed to the use of human movement with technology. This is followed by a description of the Eyetoy™ study. In the main section of the paper, four frameworks and approaches are introduced and applied to the findings from the Eyetoy™ study. We conclude with a discussion of the relative value of each of the frameworks and approaches for providing different perspectives for the design of movement-based interaction.

2 Background

Our bodily experience of movement is not a particular case of knowledge; it provides us with a way of access to the world and the object.
Merleau-Ponty, 1962, p.162

The recognition that all human actions (including cognition) are embodied actions, is fundamental to recent trends in interaction design. An increasing number of researchers have contributed phenomenologically motivated theoretical perspectives on the relations between embodied actions and technology design and use (e.g., [7], [8], [9], [10], [11]). Robertson [7] drew on the phenomenology of Merleau-Ponty and a field study of cooperative design to develop a taxonomy of embodied actions that serve communicative functions in cooperative work. In later work she used the phenomenology of Merleau-Ponty to stress the importance of the public availability of actions and artefacts for maintaining awareness in distributed activities. She wrote:

For a phenomenologist it makes no sense to speak of perception, cognition and motor action, as if these are quite different activities with some definable boundary between them. This is not how they are lived. We do not perceive the world in front of us, like a picture. We are in it. (Robertson, 2002)

Dourish [9] emphasised the role of embodiment in the design of interaction when he described embodied interaction as an approach that hinges on the relationship between action and meaning as part of a larger system. Interaction design undertaken from this perspective "turns our attention away from the artefacts themselves and toward the ways in which people engage with them in different settings." Svanæs [10] promoted the application of the phenomenology of Merleau-Ponty to the design of context-aware technology, as its first-person focus on the lived body and its relation to the environment enabled understanding of such systems from the user's perspective. His analysis recognized that context must always be understood from the perspective of those whose context it is. Finally, Hornecker [11] proposed embodied facilitation as a major theme in her framework for the design of collaboratively used tangible interaction systems. She recognized that any technology offers structure that implicitly directs user behaviour by making some actions easier, while constraining others. In tangible interaction systems, structure is as much in the physical actions that users perform as it is in the software itself.

Research endeavours and design approaches/solutions directed to the use of human movement with technology over the past twenty years have grappled with the technical challenges posed by treating the moving body as input, especially in the area of visual analysis and representation of the moving body [12], [13], [14], [15]. Computer vision, for instance, is concerned with the visual analysis of human movement and aims to recognise human motion at three distinct levels - body parts, tracking of the whole body and recognising human activities. A host of sensing technologies are now available, besides computer vision, for sensing and recognising human movement, such as data gloves, infra-red sensing, video-based recognition, touch or pressure sensitive devices and more recently in the area of ubiquitous computing, the use of mobile phones or radio frequency identification (RFID) tags for detecting movement [5], [16]. More recently, the emphasis has shifted to the affective aspects of human movement and expression, focusing on recognition and simulation of expressive movement [17], [18], [19],

[20], [21]. Complementing this wealth of technical innovation are research and design approaches for gesture- or movement-based technology use that are grounded in studies of work practice and everyday life (e.g., [22], [23]). This study contributes to the conceptual tools available to ground the analysis of studies of human movement and to our understandings of how some existing design frameworks might be made valuable within novel contexts.

3 The Eyetoy Study

We explored movement as input for human-computer interaction, through a study of two Sony Playstation2® Eyetoy™games. We were using the Eyetoy™ games as prototypes of possible future systems that are based on human movement and computer vision. Eyetoy™ is a motion recognition camera that plugs into a Playstation2® game console. The Eyetoy™ games can be played using movements of any part of the body, but tend to be played mainly with movements of the arms. The player has no direct physical contact with the technology. Their movements are used to drive the interaction by coinciding spatially and temporally with buttons and game events that form part of the gamescape. The player can see a projected image of their body in the middle of the screen, overlaid on the gamescape.

During game play, only certain areas of the screen are deemed active (by the system) at any point in time depending on the game context. By active, we mean that player's movements *in relation to* particular areas of the screen can be sensed by the camera and so registered as input. There is an optimal distance for motion recognition of the player, given by a certain calibrated distance from the camera. This is set at the beginning of the game, by the player standing so that their body fills an outlined figure on the screen.

