Ears In Motion: Designing a toolkit for the sounds of sport

A thesis submitted in fulfilment of the requirements for the degree of Doctor of Philosophy

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Declaration

I certify that except where due acknowledgement has been made, the work is that of the author alone; the work has not been submitted previously, in whole or in part, to qualify for any other academic award; the content of the thesis/project is the result of work which has been carried out since the official commencement date of the approved research program; any editorial work, paid or unpaid, carried out by a third party is acknowledged; and, ethics procedures and guidelines have been followed.

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B. Abstract

Athletes hear many different sounds while playing sport: the sounds of teammates, crowds, equipment, their own body, and their mind at work. Some hear nothing at all - a complete sonic blackout. This PhD outlines the design of a new "toolkit" for describing, recording, and representing this richly varied terrain. This toolkit has two components. The first is a notation system for describing the auditory experiences of athletes. The second is a wearable microphone system for capturing these sounds in new ways. The toolkit been used by the author and other athletes to create new works of sound design that represent the body in motion.

In the design of this toolkit, I draw on a variety of disciplines that each touch on a particular aspect of sound in sport, including psychoacoustics, sports studies, anthropology, and media studies. While the auditory experience of athletes exists at the margins these disciplines, this PhD is an effort to draw these disparate fields together for a more comprehensive approach. The notation system, the first element in the toolkit, draws on these varied disciplines and defines new ways to identify specific sounds and their relationship to athletic performance.

The majority of the design work in this PhD is devoted to creating new microphone systems for capturing the sounds of sport. While existing technologies tend to capture these sounds from the side-lines, these new microphones are worn on the athlete's body or mounted to the athlete's equipment. To enable recordings from the athlete's body itself, these new microphones have been designed from the "ground up" – from circuit design to PCB fabrication to software to industrial design to 3D fabrication. These microphones isolate specific sounds in the athlete's environment to be re-assembled in the recording studio. This synthetic process of isolating and re-assembling sound allows listeners to examine these individual sounds in new levels of detail. For the sound designer, this presents new creative possibilities. For the athlete, this process can teach them to hear their sport in new ways. The toolkit is both diagnostic and creative. The research findings sit across three closely integrated advances: the toolkit comprising new notation and microphone design, insights into the auditory experience of athletes, and a framework for a transdisciplinary field in sport, media, and sound studies.

Contents

C. Figures and Tables

D. Videos

E. Accessing Media

This PhD contains 17 audio and video examples. These are indicated by the "play button" graphic superimposed on thumbnail images from the video (Figure 1). These videos are available in two ways. The first is via the RMIT Research repository, where they can be downloaded. The videos have also been uploaded to http://vimeo.com, a video hosting website. A playlist featuring all the videos can be found at https://vimeo.com/album/3293278. In the PDF document, clicking on the image will open a web browser with the Vimeo URL of the video.

Figure 1: Sample image indicating audiovisual material

1 Introduction

1.1 Run with me

“thump, thump, thump, ka-thump…”

“fizzz, fizzz, fizzzzzz, fizz…”

“kerr-unch, kerr-unch, kerr-unch…”

“tut, tut, tut, tut, tut, tut, tut…”

The walkways and paths around Melbourne’s Royal Botanic Gardens and Shrine of Remembrance, just south of the city’s CBD, swell with throngs of runners of all ages, shapes, and sizes each morning before the work day begins. Sitting on a bench next to the wide gravel strip on the main thoroughfare, Birdwood Avenue, one hears a chorus of footfalls moving past, each travelling along their own vector, drumming out their own rhythm. The gravel surface accentuates the sounds of these footfalls, and after listening for a few moments you quickly become attuned to the infinite variations of shoe tread, dirt, and fine rocks. Some shoes hit the ground heavily with a pronounced “thump,” scattering pebbles with knee-rattling impact. Others seem to glide into the sound, sliding over the gravel with a languid, unhurried “fizzzz.” Still others seem to barely tap the ground, beating out a disciplined “tut, tut,” almost floating on air with practiced efficiency.

It is tempting to stay seated and continue listening, to hear to these sounds as music, each runner an individual percussionist in an advancing and receding chorus. But what if we were to stand up, adjust the laces on our own running shoes, and set off ourselves? Would we continue to focus on the chorus of other footsteps, or would our own footsteps occupy our attention? Would the sound of our breathing, the beating of our pulse, the rustle of our clothing take precedence? Would the sound of another’s footsteps slowly approaching behind us spur us on to run faster? Would we quit listening altogether, allowing our mind to wander? Or would we turn on our portable music player, pop in our headphones, and resume listening to the playlist labelled “work-out”?

Whatever we have heard, after finishing our run, how could we describe what we hear to another person? How could we refine our own listening to increase our performance, enjoyment, and self-awareness for our next run? How could we create a sound recording that conveyed parts of that experience? The work described in the following chapters attempts to do just that: to examine the athletic experience from the inside; to design new ways of describing, recording, and communicating the individual sonic experiences of athletes.

1.2 Contours of the athletic soundscape

What do athletes hear? This simple question has animated my research now for almost four years. Researching the auditory experiences of athletes, one finds incredible variation, even within the same sport. Some athletes report a hyper awareness to sound, with certain sounds being crucial to their technique. Martina Navratilova, when describing tennis, has written that "it is important to hear the ball hit the racket; you can hear a bad shot before you can see it and the sound is an imperative part of the game."[1] She continues to note that the spin, velocity, and direction of the ball as it comes toward you can all be inferred, in part, from the sound of the ball on your opponent's racket.

Many athletes report a conscious awareness of specific sounds. Snowboarder Terje Haakonsen has said that "the snow actually makes lots of interesting sounds as you ride down it."[2] Surfer Corky Carroll characterizes the sound inside the barrel of a wave as akin to being in a "drainpipe," with a particular resonance all its own.[3] Downhill skier Jared Goldberg focuses on the sound of the wind in his ears as an index for the aerodynamic nuances of his body position.[4] And, as shown in Chapter 2, many other athletes - rowers, runners, golfers, cyclists, professional athletes in team sports - all report individual sounds as essential to their performance. Chapter 3 attempts to make sense of these specific sounds through the design of a new categorization and notation system.

Other athletes report a subconscious awareness of sounds. This awareness is most often revealed in absence. For example, it is at the end of a long hill climb up France's storied Mt Ventoux that cyclist Justin Spinney realizes that his heartbeat had been echoing loudly in his ears, and a chorus of imagined voices had cajoled him up the last few kilometres.[5] Surfer Dave Rastrovich realizes the myriad of sounds that the curl of a wave produces only after riding a special 16-foot long surfboard, called the Olo, that can only be surfed on the shoulder of the wave, out of earshot of the curl and whitewater.[6] It is only when some sounds are gone that we realize their importance.

In an extension of this subconscious listening, other athletes report blocking out all sound completely. For example, snowboarder Mark Landvik has said that "After I drop in, I don't hear anything at all until I get to the bottom," despite the helicopter filming him close overhead.[7] Surfer Gerry Lopez has described the sound inside the barrel of Pipeline, the world's most famous wave, as a "deafening" silence.[8] Downhill skier Jan Hudec speaks of the moment before impact after a jump gone wrong as "totally silent."[9]

[1] (Navratilova, 2009)
[2] (Aho, 2014)
[3] (Carroll, 2009)
[4] (Catherine Spangler, 2015)
[5] (Spinney, 2006)
[6] (Oldfield, 2014)
[7] (Laboratories, 2012)
[8] (Lopez, 2011)
[9] (Catherine Spangler, 2015)

Studying what athletes hear is somewhat paradoxical. How do you measure or record silence? How do you reveal subconscious listening in an environment suffused with sound? How do you approach a category of experience that, on its surface, appears completely subjective? These problems are exacerbated by the lack of comprehensive research on what athletes hear. The visual experience of athletes is well documented, theorized, and incorporated into the standard training regimes of many sports.[10] The contemporary auditory experience of athletes, however, exists at the margins of a variety of disciplines – psychoacoustics, sports science, psychology, design history, audio engineering, and media history, to name a few. The research described here goes hunting in these margins, assembling conceptual tools from existing fields of study, and designing new ways to describe, record, and represent the auditory experiences of athletes.

1.3 Auditory Perspectives

Perspective is central to the question "What do athlete's hear?" Can we squeeze ourselves into another person's ears and hear the world from their perspective? We are often asked to assume another person's 'Point of View,' yet the same subjective leap is made far less frequently for hearing. To even find a phrase that approximates point-of-view-for-hearing, we need to turn to specialist literature. Scattered through the annals of audio engineering and film sound we find "Auditory Perspective" – a potential candidate. The phrase was first used in the early 1930s by audio engineers working in film sound and product research to describe the emerging spatial dimension of new sound recording technologies. Tracing the origins of this phrase can help us situate ourselves in the history of the development of 20th century audio technologies and their far reaching impacts on the way we consider the audible world.

One of the first published uses of the term "auditory perspective" dates to a 1933 technical exposition by engineers at Bell labs in collaboration with conductor Leopold Stokowski and the Philadelphia Orchestra.[11] Musicians in Philadelphia's Academy of Music concert hall played to three microphones connected to special long-distance telephone lines terminating in three speakers on the stage of Washington DC's Constitutional Hall. The goal was "perfect reproduction" between the two venues, enabling the concert to be reproduced *in* auditory perspective.[12] With the invention of sound-on-film, magnetic tape, and higher quality consumer audio gear in subsequent decades, enough sonic detail could be conveyed that listeners were able to get a sense of the "space" of the recording, and their place in it.

The increasing sensitivity of sound recording technologies is part of a larger story of 19th and 20th century audio technologies. Scholars such as Lawrence Harvey have drawn parallels between the rapid development of linear perspective and other visual technologies in 15th century Florence and the development of auditory technologies in the 20th century.[13] The

[10] For example, see (Williams, Davids, & Williams, 1999)
[11] See (Fletcher, 1934a) and (Steinberg & Snow, 1934)
[12] (Fletcher, 1934b) p239
[13] (Harvey, 2008) p20

result is a kind of "auditory renaissance." Just as linear perspective changed not only art and architecture but trade, mapping, agriculture, and many other aspects of 15th century life, the development of sound transmission and recording technologies has transformed our 20th and 21st century aural world. To cite but one far-flung example, the word "hello" would likely remain an obscure literary reference were it not adopted by Thomas Edison as the preferred greeting for the early telephone system in the 1880s.

This auditory renaissance, and particularly the work surrounding "auditory perspective," has mostly been pursued from a seated position. This emphasis on seated listeners has practical causes, as the architecture of the psychoacoustics lab, concert hall, movie theatre, and living room sound system all involve seated listening. However, this immobility is also the result of cultural preference, as early sound recording often focused on Classical music, with the goal of capturing the listening experience from "the best seats in the house."[14] Historian James Lastra, in tracing the arc of sound recording from its early days to the mid-20th century, has said that "the demands of one social practice of sound reproduction and reception, those typical of serious concert music, shaped the theorization of a whole range of sonic phenomena."[15] In essence, the ideal concertgoer – perfectly silent and still – bodiless – became the model pair of ears to hear the world from.

In keeping with this model pair of ears, auditory space in general is often theorized as disembodied and homogeneous, especially in comparison to visual space. Marshall McLuhan, one of the most influential thinkers in the 20th century on space and the senses, wrote in 1960 that:

> "The eye focuses, pinpoints, abstracts, locating each object in physical space .. the ear, however, favors sound from any direction. We hear equally well from right or left, front or back, above or below. If we lie down, it makes no difference" [16]

This dichotomy between vision as focusing and objectifying and the hearing as unfocused and immersed is common to many 20th century theorists. R Murray Schafer, for example, uses this distinction in his pioneering definition of the world "Soundscape" in the late 1960s.[17] Historian Jonathan Sterne has critically termed this division the "Audio-Visual Litany,"[18] tracing its roots in Christian theology, and noting that it still influences a great deal of scholarship on sound and hearing. According to the litany, vision is capable of distancing and identifying objects while sound is immersive, omnidirectional, spherical. While McLuhan and others used this litany to argue for the primacy and importance of sound, their division of the senses de-emphasizes the role of the body in hearing. The movement and position of the body of McLuhan's listener make no difference to their perceptions.

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[14] (Lastra, 2000) p 163
[15] (Lastra, 2000) p 164
[16] (Carpenter & McLuhan, 1960)
[17] See (Schafer, 1969)
[18] (Sterne, 2003)

The dominance of "serious music," the concert hall as model, and the disembodied quality of 20th century theories of sound has excluded dance, movement, and the bodies of listeners in general. This is not to say that dance or movement has been excluded from sound technology – far from it, especially from the late 20th century onwards – but it has been excluded from privileged cultural sites such as the psychoacoustics lab. Part of reclaiming and re-activating "auditory perspective," then, involves putting it in motion.

Contemporary technology already follows this trend, with the Walkman, portable music player, and smartphone each catering for a pair of ears in motion. Various practices in contemporary music, from the sound installations of Max Neuhaus to the sound walks of Janet Cardiff, also interrogate notions of fixed vs. moving auditory perspectives. The auditory perspective of the athlete, though, involves not only sounds external to the body in motion, but the sounds made by the body itself. In other words, the body listens to itself.

Another way of re-claiming "auditory perspective" involves expanding it beyond the purely physical and purely receptive to include *ways of hearing and making sound*. Perspective, is more than just a sensory artefact – it is a relation between subjects and environments involving cognition, culture, subjectivity, race, class, and "point of view" in addition to spatial location. In this way auditory perspective is connected to "body image," affecting the way you control and regulate the sounds your body makes socially. Auditory perspectives in motion mean apprehending not only the world around you, but yourself in that world.

1.4 Reproduction, Representation? Articulation.

The relationship between the body of a listener and audio technologies remains a contested issue. Some demand a symmetrical relationship between recorded sound event, sound playback environment, and listener. Fletcher's 1933 experiment in "perfect reproduction" is one example, with microphones, loudspeakers, and listeners all in equivalent spatial relationships. In early film, sound, too, many engineers demanded that soundtracks exactly mimic the vantage point of the camera. For example, film sound engineer John Cass, writing in 1930, complained that mixing together sources from microphones in a variety of spatial locations produces "the sound which would be heard by a man with five or six very long ears extending in various directions."[19]

Instead of this bodily distortion, many sound film technicians of this era called for "naturalness" in sound recording. Engineer JP Maxfield advocated that a single microphone should be used for each camera, and in 1931 published a graph that correlated lens focal length to microphone position.[20] In other words, these engineers advocated a kind of symmetry between the events on screen, the position of the microphones, the loudspeakers in the theatre, and the seated bodies of listeners. This arrangement accompanies notions of sound fidelity – the faithfulness of the sound system to its recorded source – still a dominant

[19] (Cass, 1930) p325
[20] Reproduced in (Altman, 1992) p52

paradigm in audio engineering and product development. As historian Steve Wurtzler has noted, for these engineers, breaking this covenant of sound fidelity was seen as not just ideologically incorrect, but physically grotesque.[21]

In contrast to the calls for symmetry between sound source and listener, many early film sound technicians used mixes from multiple microphones hidden on-set or held above the actor.[22] These practices favoured the intelligibility of actors' voices and continuity of audio between multiple camera angles. Historian James Lastra has called this the "telephonic" approach, as opposed the "phonographic" approach favoured by Maxfield.[23] Historian Steve Wurtzler has termed this debate "transcription" vs. "signification," with signification acknowledging the multiple layers of interpretation and artificiality existing between recorded sound source and listener. In this case, emotional and narrative requirements trump physical realism. The terms "reproduction" and "representation" also capture the flavour of these two approaches.

Echoes of these debates in early cinema are felt today, especially around discussions of sound fidelity in audio products and "auditory realism" in contemporary music.[24] Historian Jonathan Sterne is blunt: "Sound Fidelity is a lie we tell ourselves in order to stitch together separate pieces of reality."[25] Fidelity requires a leap of faith on the part of the listener, an ability to fill in the gaps caused by the inevitable imperfections of the system, an ability to separate intended signals from the noise of the media itself. Representation gives creative agency back to sound recordists and producers, acknowledging issues of framing and mixing as a crucial part of the process. In this formulation, we are active participants in the consumption of audio media – listening *through* rather than *to.* Wurtzler proposes that what emerged from the hotly contested first five years of early cinema was a new approach that he terms "signifying fidelity" – a way to "use the creative potential of electric sound technology to signify a mimetic relationship to an (often non-existent) original sound event."[26]

The physicality of representation is much more complex than the symmetrical relationships proposed by Cass, Maxfield, and a variety of others throughout the 20th century. Rather than a strict one-to-one relationship, it involves layers of interpretation and multi-sensory interactions. Measuring an effective representation is difficult, as the annual controversies surrounding entertainment awards attest. Sound fidelity, still the dominant paradigm in many areas of audio engineering, has the benefit of measurements, standards, and tests.

These issues around sound technology, while incredibly broad, are vital to the design work described here. The auditory experiences of athletes are influenced by representations of sport in the media and, more recently, by recordings that the athletes make of themselves.

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[21] (Wurtzler, 2007) p265
[22] (Altman, 1992)
[23] (Lastra, 2000) p 161
[24] For example, see (López, 1997) and (Copeland, 1995)
[25] (Sterne, 2003)
[26] (Wurtzler, 2007) p18

Much of my work, though, has been to create new microphone designs and recording devices for recording athletes. How do you organize your work around the discipline of the signified, rather than the transcriptive? How do you design microphones if you have lost faith in sound fidelity?

1.4.1 Articulation and the Senses

For the first twelve months of my candidature the reproduction/representation rift haunted my project work, even as the solder cooled on the first working circuits of the first designs. A way through this dualism was provided by Bruno Latour in his article "How to Talk About the Body." Latour, known for his foundational role in the field of Science and Technology Studies, begins the article with a re-evaluation of the senses themselves. He proposes that the senses are not a collection of innate abilities instilled at birth through which we perceive the outside world, but are instead "an interface that becomes more and more describable as it learns to be affected by many more elements."[27] He uses the term "Articulation" for this process of "learning to be affected."

Latour best explains his notion of Articulation with an example. One of the tools for training inductees into the perfume industry is a "smell kit" with roughly a thousand vials of scents representing fine gradations between a variety of smells (bitter, sweet, etc.) The training involves learning to differentiate between vials in ever finer degrees, until you become "a nose." Critically, Latour proposes that the role of the smell kit is not to train the senses to more accurately or faithfully transmit the smells of an exterior world to an interior soul. It is not a bridge from so-called "primary qualities" of the world to the "secondary qualities" perceived by our senses. The kit itself does not disappear. Rather, it creates a new world of new recognizable differences for the trainee, inhabiting and extending the nose of the user. Technologies extend, interact, and co-exist with the senses in a rich network that becomes more and more articulated as it becomes more complex.

The application of Latour's notion of articulation to the world of audio technology and experience is also perhaps best explained with an example. Composer Pauline Oliveros describes how, after receiving a tape recorder for her 21st birthday in 1953, she made recordings sitting by an open window with the recorder's single microphone dangling outside. She would listen back to these recordings as a kind of ear-training, saying "the microphone was picking up sounds that I had missed. This taught me to listen in a new way."[28] The tape recorder, along with Oliveros's unique sonic imagination, helped her to refine a practice of ever-more-detailed listening, a practice that she applied to her compositions and later codified as the technique of "Deep Listening," currently taught at institutions around the world. According to Oliveros, "the tape recorder is the most important instrument of the 20th century," not just as a tool for composing with sound, but for the role it

[27] (Latour, 2004) p206
[28] (Oliveros, 1993) p327

has played in articulating previously unnoticed differences in the sound environments of everyday life.[29]

Latour calls the things that are articulated – the differences themselves - "propositions." They are propositional in that they can be replaced with new articulations that are more meaningful. Blok and Jensen, in their review of Latour's work, say that "Rather than talking about … knowledge as true or false (absolutes), Latour suggests talking about knowledge … as being more or less well-articulated (degrees)."[30] New propositions do not invalidate old ones, they simply render them less useful or irrelevant.

The latter half of "How to talk about the body" outlines eight principles for determining exactly what separates a good articulation from bad. Though Latour is talking about the "hard" sciences here, several of these are applicable for design.

- Good articulations must be *interesting*: interest defined not just as increasingly differentiated – more sounds, colours, smells – but the exact placement of the "cuts" between propositions
- They may redefine the field, making connections between things thought previously as unrelated.
- They are not intended to disprove earlier propositions as "untrue." Instead, these become less relevant – inarticulate in comparison. In Latour's words, these articulations "allow for a common world."
- They involve risk, challenging not just the theories the research tries to investigate, but the questions themselves

Latour's notion of articulation provides a much more engaging alternative to more traditional approaches to audio technology. We no longer need to think about sound fidelity as either gospel or an outright lie. Audio technology – its design, use, reception – does not need to be thought of in purely technical or purely social terms. John Cass's multi-eared man mentioned at the beginning of this section is no longer an abomination, but a new proposition of human hearing, articulated by the artifice of sound film. According to Latour, this artifice does not divide the body – rather it extends it:

> "For myself, I want to be alive and thus I want more words, more controversies, more artificial settings, more instruments, so as to become sensitive to even more differences. My kingdom for a more embodied body!'"

[29] (Oliveros, 1993) p327
[30] (Blok & Jensen, 2011) Glossary p2

1.5 A "Toolkit" for Articulating the Sounds of Sport

Thinking about what athletes hear, and about the possibilities for describing, recording, and representing those experiences in sound, is now less about revealing the "true" auditory experience of a particular athlete, and more about creating a "toolkit" for articulating that experience. The existing toolkits for this task are relatively blunt instruments. Professional broadcasters attempting to record athletes on the field focus almost exclusively on their voices, omitting many of the other sounds present. Sports psychology has tended to focus on sounds that can be easily recorded with existing equipment. In qualitative studies into sport and physical culture, sound is often haphazardly considered or omitted altogether. Sociologists Andrew Sparkes and Brett Smith have suggested that researchers in this area need to move beyond vision, and incorporate more sophisticated analyses of hearing and other senses into their work.[31] Many areas of athletic auditory experience remain un-articulated.

Strict disciplinary approaches have prevented a broader and more comprehensive study of the athlete's auditory experience. As an audio engineer, daunted by the standards set by "perfect reproduction" and the uncertainty of what, exactly, should be reproduced, I might focus on the athlete's voice. I might be confined by broadcast deadlines, on-screen aesthetics, and other commercial interests. As a sports psychologist, I might focus on those sounds that can be tracked and quantified with current equipment. I might also confine my study to those sounds I believe will directly impact results. As an anthropologist, observing a variety of athletes in a lab and on the field, I would surely gain a rich understanding of how people talk about and describe the sound of sport. But many of the sounds in sport involve subconscious processes, making them difficult to attend to let alone describe.

The result is a kind of "disciplinary gridlock" that creates barriers for further explorations of what athletes hear. This does not discount the validity of any one of these particular approaches – my intent is to highlight their interconnections. The work described here is part of this effort, and takes an interdisciplinary approach to the problem. Within the boundaries of any one discipline, my lines of questioning may seem naïve. To the sports scientist, for example, the extreme variations in an athlete's perceptual experience can be explained relatively easily as corresponding to the various strategies and habits of attention known to be used by athletes. To the sound recordist or musician, though, they represent a fascinating terrain. My goal has been to hold open the apparent paradoxes of athletic auditory experience long enough to find new and meaningful ways to articulate them.

The contributions of this PhD, then, are not intended as specific contributions to any one of these fields. Instead I borrow and blend methods from a variety of disciplinary sources. In addition, I have used myself as a subject for the testing phase of the project almost exclusively – limiting the general applicability of my findings, but allowing for rapid

[31] (Sparkes, 2009). For examples where visual methods dominate in qualitative research of sport, see (Smith & Caddick, 2012) and (Phoenix, 2010)

evolutions in design. Perhaps the closest disciplinary home for this work is Sound Studies, itself an interdiscipline favouring a mixture of methods as a way to fill the gaps around the study of sound technology and hearing in general. The components and products of the "toolkit" that I have produced can be evaluated as works of graphic, industrial, and sound design. I hope they will have applications beyond this PhD, in order to enrich the study of the sound of sport in a variety of fields.

1.6 Personal Background

In the ten years before starting my PhD candidature I was a practicing sound artist, composer, and pianist. At the piano, my work included extended techniques and non-standard amplification arrangements. I played the prepared piano music of John Cage using piano preparations that had belonged to the composer. I built microphones to amplify the piano in new ways. As my work progressed, I moved away from the piano altogether, instead creating sound installations, for galleries and public spaces. I developed solar-powered sound synthesizers that were placed in trees and attached to buildings. I taught university students composition, electronics, history, computer programming, and sound recording. My work often had technical demands that were not met by existing hardware or software, and required the creation of new tools in computer software and electronic circuits in its realization. In addition, I began writing about the history and theory of cultural practices in sound, and the effects of sound recording and transmission technologies on architecture and the built environment.[32] My practice was multi-disciplinary, encompassing historical, technical, perceptual, and creative fields.

Contemporary and Experimental Music, though, has a fraught relationship with the bodies of its listeners and performers. A whole range of pieces have sought to complicate this relationship though extreme volumes, durations, installation and concert formats, the amplification of race, gender, and sexuality, and many other means. Still, many practices in the field demand that listeners remain quiet, even when listeners are put in motion. For example, the practice of sound-walking, whether lead by an artist or performed in small groups, often insists that participants follow the protocols of a classical music concert – no talking, mobile phones off, and reduce the amount of noise your body makes.[33] When considering sport, contemporary music almost always assumes the role of spectator.

My interest in the sound of sport predates my work as a sound artist. At the age of 13 I bought my first snowboard video, called "Totally Board 3: Coming Down the Mountain." The music on the soundtrack was a revelation in itself, but just as important were the sounds made by the snowboards themselves, especially when the board rode over an obstacle such as a log or handrail. While I had been a competitive ski racer for several years, when I started snowboarding the sound of the experience became extremely important – the sounds of the board, the music from the videos looping in my mind. I wondered what kinds of sounds the

[32] Dan St Clair, MA Thesis, Wesleyan University, 2010 (Unpublished)
[33] For example, refer to (Drever, 2013) for an explicit comparison of classical music audience behaviour and sound-walk participant behaviour

professionals experienced, and what athletes in other disciplines were hearing as well. These unrealized sonic imaginings followed me through my artistic career, but never seemed like a serious option for the content of a work of art. Through turning to design, I am finally able to give these sounds and experiences their due.

1.7 Project Overview

1.7.1 Project Timeline

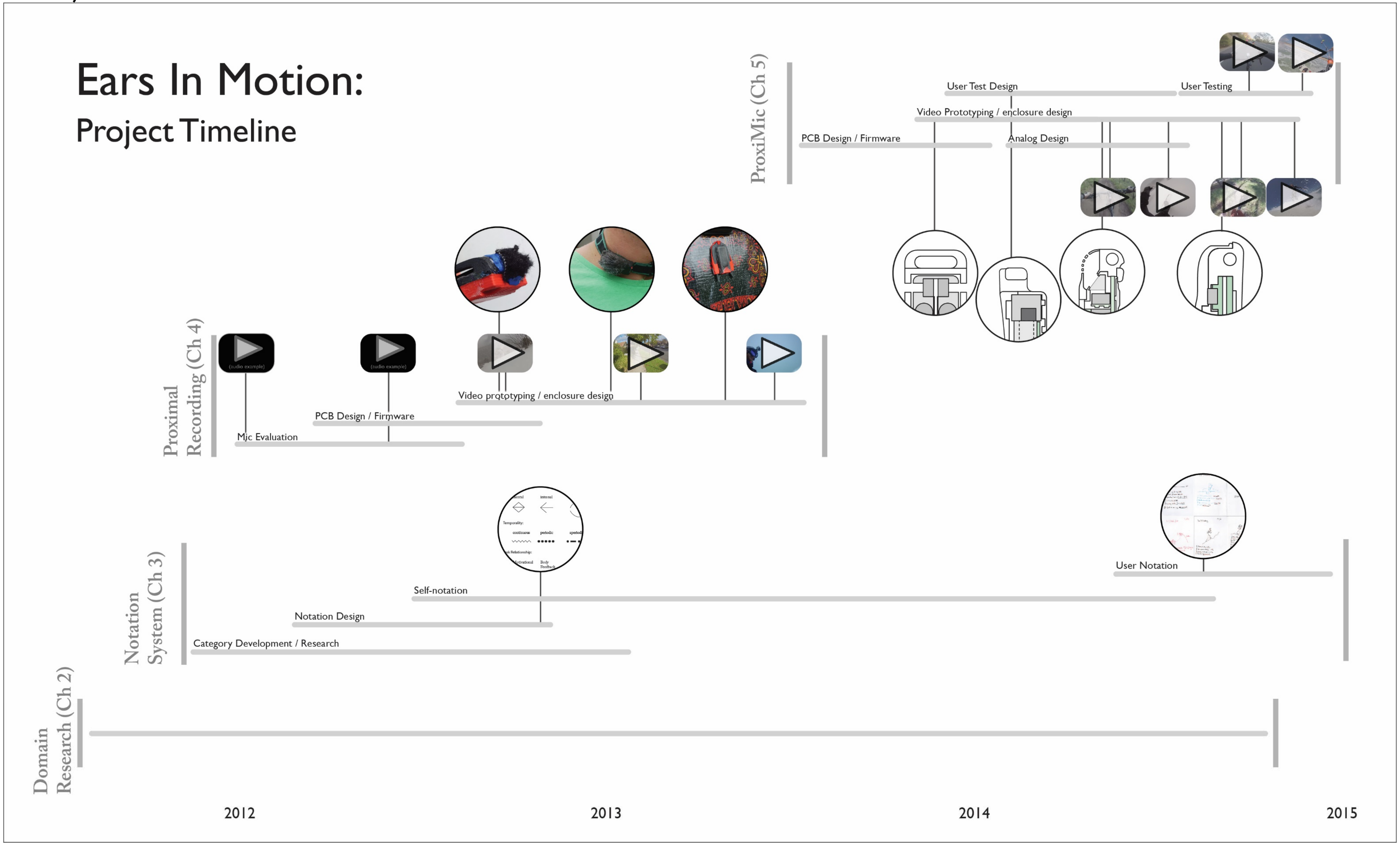

Figure 2 : PhD Timeline, with work divided between projects and background research

1.7.2 Chapter summary

As shown in the project timeline, the work contained here can be divided up into four main project streams. Each of these streams is discussed in its own chapter:

1.7.2.1 Chapter 2: What do Athletes Hear?

This chapter identifies three major disciplines related to the sound of sport: psychoacoustics, sports studies, and media studies. Relevant information from each of these disciplines is discussed in turn. Surveying psychoacoustics, we discover that while listener motion is under-studied, it in fact enhances the spatial perception of sound. Additionally, the ears are able to focus on specific sounds through a process of auditory stream segregation. Sports science provides a range of information on the importance of particular sounds to an athlete, and on the interplay between attention, learning, and the physical demands of sport. Media studies provides a rich history of the sound of sport in the media, providing a platform for speculating on how sonic representations of the body in motion affect a sonic "body image."