We examined the available Eyetoy™ games to identify the most suitable games for this study. Suitability, in this context, was defined by the range of movements that could be used within the game and the game's learnability. Two games, Beat Freak and Kung Foo, were selected. Beat Freak (see Figure 1) requires the player to move their hand over a speaker in one of the four corners of the screen at the same time as a CD flies across the speaker. The CDs fly out from the centre of the screen and reach the centre of the speaker cone in time with the music. The active area for input in this game is the circular zone representing the cone of the speaker, which is positioned in each of the four corners of the screen. For a given event such as a CD flying out from the centre to the upper left corner, the target area becomes active for a specific time period in which the user's movement can be registered.

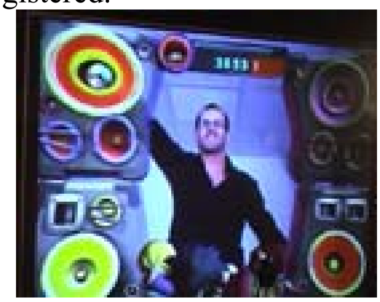

Figure 1. Beat Freak game

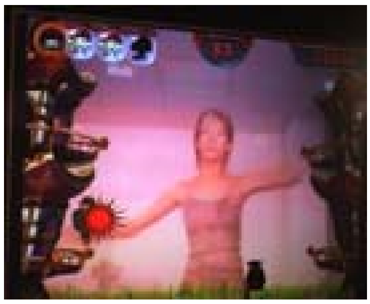

Figure 2. Kung Foo game

In Kung Foo (see Figure 2) the player has to strike the head bad guy's (Wonton's) henchmen by moving his/her limbs to intersect moving images of the attackers. If the player misses and the attackers reach the middle of the screen, then the player loses 'a life'. The henchmen appear randomly from pagodas positioned at the sides of the screen. Extra points are gained by breaking wooden boards and hitting Wonton himself when he appears. The active area for input is the area corresponding to any of the moving henchmen, Wonton, or the stationary wooden boards.

3.1 Method

Eight participants, four female and four male, were recruited to play the two games. Before playing, data on demographics and previous experience with the games were collected. The participants were introduced to each game by using the game's *Help* feature. They then played each game twice on the *easy* level and once on the *medium* level.

The participants were filmed from two angles. One view captured a projection of the participant's mirror image in the gamescape; the other view captured from front-on the participant's full body whilst playing. After playing, the participants were interviewed about their experience with the game and given a questionnaire with usability related questions.

Three of the eight participants were initially selected for analysis on the basis of variation between their movement styles. The actions and movements were identified from these three, and then evaluated against the remaining five participants. This enabled an iterative analysis of the actions and movements used in playing Eyetoy™. The video recordings were viewed multiple times by the authors, individually and together, in order to determine:

- the actions taking place in each game; and
- the specific movements used to perform these actions.

3.2 Initial observations

The two games studied engendered quite different movements. Beat Freak produced highly regular, repetitive, reaching movements of the arms to the high and low diagonals as dictated by the beat of the music. Kung Foo produced a variety of strong, fast movements in all lateral directions in space in accordance with game-initiated events. We identified four basic actions that were performed with a variety of movements reflecting the individual movement styles of the participants (see Table 1).

Table 1. Game actions and characteristic player movements

Action	Description	Game	Movement
Selection	Navigation and selection of game choices and settings	Both	Wave
Strike Moving Object at Fixed Target	Coincide with object at target location	Beat Freak	Reach, flick
Strike Fixed Target	Strike as soon as object appears	Kung Foo	Slash, punch
Strike Moving Target	Strike as soon as object appears	Kung Foo	Slash, punch, slap, swat

These two Eyetoy™ games did not encourage people to move around the space as the optimum position for play was in the centre where initial calibration took place. Moving away from this place meant successful game actions might not be registered by the technology. Most participants stayed rooted to the spot, moving only their arms and acting within the lateral plane, although two participants did perform an occasional leg-kick. Perhaps more experienced players would be more adventurous in how they moved their bodies in the space. We observed that most of the participants engaged in some sort of experimentation with how their movements resulted in a higher ratio of successful strikes. A common strategy involved holding their arms further out to the periphery which was then closer to the point of interaction with the target event. However most people tired of this strategy and reverted to a more natural posture with their arms closer to their upper body whilst readying for the next game event. Interested readers can find a fuller discussion of the findings from this study in Larssen et al. [24].