1.7.2.2 Chapter 3: Notation system for the sound of sport

This chapter outlines the first piece of the "toolkit" for athletic auditory experience – a notation system for recording athletic auditory experience. This notation system was initially developed using a literature survey from sports science and anthropology as a data set for defining broad categories of athletic sound. I identify three main categories – trajectory, temporality, and task relationship – and a number of divisions within those categories. The notation system has been tested over several years by the author during personal sporting activities. The results of the personal notations are compared to notations from the literature survey.

1.7.2.3 Chapter 4: Proximal Recording System (v1)

Chapters four and five outline the development of a new recording system for athletes, called Proximal Recording. Using the notation system as a "score," several new types of wearable microphones were developed, including custom PCBs and 3D printed enclosures. The design method was an iterative video prototyping process with the author as subject. The resulting system involved two kinds of microphones. The Strap Microphone is worn around the neck, leg, or arm of the athlete, while the Surface Microphone can be clipped onto certain types of athletic equipment. This system demonstrates the promise of using multiple body-worn microphones for recording sport, as well as outlining the many challenges involved in making such a system work well..

1.7.2.4 Chapter 5: ProxiMic (v2)

This chapter details the design of the ProxiMic, a single microphone that incorporates many of the findings from the initial proximal recording system of chapter four. The ProxiMic includes a variety of audio sensors to record sounds outside and inside of the athlete's body. It has more sophisticated analog and digital control circuitry, allowing it to respond in real-time to the athlete's sound environment. While the ProxiMic was developed using the video prototyping process first used in chapter four, it was also tested on other users. This chapter also describes more advanced mixing techniques used to spatialize the audio from the ProxiMic.

1.7.3 Back on Track

Thinking back to the runners on Birdwood Avenue, out for their morning jog, we can now ask a more sophisticated set of questions about their experiences. What are the physical components of their auditory perspective? How does their attention and training shape this perspective? How can the complexities of their auditory perspective be articulated to the athlete themselves in a way that highlights the nuances of their experiences? Perhaps most powerfully, is there a way for them to share this auditory perspective with others, with all the determination, pain, and endorphin-filled pleasure that it may contain? These questions are beyond the scope of a single PhD. The terrain is vast. Still, over the proceeding chapters we will be able to map this terrain in increasing detail and develop the tools that will enable an individual runner to answer these questions themselves.

2 What Do Athletes Hear?

2.1 Introduction

> "I was able to ride inside the Pipeline tube often, and long enough, to take a look around and think about it. The first thing that got my attention was how the noise of the crashing wave suddenly went silent. It was eerie and made me think about silence being deafening. Was it some kind of pressure that affected my ears, or something else? Another interesting aspect was how everything seemed to slow down. This slow motion sensation, combined with the silence, had me wondering whether I had entered a different world."[34]
>
> Gerry Lopez, Surfer

One of the central questions in my research has been "What do athletes hear?" This question spawns a host of related questions concerning perception and performance – How does training affect hearing? How does an athlete listen strategically? How does locomotion in general affect our perception of sound? How is the sound of sport represented in the media? In attempting to answer these questions, I have brought together existing research from three different fields of study:

- **Psychoacoustics**: the study of the physiological and cognitive processes of hearing
- **Sports Studies**: the study of the physical, mental, and cultural processes of athletes
- **Media Studies**: the study of the commercial, technical, and artistic aspects of works of representation such as books, films, sound recordings, and other cultural products

Applying knowledge from Psychoacoustics can help us understand the human auditory system and how it might react when subjected to the pressures and delights of athletic activity. To date, there has been no psychoacoustic study of athletes while they are at play. In fact, there are only a handful of studies that involve listeners free to move under their own power – the locomoting listener. For the past 100 years, Psychoacoustical practice has focused on seated subjects almost exclusively, with many studies going so far as to restrain listeners' heads to eliminate motion of the ears. More recent work, under the heading of "Ecological Psychoacoustics," has integrated findings from the study of human evolution to find that motion – of both the listener's ears and the source of sound – is an integral to how our auditory system functions and to how we derive meaning from particular sounds. In addition to moving sounds, Psychoacoustics also reveals the influence of listener attention and prior learning on how sounds are processed and interpreted. The auditory system has a tremendous ability for directed focus on individual sounds and for subconscious listening processes. These findings suggest that what an athlete hears is a product of their physical and mental training and the moment-by-moment demands of their particular sport.

[34] (Lopez, 2011)

Sports Studies, in the context of this PhD, includes a number of related disciplines: Sports Psychology, Sports Science, and anthropological approaches to sport. I have approached these fields in two ways. The first concerns athletic attention. If attention is central to hearing, then findings from Sports Psychology can illustrate the different ways in which athletes attend to their environment. Athletes are incredibly selective – blocking out unnecessary information and focusing only on that which is central to their performance. And athletic training means that much of what an athlete experiences is part of subconscious or automatic processes. The study of "flow," or optimal performance, suggests that athletes perform best when the mechanics of their task have become fully automatic, outside of conscious control.

The second approach to Sports Studies involves a literature survey that catalogues descriptions of sounds or hearing and their relation to a particular sport. These mentions of sound come from two main sources - the Sports Psychology literature, and auto-ethnographies written about sport by athletes themselves. Each description is often small, a side note, but taken together they form an important data set. In many ways, this data set confirms the theories of attention outlined in the Sports Psychology literature, emphasizing focused listening to specific sounds in isolation, rather than listening to the sound environment as a whole. However, one new theme that emerges is the social quality of sounds created by the athlete's own body. The sound of one's own breath externalizes internal levels of exertion, like sweat stains on clothing. The sound of an athlete's actions – the contact of a ball with a racquet, the sound of footfalls – reveals the athlete's spatial location and skill. Sound is social, and its meaning depends on your particular auditory perspective.

Finally, I have included a brief history of the sounds of sport in radio, film, and television. It is tempting to answer the question of what athletes hear in purely physical and psychological terms. Doing so would ignore the overwhelming influence that the representation of sporting bodies through various forms of media has on how athletes themselves experience sport, and how those experiences intersect with broader cultural practices. Mainstream sports broadcasting involves a technique that I have termed "microphones on the outside," involving a network of microphones placed just at the envelope of the field of play. This technique can be traced from the 1936 Winter and Summer Olympic games, held in Nazi Germany, to modern broadcasts of Baseball, Skiing, and many other sports. As methods for capturing an athlete's point of view have evolved dramatically over the past decade with the rise of point of view cameras, the paradigm of "microphones on the outside" has not kept pace. This stagnation in audio technology has the effect of limiting the role of sound in modern, media-rich training regimes, leaving a gap in the field for new designs that capture sound from inside of the field of play.

The sound of sport exists at the margins of a variety of disciplines, three of which I have chosen to investigate here. While Psychoacoustics, Sports Science, and the history of the media are diverse fields, they are connected in many ways. Psychoacoustics has had strong funding ties to the film, TV, radio, and music recording industries. Sports Science relies on technologies developed for film and television, and on other psychological disciplines for findings related to general physiology. And the developments from psychoacoustics, psychology, and sports science have shaped the technologies and styles of various media as they have evolved. My goal in the following section is not to comprehensively map these connections historically – instead, it is to lay the groundwork for new design approaches to the question “What do athletes hear?”

2.2 Psychoacoustics in Motion

2.2.1 Psychoacoustics and Sport

What athletes hear is influenced by what they see. Hearing and vision (along with our other senses) work together to create our sense of space and the trajectory of individual objects within it. In general, studies of multi-modal sensory integration suggest that vision dominates when determining the location of an object, giving rise to the “ventriloquist effect.” In this case, our eyes lead our ears towards the large mouth movements of the ventriloquist’s dummy, ignoring the small lip movements at the actual source of sound. However, the temporal resolution for hearing is much finer than for vision. As a general rule, our eyes tend to tend to tell us “where,” while our ears tend to tell us “when.”[35]

In addition to these multi-modal interactions, what athletes hear depends on the physiology of the auditory system itself. Most humans have two ears, located on the same horizontal plane, that sense vibrations from a lower limit of roughly 20 hertz to an upper limit that at birth is roughly 20 kilohertz and then decreases with age. The overall sensitivity of these two ears often decreases with age as well, and they can be permanently damaged by loud sounds, concussions, or blows to the head. In the United States, roughly 13% of the adult population has some form of hearing loss in both ears.[36] A hearing disability is not an insurmountable barrier in sport, as there are many deaf athletes performing at an elite level in a variety of sports.

Preliminary studies suggest that, in terms of hearing loss and physiological function, athletes in general have average hearing for their age and gender.[37] Other preliminary studies suggest that the one area in which athletes may excel is the ability to block out distracting sounds.[38] However, in the absence of large-scale audiology surveys of athletes, we are left to assume that the average athlete also has average hearing, and that general findings in psychoacoustics can be applied to athletes. There are three areas of psychoacoustics that are of special interest: spatial hearing, sounds and listeners in motion, and auditory scene analysis.

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[35] (Calvert, Spence, & Stein, 2004)
[36] (Lin, Niparko, & Ferrucci, 2011)
[37] (Furley & Memmert, 2012)
[38] (Furley & Memmert, 2012)

2.2.2 Stereo Hearing, Stationary Sounds

Our ability to hear the location of sounds in space arises primarily from our two ears. As sound waves travel through air, they arrive at one ear at slightly different times and amplitudes then they do the other. It is these subtle differences that give us the ability to precisely locate sounds around us. While spatial hearing is incredibly complex, there are two specific kinds of differences that are worth noting: difference in time of arrival, and difference in amplitude. These are called Interaural Time Differences (ITD) and Interaural Intensity Differences (IID) respectively.[39] To understand how these two qualities affect spatial perception, we first need to understand how the shape of the human head interacts with the physics of sound waves. The ears of an average adult are 21.5cm apart. As sound travels at an average of 344 metres per second, the maximum average time difference between the arrival of a soundwave at both ears is 625 microseconds (from an angle of 90 degrees to the left or right).[40] 625 us equates to a wavelength of 1600 hz (Figure 3). For frequencies above 1600hz, the human head has a significant effect on amplitude, creating a "shadow" (Figure 4). Above 1600hz, the auditory system primarily uses IIDs as its spatial cue.

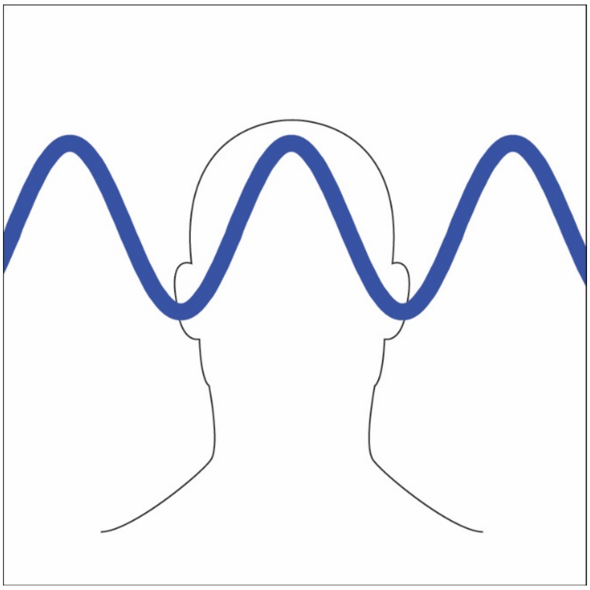

Figure 3: Soundwave of same length as ears - similar phase information at either ear

[39] (Blauert, 1997)
[40] (Middlebrooks & Green, 1991)

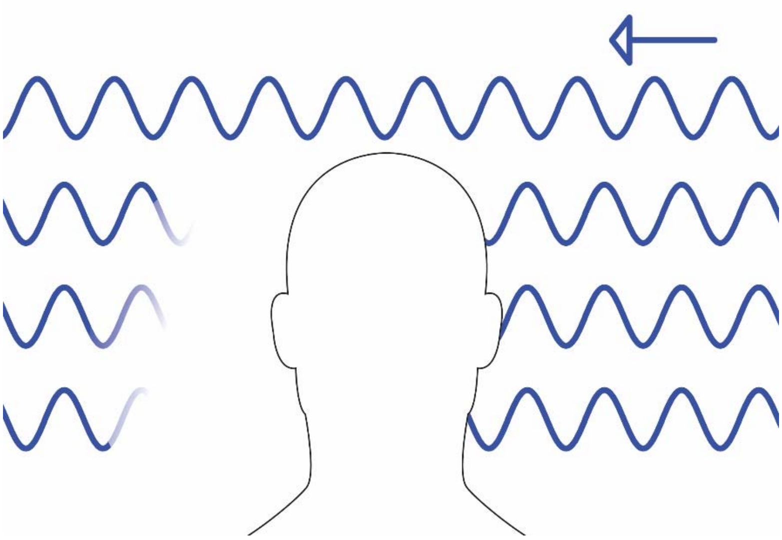

Figure 4 : Head shadow effect for sound waves above 1600hz

For frequencies below 800hz, the size of the soundwave is more than double the size of the human head. As shown in Figure 5, at these frequencies the head has little effect on the overall amplitude of a sound. In these cases, ITDs are used to determine spatial location, rather than IIDs. Between 800hz and 1600hz, both ITDs and IIDs are used. Since most sounds outside of a laboratory setting involve a broad spectrum of frequencies, rather than pure tones, both IIDs and ITDs play a role in everyday spatial hearing. In fact, spatial location is most accurately determined when a sound has a wide enough frequency range that both IIDs and ITDs are present.[41]

While the ear is remarkable in its ability to recover spatial location from complex sound waves, it is not perfect when held up to laboratory scrutiny. One of the most significant flaws is the "cone of confusion." In this "cone," sound below 800hz played from different locations have the same ITDs, and cannot be precisely located by the ear (see Figure 6). However, this zone of ambiguity is razor thin, and only requires the listener to tilt their head to be resolved. It becomes apparent almost exclusively in the psychoacoustics laboratory, where the subject is not only seated, their head is rigidly locked into position. "Motion," in the psychoacoustic context, means the freedom to tilt one's head. Motion – of a listener's head or of the sound source itself – completes our sense of spatial hearing. IIDs and ITDs become more accurate when they are changing, even slightly.[42]

[41] (Blauert, 1997)
[42] (Wightman & Kistler, 1999)

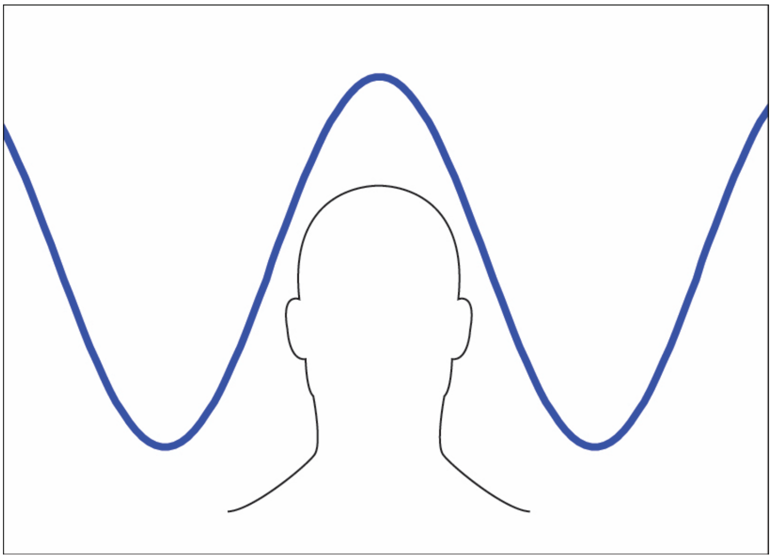

Figure 5: Soundwave below 800hz

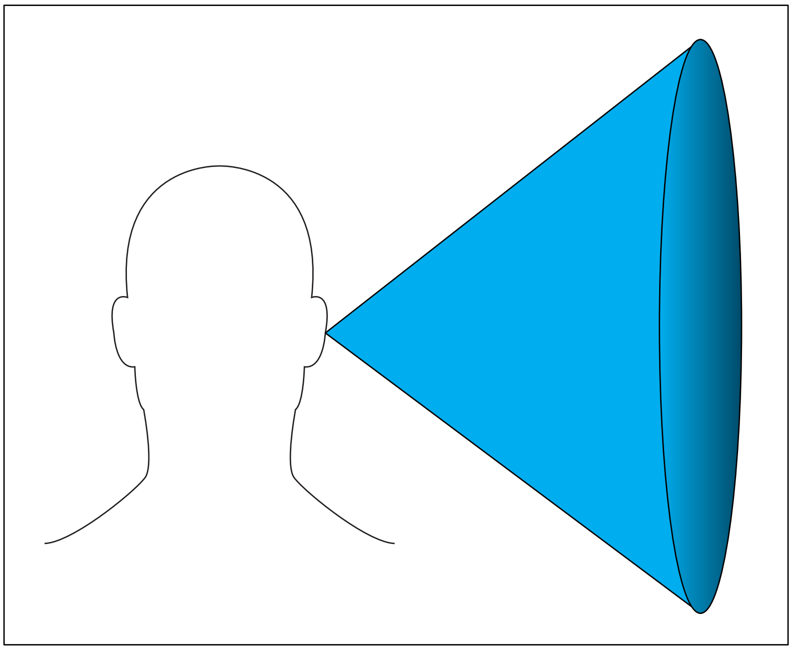

Figure 6 : Cone of Confusion

2.2.3 Moving Sources, Stationary Listeners

What happens to spatial hearing when sound sources themselves move? A moving sound source not only changes its IIDs and ITDs over time, helping to clarify its position, but its sound qualities (such as frequency, timbre, and amplitude) change as well. For rapidly moving sources, the doppler effect creates audible changes in frequency, rising on approach and dropping on retreat. In addition, rapidly moving sound sources can elicit responses conditioned through human evolution. For example, lab subjects perceive approaching sound sources as both louder and physically closer than receding sound sources of the same distance and sound pressure level.[43] Known as auditory looming, this bias towards approaching sounds is thought to be an evolutionary adaptation. Outside of the psychoacoustics lab,

[43] (Seifritz et al., 2002)

rapidly approaching sounds usually come from objects that need to be negotiated –humans, animals, projectiles, and other potential dangers. Looming emphasizes these sounds, and may enhance reaction times when dealing with incoming threats.[44]

As further evidence of this connection between sound and action, brain scans of subjects exposed to stimuli with “looming” qualities showed substantial activation of the sensory-motor cortex, while receding or stationary sounds showed less.[45] Approaching sounds prepare our bodies for action. In addition, physical fitness can account for as much as 10% difference in distance perception for looming sounds, with fitter individuals showing less looming bias and making more accurate predictions of the spatial location of incoming objects.[46] John Neuhoff, a pioneer in research into auditory looming, concludes that “the auditory perception of looming sounds may be modulated by the response capacity of the motor system.”[47] Other researchers, such as Zatorre and Ahad, have found that not only looming sound sources but moving sounds in general activate the sensory-motor cortex.[48] In other words, moving sounds call on us to move ourselves.

2.2.4 Locomotion

As studies of auditory looming show, spatial sound perception and body movement are closely linked. However, studies of auditory perception where listeners engage in full-body locomotion and not just head tilts are more uncommon. These limited studies show that full-body locomotion can help resolve the distance of a sound, especially for sounds over 5 metres away. For example, Ashmead et al found that listeners who walked 1-2 meters (several paces) were able to perceive the location of sound sources at distances of 5-20 meters more accurately than those who were stationary.[49] Two main acoustic factors are thought to influence distance perception in the locomoting listener: motion parallax (angle of source) and acoustic tau (distance of source).[50] Motion Parallax is a relationship between the perceived angle at which a sound source is coming from and the movement of the listener. If small listener movements produce large changes in perceived angle or origin, the sound must be relatively close. Acoustic Tau is related to the rate of change in the intensity of a sound source. If small changes in listener location produce large changes in intensity, the sound must also be close.[51]

Research into human locomotion and its effects on hearing has been mixed. One avenue of research has been in the evaluation of Virtual Reality systems (VR), where subjects are free to move within a limited space.[52] These studies have not found conclusive results that

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[44] (Neuhoff, 2001)
[45] (Seifritz et al., 2002)
[46] (Neuhoff, Long, & Worthington, 2012)
[47] (Neuhoff et al., 2012) p318
[48] (Zatorre, Bouffard, Ahad, & Belin, 2002)
[49] (Ashmead, Davis, & Northington, 1995)
[50] (Speigle & Loomis, 1993)
[51] (Howard, 2012)
[52] (Rébillat, Boutillon, Corteel, & Katz, 2012) (Speigle & Loomis, 1993) (Ashmead et al., 1995) (Loomis, Hebert, & Cicinelli, 1990)

listener locomotion assists in accurate distance perception. In these situations, however, it is not just listener locomotion which is under test, but the nature of the VR rendering itself. Other studies have examined human echolocation – the sounding out of the distance between a subject and an object in the environment using the reflected sound of footsteps, hand claps, or vocalizations. For example, Rosenblum et. al. found that blindfolded subjects who echolocated while in motion could better estimate the distance of a wall than stationary subjects, even when stationary subjects were allowed to move in between their echolocations.[53] This finding suggests that the auditory system may work best while in motion, rather than at rest between periods of motion.

Concerning the specifics of auditory perception by locomoting subjects, the psychoacoustics literature is incomplete. In general, the consensus appears to be that, like head motion, locomotion clarifies spatial hearing. In addition, researchers have discovered links between auditory processing and the motor cortex, suggesting that in a very basic way our perception of the sounds around us is tied to how we move our bodies. Some of these links between sound and action have been explored, such as with auditory looming and moving sound sources. While many questions in psychoacoustics still exist with regard to locomotion, the overwhelming evidence is that movement clarifies, rather than hinders, our auditory perceptions of the world around us.

2.2.5 Auditory Stream Segregation

The locomoting listener's sound world is complex. While a stationary subject in the lab generates their own sounds – their pulse, breath, and minor movements – for the locomoting listener these sounds grow and multiply. Footfalls, breath, clothing, wind in the ears, the sound of one's own voice, and other self-generated sounds are present during locomotion. When the locomoting listener breaks into a run, these self-generated sounds grow louder. In a sporting context, both self-generated sounds and external sounds become more frequent and complex. Part of the paradoxical nature of the athletic soundscape involves understanding how athletes manage this complexity – focusing on one specific sound among many, subconsciously attending to particular sounds, and blocking out some sounds entirely.

The ear has no physical lens, as the eye does. Rather, the auditory cortex performs an elaborate grouping and sorting task, parsing the sound spectrum over time into individual sounds from individual sources. This process of breaking down a multitude of overlapping sound vibrations into their component parts, each attributable to a particular source or object, is known as Auditory Scene Analysis (ASA), a field pioneered in the 1980s and 1990s by psychologist Albert Bregman.[54] One of Auditory Scene Analysis's fundamental research questions relates to the "cocktail party effect" - How is it that in a noisy environment, such as a cocktail party, we are able understand what someone is saying amidst a gaggle of loud conversation? In order to do so, the auditory system must group sound waves into individual

[53] (Rosenblum, Gordon, & Jarquin, 2000) (Gordon & Rosenblum, 2004) (Rosenblum & Robart, 2007)
[54] (Bregman, 1994) (Bregman, 1984)

sound events, and then sort these sequences of events over time.[55] These sequences of events are called “auditory streams.”

In forming these discrete auditory streams, Bregman proposed that the auditory cortex formed a signal processing chain with two major stages, called primitive and schema-based. Primitive mechanisms are the first layer of processing in the chain, and receive their input directly from the auditory nerve. These mechanisms are “hard-wired” into the auditory cortex, and include the spatial perception of sound described in Section 2.2.2. These mechanisms are shown in infants as well as adults, and also across cultures. They occur automatically without our conscious attention, and group the auditory scene into elemental building blocks of sound - individual voices, objects, musical instruments, and so on. Primitive groupings of auditory information include temporal information, such as the onset of a particular sound, and spectral information, such as multiple musical notes, processes that Bregman terms “sequential” and “simultaneous” integration, respectively.[56]

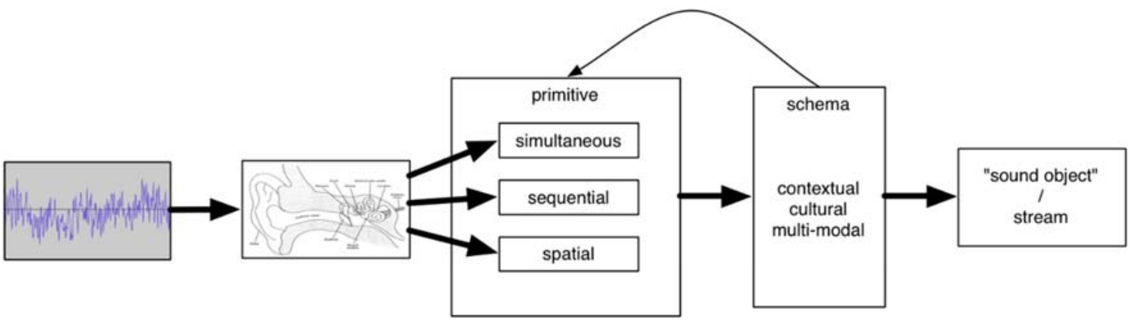

Figure 7: Auditory stream segregation, primitive and schema divisions

These primitive groups are further processed by auditory schema – higher levels of analysis that involve learning and attention. While primitive groupings often happen on a short time scale, from 0-1 seconds, schema-based groupings build up over longer periods of time, from several seconds to an entire lifetime. In music, they involve melody, harmony, rhythm, musical form, and social conventions around audience conduct and attention. In the

[55] (Moore & Gockel, 2012)
[56] (Bregman, 1994)

example of the cocktail party, they involve the sound qualities of the speaker, such as rhythm, vocal style, and timbre of voice, as well as the conscious attention of the listener. While some researchers have argued for a more rigid distinction between primitive and schema-based mechanisms for auditory scene analysis,[57] others have suggested that the divisions are less clear.[58] In addition, information from other senses plays a significant role in the construction of auditory schemas.[59] Our attentional state, goals, and information from visual and other senses all contribute to determining the sounds that we consciously hear.[60]

2.2.6 Auditory Scenes in motion

The locomoting listener is not often considered in auditory scene analysis – in fact, motion of any kind is rarely considered at all. ASA researcher Hirohito Kondo has observed that in the vast majority of the literature, "a very odd 'cocktail party' is considered: it is a cocktail party in which the listener is unable to move his/her head."[61] As explained in preceding sections, motion is a crucial part of the spatial perception of sound in general. In their experimental work, Kondo et al found that rapid head motion between periods of no motion re-sets the auditory streaming mechanisms using newly acquired spatial cues.[62] Little is known, however, about auditory scenes and *continuous* motion.

In terms of athletic activity and auditory scene analysis, we are left to speculate. Accepting the primitive/schema dichotomy, we can assume that athletes perform primitive groupings of sounds based on their spatial location, spectral, and temporal characteristics. An athlete's training, the demands of a particular sport, and the athlete's management of their attention could then be thought of as auditory schema. These particular schema would then determine how auditory streams are handled by various aspects of an athlete's attention. Some streams would be consciously or subconsciously attended to, with others discarded altogether. Athletic states of attention, then, determine what an athlete does (and doesn't) hear.

2.3 Athletic Attention

2.3.1 Types of Mental Processes

From findings in auditory scene analysis, we can assume that the auditory schema of athletes is derived from the demands of a particular sport, and an individual's specific approach to that sport. While the field of sports psychology is too large to summarize in detail in this chapter, certain aspects of the discipline can help us understand what this schema could be. Understanding athletic attention will, hopefully, allow for a greater understanding of how athletes hear.

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57 (Bey & McAdams, 2002)
58 (Carlyon, Cusack, Foxton, & Robertson, 2001)
59 (Carlyon, Plack, Fantini, & Cusack, 2003)
60 (Marozeau, Innes-Brown, Grayden, Burkitt, & Blamey, 2010)
61 (Kondo, Pressnitzer, Toshima, & Kashino, 2012) p6775
62 (Kondo et al., 2012)

Athletic attention involves a variety of mental processes. There are three mental processes that are of particular importance to athletes:

- **Pre-attentive**: Like primitive groupings in auditory scene analysis, pre-attentive processes are seen as "hard-wired" and intrinsic parts of human behaviour.
- **Conscious**: What an individual is presently focusing on. Limited capacity, but highly adaptable.
- **Automatic/Subconscious**: Actions that have been practiced to the extent that they can be performed without thinking. Seemingly infinite capacity, fast, but difficult to change once learned.

The addition of neural imaging to psychology in the past 20 years has in some ways blurred the lines between these categories as the brain is mapped. However, these categories can still provide an entry point into how an athlete's mind might be working and what they might be hearing.

2.3.2 Capacities of Conscious Attention

Human attention is a finite resource. For example, most of us can only carry on a single conversation at a time, or read a single piece of text. One way in which psychologists account for this finitude of attention is the "channel capacity" theory. This theory models attention as a communications channel that processes information from the senses – a channel with limited capacity. George Miller, in a ground-breaking 1956 paper, concluded that the overall bandwidth of our attention is 7 "bits" of information at any given time.[63] Miller defined one bit as a discrete chunk of information, such as a number, letter, musical note, or phoneme. Later research by John Orme added that the minimum duration for these attentional units is 1/18th of a second,[64] creating a maximum of 126 bits of information processed per second.[65] For reference, the technical aspects of simple conversation – decoding and producing the phonemes that make up spoken language - are thought to occupy approximately 40 bits per second, or one-third of our maximum capacity. In the years since the channel capacity theory was introduced, others have proposed alterations to the model, such as the flexible capacity theory, and the network attentional model.[66]

2.3.3 Automaticity and Learning

One interesting feature of the channel capacity theory of attention is that skill level decreases the amount of conscious attention required to perform an action. This decrease in conscious attention frees up more "bits," which can be used in a strategic way by the athlete to maximize performance. The process of learning to perform an action while gradually decreasing the attentional load that it requires is called automaticity. The general psychological consensus on automaticity is that as particular movements or tasks are

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[63] (Miller, 1956)
[64] (Orme, 1969)
[65] (M. Csikszentmihalyi & Csikszentmihalyi, 1992)
[66] See, for example, (Franconeri, Alvarez, & Cavanagh, 2013)

practiced, they migrate from conscious attention to the subconscious.[67] Most athletic movements are too complicated to fit into the limited capacity of conscious attention, and thus skill level improves as they become subconscious. One way that researchers have studied automaticity is to ask athletes to perform secondary tasks, such as scanning their peripheral vision or listening out for a particular sound, while also performing a primary task that is directly related to their sport, such as dribbling a basketball. As athletes become more practiced, their performance on the secondary task improves without hindering the primary task. In general, automaticity takes many years to develop. One study found that an average of 7.9 years of playing experience was necessary for ice hockey players before they were able to skate and handle a puck while also performing a secondary task.[68]

2.3.4 Listening to and Ignoring the Body

If mastery of a sport delegates the basic physical mechanics of performance to the subconscious, then conscious attention is freed up and may be directed in a variety of ways. One of the first researchers to tackle the issue of athletic attention head-on was RM Nideffer, who in 1976 identified six different categories of attention and created a test to identify an individual's attentional "style."[69] These six categories involve the location of the object of focus (internal vs. external) and the scope of that focus (narrow, broad, and distractible). Nideffer's test assigned positive and negative values to particular attentional styles, with distractible attention viewed particularly unfavourably. This test, called the TAIS, is still used in corporate settings throughout the world to analyse employee performance.

Subsequent work by Morgan has proposed just two major categories of attention: associative and dissociative.[70] Associative attention involves focusing on particular aspects of one's own body and performance. These can be internal to the athlete, such as breathing, or can be external objects and events that are directly related to the athlete's task at hand, such as split times or race position.[71] Dissociative attention involves focusing on things that are not explicitly related to the task at hand. These could be aspects of the external environment that don't directly affect performance, such as a marathon runner focusing on the architecture at the side of the road. They could also be thoughts that are not directly related to performance in the here and now, such as daydreams.[72]

Associative and dissociative attention have been studied most thoroughly in relation to marathon running, and both have positive aspects. A 1998 review by Masters and Ogles of the performance psychology literature concluded that associative strategies resulted in faster performance while dissociative strategies resulted in greater endurance and resistance to injury.[73] For example, Silva and Appelbaum found in a 1989 study that the vast majority of

[67] (Williams et al., 1999)
[68] (Leavitt, 1979)
[69] (Nideffer, 1976)
[70] (Morgan, 1978)
[71] (Scott, Scott, Bedic, & Dowd, 1999)
[72] (Baghurst, Thierry, & Holder, 2004)
[73] (Masters & Ogles, 1998)

elite marathon runners began their race using an associative strategy, but finished the race using a dissociative one in an attempt to block out pain and discomfort.[74] Other studies have suggested that certain associative strategies can help runners avoid injury and maintain their target pace, resulting in improved performance.[75] In addition, while selective dissociation may be a preferred strategy for many endurance athletes, others can achieve successful performances using an associative strategy.[76]

Association and dissociation have an auditory component as well. The sound environment that an athlete is in can affect their overall attentional state. For example, in one study, subjects performed a ten minute run on a treadmill while listening to one of three possible sounds: the amplified sound of their own breathing, pre-recorded ambient street sounds, and no sound at all.[77] These sounds corresponded to associative (breath), dissociative (street sounds), and unmodulated (no sound) attentional triggers. Subjects that listened to their own breath reported feeling more fatigued than the other two sound conditions, while subjects that listened to street sounds reported enjoying the experience more. In terms of how associative or dissociative attentional styles might affect auditory perception in general, we can assume that associative attention would involve an athlete attending to the streams of sounds emanating their own body while ignoring extraneous sounds not relevant to their performance. Dissociation, on the other hand, would involve ignoring all of the sounds in their environment, or attending specifically to extraneous or unrelated sounds.

2.3.5 Flow

One of the most influential theories of athletic attention is the study of "flow." Flow, otherwise known as optimal experience, is a state of attention, awareness, and immersion that is associated with peak performance in sport, the performing arts, interpersonal relationships, and almost every other aspect of human experience. In sport, it is popularly known as the "Zone" – a mental state that enables athletes to do extraordinary things under pressure. Mihaly Csikszentmihalyi, who first proposed the idea of Flow in 1975, has defined it as a complex mental state where "attention becomes completely absorbed in the stimulus field defined by the activity."[78] Other stimulus that might distract from the task at hand is ignored, including hunger, extraneous sounds, and the presence of spectators. Susan Jackson has adapted the concept of flow to sport in particular. Jackson and Csikszentmihalyi have established nine dimensions of the flow state in athletes:

- A *balance between challenges and skills* involving "just-manageable challenges…that stretch (neither overmatching or under-utilizing) existing skills"'
- A *merging of action and awareness* such that "there is no awareness of self as separate from the actions one is performing

[74] (Silva III & Appelbaum, 1989)
[75] (Stevinson & Biddle, 1998)
[76] (Gill & Strom, 1985)
[77] (Pennebaker & Lightner, 1980)
[78] (Mihaly Csikszentmihalyi & Csikzentmihaly, 1991) p 92

- *Clear proximal goals* that are immediate, achievable, and well defined temporally and physically
- *Immediate and clear feedback* received from the activity itself
- *Concentration on the task at hand*, to the point where it is almost impossible to distract the individual from their task
- Exercising a *sense of control*, free from the anxieties of everyday life that involve situations out of our control
- *Loss of self-consciousness* - "Concern for the self disappears during flow as the person becomes one with the activity"
- *Transformation of time*: Time may speed up, slow down, become irrelevant, or remain unchanged, based on the nature of the activity
- An a*utotelic experience* done for its own sake, with no expectation of future reward or benefit'

The merging of action and awareness, and the loss of self-consciousness both related to the concept of automaticity discussed in the previous section. Clear proximal goals, immediate feedback, and concentration on the task at hand recall associative attentional strategies. Csikszentmihalyi emphasizes that attention during flow is ruthlessly selective, discarding irrelevant information and relegating as much to subconscious processes as possible. Some have suggested that during flow the subconscious entirely takes over, while the conscious mind "gets out of the way."[79]

2.3.6 Subconscious Auditory Processes Relevant to Sport

2.3.6.1 Expectation Violation

Thus far we have mostly discussed attention as something under the athlete's control, to be focused, trained, and shaped. However, sound has the ability to involuntarily direct attention.[80] One way in which this occurs is through sheer loudness, proximity, motion, or other ways that trigger automatic "fight or flight" responses. A teammate's voice, a shouting spectator, or other loud sounds may have the ability to grab an athlete's attention as well. One of the most important ways in which sound may involuntarily direct an athlete's attention, however, is when it does not conform with expected sound patterns. These "expectation violations" occur when the auditory system detects a difference between the sound heard and sound learnt.[81] How much difference is required to trigger an expectation violation, and thus direct attention, is dependent on the task at hand and the training of individual listeners.[82] In sport, there are many examples where auditory expectation violation may relate to equipment malfunctions, improper technique, or other problems to be corrected. A shoelace that has become untied, a bike tyre that has lost a small amount of air, a tennis racquet that is improperly tightened – these all have sonic effects. While the sounds these objects make may not be a part of an athlete's conscious attention when they are performing as expected, the auditory expectation violations triggered when they malfunction can involuntarily direct an athlete's attention to the problem.

[79] (Werner, Aebersold, & Jazz, 1998)
[80] (Schröger, 1996) (Escera, Alho, Winkler, & Näätänen, 1998)
[81] (Parmentier, Elsley, Andrés, & Barceló, 2011)
[82] (Röer, Bell, & Buchner, 2014)

2.3.6.2 *Startle*

The suddenness or loudness of certain sounds can also direct our attention. In psychology, this property of sound is often termed the "startle" reaction, and has been extensively studied in seated subjects. A variety of sounds can produce a startle reaction, but the "onset" of the sound seems to have the most effect. For example, Blumenthal et al found that a stimulus with an onsite time of 0ms could produce a startle reaction at 50 decibels, while an onsite time of 30ms required a level of 96 decibels.[83] Other studies have found that factors such as extroversion, introversion, and task immersion can all effect startle response.[84] Judy Edworth, in studying the design of auditory warning signals, has suggested that the relationship between ambient sound levels and startle sound is another important factor in determining a sound's potential to startle.[85]

2.3.6.3 *Entrainment*

An additional aspect of auditory attention that affects athletic performance is our ability to rhythmically synchronize with a steady beat. This ability is called beat induction in the musical literature, and entrainment elsewhere.[86] Entrainment and synchronization can occur within an individual (as in synchronizing breath to running pace), within a group of individuals, and between an individual and an external stimulus such as a metronome. At the individual level, several studies have shown that athletes perform better when their breath is synchronized with the actions that they are performing, such as breathing every other rowing stroke. [87] This kind of entrainment often has to be practiced, as not all athletes synchronize their breath without coaching.[88] Between individuals, synchronization of walking or running pace often happens subconsciously.[89] Factors such as speed, leg length, and duration of rhythmic proximity all effect the likelihood that this synchronization will take place.[90] When synchronized action is required in larger groups, though, an external timing signal or group leader is usually needed, such as the role of the stroke rower or coxswain in crew racing. Many biologists have asserted that the ability to follow a single collective beat in unison is a uniquely human property, a sign of our highly evolved communication and social abilities.[91]

2.3.7 Athletic attention as auditory schema – hearing and listening to sport

The perception of sound by athletes, then, has a variety of components: the pre-attentive processing, grouping, and motor cortex interactions of the auditory cortex; the subconscious processing and monitoring of sound, with expectation violations or other stimulus potentially directing conscious attention; and the conscious focus of attention either on or away from

[83] (T. D. Blumenthal & Goode, 1991)
[84] (T. Blumenthal, 2001)
[85] (Edworthy, 1994)
[86] (Clayton, Sager, & Will, 2005)
[87] (Hong, 2013) p 18
[88] (Bechbache & Duffin, 1977)
[89] (Nessler & Gilliland, 2009)
[90] (Nessler & Gilliland, 2009)
[91] (Merker, Madison, & Eckerdal, 2009)

particular sounds. Both subconscious and conscious processes are the product of athletic training, learning, and the wider cultures of listening that an individual is situated in.

2.4 Sound, Performance, and Experience

2.4.1 Sounds in sport from the "Bottom Up"

The previous sections in this chapter have taken a "top down" approach to the question "What do athletes hear?" This section, in contrast, takes a "bottom up" approach through a brief literature survey of journals in sports science and anthropology. This survey catalogues articles where specific sounds and their connection to sport are explored, often as a component of a larger investigation. These connections, when taken as a whole, can be used to identify more general themes. The pairing of sports science and auto-ethnography may seem unlikely, but it is born out of necessity. In peer reviewed literature, these two disciplines are where the sound of sport is most actively being analysed and discussed. In fact, the dissimilarity of these two disciplines enables a more balanced survey, including the experiences of elites and amateurs from a variety of sports, those driven to compete and win and those that are more interested in the aesthetic or emotional experiences of sport.

2.4.2 Sound Events

One of the most important outcomes of this literature review is that the following general categories of sound emerge. They are as follows:

2.4.2.1 Self-talk

Many athletes talk to themselves, either out loud or internally. This type of spoken or imagined speech is called self-talk, and consists of words and phrases that an athlete uses to enhance their performance through focusing attention and regulating emotion. In one study, approximately 60% of athletes engaged in some form of internal self-talk, and approximately 80% of that self-talk was positive.[92] Only 20% of athletes studied spoke their self-talk aloud, and those that did mostly muttered or spoke at less than full speaking volume. Self-talk takes many forms, but for most athletes it consists of short, positive, familiar phrases. Participants in individual sports are more likely to engage in self-talk than those on teams. In fact, some endurance athletes report having their entire sonic attention consumed by self talk during particularly grueling sections of a race.[93] Cultural background also plays a significant role, affecting the balance of negative and positive self-talk, the frequency of self-talk, and the effectiveness of particular self-talk strategies.[94]

2.4.2.2 Body - Personal

An athlete's body generates many sounds that an athlete may consciously or subconsciously monitor for feedback about their own physical state. These sounds often correspond to the athlete's endurance and current level of exertion. Runners report hearing

[92] (Hardy, 2006)
[93] (Spinney, 2006)
[94] (Peters & Williams, 2006)

the sound of their own pulse while running, usually in moments just following periods of high intensity activity.[95] In addition, athletes report being very conscious of small variations in the sound of their own breathing.[96] A “ragged” breath signifies a loss of control and the potential for fatigue.

2.4.2.3 Body – Social

In addition to listening to their own bodies to monitor their performance, athletes are also conscious that the sounds they make can be heard by nearby teammates, training partners, or opponents. In particular, an athlete’s breath becomes a social symbol that indexes their current level of fatigue. In their 2001 article “Running the Routes Together,” Sanders-Bustle and Oliver highlight this quality of the breath of a training partner: “We listened—often enslaved to bodily voices and out of respect for one another, and found ourselves slowing down or on rare occasion stopping altogether.”[97] This quality of the sound of breath extends beyond sport. Anthropologist Margot Lyon has called respiration "a bridge between bodily and social being."[98]

2.4.2.4 Equipment

The sounds generated by athletic equipment are also an important part of athletic experience. In general, the sounds generated by a piece of equipment contribute to its overall “feel.” For example, a 2005 study of elite golfers found that the sound that a club made when impacting a golf ball had a significant effect on golfers’ perceptions of the shot. Impact sounds that were louder and “sharper” (with a shorter attack time) were perceived significantly more favourably than “dull” sounds with a longer attack time and softer overall sound level.[99] In other words, a “good” golf shot has a very particular sound. Other authors reported on the importance of sound in choosing a cricket bat.[100] Although fewer references than desired exist for this category, one can imagine that sound is also critical in monitoring the performance of equipment over time – the correct operation of a bicycle drivetrain, the proper tension in a tennis racquet, or the wear levels of the tread on a pair of shoes.

2.4.2.5 Vocal Communication

Anecdotally, vocal communication between teammates is an indispensable feature of many team sports. However, as LeCouteur and Feo note in their 2011 study of the topic, “Few studies in the sport psychology literature…have examined the nature of actual communicative practices as they occur during play.”[101] In their study of volleyball players, LeCouteur and Feo found that the frequency of vocal communication increased during times of crisis, such as when a team’s defensive strategy broke down. In volleyball, the most common speech pattern was two-word directive phrases, such as “‘up top’, ‘stay there’, ‘get

[95] (Hockey, 2006)
[96] (Hockey, 2006), (Allen-Collinson & Hockey, 2011)
[97] (Sanders-Bustle & Oliver, 2001) p513
[98] (Lyon, 1997) p91
[99] (Roberts, Jones, Mansfield, & Rothberg)
[100] (Sparkes, 2009)
[101] (LeCouteur & Feo, 2011) p124

mine', 'you're up'."[102] Often, these vocalizations were misunderstood or not acted upon by teammates – a failure that the authors attribute to the speaker having a different field of view and focus than the listener. The most successful team communication was easily understood and directly tied to action.

2.4.2.6 Opponents

The sounds generated by an athlete's body and equipment are often audible to their opponents as well. These sounds can be used or concealed to a player's advantage. One example of this is the sound of an opponent's racquet strike in Tennis. A 1993 study by Tatsuto Takeuchi at the University of Tokyo measured the performance of tennis players while wearing earplugs. While novice players were somewhat affected by the inability to hear the ball, more advanced players saw a significant drop in their abilities.[103] This is largely attributed to the lack of acoustic cue provided by an opponent's racquet strike, a sound that for experienced players is rich in information about the speed, spin, and even direction of the incoming shot. More generally, auditory cues and warnings improve performance in catching a ball by decreasing subjects' response times.[104]

2.4.2.7 Environment - safety

For athletes that train or race in public places, another category of sounds is important – those that signify potential dangers in the sound environment. For example, runners listened out for cars, dogs, bikes, and other potential dangers when training in public.[105]

2.4.2.8 Environment - Crowds

Other "environmental" sounds – sounds that signify the place or space that an athlete inhabits – arise from spectating crowds during competition. For cyclists and runners, both the roar of the crowd in general and the individual voices of family members in that crowd can have a strong effect on motivation and effort.[106] Crowd noise was not as thoroughly considered in the literature for players of team sports, though. Anecdotally, the sound of spectators can have a profound effect on athletes – it is a part of "home field advantage." In referees, crowd noise has been found to have some effect on their decisions.[107] However, further research in this area may be required.

2.4.2.9 Auditory Imagery

In preparing for competition, athletes often use a suite of techniques to imagine a successful performance. Visual, kinaesthetic, haptic, and other modes of imagery are often studied. Auditory imagery is less studied, and existing data is somewhat conflicting. In a 2005 study of elite soccer players, Jordet et al found that while auditory imagery was used less than visual or kinaesthetic imagery, players still considered it no less than 50% as

[102] (LeCouteur & Feo, 2011)
[103] (Takeuchi, 1993)
[104] (Button, Davids, Bennett, & Savelsbergh, 2002)
[105] (Hockey, 2006), (Collinson, 2008)
[106] (McCarville, 2007)
[107] (Balmer, Nevill, Lane, Ward, & et al., 2007)

significant as the other two modalities.[108] In a 2011 study by Bernier et al, however, elite golfers employed auditory imagery just 0.82% of the time.[109]

2.4.2.10 Music

Music in sport is often approached in two ways. The first approach considers the music around sporting events – anthems, fight songs, etc. – and the role that they play in the identities of athletes and spectators.[110] The second approach studies the effects of music on athletes' performance. This sub-field distinguishes between two types of music. "Asynchronous" music is heard before competition or during breaks from play. "Synchronous" music is listened to during physical activity itself (often during training). Both of these types of music have a regulatory effect on the emotions of an athlete. The Brunel Music Rating Inventory, published by Terry & Karageorghis in 2006, allows sports scientists to determine the motivational effects of synchronous music based on its rhythmic, lyrical, and instrumental content.[111] 120 to 140 beats per minute – the heart rate associated with moderate exercise – is rated as the most favourable rhythm across a variety of different sports and ability levels. In a way, synchronous music choreographs an athlete's body.[112] Asynchronous music can affect an athlete's body as well. Music calms as well as excites, and when used well can play a regulatory role in keeping an athlete's anxiety or fear in check.[113] While some studies cast doubt on the effectiveness of music in improving performance,[114] the general research consensus is that if this "regulatory" effect is considered, some individuals can improve their performance through listening to music.[115]

2.4.3 General Themes

Several general themes emerge from the literature survey overall. Chief among these is the idea of the salient sound. Salient sounds are integral to the athlete's performance, whether through physical necessity or through training. Other sounds in the environment are attenuated or blocked out completely by the individual. There were no mentions of listening to the sound environment as a whole in the literature, or listening to sounds as one would a classical music concert. Subconscious or conscious mental processes may be devoted to sounds in the environment, but these are specific sounds that require a response from the athlete. For sounds that don't directly impact performance, if the athlete can ignore that sound, they will. What athletes hear, then, is completely reliant on what athletes do.

2.4.4 Sonification

One area of research that has explored how sound is involved in athletic training is sonification. In this field, sensor data from athletes is turned into sound via computer sound

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[108] (Jordet, 2005)
[109] (Bernier, Codron, Thienot, & Fournier, 2011)
[110] (Snyder, 1993)
[111] (Karageorghis, Priest, Terry, Chatzisarantis, & Lane, 2006)
[112] (Hefferon & Ollis, 2006)
[113] (Pates, Karageorghis, Fryer, & Maynard, 2003)
[114] (Hagen et al., 2013)
[115] (Bishop, Karageorghis, & Loizou, 2007)

synthesis and played back to the athletes as they train. “Correct” technique can be associated with a particular sound, giving athletes immediate feedback in the moment on how well they are performing. As a training technique, sonification has been shown to be especially effective for beginners learning complex motor sequences.[116] For example, a 2004 study by Takahata found that beginner karate students found sonification to accelerate their learning while results amongst more advanced students were mixed.[117] Rowing has been sonified in a number of experiments,[118] each mapping the speed of the boat to the pitch of the sonic output at various phases of the stroke. Running pace,[119] running form,[120] and ice skating technique,[121] can also be measured and corrected with auditory feedback. Sonification studies, while suggesting that hearing can have a significant effect on learning, often ignore the existing modes of sonic feedback that occur as part of many sports, and most studies use headphones to block out existing auditory cues.

2.5 Mediated Athletic Auditory Perspectives

2.5.1 “Body Knowledge” and electronic media

The auditory experience of athletes is not only determined by the athlete’s training, equipment, physiology, sporting discipline, and other physical factors as explored in previous sections of this chapter- representations of the audible body also play a role in conditioning athlete’s perceptions. As Jan Wright notes, “our knowledge of the body and the body itself is constituted in specific cultural and historical circumstances and in the context of particular relations of power.”[122] Sport is a way in which larger cultural issue around the body – race, gender, and power – are reproduced, modelled, and constructed.[123] Since the early 20th century, audio-visual media have played a crucial role in the ways that an athlete develops this “body knowledge.”

The relationship between representations of the sporting body and what athletes hear can be thought of in two ways. The first concerns “body image” in sound – how the body is embedded in its surrounding culture and how it is expected to sound, look, and move. The second is the way that media train and “articulate” the senses of athletes themselves, to use Bruno Latour’s terminology. Broadcast media and professional sport have historically played a significant role in representing sporting bodies. However, with the recent proliferation of body-worn camcorders and smartphone video, many athletes are now recording themselves and publishing these videos online.

Many historians have charted the effects of audio recording technologies on the human body. Historian Mara Mills has catalogued the ways in which the telephone and the human

[116] (Sigrist, Rauter, Riener, & Wolf, 2013)
[117] (Takahata, Shiraki, Sakane, & Takebayashi, 2004)
[118] (Dubus, 2012), (Schaffert, Mattes, & Effenberg, 2009)
[119] (Hockman, Wanderley, & Fujinaga, 2009)
[120] (Eriksson, Halvorsen, & Gullstrand, 2011)
[121] (Godbout & Boyd, 2010)
[122] (Wright, 2000) p1
[123] (Cole, 2000) p 339

ear were measured and tested against each other from the late 1800s to the 1930s.[124] Paula Lockheart has charted the effect of the development of condenser microphones in the 1920s and 30s on ideal singing voices and speech.[125] And Michael Chanan has analyzed how recording has changed the interpretation of classical music, with one pronounced effect being more regulated and even time-keeping in live performances.[126]

To write a similar history for the sound of sport would easily overflow the boundaries of this chapter. However, this section identifies key themes in that history and areas for future research. In the 20th century, the dominant technique for recording sport involved placing an increasingly sophisticated network of microphones ever closer to the envelope of the action, a technique I term “microphones on the outside.” In conjunction with the zoom lens of the television camera, these microphones assume the auditory perspective of a “super-spectator,” able to hover around and above the field of play. For the past 10 years, though, microphones are increasingly moving inside of the field of play through body-worn microphones connected to wireless transmitters or miniaturized video cameras. These “microphones on the inside” have focused almost exclusively on the voices of athletes, rather than other salient sounds. In some sports, these microphones are changing athlete behaviour and coaching strategies.

2.5.2 Microphones on the Outside

2.5.2.1 Microphones on the Outside – Germany 1936

Throughout the 20th century, broadcasts of live sporting events have been key pieces of programming for radio and television. For example, one of the first significant live radio broadcasts in the United States was not a political speech or musical performance but the 1921 Heavyweight Title fight between Jack Dempsey and Georges Carpentier.[127] This broadcast was made from a single microphone placed near the announcer, and it is the announcer’s voice that has dominated the sound mix in most broadcasts of sport. Over the years, this mix has gradually been supplemented by additional sounds captured from the field of play. From the 1930s to the 1960s, live TV broadcasts of Baseball used a single microphone for the announcer.[128] By 2001, baseball stadiums were rigged with up to 70 microphones concealed around the stands, at the perimeter of the field, and even hidden below the bases themselves, all mixed by a team of engineers in real-time during live broadcasts.[129]

The journey from the single announcer’s microphone to the entire stadium rigged for sound has happened for many sports, mostly during the 1980s and 1990s. However, the first broadcasts to use this “microphones on the outside” technique in depth were of the 1936 Olympic games, held in Germany, and organized by the Nazi party. Both Winter and

[124] (Mills, 2011)
[125] (Lockheart, 2003)
[126] (Chanan, 1995)
[127] (Fisher, 2007)
[128] (Hoffarth, 2009)
[129] (Farinella, 2001b)

Summer games were held in Germany that year, the Winter from February 6 to 16 in a small village in Bavaria, and the Summer from August 1 to 16 in Berlin. Both games were opened and closed by Adolf Hitler, and were a key part of his propaganda strategy that year, both domestically and internationally.[130] In service of this strategy, Germany's highly developed radio and film industries were devoted to covering the games in unprecedented new ways, including live television broadcasts to viewing locations around Berlin, and live international radio broadcasts. To provide a background soundtrack for these radio broadcasts, German engineers installed networks of microphones in each venue for both Games, using telephone cable to connect these microphones to a central switchboard where they could be mixed and recorded to wax discs.

The main surviving documents from the 1936 Winter games are a report submitted by the Germans to the International Olympic Committee, and a 37 minute film by directors Herbert Brieger and Carl Junghans commissioned by the Nazi party and released in Germany and Czechoslovakia later that year.[131] The report devotes several pages to sound recording and the games. A total of 75 microphones were installed to cover the 17 individual sporting events. Figure 8 shows radio technicians installing microphones in the snow, using weather-resistant covers to protect the microphone circuitry from moisture. A network of telephone cables, running under the snow, connected these microphones to a central switchboard. Figure 9 shows a map of the downhill ski course with 5 telephone stations marked along its path, and these likely provided connection points for these microphones.

Figure 8 : German radio technicians installing microphones and cables in the snow for the 1936 Winter Olympics[132]

[130] (Hilton, 2011)
[131] (Herbert Brieger, 1936) (OlympischeWinterspiele, 1936)
[132] (OlympischeWinterspiele, 1936)

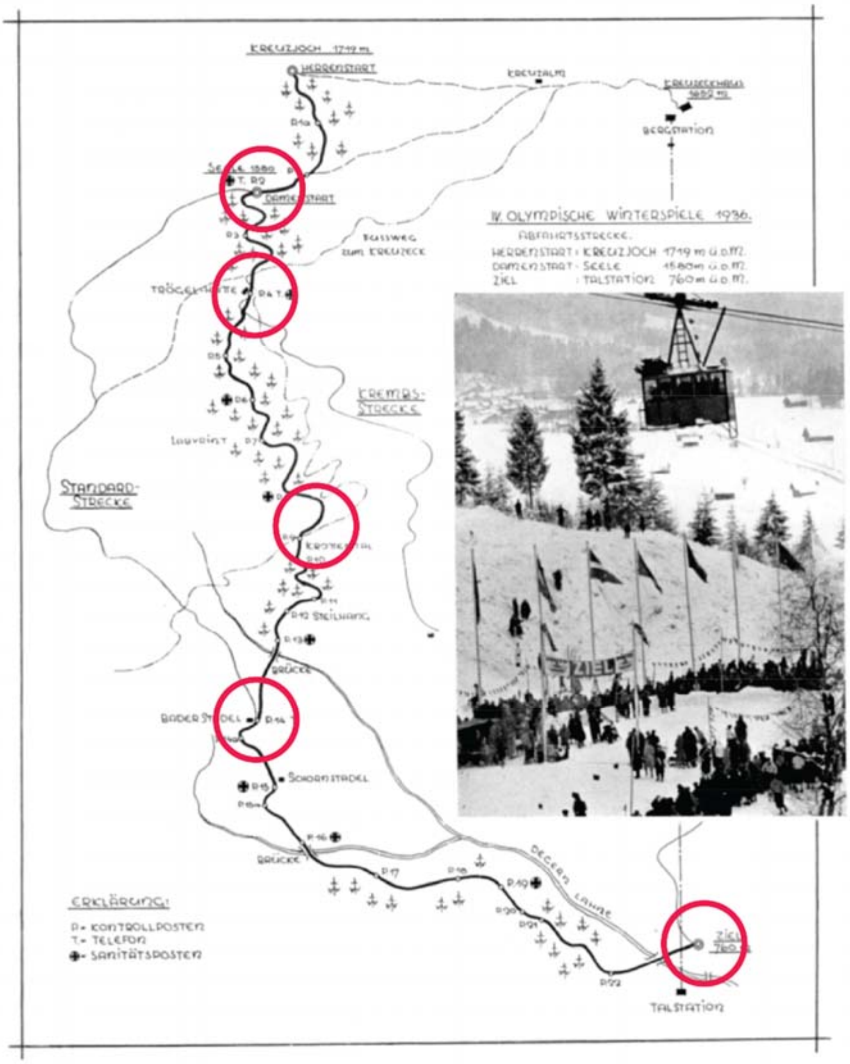

Figure 9 : A map of the German downhill ski course, with telephone stations marked[133]

The Summer Games massively scaled up the media strategies that had been tested in winter. These strategies were integrated into even the early stages of planning for the event. Microphone cables were integrated into the construction of the various stadiums around the city, laid under stucco, natural stone, and earth.[134] 70 microphones were permanently installed in the Olympic Stadium alone for the purposes of capturing the sounds of the event.[135] In their 1936 report, the Nazi Olympic committee distinguishes these microphones as “noise microphones” whose purpose was to capture “the natural ‘background of sound’ so necessary for the general impression.”[136] In addition to using radio condenser microphones in this role, special microphones were developed or repurposed. For recording water sports such as rowing and sailing, a parabolic dish was used to create a long-range directional

[133] (OlympischeWinterspiele, 1936)
[134] (Olympiade, 1936) p 344
[135] (Olympiade, 1936) p 345
[136] (Olympiade, 1936) p 346

microphone, as seen in Figure 10. For swimming and diving, several specially designed water-resistant microphones were placed at the edge of the pool, as seen in Figure 11.

The primary surviving document from the Winter Olympics is the film *Jugend der Welt* (Youth of the World), a 37 minute documentary with excerpts from many of the events set to an orchestral score. This score provides the sole soundtrack for some of the events, such as figure skating. However, the biathalon, Nordic skiing events, downhill skiing, bobsled, and ski jump all incorporate sounds that appear to have been recorded at the event itself. The sounds created by various crowds of different nationalities are used most often, perhaps to emphasize rivalries between states. But salient sounds from the sports themselves are also included. The biathalon, a combined Nordic skiing and rifle shooting discipline, includes sounds of gunshots. The bobsled incorporates sounds of the sled sliding across the ice. The ski jump includes sounds of skis impacting the landing ramp. It is difficult to know the precise source of these sounds, whether or not they come from the wax disks recorded as part of the radio broadcasts, come from sound recorded with the film itself, or come from foley sound recorded in the studio after the fact.

The Summer Olympics, a much larger event, was the subject of Leni Reifenstahl's two-part film series *Olympia*. Like *Jugend der Welt* it features an orchestral score and the sounds of cheering crowds. An announcer's voice narrates most of the events. However, many salient sounds from the sports themselves are included. Rowing is particularly well recorded, with the splash of the oars and the sound of the coxswain clearly audible (likely recorded using the highly directional parabolic dish seen in Figure 10). In addition, some of the sounds of the swimming events are audible, including the splashes from divers. These were likely recorded using the purpose-built water resistant microphone seen in Figure 11.