4 Extending the analysis

The results of the study were analysed using four existing frameworks and approaches, drawn from different disciplines that relate to interaction and movement. This enabled the exploration of the relationships between bodily actions and the corresponding responses from technology from the four different perspectives provided by these frameworks and approaches. These included interaction analysis [3], two design frameworks [4], [5] and Laban movement analysis [6]. Suchman's [3] framework reveals the communicative resources available for interaction between humans and machines. Benford et al.'s [4] framework, *Expected, Sensed and Desired: A Framework for Designing Sensing-based Interaction*, was developed to assist in the design of moveable, physical interfaces, such as mobile devices or interactive furniture. Bellotti et al. [5] proposed a framework for the design of sensor-based systems, *Making Sense of Sensing Systems: Five Questions for Designers and Researchers*, that is based on a model of human-computer interaction as human-human interaction. Finally, Labanotation [25] is a system of analysing and recording movement, traditionally used in fields such as dance choreography, physical therapy and drama. In the remainder of this section, each framework and approach is introduced and discussed in turn.

4.1 Interaction Analysis - Suchman

> *The starting premise is that interpreting the significance of action is an essentially collaborative achievement. Rather than depend upon reliable recognition of intent, mutual intelligibility turns on the availability of communicative resources to detect, remedy, and at times even exploit the inevitable uncertainties of action's significance.*
> *Suchman, 1987, p.69*

Suchman's pioneering work on human interaction with technology claims that action is always situated and improvisatory in nature [3]. In her classic study of photocopy use, she draws on conversation analytic techniques for human-human interaction and uses an *analytic framework* ([3], p.116) to emphasise the resources available for human-machine interaction. This framework incisively reveals the disparity in the communicative resources for interaction between human(s) and machine.

We have taken Suchman's analytic framework and used it here to analyse the interaction between the player and the Eyetoy interface, for the two games chosen. We adapted the framework to fit our particular context. The column labeled "Actions not available to the machine" has been split into two, to bring out the details of the movement description for the user's actions. The column labeled "Effects available to the user" has also been split into two, to clarify the game context in which specific actions are occurring. In the original framework there is a fourth column on the right-hand side, "Design rationale", for the machine. This has been omitted due to our lack of access to the designers' intentions for the Eyetoy games.

An example of a fragment of the interaction analysis for the Beat Freak game play by participant 8 is given in Table 2. The data is purposely laid out in the table (after Suchman) so that the columns labeled "Actions available to the machine" and "Effects available to the user" constitute the interface of the system that is available to both human and machine.

Table 2. Interaction analysis framework - Beat Freak 1st game play, Participant 8

The User			The Machine	
Actions not available to the machine		Actions available to the machine	Effects available to the user	
User activity/action	Movement description	Via camera	Output: Visual display and audio	Game context
Awaiting start of game.	Ready position: Standing feet hip width apart, both hands held at navel, closed fist.	Calibrated image of user	Gamescape Visual text: Countdown	Game starts
Attempt to hit CD as it intersects speaker cone.	Reach out to upper front left with left arm, fingers spread.	(no machine input besides image of user)	CD emerges from centre and travels to upper left speaker.	Event – CD launched
Successful strike on the beat.	Left hand intersects speaker cone simultaneously with CD.	Motion detection over area representing upper left speaker cone as CD passes through it	Speaker vibrates and CD shrinks. Sound of cymbal clash.	Event - successful strike
Return to ready position.	Lower left arm to ready position.	(no machine input besides image of user)	Gamescape with animated characters dancing along	Pending next event
Waiting for next event, rhythmic sway to music.	Shifting weight side to side.	(no machine input besides image of user)	Gamescape with animated characters dancing along	Pending next event

The critical point here is that the machine has available only what is in the grey column of the table for interpretation of the interaction – and the human user has everything else! Laying out the interaction in this form makes clearly visible the perceptual asymmetry, between the human and the machine points of view, that Suchman wanted us to see in her original work. We can see that the player has an exceptionally rich perception and interpretation of the action and game activity. The resources continually available to the user consist of the visual display, sound output, the game action and events - all of which are synthesised by the user to create a space in which to perform meaningful physical actions within the context of the game. As humans we are able to create the necessary context for a satisfying experience, regardless of the sophistication of the technology. We create a world to inhabit and within which to perform movements as part of meaningful actions for interaction. The moment of interaction is embedded in a gestural phrase [4] that is part of an overall activity that gives the movements their meaning and distinctive quality. For example, in the Beat Freak game the player reaches out to strike the flying CD as part of a rhythmic activity dictated by the beat of the music. In Kung Foo, the player strikes attacking henchmen as part of a martial arts fighting situation.

In contrast, the machine (in the grey column) has limited resources available for interpretation of the action. This is related to the choice of input technology for Eyetoy™ - a single camera provides motion detection of the player's movements within its frame of view. The machine perception is thus limited to motion detection typically over a narrowly defined spatial area within a given time period, as directed by the context of a particular game event.
For example, in Beat Freak, the machine only detects motion in the area corresponding to the speaker cone when the CD is passing through it. Likewise, in Kung Foo, the machine detects motion in the area(s) corresponding to the moving henchmen as they jump towards the centre of the screen. This particular technology implementation makes no attempt to track or recognise human movements - it simply detects motion.

The analytic framework derived from Suchman was valuable in two key ways. Firstly it *made clearly visible the resources available to the user and to the machine* for perception of action. Its prime function was to lay out the sequence of interaction and the interpretation of the interaction from both the human side and the machine side. Second, and most significantly in terms of understanding movement, we were able to *describe the movements as actions occurring in context*, without losing the situated and contextual aspects of the performed movements. For example, the player is involved in an act of striking an attacking opponent in Kung Foo. The movements performed to effect this action, in a particular instance, took the form of the player moving their left arm to the lower left side, with a slashing quality. In between defensive strikes, the player was observed to perform readying or preparatory movements, such as shifting their weight from side to side. The richness of perception for the player is in sharp contrast to the machine’s simplicity of perception of the action.

4.2 Benford et al. design framework

The framework by Benford et al. [4], *Expected, Sensed and Desired: A Framework for Designing Sensing-based Interaction*, was developed to assist in the design of moveable, physical interfaces, such as mobile devices or interactive furniture. This framework focuses on the often complex relationship between physical form and sensing technologies. The movements of the user in relation to the physical interface can be analysed and compared in terms of expected, sensed and desired movement properties:

- **Expected** movements are those that users naturally perform. These are normally considered independent of any specific application. For the Eyetoy interface, a single motion detection camera and a display screen, expected movements include performing physical movement of any sort within the space dictated by the camera frame of view.

- **Sensed** movements are those that can be measured by a computer, given the available sensing technologies. For the Eyetoy interface, any player movements are sensed movements if they correspond spatially and temporally with the input region of the interface (governed by the camera's frame of view).
- **Desired** movements are those required by a given application. For Eyetoy game play, waving a hand over a virtual game button to select a game setting, or striking sideways with the arm to hit a virtual game object, are desired movements.

Key aspects of this framework are that expected, sensed and desired movements only partially overlap and that mismatches between the categories can reveal potential problems, as well as opportunities to be exploited, in design solutions. The framework can be related to existing taxonomies for input and input devices (e.g. [26], [27]) that explore how to analyse sensed movements in relation to expected ones. Benford et al.'s focus on the overlaps and less expected or non-sensed movements differentiates this framework from these earlier ones.

For the purposes of our study of movement-based interaction, we applied the Benford et al. framework to an analysis of the Eyetoy games, solely with regard to the movements of the user. We disregarded the movements of the technology itself, since the Eyetoy interface is not intended to be a mobile technology and proper functioning relies on precise placement of the Eyetoy camera in relation to the screen and the player. The possible user interactions with the Eyetoy interface were studied using the expected and sensed categories of movement, without regard to the particular application (addressed by the desired category). Within this, we considered the less expected and non-sensed movements. The set of desired movements was evaluated for the specific application of the two Eyetoy games. Desired movements were initially taken to be those corresponding to successful actions performed during actual game play, and thus could also be classified as expected and sensed. In this case, the actions are for selection of game settings and game-specific movements. Finally we considered the unsuccessful actions and other un-sensed movement as part of the set of desired movements that are part of normal game play.
The results of the analysis are summarised in a Venn diagram (Figure 3) that shows the combinations of movement categories (labeled A, B, C and D) that we found relevant to our study. The diagram illustrates that the movements that fall into combination A: expected, sensed and desired, are probably the movements intended for normal operation of the technology. These are movements that are sensed by the computer and make sense for normal game play. One example is of a successful action by the player of reaching to the upper diagonal to hit the CD as it intersects with the speaker cone.
Sensed movements that players can naturally make, but breach game etiquette, such as unfair positioning of body or limbs, fall into combination B: expected and sensed, but not desired. Movements not sensed by the computer but that make sense for game play fall into combination C: expected and desired, but not sensed. Examples include free and expressive movement, or moving outside the active sensing region of the screen to rest or swap players. The final combination D: sensed, but not expected or desired, accounts for sensed movements that may be