Figure 10 : A parabolic microphone used in the 1936 Olympics for capturing rowing and sailing

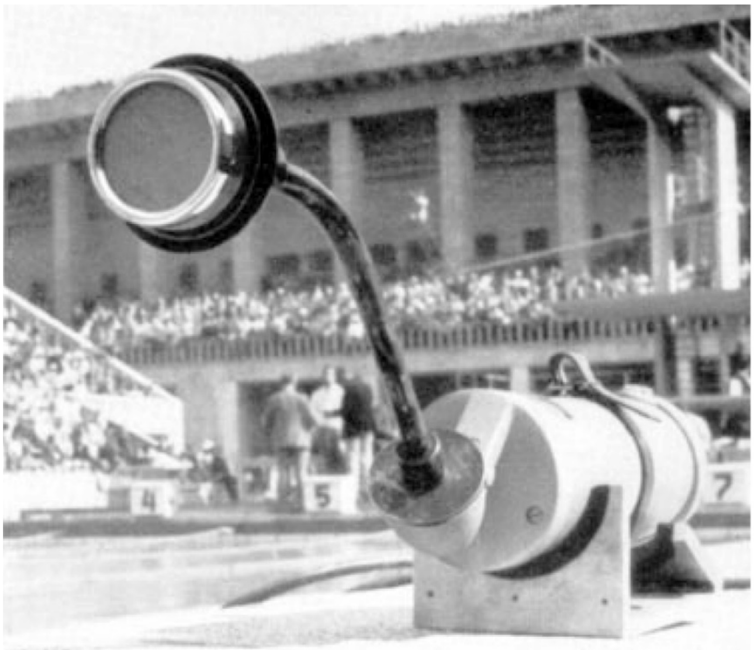

Figure 11 : A pool-side microphone with water-resistant enclosure, used in the 1936 Olympics for capturing swimming and diving

The 1936 Olympic Games served as a work of major propaganda for Adolph Hitler and the Nazi party. Internationally, the Games promoted the idea that Germany was able to cooperate in friendly competition. Inside of Germany, while Hitler's predictions of German athletic dominance were proved wrong, the magnitude of the event itself and its unprecedented levels of production became a symbol of Germany's greatness. The technical innovations created by the engineers of German Radio were embedded within these larger propaganda efforts. They are also embedded in the media landscape of the time, when radio was the primary broadcast medium. The sounds of the bodies of athletes, and the ways in which those sounds are recorded and represented, are inextricable from larger cultural forces.

2.5.2.2 Microphones on the Outside – Post WWII to present

The scale of the "microphones on the outside" techniques employed during the 1936 Olympics would not be replicated until the 1980s. The sheer complexity of the endeavour likely dissuaded post-war radio broadcasters. In the 1950s, Television became the dominant mass medium, with reduced audio quality compared to radio. Most broadcasts from this era use a single microphone for the announcer. Beginning in the 1970s, though, there was a gradual proliferation of microphones through the stands and up to the edges of the sports field. As zoom lenses allowed audiences to experience the action close up, so networks began attempting to capture focused sounds from the field of play to match these shots.

After purchasing the broadcast rights for Major League Baseball in the early 1990s, broadcaster Fox Sports rapidly expanded the audio infrastructure in stadiums around the US. As mentioned previously, by 2001 most stadiums had been outfitted with a bevy of microphones in the stands, on the side-lines, and hidden in the bases themselves. Directional "shotgun" microphones were placed at the periphery of the field, pointing inwards at the bases, base-lines, pitcher's mound, and outfield.[137] Omnidirectional microphones were placed to capture particular areas of the crowd. And specially designed mounting plates for the bases were designed (and patented) that hid microphones and wireless transmitters, capturing the sounds from *under* the field of play as well as next to it.[138] Figure 12 outlines the placement of these microphones. An audio team, with equipment for monitoring and mixing these microphones in real-time, worked throughout the broadcast to create a live mix. Similar changes took place in many professional sports during the 1990s and 2000, including Ice Hockey, Basketball, American Football, and the Olympic Games themselves. For most broadcasts of professional sport, this technique is now standard.

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137 (Farinella, 2001a)

138 (Hill, Gepner, Meis, & Meis, 1999)

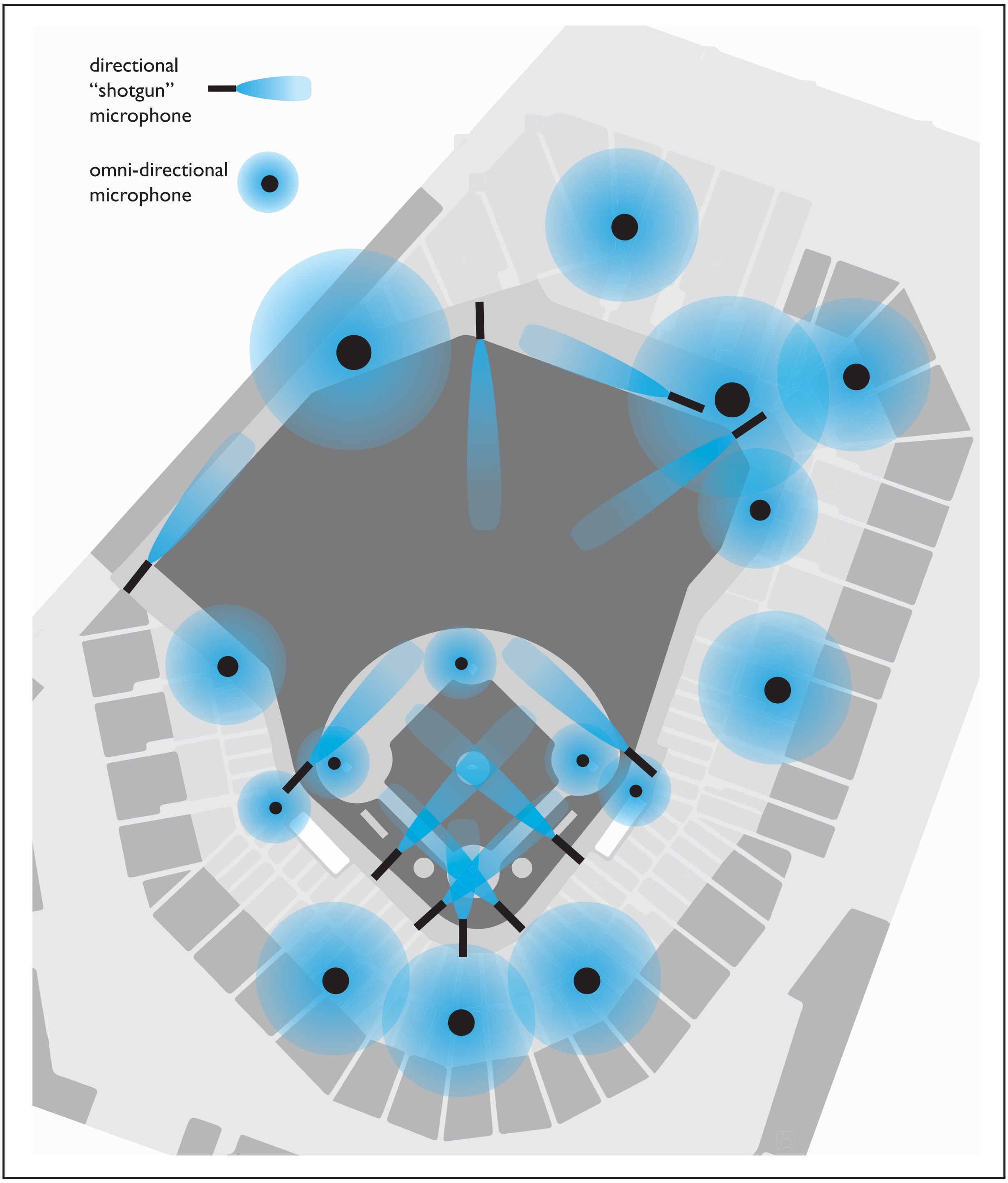

Figure 12: Baseball stadium microphone placement, example, Fenway Park

2.5.3 Microphones on the Inside

2.5.3.1 Team Sports

Starting in 2007, the National Football League and ABC Sports began placing microphones on individual Football players during practices and games and editing the footage into 3-5 minute segments for TV broadcast. NFL Films had been placing microphones on coaches and staff since 1968, especially for post-season games, but this new initiative represented the first sustained effort to record the players themselves on field. By the 2014 season, this “Sound FX” series had grown significantly, with many players wearing microphones each week. In the past ten years of professional sports in general, it has become increasingly common for players to be “mic’d up.” In the sport of Curling, entire teams are outfitted with personal microphones.[139] Recordings from these “microphones on the inside” are often supplemented by existing external microphone networks.

In general, the voices of athletes are the primary sound event that makes up these “microphones on the inside” recordings. Interactions between teammates, coaching staff, and other players are featured. Other salient sounds are either not included, or are masked by wind and other noises from the microphones themselves.

2.5.3.2 Sports Documentary and Action Sports

Microphones worn by athletes are also becoming more common in the production of sports documentaries and action sports movies. These sounds are integrated into a sound mix that often includes music, narration, and foley sound effects. One example of these techniques is the snowboard movie “The Art of Flight,” released in 2011. In this movie, the voices of snowboarders were recorded using wireless audio transmitters and lavalier microphones placed inside of the athlete’s clothing, as other sounds were recorded by microphones just off-screen. Sound from the athletes is included sparingly, and is used to highlight moments of high drama, such as when one of the riders nearly escapes burial by a large avalanche. For most of the film, images of snowboarding are accompanied by music, with subtle sound affects added in post-production mimicking a snowboard sliding over snow. In making overall choices regarding the presence of sound in the film, Director Curt Morgan has spoken of the need to maintain an “emotional connection” with the action on-screen.[140] The details of this connection are complex, but as a general rule, the types of sounds present in the mix, and the level of those sounds, should be calibrated to the camera angle of the current shot.

2.5.3.3 Technical aspects of microphones on the inside

The technical aspects related to placing microphones on athletes are usually protected trade secrets in the broadcast industry, and have not been disclosed. However, Q5X, the recording devices manufacturer with an exclusive contract with the NBA, has released several technical videos that detail how they place the microphones for recording the “Inside Trax” series of player microphone videos for the TNT broadcasting network. The system uses a wireless transmitter roughly 120mm x 60mm x 15mm, with a small lavalier microphone attached by wire. This lavalier microphone is clipped to the collar of the player’s jersey and secured with several pieces of adhesive-backed fabric. The transmitter itself rests in a Velcro pouch sewn into the player’s jersey. For the 2014-2015 season, these velco pouches have been sewn into every player’s jersey.

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[139] Curling was, by all accounts, the first sport to be broadcast with entire teams wearing microphones at the Salt Lake City Olympic Games in 2002.

[140] (Laboratories, 2012)

For NFL players, little is known about the current system in use. However, photos released in 2007 show wireless audio transmitters and microphones integrated into sets of shoulder pads. To augment the recordings made from the pads themselves, the NFL uses hyper-directional parabolic sound reflectors. When used from the side-lines, these reflectors allow technicians to capture conversations that the player wearing the microphone may have with players who are not wearing one. They also provide an additional source of audio during the intensity of play, when the players' microphones are often overloaded with high sound levels, wind noise, or noises from the microphone element rubbing against nearby fabric.

One reason for the general secrecy around microphone techniques is that the lavalier microphones being used were not designed for the body in motion. Anecdotal reports suggest that these techniques are the result of a considerable amount of trial and error, tailored to each sport. Even using state-of-the-art techniques, the body worn microphones of professional athletes are still prone to a great deal of noise when the player is in motion. In videos from a variety of sports, wind noise and clothing rustle overpower any other sounds that might be picked up as soon as the athlete begins to run. With current technology, professional broadcasters have a hard time recording the sounds of bodies in motion from inside the field of play, and instead rely on more traditional techniques of microphones on the outside.

Figure 13: NBA Player Microphone and Clip[141]

Figure 14: NBA Player Microphone with taping

[141] (Q5X, 2013) image source credit for Figure 13 to Figure 15

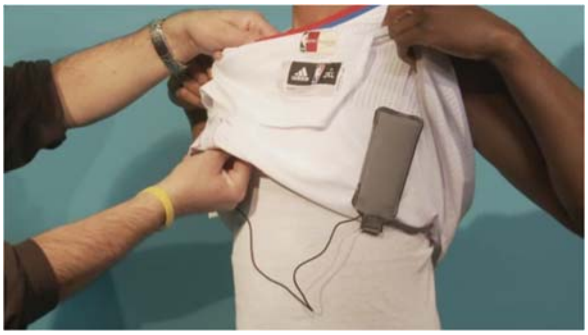

Figure 15: NBA Player Microphone transmitter pouch

Figure 16: NFL films, wireless audio transmitters on pads[142]

[142] Image credit: (Lectrosonics, 2007)

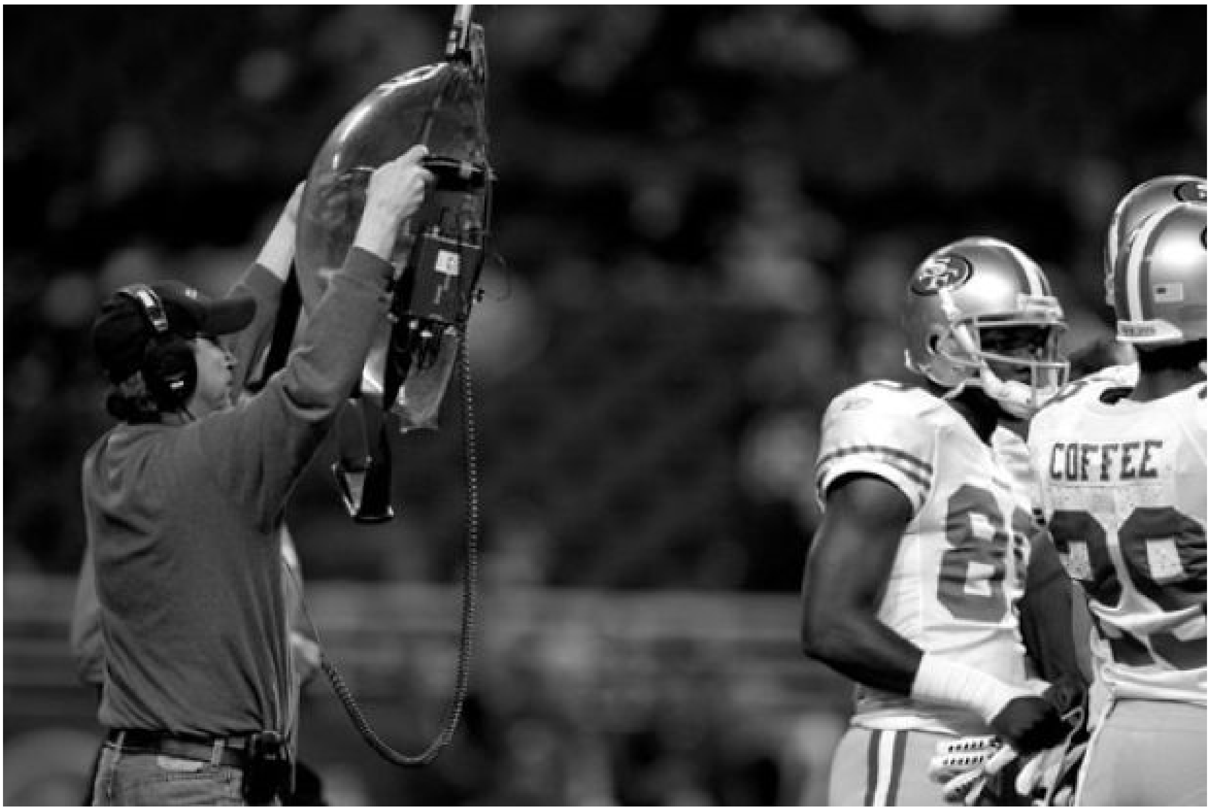

Figure 17: NFL Films, parabolic microphone reflector[143]

2.5.4 Point of View Cameras, Athlete-operated microphones

One of the most important technological developments for the documentation of sport of the past 10 years is the Point of View camera. Originally known as "Helmet Cams," as their weight required the additional armature of a helmet for support, these devices are now sold in small and durable form factors with a variety of mounting systems for wearing the camera or attaching it to sports equipment. These cameras are now widely used by amateur and professional athletes alike for their own training purposes and as a way to easily create videos of themselves to publish online. While the user base of these cameras has traditionally been action sports athletes, body-worn cameras are becoming more common in team sports, including at the professional level.

In terms of engineering, sound is often short-changed in the design of these cameras. Lower quality components and construction methods are often chosen, resulting in undesirable artefacts such as increased noise and distortion. Further, the on-board microphones for these cameras are often shielded by a thick plastic waterproof housing, further restricting the range of sounds that they can capture. Audio recorded with these cameras is often restricted to wind noise or, with editing help, the voices of athletes. Some athletes, though, use the POV camera's ability to connect external microphones. Teton Gravity Research, for example, has used POV cameras and an NBA-style microphone

[143] Image source: (Cohen, 2014)

mounting scheme to record the entire on-screen cast of their latest ski and snowboard movie *Almost Ablaze*.[144] In general, the field of POV audio has thus far opened up many un-realized possibilities in exploring what athletes hear.

2.5.5 Synthetic Sounds

While live television practices have involved an expanding repertoire of microphone techniques, Film and Video have generally favoured post-production sound effects to represent the sounds of the body in motion. The official Olympic films, produced for every Games from 1948 onwards, use these techniques extensively during the 1960s and 1970s. Many of these films allow for creative exploration of the athlete's sound world. For example, the film of the 10,000k race at the 1964 Tokyo Olympics uses sound effects of runners' footfalls during close-up shots, mixed with the sounds of the crowd and announcer. The slow-motion shots of the long jump include no crowd noise, only isolated sound effects each time the jumper's feet touch the ground.[145]

2.5.6 Microphones and What Athletes Hear

How are athletes affected by the presence of microphones outside and inside of the field of play, whether that field is a football stadium or the side of a mountain? How does the process of being recorded and listening back to oneself perform affect player behaviour? How does it affect the way they hear the game as they are playing it? These questions, at present, have no definitive answers. Anecdotal evidence suggests that for players of team sports, being "mic'd up" affects how they relate to their teammates on and off the field. For example, in one video produced by the NFL, player Richard Sherman can be heard telling another player "I've got a mic" as they are speaking, a possible warning that anything said could be made public.[146]

Microphones may constrain player interactions in some cases, but in others they may provide trainers and coaches additional insight into what is happening on-field. One example of this additional insight comes from psychologist Peter Clarke, employed by Canada's Curling team during their disastrous performance at the 2002 Salt Lake City Olympics. The coaching staff and Clarke had positively evaluated team cohesion in the months leading up to the games. The breakdown of cohesion in the team that lead to their early exit was only apparent to coaches after hearing the audio from the players microphones on the television broadcast, and not from their vantage point next to the ice.[147] In the modern-day NFL, the audio recorded on-field is used by opposing teams to decipher play calls and possible points of weakness, and has had a significant impact on game preparation and strategy.[148]

Microphones worn by athletes provide increased scrutiny of athletes, scrutiny that can alter behaviour or give players and coaches additional insight into what happens on the field.

[144] (Todd Jones, 2014)
[145] (Olympics, 2013) 51:00
[146] (Films, 2014)
[147] (Thatcher, Jones, & Lavallee, 2011)
[148] (Farmer, 2014)

However, the presence of recording devices – audio and video – also has more general effects on how athletes behave. In the context of POV cameras, anecdotal evidence suggests that the presence of microphones may push amateur athletes to take undue risks. Increasingly, the quest for more striking video, to be posted online, is being reported by accident victims as contributing factor to their injury.[149] For professionals, the increasing presence of media in their lives on and off the field certainly has an effect on how they approach their training, competition, and leisure. Media is tied to the larger issue of the "performance" of identities in professional sport. According to historian Michael Gard, the post-war professional athlete engages in displays of emotion that would have been unthinkable to the pre-war athlete.[150] Gard ties this dramatic shift in behaviour to the rise of professional salaries and the need for athletes to justify those salaries. However, the increasing ubiquity of audio and video recording surely amplifies those displays of emotion far beyond the playing field.

Broadcast professional sports are not specifically interested in the auditory experience of players themselves. Rather, the goal of broadcast sports audio seems to be to create the ultimate in spectatorship, enabling viewers an omnipresent auditory perspective that seamlessly moves from the announcers' box to the playing field itself to the team benches on the side-lines to the locker room. In this context, the focus of broadcast sports on players' voices and conversations makes sense. Sports documentary, with its inclusion of POV footage, attempts to communicate the experiences of athletes more directly. However, in terms of sounds recorded from microphones worn by athletes, these films often only use the sounds of the players' voices. The generally ubiquity of POV footage in contemporary social life, and the lack of attention paid to the audio that accompanies these recordings, reveals a potential gap in contemporary practice that can be addressed through design.

2.6 Conclusions: Gaps in the fields

The preceding survey of Psychoacoustics, Sports Studies, and Media Studies has revealed a tremendous diversity in the types of auditory experiences that athletes have. From this survey, we can distil several key points:

- Movement and hearing are integrated at a physiological level. Head movement is necessary for accurate spatial hearing, and moving sound sources can urge our bodies to move.
- Our auditory system can isolate individual "streams" of sound, even in noisy environments, and ignore or attend to those sounds in a variety of ways, both consciously and subconsciously.
- Athletes report a wide variety of sounds as important to their performance, including mental self-talk. Athletes tend to focus on these salient sounds, rather than listen to the environment as a whole. Athletic auditory experienced is highly focused and interrelated with the physical demands of a particular sport.
- Media has a significant impact on amateur and professional athletes. Microphones and cameras have increasingly moved from outside of the playing field to the inside in the

[149] (Clark, 2014)
[150] (Gard, 2013)

past two decades. The increased presence of recording devices channels and amplifies players' displays of emotions, reveals tactical secrets, and likely has other unforeseen effects on the sounds that players make on the field.

While there is much that we can infer from this interdisciplinary analysis of the sound of sport, the preceding chapter has in many ways raised more questions than it has answered. We still do not know how the auditory system responds during strenuous activity. How does running affect the perception of sound? How do the sounds generated by one's own body affect the perception of external sounds? If sounds can induce a physical response (as in auditory looming), does physical activity enact changes in audition? These questions, and others, point to a vast psychoacoustical terrain that is yet to be explored around the experience of the locomoting listener.

The notion of salient sounds is an important first step in understanding how athletes selectively attend to their environment. However, many questions still remain. What makes one sound more salient than another? How do acoustical properties, an individual's training, or other factors influence salience? How is sound integrated into the subconscious as an athlete trains? What affect do cultural ideas about the body have on an athlete's perceptions of sound? What effects do the presence of microphone have – long term – on the way athletes perform on and off the field? What effect does recording the sound of one's own training, competition, or overall experiences have on what an athlete hears? These questions, as yet, have no definitive answers.

There is an important gap between our current knowledge on the auditory experiences of athletes and the practices of recording and representing those experiences in contemporary media. While both professional broadcast media and independent sports documentaries focus predominantly on what players say, they focus less on the myriad of other sounds that make up a player's auditory experience. As the preceding survey of athletic literature reveals, the voice of oneself or other players are only one type of sound among many that are important to the athlete. These additional sounds are left to be captured by stationary networks of microphones outside of the field of play, and are mostly ignored by current practices of placing microphones on the bodies of players.

This gap between what players experience, and how those experiences are currently recorded, represented, and analysed, is the result of two main factors. The first is the lack of a comprehensive framework for discussing and analysing athletic sounds. How can we begin to make sense of the complexity of athletic auditory experience, let alone record it? The second is a lack of audio equipment designed specifically for the body in motion. The lavalier microphones currently available are designed to be worn on stationary bodies. As a result, the sound of a moving body is full of artefacts internal to the microphone itself – wind noise, vibration noise – rather than the sounds that the athlete might be hearing.

In the proceeding chapters I will document my investigation of these two factors – an analytic framework and a system of wearable microphones – through design work in several mediums. In doing so, I hope to create a “toolkit” that can be used to think about and record the sound of sport in new ways.

3 A Notation System for the Sound of Sport

3.1 From description to notation

One important gap in the study of the sound of sport is the lack of sufficiently descriptive language. Sound is often described and analysed haphazardly, with some sounds attended to and others ignored. The sound-world of athletes is complex, and we need a way to methodically unpack its layers. This chapter outlines the development of an analysis method for the auditory experiences of athletes. This method involves thinking about the sounds in an athlete's environment according to three main categories – trajectory, temporality, and task relationship. These categories have been developed from the literature used in Chapter 2. This notation system evolved over the course of six months, and was then used by the author to notate his own athletic activities for a period of two years.

One of the goals of the notation system is to more fully articulate the auditory experience of athletes and of the locomoting listener in general, enriching the vocabulary. Additionally, thinking through the three main categories can reveal aspects of sonic experience that might otherwise go unnoticed. Aside from its descriptive potential, the notation system has been used as a data collection instrument, charting the distribution of sounds across the various categories and sub-categories. Significant differences have been found in the data collected from the literature survey and the data collected by the author. For example, sounds exterior to the athlete's body were mentioned most frequently in the literature, while the sounds of the body itself were more frequent in the author's self-notations. This difference has a variety of influencing factors, not the least of which is the type of sport under consideration, but it points towards new ways of comparing what athletes hear across teams, cultures, and sporting disciplines.

Further, the concepts developed through the design of this notation system have been crucial to stimulating the design of a new microphone system for recording sport. The final form of the notational system was developed in conjunction with the Proximal Recording system, and revealed new areas for microphone design that were then integrated into the ProxiMic. The analysis framework and notation system described here form a kind of intellectual backbone that supports the physical designs displayed in subsequent chapters, and the notation appears throughout the rest of this document.

3.2 Methodology

3.2.1 Literature Review

As a point of departure, the literature collected and reviewed in Chapter 2 from sports science and anthropology was re-investigated. Instead of broad themes, it was analysed for specific mentions of sounds. These mentions ranged from the comprehensive (an entire study) to the fleeing (a sentence or two). The entire list of 31 references can be found in section 8.1.1. I chose to confine this list of references to only sports science and anthropology, because these two disciplines represent the most significant collection of peer-reviewed analyses of various aspects of the sounds of sport from an athlete's perspective.

The method for recording and analysing this literature involved isolating individual sound events in each article or study. In sports science, if a study was focused on a particular sound event then that sound event was recorded. When no clear sound event was present, the method of the study itself was recorded, such as music delivered via earphones to runners on a treadmill. In anthropology, with a focus on auto-ethnography, I recorded any mention of sound in the authors' descriptions of their activities, even if that mention was only a sentence or two long. Each sound recorded this way was its own data point in a list that grew to 41 individual sounds over two years.

3.2.2 Approaches to Sound Categorization

The sounds described in the literature surveyed here can be categorized in a number of ways. There are many existing approaches to sound categorization. Most of these are inherited from musical composition and practices of orchestration, grouping instrument sounds by sound quality (timbre) and range. This "spectral" approach has been carried over to computer sound analysis, where algorithms rank each sound according to its frequency, noisiness, onset, and other characteristics. This method of classification is used extensively for everything from discriminating bird species, to classifying pop music recordings by genre.[151] Outside of music, other methods take a different approach, focusing on the evocative effects of different sounds rather than their inherent sonic qualities.[152]

Existing methods for categorizing sounds are unsuitable for application to sport. First, they are designed for a different kind of listening environment, such as the concert hall, where the sound itself is the object of a listener's attention. In sport, sound is part of a much wider range of stimuli. Second, spectral methods for sound analysis excel at classifying sets of similar sounds, such as bird calls or pop music recordings. These methods might be applicable to classifying specific types of athletic sound (i.e. distinguishing a bad shot from good in tennis, or diagnosing equipment malfunctions), but are less suited to developing a common language across sporting disciplines. Further, it is not just that the sounds of sport are too wide ranging for spectral techniques to work, it is that we wish to think beyond the mechanics of individual sports in order to develop a language that can be used across different sports, or can describe different activities within a single sport.

3.2.3 Applications of Notation

3.3 Categories of Athletic Sound

[151] See (Ellis, Whitman, Jehan, & Lamere, 2010) and (Stowell & Plumbley, 2010)
[152] See (Bergman, Sköld, Västfjäll, & Fransson, 2009) and (Augoyard & Torgue, 2006)

The categorization system that I have developed analyses sounds based on three properties:

- Trajectory – the path that a sound travels from point of origin to point of reception
- Temporality – the rhythmic properties of a sound
- Task relationship – the connection between a sound and the athlete's current activity

Each of these properties has multiple sub-properties that encompass a wide variety of sounds. Indeed, the framework can be used to describe any situation, not just an athletic one. Temporality is the only category that relates to the actual sonic qualities of a sound – its amplitude envelope and duration. Trajectory, in charting the location of a sound in reference to the athlete, captures potential information about the social role of a sound and its spatial relationship to the athlete's body. Task relationship attempts to capture additional information about how a sound might relate to the current movements, goals, and attentional state of an athlete. Taken together, these three categories reveal much about the role that a particular sound might play in an athlete's overall auditory experience.

3.3.1 Trajectory

Trajectory – *the path a sound travels from point of origin to point of reception*

One of the most significant findings from the study of the locomoting listener in Chapter 2 is that the sounds of the moving body exist in social space. The qualities of an athlete's breath, for example, can tell the athlete about their level of fatigue as well as communicating that information to other listeners within earshot such as opponents, training partners, or observers. In addition, the location of and motion of a sound encodes its own meanings, such as with auditory looming. *In sport, the "where" of a sound is crucial to how that sound is perceived by an athlete.*

The general category of Trajectory attempts to encode the "where" of athletic sound. It has been broken up into four sub-categories:

- Spatial - **from** events not directly connected to the body **to** the ears
- Proximal - **from** the surfaces of the body (including equipment) **to** the ears and out into the environment
- Internal - **From** inside the body **to** the ears - Non-airborne sound events
- Mental - **From** inside the mind **to** inside the mind

These last two categories, internal and mental, are sounds that exist within the body itself as physical vibrations conducted through bone or tissue, and as sounds such as self-talk that exist only in the mind of the athlete.

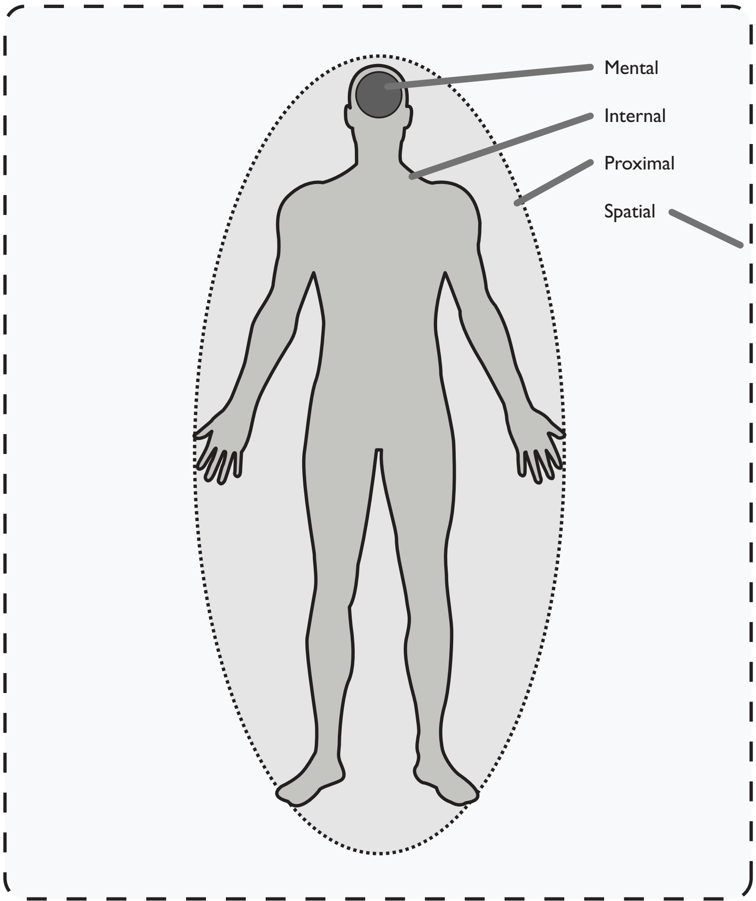

Figure 18 : Basic categorization of sound source location for trajectory categories

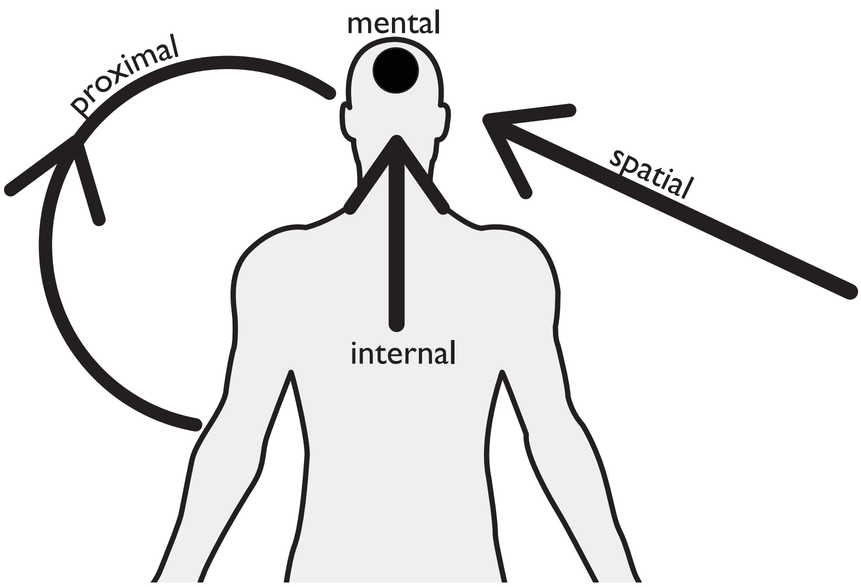

Figure 19: Trajectory categorization, vectors

3.3.1.1 Spatial Sounds

Spatial - ***from*** *events not directly connected to the body* ***to*** *the athlete's ears*

Spatial sounds originate from events external to the athlete's body. In team sport, these sounds are highly varied and include the sound of spectators, teammates, opponents, referee whistles, and a host of other sounds. In one-on-one competition, the most important spatial sounds are often those made by an opponent. In tennis, for example, the sound quality of an opponent's shot can help to determine the speed and direction of the incoming ball. In individual sports, such as running, spatial sounds can help to determine environmental dangers, such as cars, dogs, or people.

Spatial sounds are known as "environmental sounds" in contemporary music and sound studies literature. In psychoacoustics and other disciplines, spatial sounds are the trajectory of sound most often considered. When the body is made still, and the mind focused on listening, spatial sounds dominate. Going to a sit-down concert, quietly listening to the sounds occurring outside of your window, listening to recorded music through speakers – these are most often primarily spatial experiences. That is, until the listener becomes lost in thought, or gets up and begins to move, or starts typing on their computer keyboard. For locomoting listeners, and athletes in particular, spatial sounds can be especially salient to their present task and goals, but not always. There are many situations in which athletes ignore spatial sounds and instead focus on other trajectories.

3.3.1.2 Proximal sounds

Proximal - ***from*** *the surfaces of the body (including equipment)* ***to*** *the ears and out into the environment*

Proximal sounds arise from the athlete's immediate actions. They are physically connected to the surfaces of the body, clothing, or equipment. In many cases, proximal sounds provide auditory feedback about how an athlete is performing. For example, the breath of an athlete is the often mentioned. Athletes listened to the "raggedness" in their own breath as yet another indicator of their level of fatigue.[153] In running, sound is an indicator of technique, with footfalls providing valuable information about cadence and foot-strike.

Sounds arise from an athlete's equipment as well. These proximal sounds help determine the "feel" of that equipment and how well the athlete is using it. This process of feedback is part of a complex interplay between equipment and technique that the athlete has developed over a period of training. In golf, cricket, baseball, tennis, and other sports involving contact between a ball and an object – a club, bat, or racquet – the sound produced at the moment of impact is crucial. Athletes use the quality of this sound to determine which

[153] (Hockey, 2006) p192

club to purchase, or whether or not their equipment needs maintenance. They also use this sound of the moment of contact to determine if their shot was a good one. In racquet sports, where there is a sequential interplay between your moves and your opponents move, the sound of your own good or bad shot can determine where to move next. In racing disciplines, athletes reported similar tactics of listening to proximal sounds. In cycling, speed skating, rowing, and running, the sound of your equipment moving through space is a key indicator of pacing, speed, and the health of the equipment.

While proximal sounds provide an important source of auditory feedback to athletes in many different situations, they also have the potential to be heard by other pairs of ears. Often this is intentional, such as when an athlete calls to a teammate to perform an action. This relationship can also be sympathetic, as with training partners. With opponents, however, sound becomes tactical. Grunting in Tennis, for example, is seen by some as a way in which athletes are able to mask the potentially revealing proximal sound of their racquet strike with the comparatively uninformative sound of "grunting." In many sports, athletes practice their "game face," by attempting to erase signs of fatigue from their facial expressions in order to gain a psychological advantage.154 The control of one's proximal sounds is also a part of these psychological tactics.

3.3.1.3 Internal Sounds

Internal - ***From*** *inside the body* **to** *the ears – (Non-airborne sound events)*

Internal sounds are those sounds that travel through bone and tissue to reach the ear drum. These sounds are often generated by the athlete's body itself. Some of these sounds can be heard both inside and outside of the body, while some can only be heard by the athlete. An athlete's speaking voice and breath are two examples of sounds that have both an internal and proximal component. An athlete's pulse, often audible to an athlete especially during moments of high exertion, has only an internal component.

The internal sound properties of the human voice have been studied extensively. The voice is conducted from throat and mouth through bones and tissue in the head and neck. This phenomenon is in part why listening back to recordings of oneself is so distressing, as they lack the internal component of the sound that we are used to. The internal sound components of the breath are less studied, as are the effects of forceful breaths on the human auditory system in general (with their rapid changes in internal air pressure). Impacts have the potential for an internal sound component, especially if the head is involved. In addition, it is possible that vigorous vibration from external equipment, such as a bike seat, could be conducted through the body as well as through the air. In general, the physiology for body-conducted sound from external vibrations is not well known enough to accurately classify these potential internal sounds.

[154] (Gallmeier, 1987)

3.3.1.4 Mental Sounds

Mental - ***From*** *inside the mind* ***to*** *inside the mind*

Mental sounds are those sounds imagined by the athlete. Of the myriad of sounds in this category, self-talk has received the most attention. The most common form of self-talk involves short phrases that an athlete thinks to themselves, with some athletes mouthing the words as well. Another group of mental sounds discussed previously are the lingering effects of listening to music before competition or training. Imagined fragments of what was listened to can persist after the recording has been switched off. In both of these cases, mental sounds play a role in the emotional regulation of athletes. Yet another group of mental sounds involves auditory imagery during training or preparation.

3.3.2 Temporality

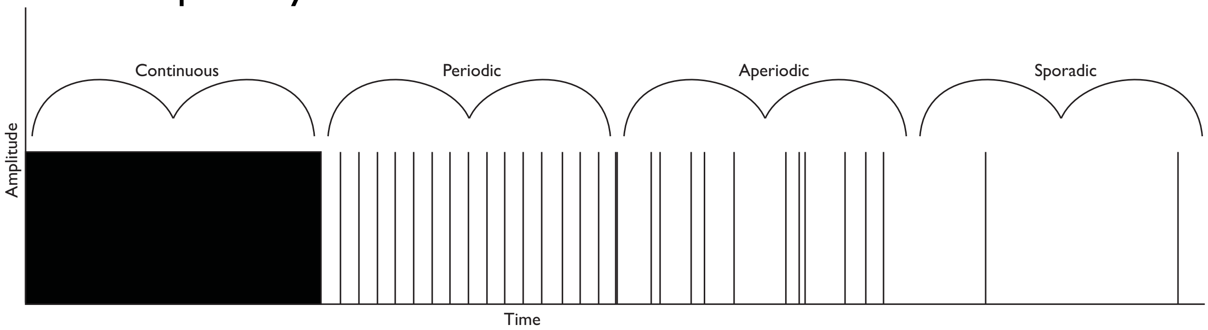

Figure 20 : Temporal Categories, graphed as amplitude vs time

In addition to trajectory, the temporal qualities of a sound are an important factor in determining its role in the athletic soundscape. By temporal qualities, I am referring to the rhythmic qualities of a sound, or its amplitude envelope over time. Figure 20 shows these categories graphed as amplitude vs. time. While the literature in music composition, sound synthesis, and psychoacoustics has a rich vocabulary with which to discuss the finer points of temporality, individual sounds in the athletic soundscape can be divided into four main categories:

- continuous – constantly audible
- periodic – constant tempo, predictable
- aperiodic – frequent, but no regular tempo
- sporadic – infrequent, with no regular tempo

It should be noted that these categories are more descriptive than absolute, and that some sounds will exist between categories. For example, continuous sounds may have periodic qualities, such as the flow of water past a swimmer's ears. In these cases, the sound may belong to two categories or only the dominant category may be included.

3.3.2.1 Continuous Sounds

Continuous sounds are constantly audible to the athlete. Their amplitude and sound quality may change over time, but the sound is always present. Examples of continuous sounds include bicycle tyres on pavement, car and motorcycle engines at various rpms, boat hulls moving across water, or wind in an athlete's ears at prolonged high speeds. Many continuous sounds are created by an athlete's equipment, and move with the athlete. However, in some situations the noises from crowds of spectators or other environmental factors may be considered continuous sounds

3.3.2.2 Periodic Sounds

Periodic sounds occur in a regular or predictable cycle. In musical terms, periodic sounds are equivalent to rhythmic sounds in a regular tempo. Examples of periodic sounds include the footfalls of running feet at a steady pace, the breath and pulse of an athlete, and the stroke of a rowing team. Cadence and pacing are associated with periodic sounds. Because of this, period sounds often occur in endurance sports, running intensive ball sports, and other situations where the body maintains a steady pace for a significant period of time.

Periodic sounds deserve special consideration for two reasons. The first involves entrainment, as discussed in section 2.3.6.2, where individuals tend to synchronize the rhythm of their movements to other rhythmic stimuli in their environment. The second involves what is known as Spontaneous Motor Tempo (SMT). When no other rhythmic stimuli are present, individuals tend to perform rhythmic tasks such as finger tapping, walking, and clapping at the same tempo. [155] For most people, the SMT is roughly 2 hertz, or 120 beats per minute, and is constant across a wide range activities.[156] Athletic training and the physical demands of a particular sport are likely the most important factors in determining the tempo at which periodic sounds occur. For novices, though, the SMT likely influences the tempo that feels "right."

3.3.2.3 Aperiodic Sounds

Aperiodic sounds occur often, but not in a consistent or predictable rhythm. They are a common feature of play, rather than an exceptional event. Examples of aperiodic sounds include the racquet strike in tennis, squash, and ping pong, or the vocal communication between teammates in a variety of team sports. Footfalls and other sounds from running can also be aperiodic during periods of high intensity, as when one is trying to get past an opponent.

3.3.2.4 Sporadic sounds

Sporadic sounds do not occur often, and are not predictable. One way of distinguishing sporadic sounds from aperiodic sounds is that they are not a common feature of play, but are instead related to more exceptional events. In soccer, for example, the referee's whistle could be considered a sporadic sound, while vocal communication among teammates could be

[155] (Delevoye-Turrell, Dione, & Agneray, 2014)
[156] (MacDougall & Moore, 2005)

considered an aperiodic sound. Sporadic sounds may occur in relation to an athlete's equipment – the sound of a tire loosing air pressure as it goes flat – or to external events – a passing car on an otherwise uncrowded road.

3.3.3 Task Relationship

While the first two sets of categories dealt with the physical properties of sound, the final categorization method relates a particular sound to the athlete's task at hand. As we have seen in Chapter 2's review of sound in sport, what an athlete hears is influenced by a relationship of sound, action, and an athlete's goals. While physical factors certainly play a role, task relationship is perhaps the most significant factor in determining whether a sound is heard consciously, subconsciously, or ignored altogether.

Unlike physical factors, though, task relationship does not fall into a clear continuum. There are many possible ways for sound to relate to the athlete's body and mind, and one sound can have many possible meanings. Taking the highly contingent nature of task relationships into account, I have identified seven categories from the literature review:

Motivational – sounds that aide in the emotional regulation of the athlete. Examples: self talk, music

Body performance feedback: sounds made by the athlete's own body. Examples: breath, voice, footfalls.

Equipment performance feedback – sounds made by the athlete's equipment. Examples: racquet strike, skateboard, bicycle drivetrain.

Personal Safety – sounds from objects that may collide with, attack, or otherwise affect an athlete. Examples: cars, dogs, opponents.

Environmental – sounds that tell the athlete something about their environment. Examples: crowd noise, birdsong, running water

Teammate Communication: sounds related to communication (mostly vocal) with teammates on the playing field. Examples: play calls, movement commands, celebrations.

Oppositional Feedback – sounds made by an opponent that indicate their physical state, location, or intentions. Examples: racquet strike, opponent's breathing, opponent's footfalls.

These categories cover the sounds mentioned in the literature review, as well as subsequent testing in my personal athletic practice. However, this section is meant to be relatively open-ended and extensible. In future use with a wider variety of athletes and sporting disciplines, I expect these categories to grow considerably.

3.3.4 Categorization Data

Reference	Year	Source	Path	Sport/Activity	Trajectory				Temporality				Task Association						
					Mental	**Internal**	**Proximal**	**Spatial**	**Contin.**	**Periodic**	**Aperiodic**	**Sporadic**	**Motiv**	**BPF**	**EPF**	**PS**	**TC**	**OS**	**Env**
(C. I. Karageorghis et al., 2013)	2013	*Music imagined*	mind	swim	x					x			x						
(Tenenbaum et al., 2004)	2004	*Music via headphones*	ear canal	run - treadmill		x	x			x			x						
(C. Karageorghis et al., 2010)	2010	*Music via headphones*	ear canal	gym circuit		x	x			x			x						
(Landin & Hebert, 1999)	2006	*Self-talk mental*	mind	tennis	x						x		x						
(Landin & Hebert, 1999)	2006	*Self-talk spoken*	bone, air	tennis		x	x					x	x						
(Razon, et al, 2009)	2009	*Music via headphones*	ear canal	hand gripping		x	x			x			x						
(Hagen et al., 2013)	2013	*Music via headphones*	ear canal	cycle - stationary		x	x			x			x						
(Bishop, et al, 2007)	2007	*Music imagined*	mind	tennis	x					x			x						
(MacPherson, Collins, & Obhi, 2009)	2009	*External metronome*	air	tasks - walk, tap				x		x			x						
(Bernier, et al, 2011)	2011	*Sounds imagined*	mind	golf	x								x						
(Jordet, 2005)	2005	*Sounds imagined*	mind	soccer	x								x						
(Landin & Hebert, 1999)	1999	*Self talk*	mind	tennis	x						x		x						
(Takeuchi, 1993)	1993	*Opponent racquet strike*	air	tennis				x			x							x	
(Balmer, Nevill, Lane, Ward, & et al., 2007)	2007	*Crowd noise*	air	soccer				x	x										x
(Hardy, Hall, & Hardy, 2005)	2005	*Self-talk*	bone, air	tennis		x	x				x		x						
(Lenzen, Theunissen, & Cloes 2009)	2009	*Voices of players*	air	handball				x			x						x		
(Button et al, 2002)	2002	*Ball relese from machine*	air	ball-catching				x			x								x
(Maivorsdotter & Quennerstedt, 2012)	2012	*Music in headphones*	ear canal	run - treadmill		x	x			x			x						
(Jackson, 1992)	1992	*Music over PA*	air	ice skating				x		x			x						
(Roberts, Jones, Mansfield, & Rothberg 2005)	2005	*Golf club strikes ball*	air	golf			x					x			x				
(Hockey, 2006)	2006	*Footfalls*	air	run			x			x				x	x				
(Hockey, 2006)	2006	*Breath, self*	air, bone	run		x	x			x				x					
(Hockey, 2006)	2006	*Cars in street*	air	run				x				x				x			
(Hockey, 2006)	2006	*Pulse in ears*	bone, fluid	run		x				x				x					
(Sanders-Bustle & Oliver, 2001)	2001	*Breath, training partner*	air	run				x		x							x		
(Collinson, 2008)	2008	*Breath, self*	air, bone	run		x	x			x				x					
(Sparkes, 2009)	2009	*Cricket bat strikes ball*	air	cricket			x					x			x				
(Nolte, 2011)	2011	*Sound of boat on water*	air	crew			x		x						x				
(Spinney, 2006)	2006	*Self-talk, multiple voices*	mind	road cycle		x					x		x						
(Throsby, 2013)	2013	*Heartbeat in ears*	bone, fluid	swimming						x				x					
(Merchant, 2011)	2011	*Pressure in ears*	bone, fluid	diving		x			x					x					
(Drummond, 2010)	2010	*Announcer's voice at finish*	air	run				x				x	x						
(McCarville, 2007)	2007	*Individual voices in crowd*	air	road cycle				x				x	x						
(McCarville, 2007)	2007	*Wetsuit sounds*	air, skin	swim		x	x				x				x				
(McCarville, 2007)	2007	*Announcer's voice at finish*	air	run				x				x	x						
(McCarville, 2007)	2007	*Roar of crowd*	air	run				x	x				x						
(Denison, 2006)	2006	*Competitor taunts*	air	track - run				x			x							x	
(Caudwell, 2011)	2011	*Coxswain instructions*	air	crew				x		x							x		
(Purdy, Potrac, & Jones, 2008)	2008	*Coxswain instructions*	air	crew				x		x							x		
(Purdy, Potrac, & Jones, 2008)	2008	*Coach boat*	air	crew				x	x										x
(Allen-Collinson & Hockey, 2011)	2011	*Footfalls*	air	run			x			x				x	x				
				totals	6	13	15	16	5	18	9	7	20	7	6	1	4	2	3
				percentages %	15	32	37	39	12	44	22	17	49	17	15	2	10	5	7

Table 1: Categorization data from literature survey

Categorization – preliminary results

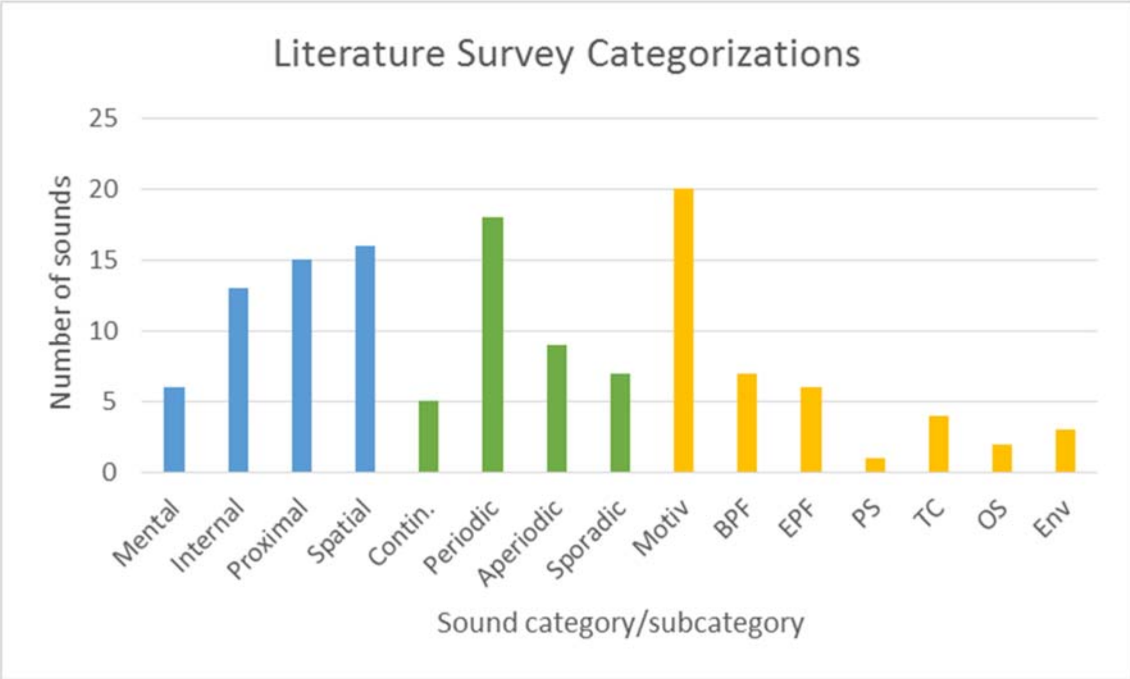

Figure 21: Literature survey categorizations, number of sounds in each category

Figure 21 shows the distribution of sounds in the literature in the three different major categories. In terms of trajectory, internal, proximal, spatial are roughly equal. One of the reasons for the balance between internal and proximal is that many sounds fall into both categories, especially an athlete's breathing. In terms of temporality, periodic is most often heard for several reasons. Many sounds in an endurance athlete's world are periodic, and most of the autoethnographies describe endurance sports. In addition, studies of the effects of music on athletes most often use music with a steady, periodic, tempo. The influence of studies of the effects of music on athletes also accounts for the majority of task relationships falling into the motivational category.

3.4 Evolution of Notational System

3.4.1 First Steps towards notation – photo annotations

One of the deficiencies of the literature survey as a foundation for categorizing sound is that it tends to favour sounds that are consciously listened to. Sounds that are monitored subconsciously may not be reported by authors, and authors also might not report sounds that are ignored altogether. What is needed, then, is a method by which we can capture the range of sounds present in an athlete's environment, regardless of whether they are relevant or not. The categories above can then be used to make sense of these various sounds, along with the athlete's own reporting.

The early stages of developing notation all involved digital drawing over photos of athletic activities using Adobe Illustrator. One attempt involved the use of coloured dots to represent the trajectories of individual sounds. An example of this system can be seen in Figure 22. Note that this image was made using three categories rather than four. The size of the dot is related to the perceptual importance of the sound – how loud the athlete perceived it to be. The dots and color-coding make the various trajectories visually very clear. However, they limit the amount of other categories that can be displayed on a single image, requiring multiple images to be used. In addition, the sizing of dots by perceptual importance is difficult to capture accurately.

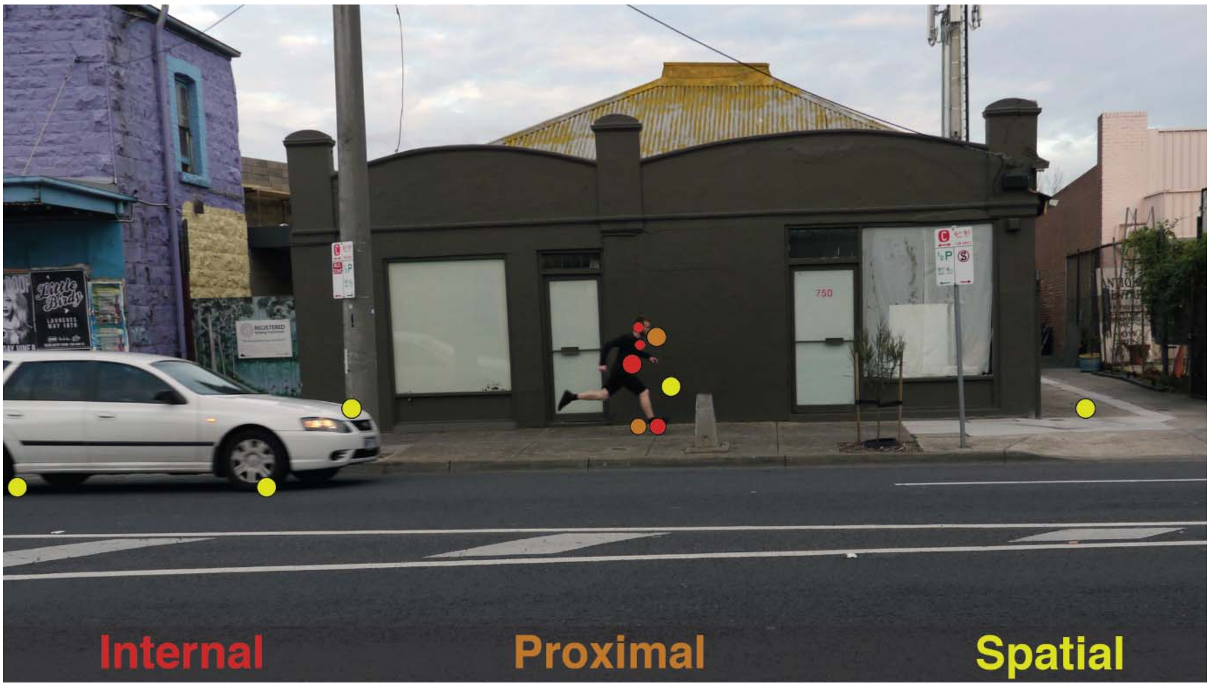

Figure 22: Early version of notation system, using coloured dots

3.4.2 Building a symbol system

Rather than color-coding individual categories, I developed a system of graphic symbols for each category. These symbols can then be combined to notate a sound according to trajectory, temporality, and task relationship. A picture or sketch of an athlete can then be "marked up" using this notation as a way to describe, analyse, and investigate what that athlete might be hearing at a given moment.

The symbols for each category are as follows:

Trajectory:

Figure 23: Trajectory symbols

Temporality:

Figure 24: Temporality symbols

Task Relationship:

Motivational: **M**

Equipment performance feedback: **Ef**

Teammate Communication: **Tc**

Body performance feedback: **Bf**

Personal Safety: **Ps**

Oppositional Feedback: **Of**

Figure 25: Task relationship symbols

3.4.3 Combining categories to form notation

These individual symbols can be combined to form “blocks” of notation that signify how an individual sound can be categorized. Figure 26 shows an example of one such block for the sound of footfalls when running. The trajectory of the sound, in this case proximal, is to the left, with temporality and task relationship to the right. Other examples of notational blocks can be seen in Figure 27 and Figure 28. For sounds that fall into multiple categories, multiple symbols can be combined, as shown in Figure 29 notating the author’s breath while running.

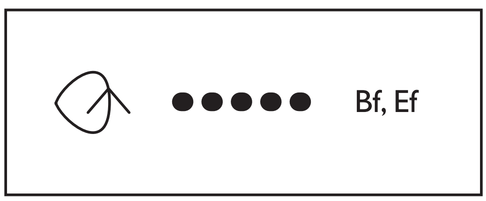

Figure 26: Notation block, footfalls while running

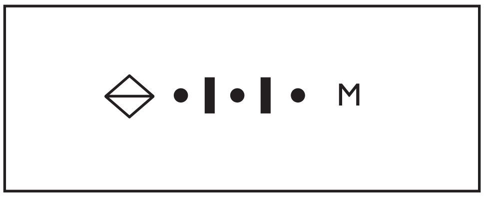

Figure 27: Notation block, self-talk while running

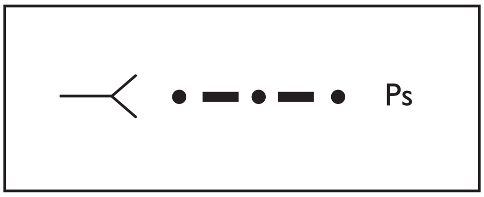

Figure 28: Notation block, traffic while running

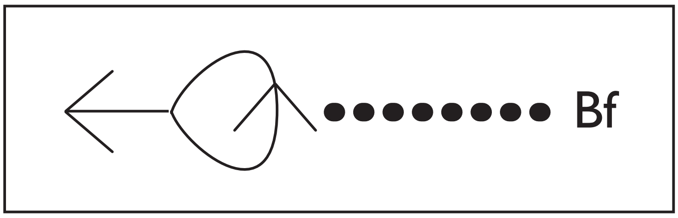

Figure 29: Notation of the author's breath while running

3.4.4 Notation Method

After a period of experimentation, I devised the following series of steps to create new notations:

1. Begin with a visual image of the athlete. These could be a photograph (as in Figure 30) or a sketch. If multiple athletes are present, mark the athlete under consideration with a dot.

2. Catalog the various sounds seen in the picture, drawing a number over their source. Below the image, or on another page, make a list of the sounds by name and number.

3. Move through the list of sounds, categorizing each by trajectory, temporality, and task relationship, placing blocks of notation next to the names of sounds in the list

Figure 30: Example of an appropriate image for notation. The author running near his home.