interpreted as action by the computer, but were not made intentionally by the player. For example, the player accidentally intersects with a game object resulting in a lucky strike.

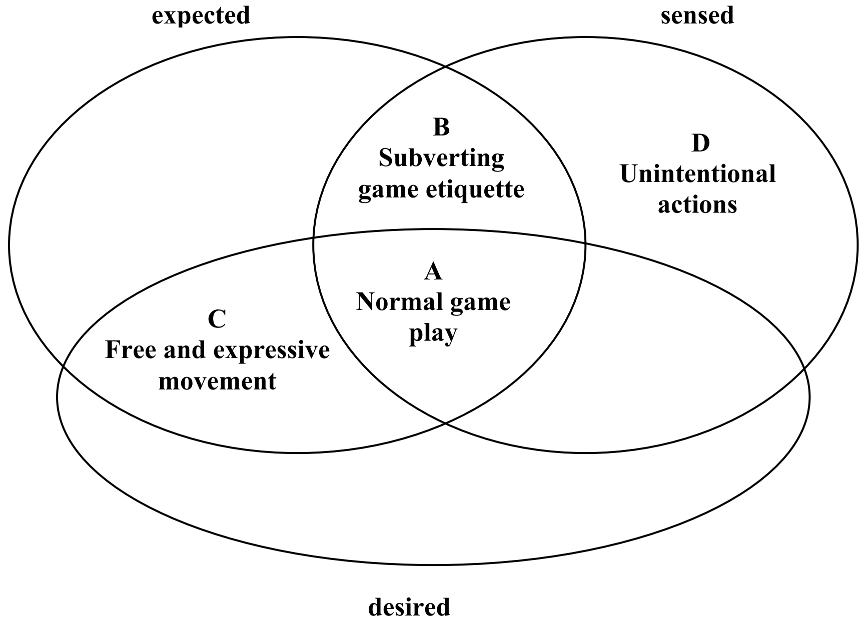

Figure 3. Combinations of Expected, Sensed and Desired Movement

Movements outside these combinations were physically unlikely, technically not able to be sensed or undesired for these particular games. The analysis clarified the relationship between the user, the technology (the form of the interface and devices) and the game application. It also suggested areas of potential redesign, such as pausing the game by stepping outside the camera's frame of view. But also, perhaps more interestingly, the framework reveals the ways in which the user can subvert this relationship, through an examination of the non-sensed, less expected or less desired movements.

4.3 Bellotti et al. design framework

Bellotti et al. [5] proposed a framework for the design of sensor-based systems, *Making Sense of Sensing Systems: Five Questions for Designers and Researchers*. They focused on what happens when technology moves into the environment around us and the challenges this poses to the interaction between people and computers. Their framework was informed by understandings of human-human interaction derived from the social sciences; human-computer interaction is viewed as *communication* between the user and technology and the concern is how to achieve *joint accomplishment* ([5], p. 416) in realising the interaction. The framework is composed of a set of five issues that Bellotti et al. suggested could be posed as questions that system users must be able to answer to accomplish some action:

- **Address**: Directing communication to a system
- **Attention**: Establishing that the system is attending
- **Action**: Defining what is to be done with the system
- **Alignment**: Monitoring system response
- **Accident**: Avoiding or recovering from errors or misunderstandings.

Drawing on comparisons with graphical user interfaces (GUIs), their subsequent exploration focuses on how to handle input and output issues in systems where the user interface might or might not be graphical.

We applied the Bellotti et al. framework to our analysis of the Eyetoy game play by considering how movement as input would hold as communication in the interaction. This was achieved by addressing the five questions posed by Bellotti et al.'s framework to the two Eyetoy games. The results of the analysis are presented in Table 3.