3.4.5 Example 1 – the sound of running

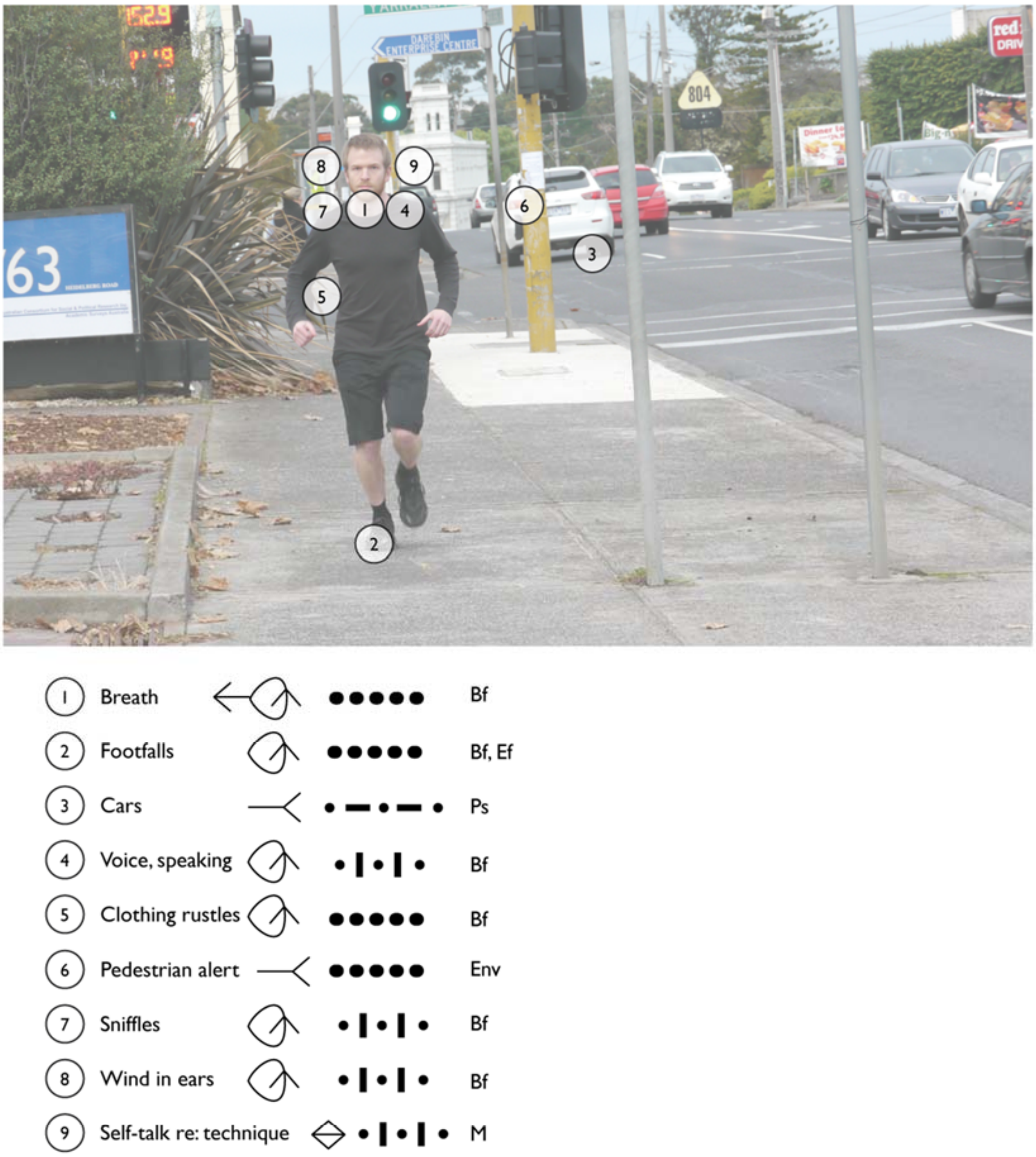

Figure 31 : Notation system, complete

Figure 31 shows an image of the author running that has been notated using this method. Nine sounds in total have been notated, with five proximal, two spatial, one mental, and one proximal and spatial. In this version of the notation, the ordering of the sounds is according to importance as remembered by the author. Other sounds, such as the pedestrian crossing alert and the sound of wind in the ears, were not apparent to the author at the time, but would likely have been present.

Figure 32 shows a previous iteration of the application of the notation system, using an alternative method. A different notational block is used, with temporality forming a circle, task relationship inside that circle, and trajectory connected to the outside of the circle. These notational blocks are then placed directly on the photograph or sketch over the location of the sound. This form of notation was the first to be tested. While it may be more visually striking than numbering and listing the items, it has a number of drawbacks. First, it lacks specificity. There is no way to precisely label the sound by name for later reference. Second, the notational blocks themselves are difficult to draw by hand. Third, it lacks visual clarity, making it difficult to determine exactly how many sounds have been notated and what categories they fall into. The current system of numbered sounds is a more effective compromise between specificity, clarity, speed, and ease of use.

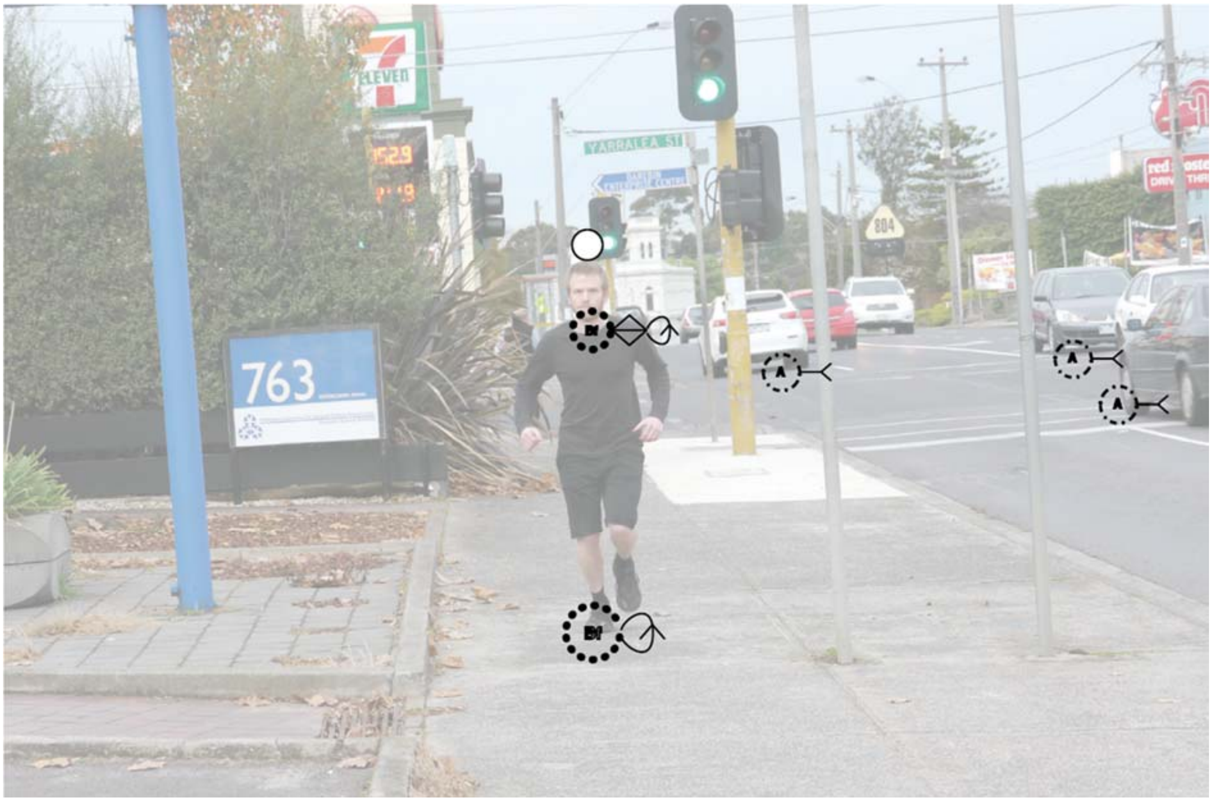

Figure 32: Development version of notation, photo overlay

3.5 Self-notating

3.5.1 Notation of personal athletic activities

This notation system has been used by the author over 12 months to analyse his personal auditory experiences. The activities that have been notated include cycling (road and mountain), running, surfing (prone and stand-up paddle), snowboarding, ski touring, weight-lifting, wakeboarding, sailing, skateboarding, soccer, Australian rules football, tennis, and golf. These activities have been quickly sketched and notated, often within 24 hours of the activity. Examples of these sketches are Figure 33, Figure 34, Figure 35, and Figure 36.

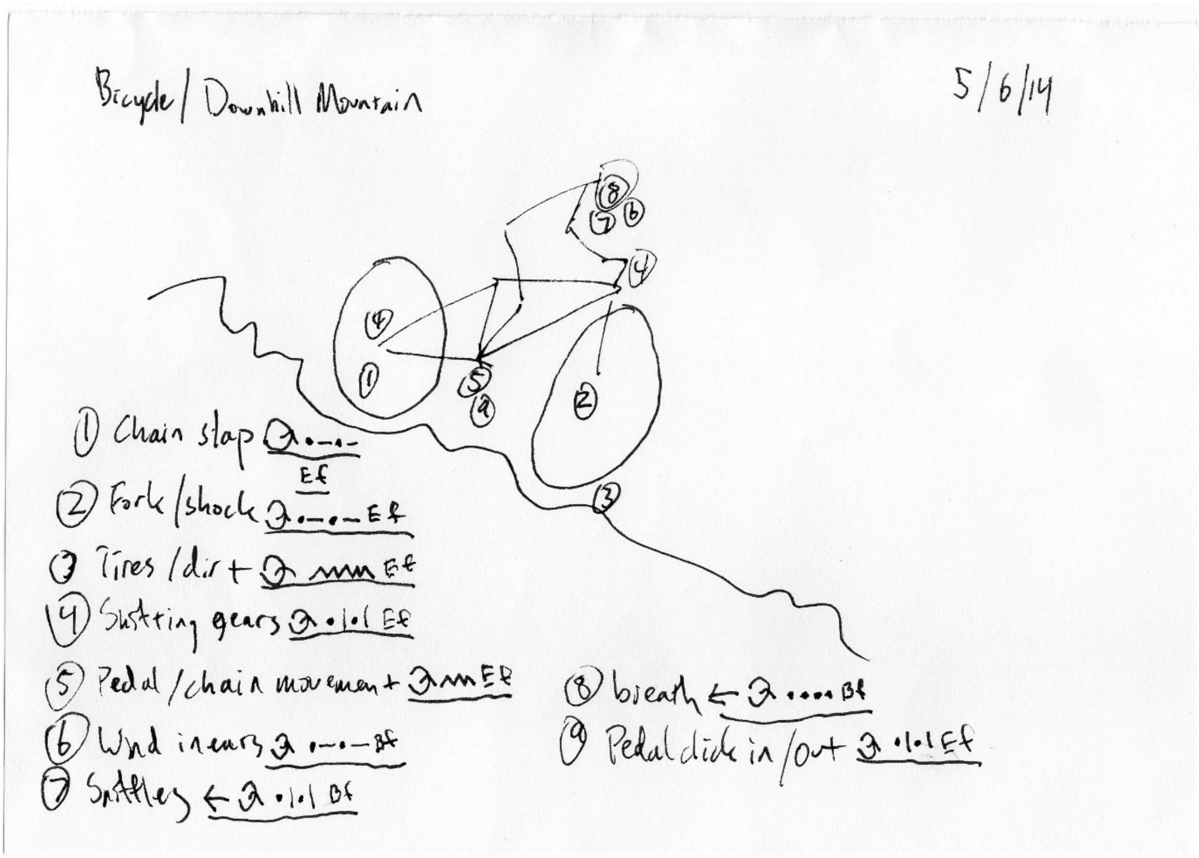

Figure 33 : Notation produced by the author on June 5, 2014 after Mountain Biking

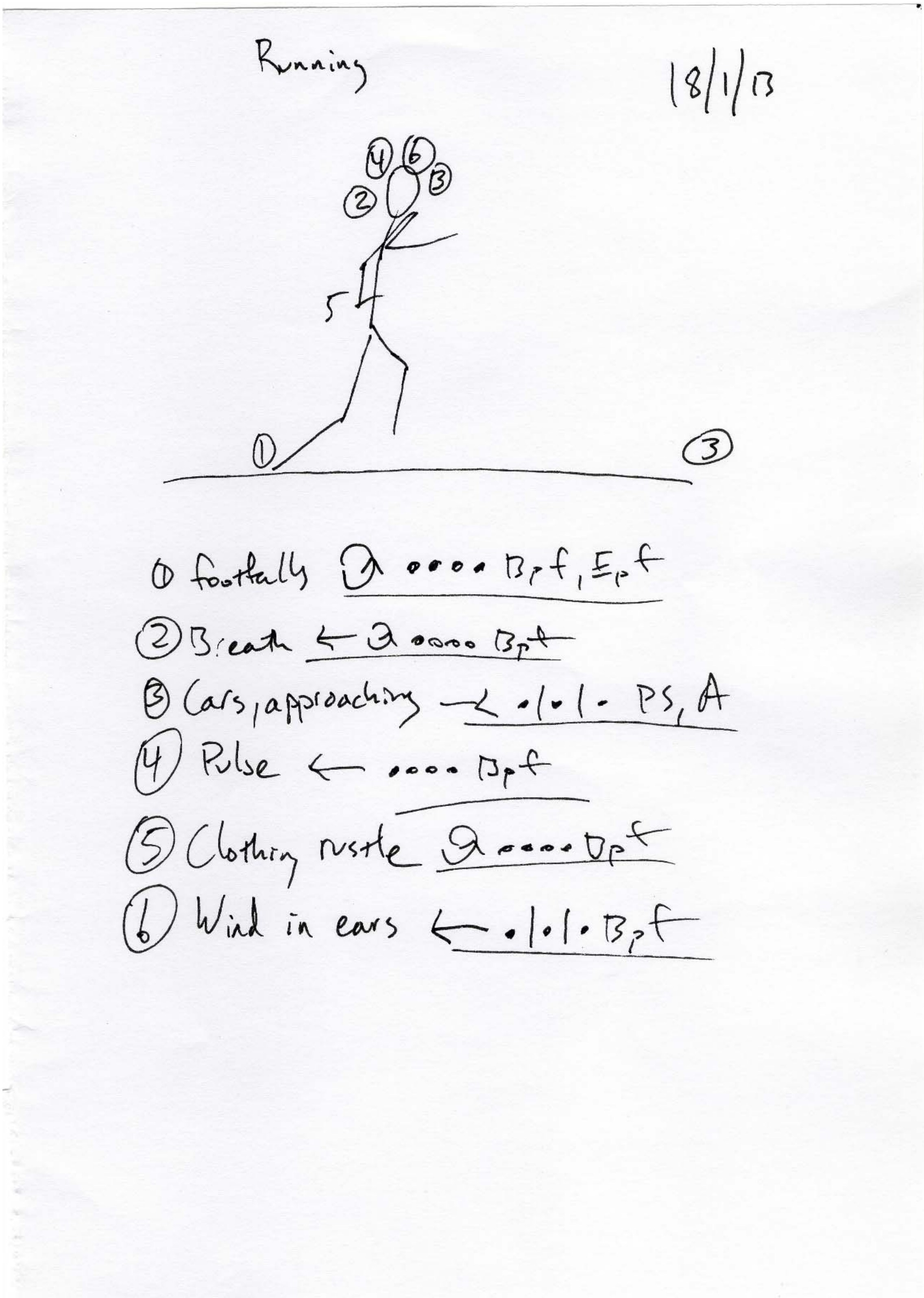

Figure 34 : Notation produced by the author on January 18th, 2013 while running

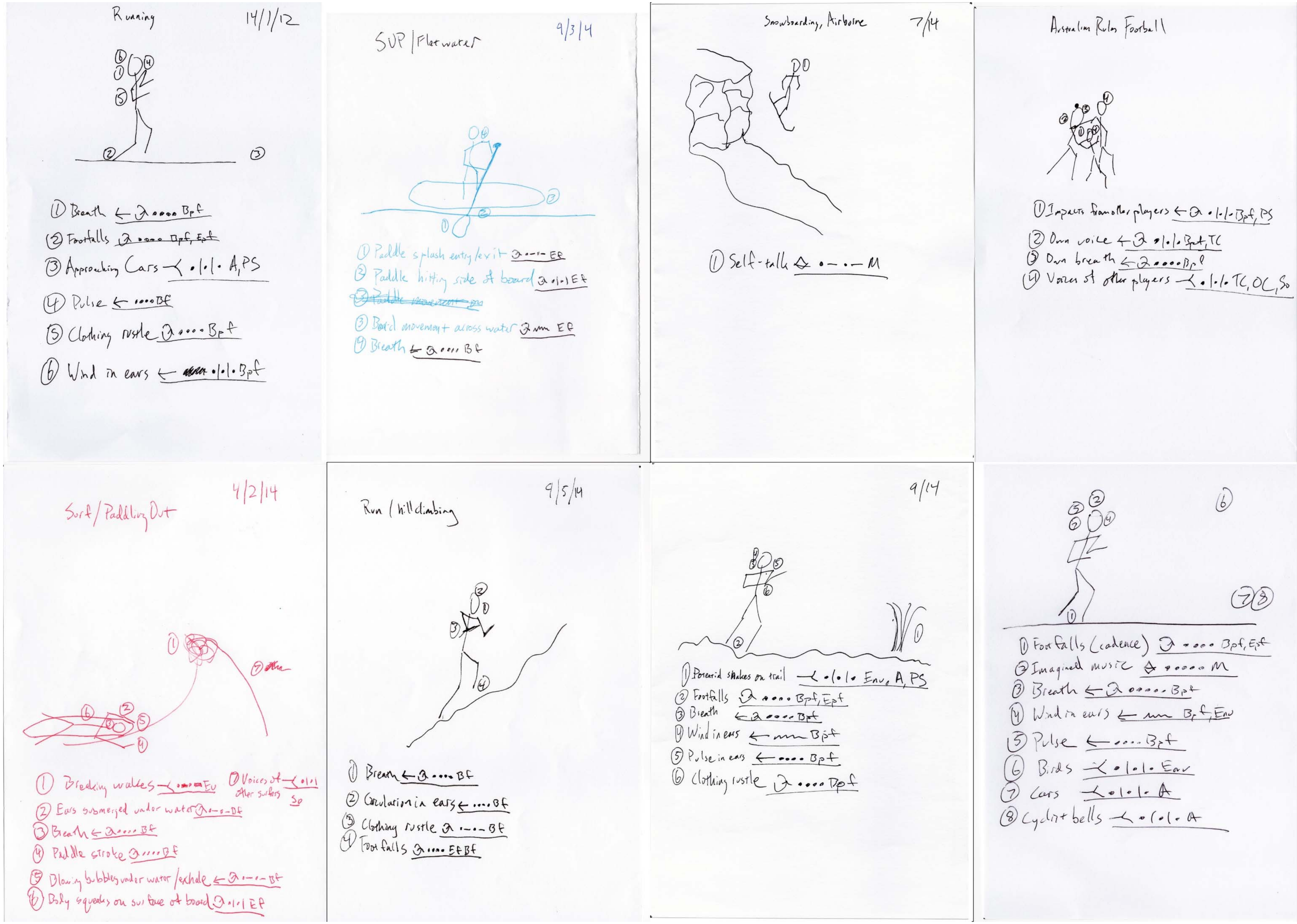

Figure 35: Self-notation examples, sheet 1

Figure 36: Self-notation examples, sheet 2

3.5.2 Results of notating personal athletic activities

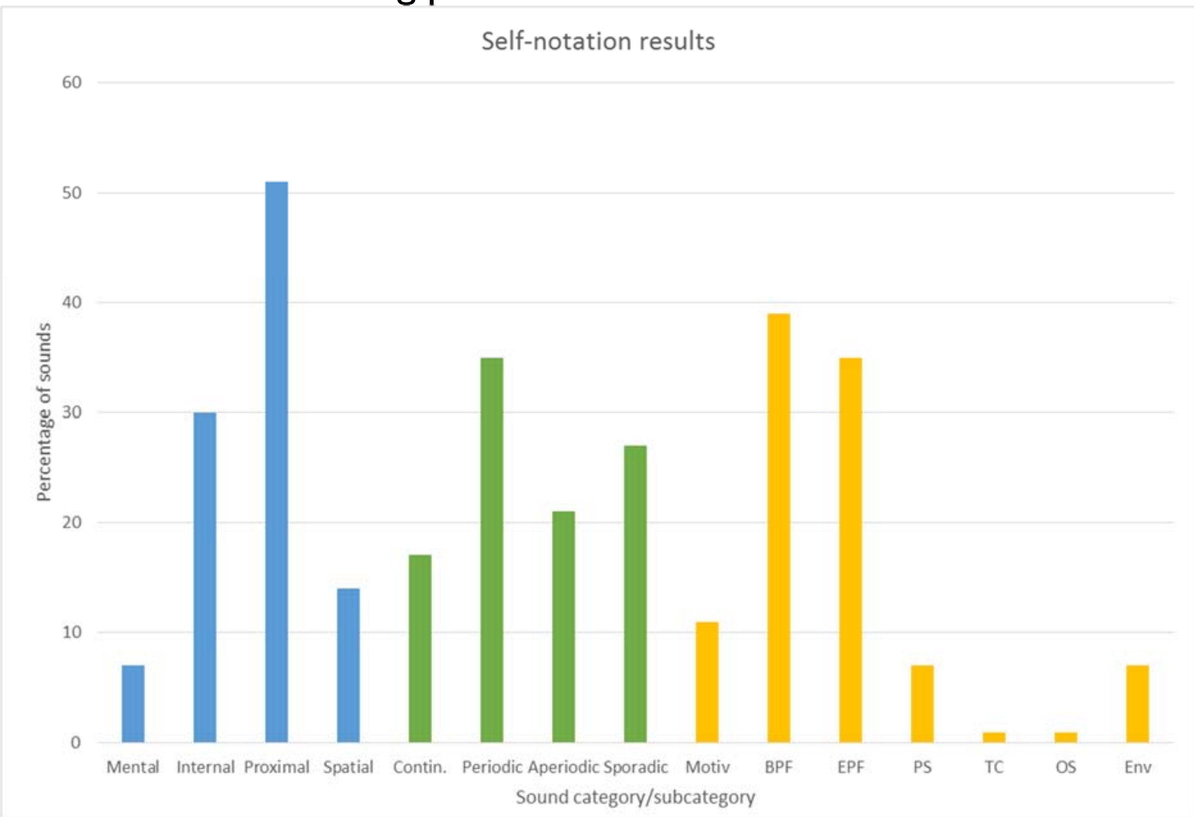

Figure 37: Self-notation, distribution of sounds across categories

Figure 37 shows the distribution of sounds recorded by self-notation. 32 drawings in total were used. Of those, 8 were of the author running. Percentages were calculated in relation to the total number of sounds. As shown in the example notations above, many sounds fall into more than one category, so percentage totals for each category may exceed 100.

In my own self-notations, there are significantly more proximal sounds than other trajectories. Likewise, there are more body performance feedback and equipment performance feedback sounds than other task relationships. The higher percentages of these categories is perhaps driven by the nature of the sporting disciplines that the author pursued. Running, cycling, snowboarding, skateboarding, surfing – these are all mainly solo sports that do not require communication with teammates. These results also suggest that the author was using an associative attentional strategy when performing these activities, as a dissociative strategy would have increased the frequency of mental and/or spatial trajectories.

3.6 Literature survey vs. self-notation

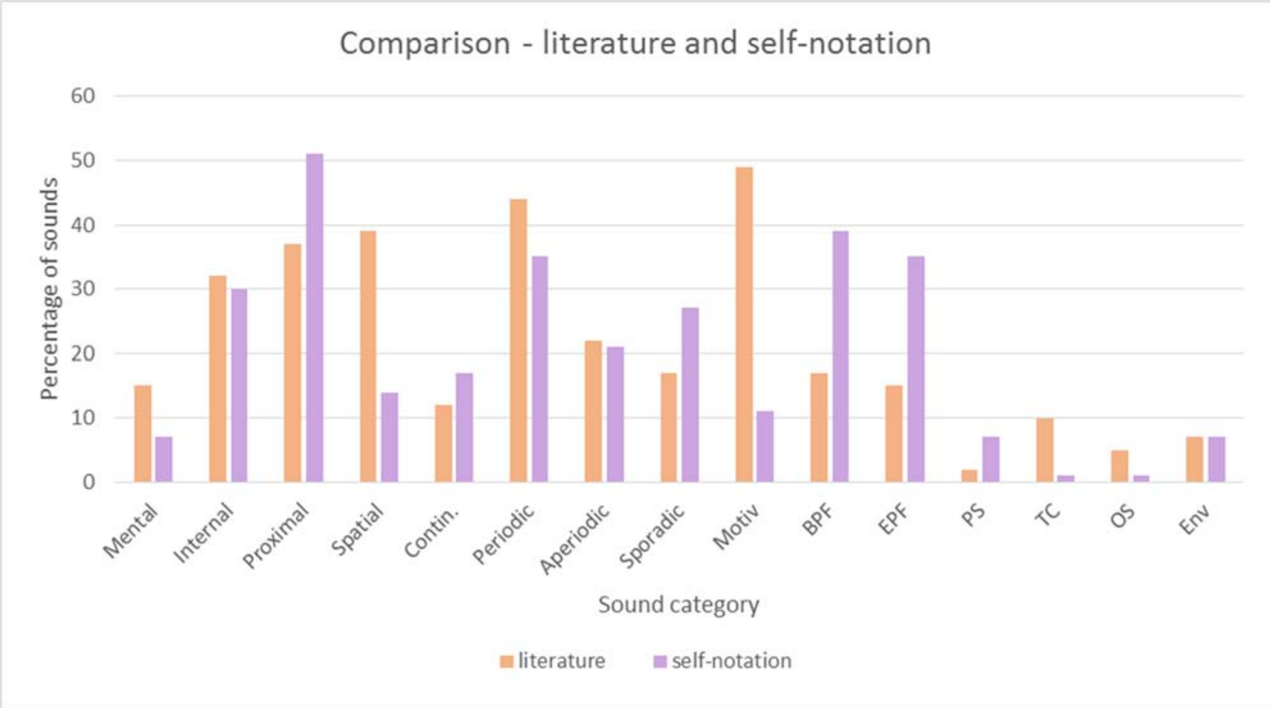

Figure 38: sound categories - comparison of literature and self-notation

Figure 38 shows a comparison between the sounds comprising the literature survey and the results of the self-notation. It should be said that these two data sets are the products of vastly different methodologies, each with their own idiosyncrasies. We cannot expect to generalize these results to other literature surveys or other athletes. However, we do now have a language to begin to make these comparisons, and the development of this language is a finding in itself.

Bearing in mind the "propositional" nature of these conclusions, several important distinctions exist between the author's self-notation and the literature survey. In terms of temporality, the data is roughly equivalent, with a slightly increased emphasis on periodic sounds in the literature. This increase may be due to the prevalence of studies of music in the literature, while the author does not listen to music during sport. The prevalence of music and self-talk studies may also account for the wider gaps in task relationships.

The differences in trajectory are perhaps the most significant. While proximal sounds predominate in the self-notation, in the literature there is a rough equivalency between internal, proximal, and spatial sounds. This could be due to the differences in sporting activities, as the author pursued individual sports most often. This could be due to the lack of "weighting" in the self-notation - perhaps internal and proximal sounds are less important overall, and thus are not the focus of studies or of athlete's self-reporting. A look through the self-notation samples above, though, shows that proximal sounds are frequently the first reported. Further studies could control for this weighing of sounds through various means.

This difference in trajectory could also be due to the notation system itself. In thinking through the various trajectories the author could have been made conscious of previously subconscious or automatic listening processes. Proximal sounds are likely to be attended to by these processes, as they are related to the athlete's own automatic and highly-trained movements and actions. One additional factor could also be the dominance of spatial trajectory listening in most Western cultural experiences of "sound" – music, film, etc. The predominance of "microphones on the outside" in representations of sport could also be a factor. Whatever the reason, the role of proximal sounds in the athlete's sound world deserves further study.

3.7 Conclusions

The categorization scheme and notation system described here have provided a common language to analyse and describe the auditory experiences of athletes. This new analytical framework emerged from a survey of existing literature and generated a new notation system. This system has been used by the author over a period of two years to analyse his own sporting activities. Collectively, this work has enabled the following findings:

- One productive way of categorizing the athlete's soundscape is by trajectory, temporality, and task relationship. Frequency spectrum, the basis for most existing categorization systems for sound, is notably absent from this new system.
- Notation, developed from these categories, can be used to analyse a wide array of sporting disciplines. Here, it has been used by the athlete himself.
- For individual sports, sounds made by an athlete themselves (proximal sounds) are the most numerous. For the author, proximal sounds are likely the most important. This focus on proximal sounds differs substantially from the existing literature.

These new findings, though they apply to only a small slice of athletic experience, suggest that a broader study with a wide variety of athletes has the potential to reach substantial conclusions about the specifics of what athletes hear. The framework described in this chapter gives these future studies a common language and a field-ready analytical tool with which to proceed.

The notation system is not without its drawbacks, however. One deficiency is its "snapshot" quality. While the temporality of individual sounds is somewhat addressed, the system does not deal with the evolution of those sounds over time. In working with photographs or drawings, the fast moving nature of the athletic soundscape is frozen into a single moment or frame. These static representations deny the fluidity inherent in the athletic soundscape. In order to address this problem, sequences of images could be used, with each of these analysed and connected together. Video and animation could also be used to follow particular sounds over time, introducing an overarching temporality that is currently lacking. In pursuing this future work, the current notation system or system of categorization may need to be re-designed to better suit the medium of video.

In my own practice, the notation system outlined here has been essential to my design work. Rather than existing as an end in itself, it has served as the “score” from which new strategies for recording the sporting body have been derived. The location of sounds, their relationship to the task at hand, and their temporal structure all provide a kind of blueprint for recording and mixing the sounds of athletes. To record these sounds, new ways of enclosing, wearing, mounting, and controlling microphones had to be devised. This process of using the notation described here as a “score” for future design work is described in Chapters 4 and 5.

4 Proximal Recording System v1

4.1 Timeline

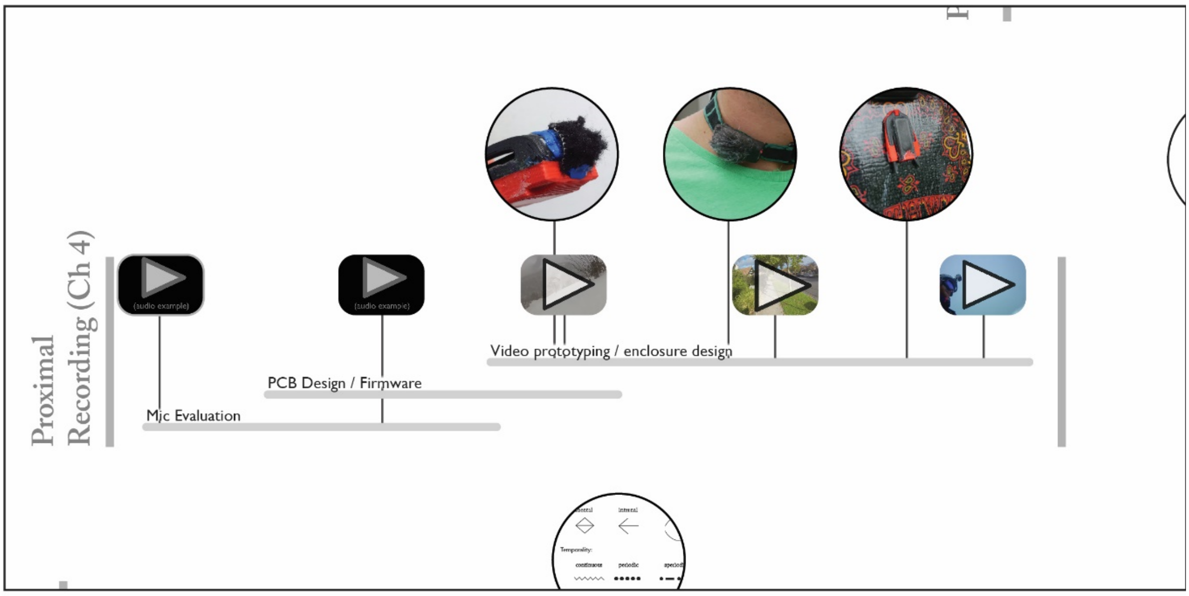

Figure 39: Proximal recording system timeline

4.2 Proximal Recording – introduction

The notation system, sound categories, and analysis framework described in Chapter 3 were developed concurrently with a new system for recording the sounds of sport. The analysis framework revealed new areas of athletic sonic experience that existing methods of recording athletes have ignored. Proximal sounds, in particular, are often neglected by these existing methods. However, in my personal athletic practice and "unrealized sonic imaginings" of sport, these proximal sounds seemed to be vital to the experience, and I wanted to find ways capture them.

This chapter traces the emerging design of a new system for recording the sounds of sport termed "proximal recording." The system consists of wearable microphones placed on the athlete's body and equipment. The design work can be broken down into three broad phases – evaluation of existing microphones, circuit design, and video prototyping/enclosure design. After commercially available microphones are found to be unsuitable, a totally new recording system has been designed from the ground up, using a variety of microphones and audio sensors enclosed in 3D printed cases designed for sport. Multiple microphones are worn by the athlete. The audio recorded by these individual microphones is then mixed in post-production to reconstruct the auditory perspective of the athlete.

My primary method for designing and evaluating these new ways to wear and mount microphones has been through a "video prototyping" process. Using myself as a test subject, equipped with a head-mounted POV camera, I created a series of video pieces documenting various sporting activities. The notation described in Chapter 3 was used as a kind of "score," suggesting the component pieces of my auditory experience to be represented. As a score, these notations have many possible realizations in sound. Their lists of sounds suggest possible mixes, focusing on some sounds and omitting others. In navigating these relationships, I drew on my previous experience realizing the indeterminate works of John Cage, David Tudor, and other composers.

In reality, the challenges of recording sound at an athlete's extremities – with wind, shock, moisture, and other factors at play – meant that only a small subset of the possibilities suggested by the notation-as-score could be realized. These challenges also limited the ability of the system to be tested by other users. Still, the proximal recording system enabled several important findings. Placing microphones close to salient sound sources *can* produce recordings that capture new aspects of an athlete's auditory experience. Electret condenser microphone capsules can be effective in some cases, but in others piezoelectric "contact" microphones are more effective. Proximal recording also uncovered new implications for design, explored in subsequent chapters.

4.3 Trajectories and Techniques

4.3.1 Trajectory determines technique

There are many possibilities in the transition from notation-as-score to the realization of sounds and images. In terms of recording and capturing sound live, the category of trajectory is the most important. As trajectory describes the path that a sound travels between its point of origin and reception, it also describes the location of that sound and the possible techniques that could be used to record it. These links between trajectories and possible recording or studio techniques are outlined in Table 2.

Trajectory	Technique	Distance
Mental	Post Production techniques, voiceover	n/a
Internal	Throat microphone, Stethoscope, Piezoelectric Microphone	0m
Proximal	Close microphone placement, Binaural Recording, Piezoelectric Microphone	0-2m
Spatial	Medium to far stereo microphone placement, Binaural Recording	>1m

Table 2 : Comparison of sound trajectory and recording techniques

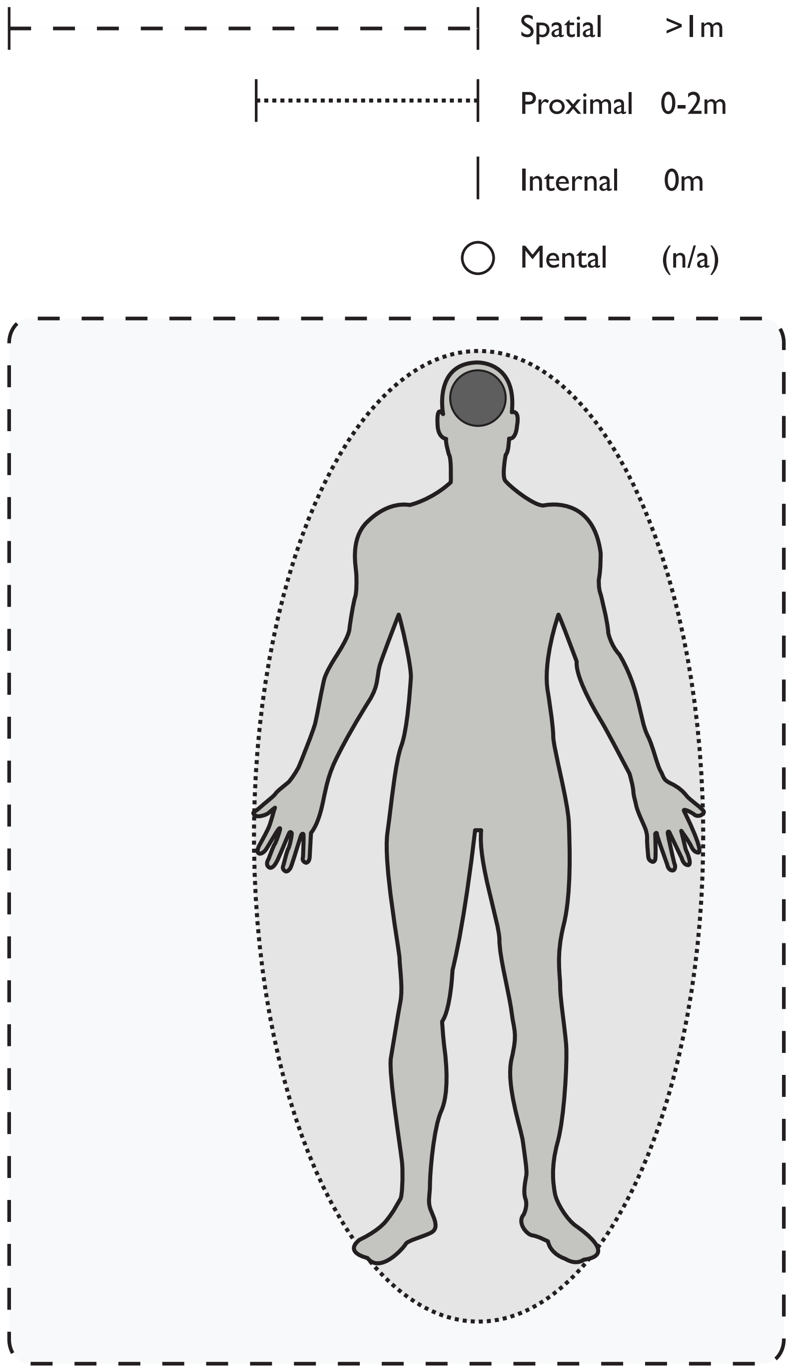

Figure 40: Comparison of sound trajectory and recording techniques - visual

Figure 40 shows a visual representation of the physical distances involved with each trajectory. Each trajectory is described in detail below:

4.3.2 Trajectories

4.3.2.1 Mental

Trajectory Technique Distance

Mental	Post Production techniques, voiceover	n/a

The only category of sounds that cannot currently be captured in real time are mental sounds. These require a voice-over, soundtrack addition, or other post production techniques to be rendered as audio. One can imagine a technique for recording mental sounds where athlete interviews are used to create scripts for these voice overs to add to sound recordings from other trajectories. However, this and other techniques are outside of the scope of the current research. While mental sounds are crucial to athlete experience, the recording techniques described here have been limited to sounds that are physically present in the environment.

4.3.2.2 Internal

Trajectory	Technique	Distance
Internal	Throat microphone, Stethoscope, Piezoelectric Microphone	0m

Internal sounds are difficult to record with standard microphones. However, using specialized audio sensors, these can be recorded in real-time. Stethoscopes are perhaps the best example of this kind of device, with a large sensitive membrane that conducts sound through the skin. Throat microphones, first developed for pilot-to-pilot communication in WWII, use two small microphones placed on either side of the larynx. Inside of many modern throat microphones is a piezoelectric microphone element. Piezoelectric microphones are discussed in section 4.3.3.3. In the proximal recording system, internal sounds have been mostly omitted. However, the ProxiMic, described in Chapter 5, does integrate the capture of internal sounds.

4.3.2.3 Proximal

Trajectory	Technique	Distance
Proximal	Close microphone placement, Binaural Recording, Piezoelectric Microphone	0-2m

Proximal sounds can be recorded with more conventional microphones, as they involve the movement of sound through the air rather than the athlete's body or mind. In general, most proximal sounds originate within a maximum radius of two meters from an athlete's ears. This radius is determined by an athlete's height, arm length, and the dimensions of their equipment. Many proximal sounds are omnidirectional, propagating through the air evenly on all sides. Impact sounds, such as racquet hits and footfalls, are in this category. The human voice, however, is more directional, and will be substantially louder in front of the mouth rather than off to the side or below. One of the challenges involved in recording proximal sounds is how to capture them in a way that moves with the athlete's auditory perspective. Close microphone placement, binaural recording, and piezoelectric microphones are all discussed in section 4.3.3.

4.3.2.4 Spatial

Trajectory	Technique	Distance
Spatial	Medium to far stereo microphone placement, Binaural Recording	>1m

Spatial sounds occur at a distance of roughly one meter and greater. For an athlete, objects closer than one meter generally involve physical contact or coupling, and are either proximal sounds or a combination of proximal and spatial. One feature of spatial sounds is that they often contain reverberations or other audible signatures of the terrain, field of play, or court. In other words, a spatial signature is encoded onto these sounds and becomes integral to their meaning.[157] While many aspects of this spatial signature can be captured with a single microphone (such as frequency effects, and reverberation qualities), these effects are best captured with two or more microphones. Two microphones can capture the subtle variations in phase and amplitude that would be heard at each ear. Binaural miking techniques take this a step further, and are discussed in section 4.3.3.3.

4.3.3 Recording techniques explained

4.3.3.1 "Microphones on the outside" and auditory focus

A full explanation of modern-day microphone and studio techniques is outside of the scope of this PhD.[158] However, it is important to note the links between representations of auditory perspective and microphone selection and placement. As noted in section 2.5.2, the practice of "microphones on the outside" popular in sports broadcasting assumes the auditory perspective of a "super-spectator" capable of both wide-angle and ultra-telescopic auditory foci that follow the camera's movements. Broadcasters use a variety of microphone types and placements to achieve these focal effects. In the design and testing of the Proximal recording system, though, three microphone techniques are particularly important: close miking, binaural recording, and piezoelectric "contact" microphone recording.

4.3.3.2 "Close" microphone placement

One way in which microphones can achieve "focus" is by being placed closer to one sound source than another, thereby increasing the volume of the intended source and reducing the volume of other sources. While actual practice varies widely, close miking is generally defined as a microphone placed 6 to 30 cm from the sound source.[159] In popular music, almost all vocal and instrument tracks are close miked.

4.3.3.3 Piezoelectric microphones

Another way in which recording engineers and musicians achieve focus is through the use of specialized "contact" microphones. These microphones, made from piezoelectric

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157 (Blesser & Salter, 2007)
158 For an introduction to these techniques, see (Rumsey & Mccormick, 2012)
159 (Hodgson, 2010) p 31-33

crystals, respond to physical vibrations with much more sensitivity than air-borne vibrations, and must be physically attached to the sound source they are recording. They are often placed on acoustic stringed instruments, especially for amplified live performances, as they can isolate the often subtle sounds of these instruments for mixing.

4.3.3.4 Binaural recording

Binaural recording provides a counterpoint to the close-mic-and-mix school of audio production. The technique involves placing a small microphone at the outside of each ear canal, not unlike a pair of earbud headphones. In contemporary practice, a "dummy head" is often used. These microphones capture the sound waves that arrive at a subject's ears, including the subtle filtering effects of the ears themselves. To fully experience these subtleties, binaural recordings should be played back via headphones. At certain points in the development of the proximal recording system, binaural recordings using microphones designed by the author have been compared to proximal recordings for reference.

4.3.4 "Proximal recording"

As described above, each trajectory of athletic sound can be recorded and represented in a variety of ways. Professional sports broadcasting, and contemporary recording practice in general, have only addressed a fraction of these various techniques. As proximal sounds are the most numerous and often most important sounds for an athlete, I have chosen to focus my design work on this trajectory above others. How can we effectively capture proximal sounds beyond the athlete's voice? To do so requires microphones to "close mic" a variety of sounds on the athlete's body – sounds that can be later mixed together in different proportions to represent variations in athletic auditory experience. I have termed this technique "proximal recording," and defined it in the following way:

> proximal recording*: a technique for recording athletes that involves multiple microphones worn by the athlete or mounted to their equipment in order to capture important sources of sound in isolation.*

Proximal recording extends the contemporary practice of "microphones on the inside" (section 2.5.3) beyond simply the voices of athletes to include a myriad of other sounds that athletes make. However, it involves placing microphones in physically challenging situations. As examined in section 2.5.3.3, contemporary microphones already have trouble coping when worn on an athlete's chest, let alone their feet or hands. Physically, the extremities move much faster than the trunk, and are subjected to high impact forces. An athlete's equipment is often subjected still higher impact forces. How can the extremities of the body be effectively captured, without noise artefacts from the microphone itself dominating the recording? How can the sounds an athlete's equipment makes be effectively recorded? Once recorded, how can these sounds be effectively mixed together in ways that are informed by the notation system described in Chapter 3? These questions have animated the design of the proximal recording system.

4.4 Proximal recording – modifications to available technologies

To begin the design exploration into proximal recording, existing microphones and sound recorders were tested. An example of one such system, tested by the author, can been seen in Figure 41. The goal of this system was to record the sound of footstrikes while jogging. This recording system uses a commercially available electret microphone capsule, the Panasonic WM-61A, soldered to 1.5 metres of Mogami W2784 Ultraflexible Miniature Cable.[160] These microphones were then covered in open-cell foam and mounted on or near the author's feet. The cables were secured to the author's legs using flexible Velcro straps. A Zoom H4n sound recorder was worn in a hip pouch, which also contained the excess cable. This setup was then tested by the author on short jogs of 5km or less.

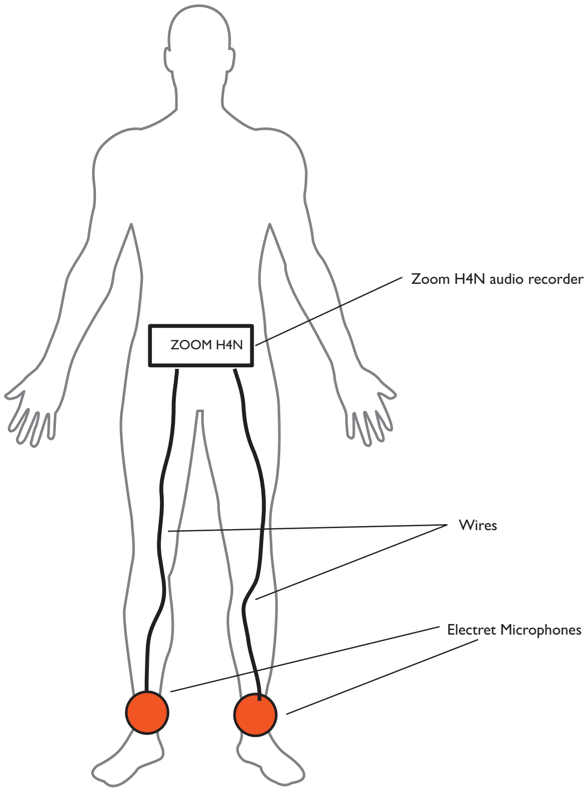


Figure 41: Setup for recording footstrikes

This system was tested on several occasions, with adjustments made to the placement of the microphones in order to reduce wind noise. The best position was found to be tucked into the author's sock just behind the Achilles tendon. These results can be heard in Video 1. However, these recordings were plagued by a number of issues. In terms of sound, wind noise dominates the recording, making it very difficult to hear the sound of the foot strike. The sound of cable movement was very difficult to eliminate, creating low-frequency

[160] (Corporation)

“thumps” on impact. In terms of practicality, the cables were awkward, uncomfortable, and required a long period of time to set up.

Video 1: Audio example of running recorded with foot-mounted microphones - https://vimeo.com/121630009

Figure 42: Footstrike microphones and wire placement

Another preliminary test occurred early in my candidature, as my research area was just beginning to take shape. As a passionate snowboarder for over 20 years, I was interested in recording the sounds that the snowboard makes as it glides over the snow. Wary of potential wind noise, I decided to use a piezoelectric microphone attached directly to the snowboard to see if the sounds that it recorded in any way matched the sounds I experienced as a snowboarder. I fabricated a waterproof contact microphone using a piezo film tab shielded with conductive foil and surrounded with heat-shrink tubing. This microphone was then attached to the snowboard using cloth tape. The Zoom H4n recorder was carried in a hip pouch, with a cable running from the snowboard to the recorder.

Video 2: Audio example of piezoelectric microphone on snowboard - https://vimeo.com/121618263

The sounds captured by the piezoelectric microphone attached to the snowboard were somewhat successful. Sometimes, the sounds produced by the microphone were extremely vivid, capturing many of the nuances of various snow surfaces in complete isolation. The sound of wind, other snowboarders, and my own voice was eliminated, leaving only the sounds produced by the snowboard itself. However, these moments of clarity were obscured by noise artefacts produced by the microphone and the cable. While the microphone amplified the snowboard, it also amplified the cable. Snow and body movements could create pops, clicks, and low frequency noise. Eliminating these sounds in post-production proved very labour intensive and sometimes impossible. To create a usable sequence of audio, many takes were required. An example of a successful edited sequence free from noise can be heard in Video 2. In addition, having to "plug in" to the snowboard when strapping in proved an additional hindrance, especially when riding with a group in the backcountry where time is of the essence.

These preliminary tests point to both the promise of proximal recording and the limitations of existing recording systems in recording the human body. Wired systems are extremely limiting for two reasons. First, they take a considerable amount of time to setup for each use. Second, the wires themselves create undesirable noise artefacts. Existing microphones are prone to wind noise when worn at the extremities, even when wrapped in acoustic foam. One of the primary challenges of proximal recording, then, involves finding ways to unobtrusively place microphones in a variety of locations on the human body while reducing noise artefacts such as wind, tactile rubbing, and wire movements.

4.5 Proximal recording system design

4.5.1 Circuit architecture

To overcome some of the deficiencies of existing possibilities for creating proximal recordings, it was necessary to design new microphones from the ground up. I began by developing a new electronic system that would enable small, battery-powered, short-range wireless microphones, and a larger "base-station" that would record these microphones. The wireless transmitter PCBs were designed to be flexible, permitting either piezoelectric contact microphones or electret condenser microphones to be used as an audio source. The base station was designed to act as an accessory for GoPro camcorders, including a connector that plugged into the back of then-current Hero 2 cameras. It included a micro SD card port for data storage, as well as its own battery. The circuit topology of the final electronics design is shown in Figure 43. The circuits, once designed, fabricated, and programmed, then became a test-bed for designing a variety of microphone enclosures and mountings, described in Section 4.5.3.

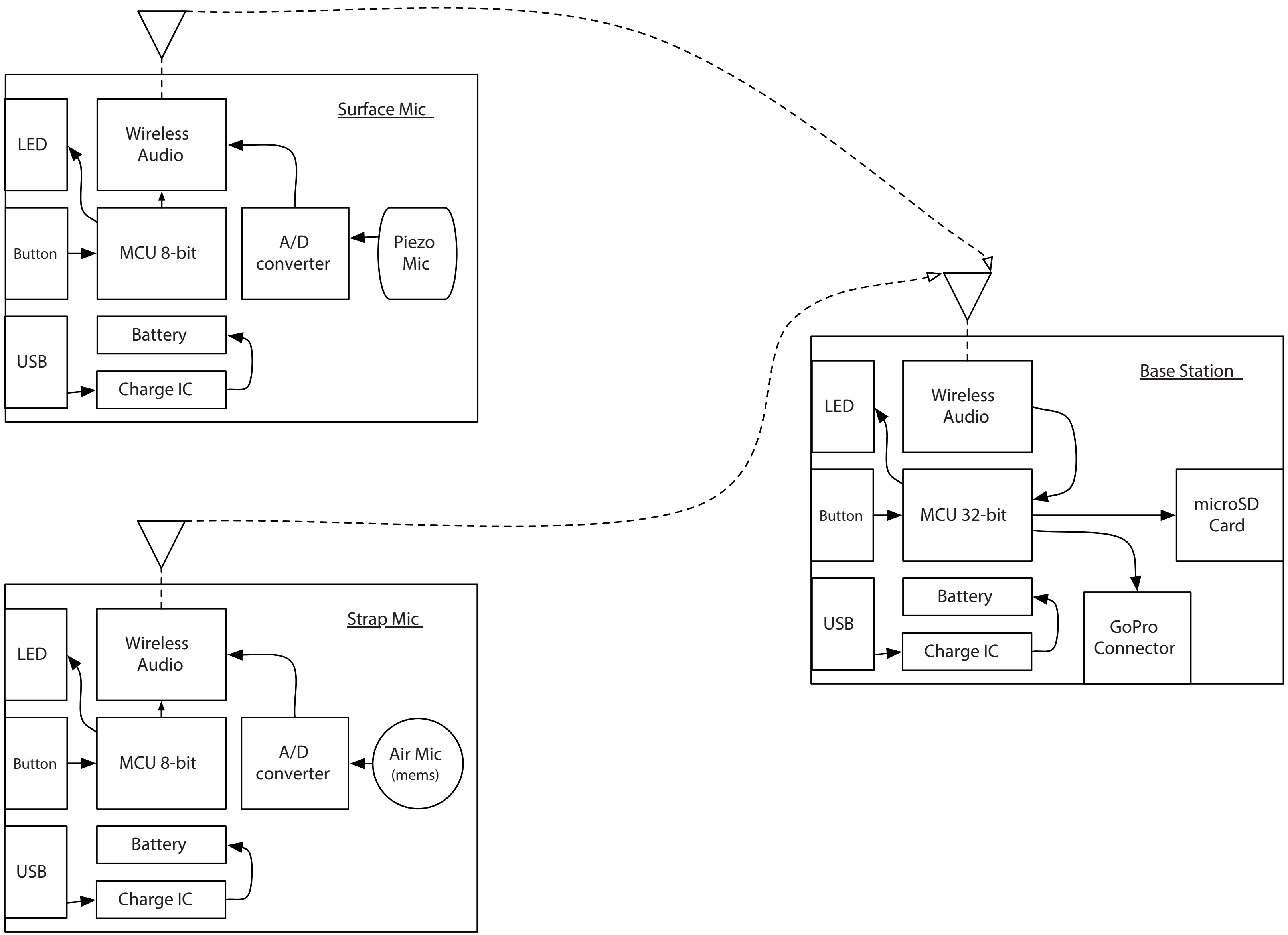


Figure 43: Proximal recording system block diagram

4.5.2 Home fabrication and lab setup

These new microphone designs were fabricated in my home studio using a range of equipment. The PCBs were the only component manufactured off-site. To fabricate the cases, a "Rapman" 3D printer was used. The Rapman was able to print 3D models in PLA plastic with a minimum feature size of 2mm and a tolerance of 1mm. Parts could be printed in both rigid and flexible materials.

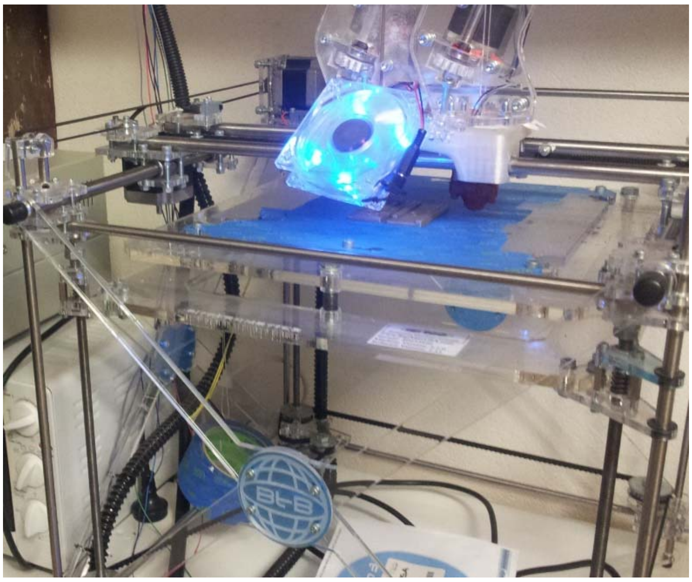


Figure 44: Rapman 3D printer, used in fabricating microphone enclosures

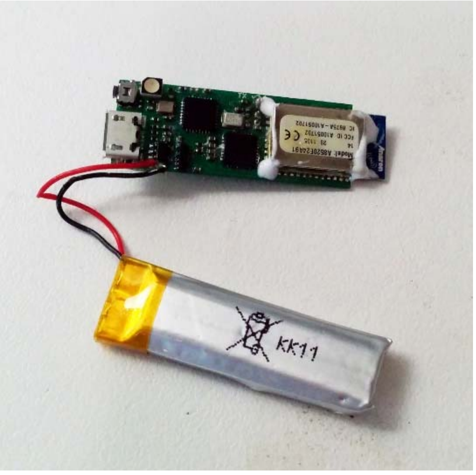


Figure 45: Microphone PCB and battery, assembled

Figure 46: Base station PCB in case

4.5.3 "Video Prototyping"

For 12 months, I used the new electronics platform I had developed to design and test a number of different microphone enclosures. The primary methodology used to iterate through these designs involved the creation of "video prototypes" – short audio-visual works capturing a particular sport. The components of this method are shown in Figure 47. First, the sport was sketched and notated using the system described in Chapter 3. Microphone placements were derived from this notation. If necessary, new microphone enclosures were fabricated to suit these new microphone placements. Microphone enclosures were also modified with fur windscreens and other additions. Following these preparations, recordings of the sporting activity were made over several days or weeks, sometimes with modifications to the system occurring in between recording sessions. Following each recording session, when possible, the audio tracks from the microphones and the video clips were synchronized and the audio was mixed to two stereo channels. Through the creative process of mixing and editing, I evaluated the effectiveness of the microphones and the next steps in the design of the system were determined. This methodology allowed the Proximal Recording system to evolve considerably over a one-year period.

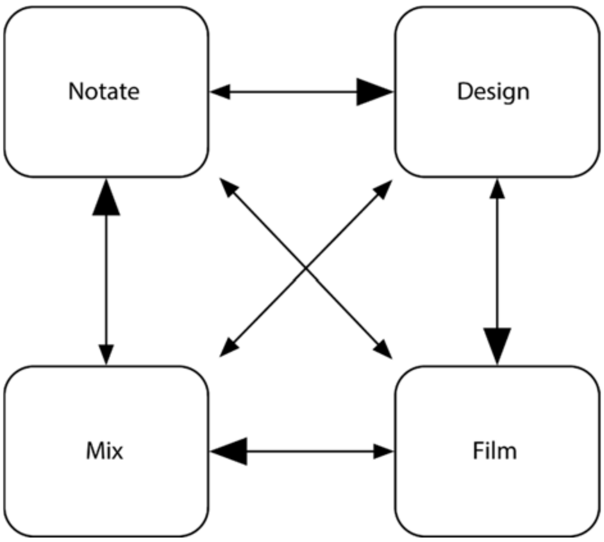


Figure 47: Video prototyping methodology

4.5.3.1 POV video setup

The video prototyping method included capturing "Point of View" video from a GoPro camera mounted on my helmet or chest. This visual perspective served as a reference for the audio mixes created for each sport. The POV camera is an ideal complement for the proximal recording setup described here. As the proximal recording system is worn on the athlete's body and moves with the athlete, so too does a camera worn on the head or torso. At both the consumer and professional level, POV cameras are the current standard in capturing an athlete's visual perspective. The proximal recording system, has thus been optimized to provide the auditory perspective to accompany POV video.

4.5.4 Snowboarding

Test Dates: August-September 2012

Notation Example:

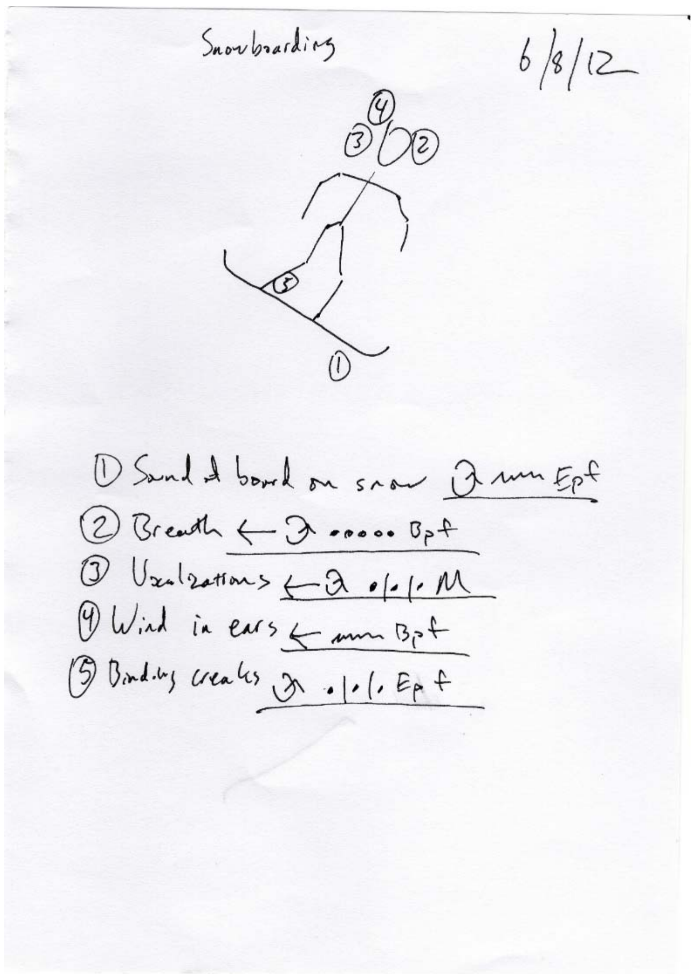


Figure 48: Notation example, snowboarding

Preparations for Recording:

For the first test of the Proximal Recording system, I chose to use Snowboarding as the target activity. I have been snowboarding consistently since 1993 and have achieved an expert level of skill, the most advanced in any sport I currently practice. The video was recorded just outside the boundaries of Mt Hotham Alpine Resort in Victoria, Australia, from September 7 to 9, 2012. An initial visit was made to the site in early August, 2012, in order to assess possible locations for the shoot, address safety concerns, and to create diagrams and notation for subsequent microphone placements.