Table 3. Application of Bellotti et al.'s framework to Eyetoy game play

Questions	Eyetoy™ "Answers"
Address: How do I address one (or more) of many possible devices?	- Only one device to *address*, but the player has to be positioned, i.e. calibrated with system. Player chooses to step into position to initiate interaction, although interaction is possible when not optimally positioned. - Interface elements designate areas to *address*. Motioning over the spot corresponding to the 'button' or intersecting with game objects *address* the system. - The system can also be addressed by other moving objects passing through sensing range, e.g. another person. - No means of *not addressing* the system other than quitting the game. *Pause* not possible.
Attention: How do I know the system is ready and attending to my actions?	- Player sees their image in the projection - this is a constant reminder of the system's attention. System attention is signalled with request for command/input or game events. - Feedback is in the form of text, images, animation, audio, e.g. animation of circle closing when "selected", and visual and audio feedback when intersecting successfully with object.
Action: How do I effect a meaningful action, control its extent and possibly specify a target or targets for my action?	- User interface with button and game objects that designate areas to effect action. - Game directs the sequence of action. Player responds to events by moving limbs to intersect with target. Issue command to change game settings by waving in a defined area in space- time, i.e. interface specifies targets. - Limited number of objects in the interface to manipulate to effect action.
Alignment: How do I know the system is doing (has done) the right thing?	- Visual output on screen in the form of text (e.g. score, stats) and graphics (e.g. smashed enemies). Audio output (e.g. cheering).
Accident: How do I avoid mistakes?	- Not possible to undo action during game play, given that this is a game this would be cheating. You can change selections only by using cancel which takes you "back" one step. - Mistake in terms of game play would be failure to intersect with object, resulting in loss of a life, lower score or end of game. - Unintentionally intersecting with game objects during game, resulting in a lucky strike with visual and audio feedback, but no disadvantage in the form of lost points.

The use of this framework enabled us to focus on the input and output mechanisms of the Eyetoy™ interface. Since the Eyetoy™ operates with a GUI-like display, some of the challenges that Bellotti et al. set out to tackle are solved in conventional GUI ways. The questions of Address, Attention, Action and Alignment, address the traditional concerns of user interaction of knowing when and how to initiate action, and of receiving adequate confirmation of this action from the machine. The Eyetoy™ interface provides a visual display of the gamescape with a mirror projection of the player inserted. The games control the sequence of events. Thus the player is directed by the game as to when it is appropriate to interact through physical movements. Confirmation of the player's actions is given through changes to the visual display and sound effects. The question of Accident (How do I avoid mistakes?) revealed one of the differences in designing for traditional task-oriented interactions and more novel forms of interaction such as games. The Eyetoy™ games are designed to test and develop a player's physical skill. A mistake in a game, such as a missed strike, is a normal occurrence in game play and would typically result in loss of points. Accidentally intersecting with an attacking henchman in Kung Foo could be considered a mistake, albeit a lucky one.

4.4 Movement analysis – Labanotation

> *Movement not only speaks through an object; a living organism owes its final form to it; movement leads to growth and structure…*
> *Rudolf Laban, quoted in Bartenieff, 1980*

Labanotation is a system of analysing and recording movement, originally devised by Rudolf Laban in the 1920's and further developed by Hutchinson and others at the Dance Notation Bureau, New York [25], [6], [28]. It continues to be used in fields traditionally associated with the physical body, such as dance choreography, physical therapy and drama. It has also been applied in anthropology and industrial production. It can be used for analysis and choreography of all forms of human movement. Traditionally Labanotation has been used in dance and movement observation for recording both natural and choreographed movement and for exploring movement.

The aim of this analysis was to investigate how Labanotation might be used for describing movement-based interaction with technology. We used Labanotation and its system of movement analysis to analyse and transcribe the movements of individual players interacting with the two Eyetoy games. For each of the four game actions (refer Table 1), we transcribed a selection of players' movements using the Structural form of Labanotation. The Structural form provides the fullest and most specific description of movement in clearly defined and measurable terms: the body and its parts, space (direction, level, distance, degree of motion), time (meter and duration) and dynamics (quality or texture, e.g. strong, heavy, elastic, accented, emphasised). It uses a symbolic notation, related to music notation, where symbols for body movements are written on a vertical 'body' staff. The expressive quality of the movement was analysed using the Effort description in terms of the player's relationship to weight, space and time. The process of notating was done by each researcher individually before arriving at an agreed form for each participant's movements. This involved a reflective cycle of revisiting the video data and re-enacting the observed and notated movements for a practical and embodied understanding of Laban's theory (after Newlove [29]), while refining our transcription.
In order to capture the context of interaction in which the movements were performed, we augmented the movement transcriptions with computer interface elements depicting the screen and significant game event trajectories. Labanotation allows for reference to other people, objects, music and spatial environment, and can easily be extended to describe a person's relation to virtual

or computerised events, objects and environment. An example of such a contextualised movement transcription is given in Figure 4.

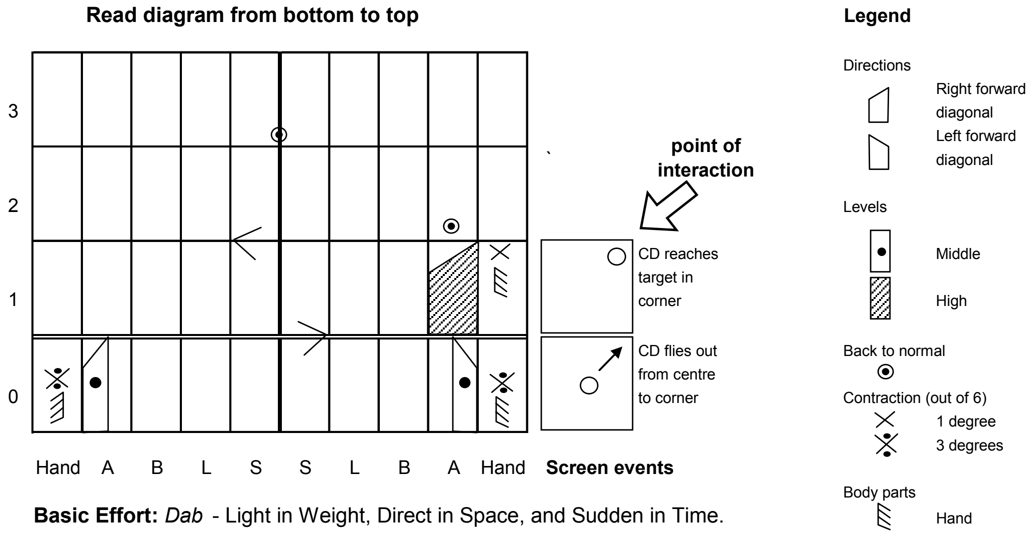

Figure 4. Movement transcription for player 2, Beat Freak game

Before we explain the movement transcription, a brief introduction to the Labanotation staff is required. The structural form of Labanotation is read from the bottom to top, with time in the vertical axis. Time can be split into measures (rows in the diagram), just like in musical scores. We have numbered each measure to facilitate explanation. The vertical staff represents the body, the centreline being the centreline of the body, the right hand columns represent the right side of the body and likewise for the left. The columns are used for main parts of the body, such as S - Support, and A - Arm; for example, movements of the arms are written in the 'A' column. Symbols for indicating direction and level of movement in space can be combined and placed in the columns associated with the major body parts. Timing and duration of movement are indicated by the position and length of the symbol. No symbol in a column implies no movement.

The notated movement for the *Strike Moving Object at Fixed Target* action of player 2 in Figure 4 shows, in row 0, the player in a starting position with both arms bent at the elbow (the position of the lower arm is indicated by the placement of the symbol in the outer half of the A - Arm column), the fists lightly closed (indicated by contraction of the hand) and held just in front of the navel, and the weight evenly distributed on both feet, feet about hip width apart. We have indicated the game events alongside the body staff - here a circle representing a flying CD is displayed emerging from the centre of the screen and moving towards the upper right corner of the screen. In the first row (measure 1), the player reaches to the right upper front with the right arm; the hand opening as they fully extend their arm. They shift their weight to the right (indicated by the caret symbol > in the S - Support column) as the right arm extends. The point of interaction occurs when the arm is fully extended to the upper right at the same time as the CD reaches the upper right speaker cone on the screen. Then in measure 2, as the player lowers their right arm to the starting position (indicated by the 'back to normal' symbol), they shift their weight to the left and then in measure 3, they return to centre. The Effort description is a *Dab*; a Labanotation category that is Light in Weight, Direct in Space, and Sudden in Time. The types of Effort identified for each game action resonated with the typical physical action associated with that game. Typical physical actions for Beat Freak would be lightly and quickly reaching to a point in space and retracting - these would tend to exhibit a *Dab*-like Effort. For a fuller description of the application of Labanotation to the analysis and design of movement-based interaction, see Loke et al. [30].

We found that we only used a small set of the descriptive forms of Labanotation in our analysis; specifically directional destination, relationship (to virtual and physical objects), and dynamics (expressive quality) in terms of Effort. This was because of the particular forms of movement people used when playing Eyetoy. But this is not to imply that other kinds of movement-sensing technologies would not exploit more of the options available within Labanotation.

Primarily, Labanotation gave us a language and vocabulary for describing or talking about human movement, with the moving body as the central focus. It provided us with a systematic approach for observing and describing the moving body in space and time. Some of the value of using such a system of movement analysis and notation lies in the doing, in the work of transcribing, as it forced us to perform rigorous observation of bodily movements and to understand how these movements related to the context of interaction.

5 Discussion

Each framework and approach provided a different, yet still useful, perspective to inform the design of movement-based interaction. Each of them allowed us to examine the interaction between the player and the game technology in quite distinctive ways. Each contributed insights that the others did not.

Suchman's analytic framework exposed the inherent asymmetry in the relationship between the human and the machine in terms of the resources available to both sides for interpretation of the interaction. It enabled a rich and coherent picture of the player's activity within which they performed bodily movements for meaningful interaction. We were able to describe the movements as actions occurring in context, without losing the situated and contextual aspects of the performed movements. At the same time, from the machine point of view, the framework helped to pinpoint and explore the possible options for detection and interpretation of the player's action, given the sensing technology of single-camera computer vision implemented in the Eyetoy interface.

The Benford et al. framework helped to clarify the relationship between the player's movements and actions and the sensing technology used in the Eyetoy interface. The expected, sensed and desired categories, and the combinations and permutations of them, proved very useful for exploring possibilities for meaningful action through movement. The framework showed what is possible for the user through an examination of the less expected, non-sensed and less desired categories. For example, thinking in terms of expected and desired, but not sensed movements allows for movements that are free and expressive and it allows for periods of rest. It also encourages consideration of the ideal movements for the interaction. Basing design on these movement categories can influence the choice of sensor, rather than limiting the movements of the user to fit with the capabilities of a given sensor.

The strength of Bellotti et al.'s framework was in the questioning of the five fundamental stages of human-computer interaction, following the model of human-computer interaction as a dialogue. Through this, we formed a clear understanding of the input and output mechanisms of the interface, and the corresponding relationship between player action and machine response and confirmation. One contention arising from our application of the Bellotti et al. framework, that treats interaction between human and machine as a dialogue, is viewing movement as communication. It may not be the appropriate metaphor for the Eyetoy games, as raised by Rogers and Muller [16] in their *Stop Making Sense* framework that looks at using sensor technologies for user activities that are exploratory, playful or reflective in nature. The Eyetoy interface can be located somewhere between traditional GUI interfaces with discrete controls and interactive spaces with diffuse sensor input, as it replaces a more traditional joystick, mouse, or keyboard control with sensing of bodily movements through single-camera computer vision. Here the user actions are physical actions that correspond to physical actions within the game itself.

Labanotation and its system of movement analysis was the sole approach that focused specifically on the moving body. In this study we attempted to investigate how Laban movement analysis and notation could be used in the design of movement-based interaction with technology. The movement transcriptions in Labanotation of player activity contained visual, graphical representation of the interaction with the movements of the human body as the central focus. Extending the movement transcriptions to include aspects of the interface, provided a way of representing movement that retains its reference to actual, lived movement as performed through interaction with the Eyetoy interface.

Understanding movement from the perspectives offered by the four frameworks and approaches that we examined in this study, is a step towards designing systems that take into account human agency produced by our embodied capacities to meaningfully engage with technology through our moving bodies. An awareness of the interplay between, and constant intertwining of, body and mind, action and perception, as elucidated by Merleau-Ponty [31], highlights the significance of movements prescribed for interaction with technology. The movements that are encouraged and allowed for interaction have a corresponding impact on the kinds of experiences we might have in computer-mediated environments.

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