The notation suggested that the most important sounds for me as a snowboarder were the sound of the board on the snow and the sound of my breath and voice. To capture the sounds of my breath and voice, I designed a microphone enclosure that clipped to my helmet's chin strap and used an electret condenser microphone (see Figure 49). Inspired by the promise of my experiments with piezoelectric microphones and snowboards several months previous, I designed a simple box that was permanently attached to the surface of the snowboard and housed a piezoelectric microphone (see Figure 51).

Figure 49: Clip microphone

Figure 50: Clip microphone on helmet strap

Figure 51: Piezoelectric microphone box on snowboard

Video:

Video 3: Proximal recording, snowboarding example 1 - https://vimeo.com/121618257

Discussion of Video:

The Proximal Recording system was able to capture audio reliably over several days of filming in the snow – an accomplishment in itself. The "board" microphone captured detailed audio of the snowboard's interaction with the snow. Changes in speed, edge pressure, and snow type were all made audible, without wind noise. The clip microphone captured moments of self-talk and other vocalizations quite well, but was less successful in capturing the sound of breathing. While some breathing was captured, noisy artefacts caused by the high winds diminished its effectiveness. Considerable editing was required to obtain a usable audio track. Both the voice and the snowboard were panned in the centre of the two-channel stereo field, approximating their spatial location in the video.

Implications for Design:

Two major design outcomes resulted from this test. The Surface Mic, being attached directly to the snowboard, was clumsy to charge and re-program. In addition, this direct attachment meant building a discrete circuit for each piece of equipment to be recorded. An alternative was needed. In addition, the helmet-strap clip microphone was uncomfortable over long periods and tended to jettison itself from the strap during falls, resulting in frustrating searches through the snow. These deficiencies resulted in the design of a softer, more comfortable "strap" microphone, and a removable "surface" microphone, designed for subsequent videos.

4.5.5 Running

Test Dates: January-April 2012

Notation Example:

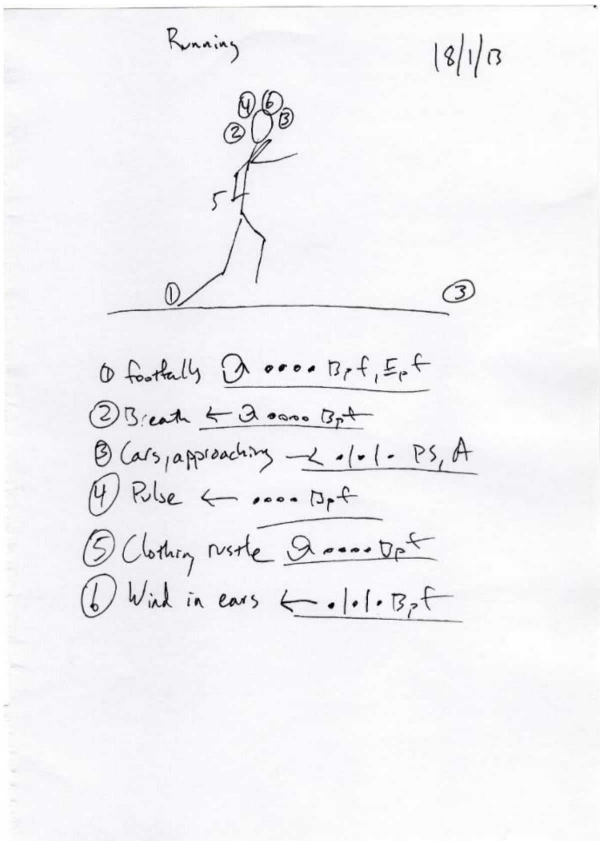


Figure 52: Notation example, running on sidewalk

Preparations for Recording:

Over a period of four months, I tested the microphone during non-competitive road running around the city of Melbourne, Victoria, Australia. I have been running for conditioning and general well-being since 2008, though never competing or running long distances. Following from the notation included in Figure 52, three microphone locations were chosen: one close to each foot to capture footfalls, and one close to the mouth to capture breath and vocalizations.

To capture these sounds comfortably and effectively, I designed the "strap microphone." The strap mic uses a miniature electret condenser microphone attached to the wireless audio transmitter PCB. The enclosure for the strap mic is created from RTV silicone cast into molds printed with the Rapman 3D printer. This silicone-molded enclosure (Figure 53) is then further modified with wind-resistant materials such as fake fur and acoustic foam. Various combinations of these materials were used (Figure 54). The resulting design can be comfortably strapped around neck, leg, arm, or other parts of the body.

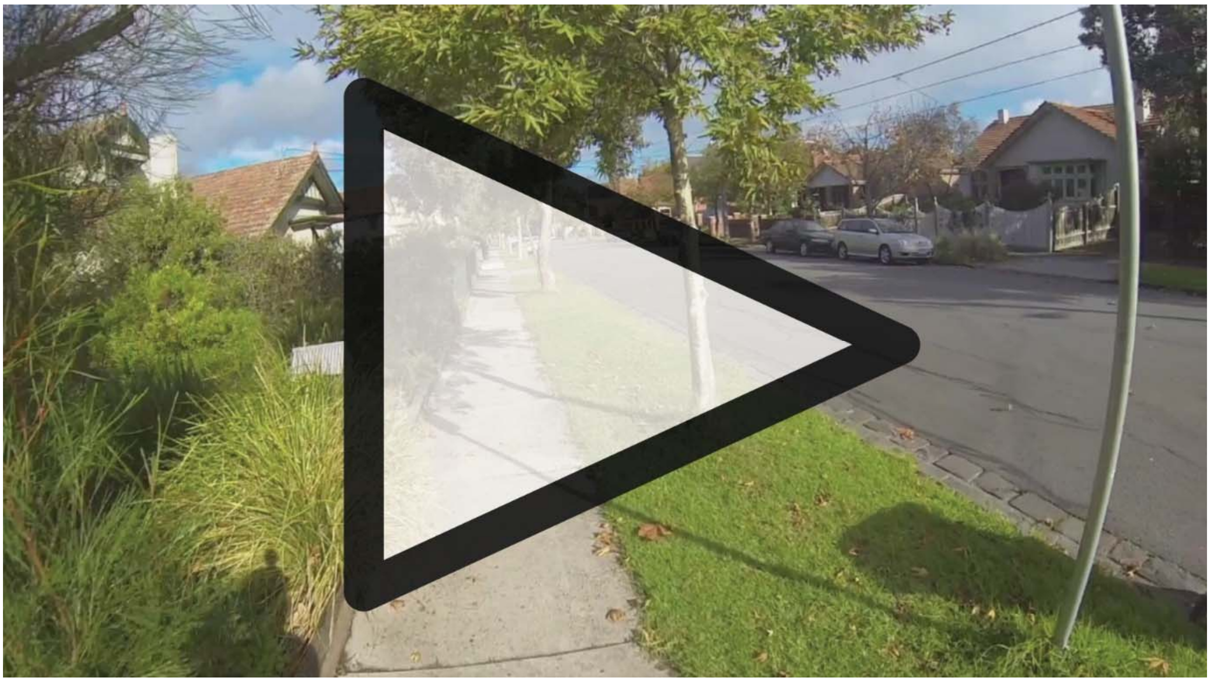
Figure 53: Proximal recording strap mic without windscreen

Figure 54: Proximal recording strap mic with windscreen

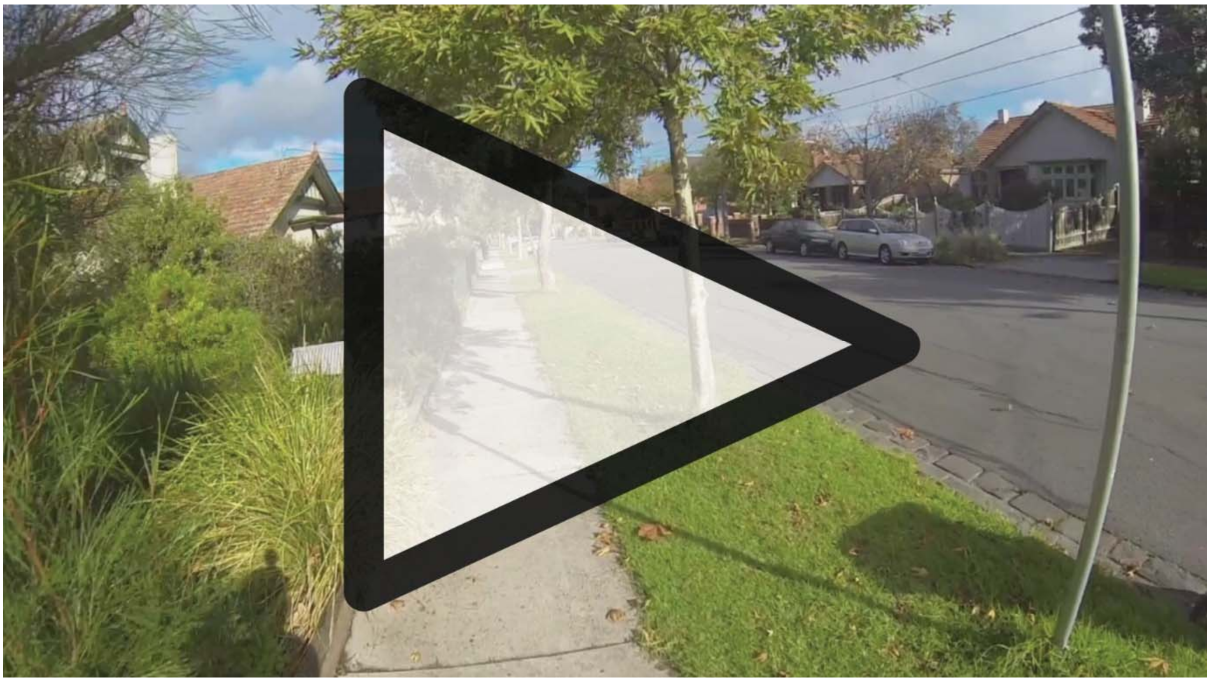
Figure 55 : The ProxiMic Strap Mount with windscreen mounted on the author's ankle

Three Strap Mics were used to record running: one mounted around the neck and one around each ankle. While I was able to record clear audio of my voice and breath using the redesigned Strap Mic, the sound of footfalls was more challenging. The tremendous speed of foot movements caused a great deal of wind noise. This problem was gradually overcome over several weeks of modifying the microphones, gradually enlarging and layering the windscreens. Several mixes were created – one including all three microphones (Video 4), and the other including only the feet (Video 5).

Videos:



Video 4: Proximal recording, running, feet and neck mix - https://vimeo.com/121635967



Video 5: Proximal recording, running, feet microphones only - https://vimeo.com/121640073

Discussion of Video

To spatially mix the audio for stereo playback, in both videos the left foot was panned entirely to the left, while the right foot was panned entirely right. In Video 4 the neck strap microphone track was positioned in the centre. The level of the voice in relation to the feet could be adjusted. Mixes where the feet dominated tended to be more tactile and brought out issues of running form and technique. Mixes where the head dominated tended to communicate levels of exertion, breath control, and emotion. The affective qualities of the different sound mixes influenced the perception of the video, focusing the viewer down towards the running surface in Video 5 and behind the camera's field of view (towards the head and body) in Video 4.

4.5.6 Running - Binaural vs Proximal

4.5.6.1 Binaural Recording setup

As mentioned in Section 5.2.6, binaural recording provides an interesting alternative to proximal recording. In order to compare proximal recordings with binaural recordings, I developed a set of binaural microphones that would be able to withstand the rigors of sport. These microphones used a water-resistant electret microphone capsule from CUI Manufacturing soldered to 1 metre of Mogami W2784 Ultraflexible Miniature Cable. These capsules were embedded in the plastic ear-pieces from a pair of conventional earbud headphones, which were in turn coated in Sugru RTV silicone rubber and custom-molded to the author's ears. A small piece of wind-insulating fur was then adhered to the microphone.

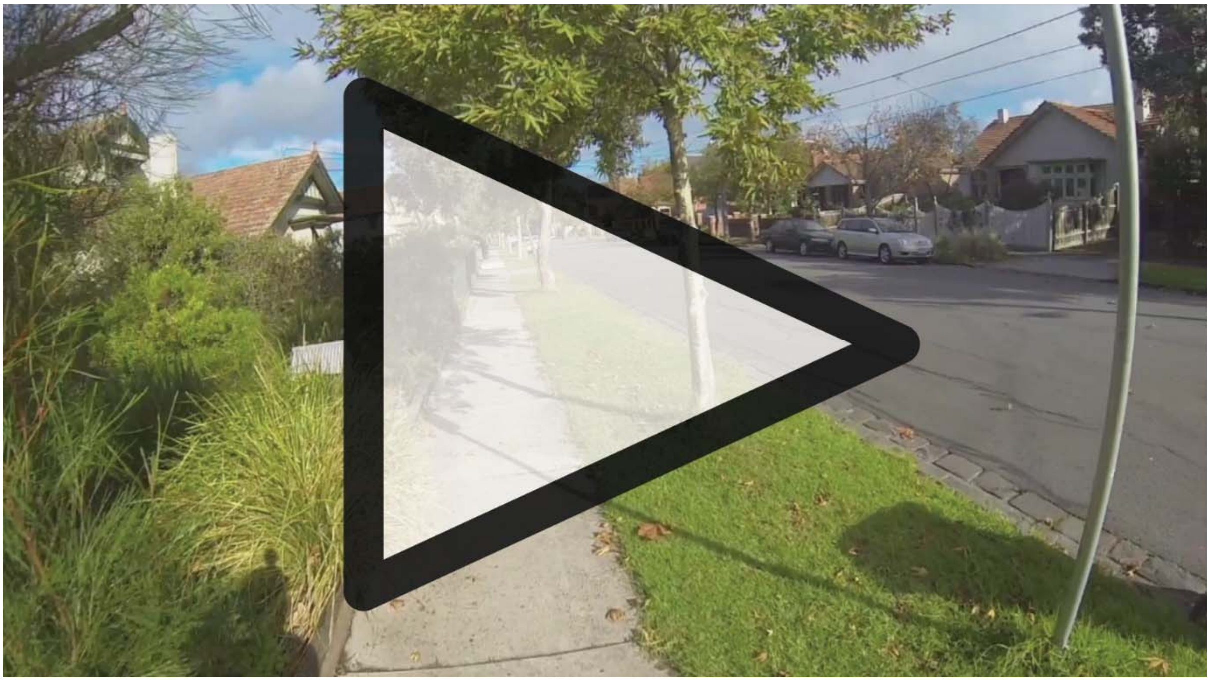
To provide further wind insulation, a helmet was modified with fur ear-flaps. This two-layer wind insulating design was effective at reducing wind noise at speeds up to roughly 25kph.

Figure 56: Binaural recording microphones

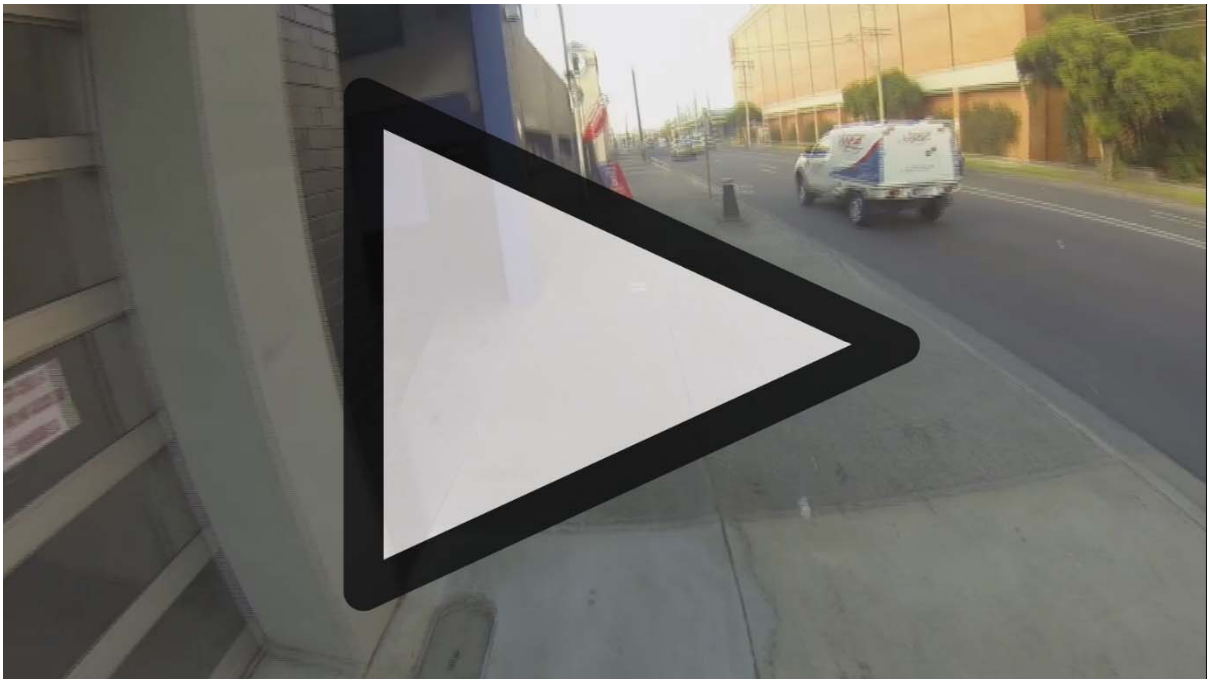
Figure 57: Binaural recording windscreens, worn by the author

4.5.6.2 Comparison

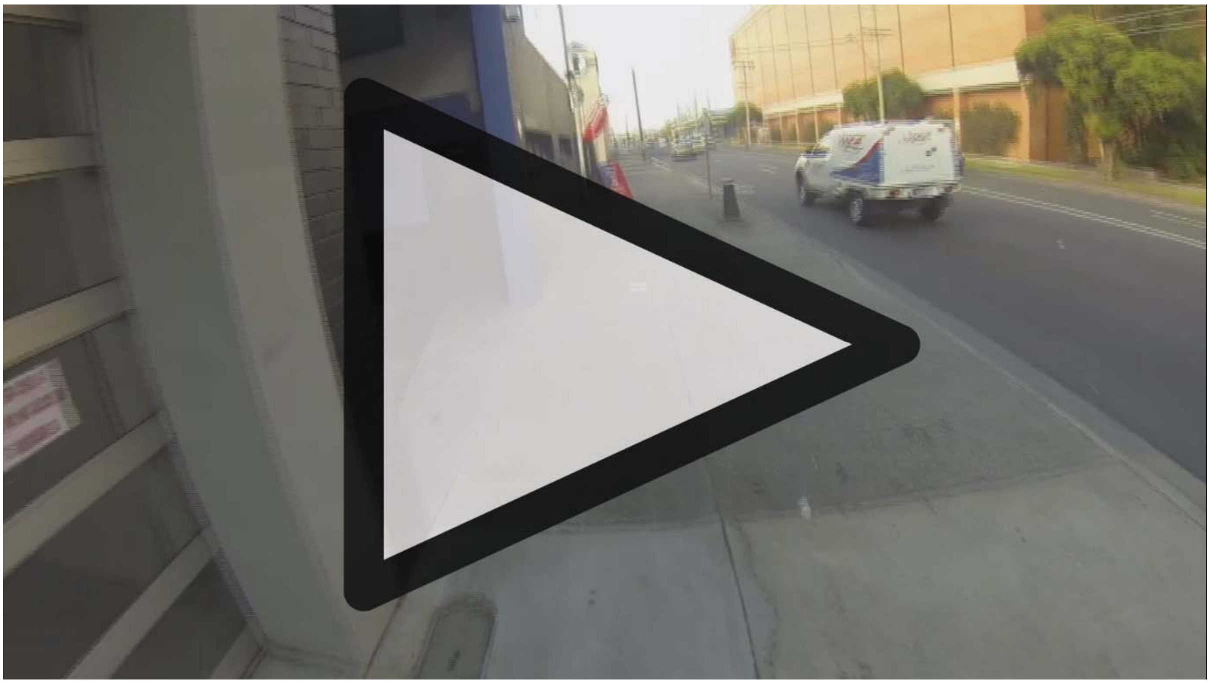
Video 6 and Video 7 are binaural recordings made with this setup.



Video 6: Binaural recording, running, compare to Video 4 and Video 5 - https://vimeo.com/121635963



Video 7: Binaural recording, running, high ambient noise, compare to Video 8 - https://vimeo.com/121635968



Video 8: Proximal recording video, running, high ambient noise, compare to Video 7 - https://vimeo.com/121635969

Binaural recordings are able to convey a wonderful spatiality, especially when listened to on high quality headphones. However, the mix of sounds between proximal and binaural recordings has some notable differences. For example, the sounds of footfalls are significantly louder in relation to the breath in the proximal mix of Video 4 than they are in the binaural recording of Video 6. These differences suggest that my attention, as both an athlete and a sound recordist, may give the feet additional perceptual weight.

Another test of binaural and proximal recordings was made while running next to a noisy main road in traffic. This is an environment where spatial sounds dominate. In the binaural recording (Video 7), the sound of my footfalls and breath are almost completely drowned out by the sound of passing cars. In the proximal recording (Video 8) both footfalls and breath are audible. These results make sense given the physical arrangement of microphones “close miking” both footfalls and breath, and yet they have interesting ramifications – *the sound that arrived at my ears did not necessarily match my perception*. The notation created when recalling this section of the run is shown in Figure 58, and prioritizes both breath and footfalls over the sound of cars. In some situations, proximal recordings have the flexibility to create representations of sound that can be adjusted to suit perceptual realities. Given the emphasis on “perfect fidelity” in sound recording, this somewhat foregone conclusion deserves to be stated.

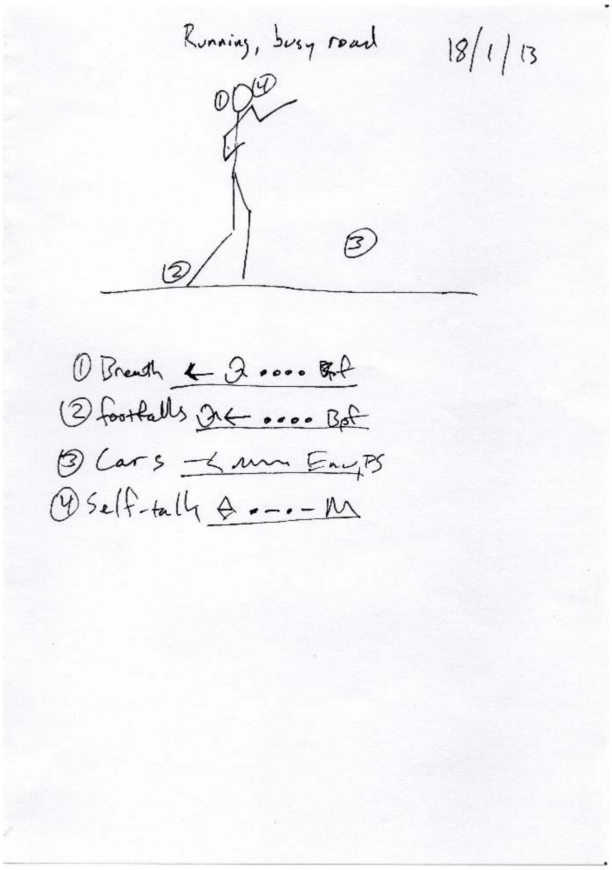


Figure 58: Notation example, running, busy road

4.5.7 Snowboarding – take 2

Test Dates: August 2013

Notation Example:

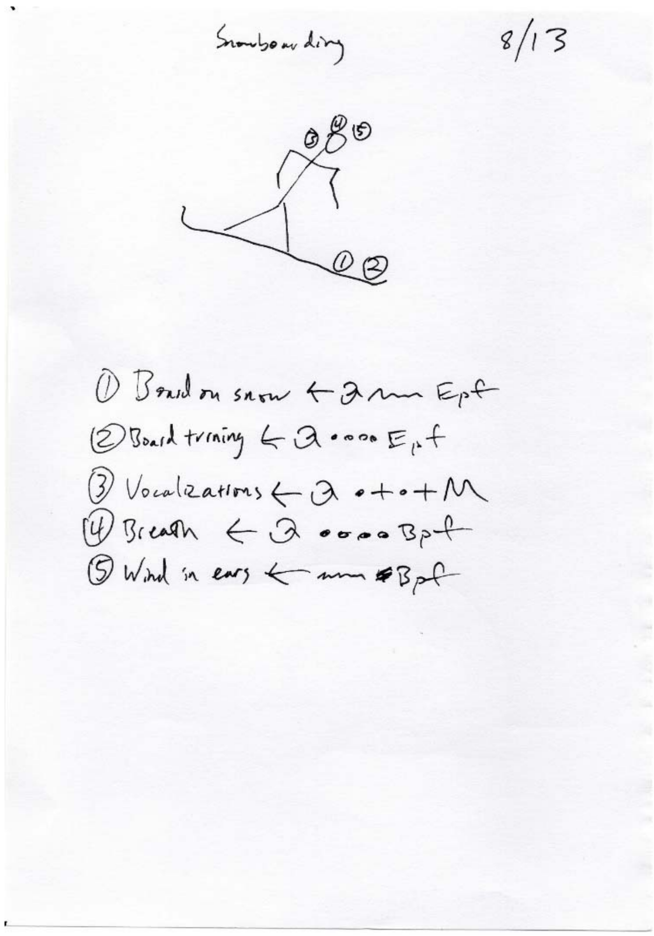


Figure 59: Notation example, snowboarding

Description of Preparations:

Returning to snowboarding after a year of development allowed for different aspects of the proximal recording system to be refined. Again, tests took place outside the boundaries of Mount Hotham Alpine Resort in Victoria, Australia, with locations determined by snow conditions and weather. The notation was developed while snowboarding in the weeks and months before the recording was made. This notation was largely unchanged from the previous year. In addition to creating notation, part of the preliminary work involved recording snowboarding using strap microphones placed not just on the neck but in a variety of locations such as the upper arm (Figure 60), lower leg, and forearm. Due to the speeds involved in snowboarding, each of these microphone placements produced significant wind noise that drowned out the proximal sounds on the notation.

Figure 60: strap microphone placed on upper arm, snowboarding

One of the main design iterations produced in advance of this recording was a system for attaching and removing the “surface” microphone for piezoelectric recordings of the snowboard itself. To accomplish this, a clip and microphone housing were designed to allow the surface mic to be removed for charging. The clip adhered to the surface of the snowboard using Scotch VHB tape. The microphone housing was printed in rigid impact-resistant PLA plastic, while the clip was printed in more flexible PLA of roughly 90a durometer. The clip and housing are shown in Figure 61.

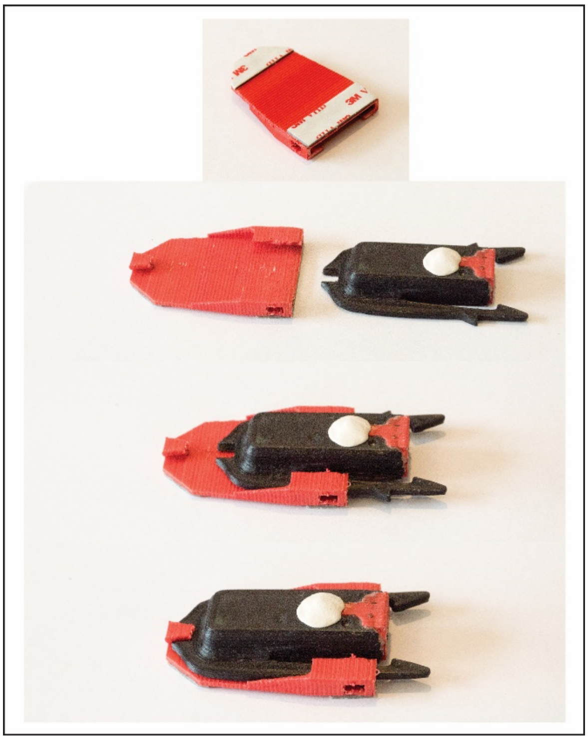


Figure 61: surface microphone and clip

Video 9 was recorded using a strap microphone around my neck, and a surface microphone on the snowboard.

Video:

Video 9: Proximal recording, snowboarding example 2 - https://vimeo.com/121618259

Discussion of Video:

The proximal recording system was again able to function in the backcountry in cold and wet weather. As can be seen in the video, the system survived several crashes and continued to function. The strap mic around my neck achieved mixed results. While it succeeded at recording my vocalizations while riding, it failed to adequately record the sounds of my breath, omitting one important sound from the notation. Breath sounds *were* recorded during uphill climbs and in the moments following a run. However, the sound of wind when riding raised the noise floor of the recording above the level of breathing. In this case, recording the breath of a fast-moving athlete remained difficult to achieve.

The sound of the snowboard moving across the snow remained the most important sound in terms of notation, experience on the snow, and when mixing and editing the video. The recording technique for this video tested two techniques for recording the sound of the snowboard. The first was a Surface Mic placed on the snowboard itself. The second was a strap microphone worn around my shin. Both microphones captured sounds of the snowboard, but in different ways. The Strap Mic captured not only the sound of the snowboard but other environmental sounds, such as the author's voice. Some wind noise was present. The Surface Mic was able to capture the nuanced sonic detail of the snowboard moving along various snow surfaces. When the snowboard leaves the ground during a jump, the Surface Mic track is largely silent except for the sounds made by movements of the bindings. In this case, the Surface Mic provides maximum flexibility and sonic detail when recording the sound of a snowboard.

Implications for Design:

Coming back to the snow after a year's worth of design work revealed much about the ProxiMic system. The Strap Mic was able to effectively record my voice while snowboarding, but not my breath. In capturing the sound of the snowboard itself, the Surface Mic continued to be the most effective technique.

4.6 Proximal Recording System v1

4.6.1 Surface Microphone

The Surface Microphone contains a piezoelectric microphone, housed in a durable plastic enclosure fabricated by a 3d printer. This enclosure snaps into a clip, which in turn is mounted to an object using Scotch VHB tape. The Surface Mic can be detached from the object for charging and programming, re-attached for recording, and used on multiple objects.

Figure 62 : The Surface microphone, mounted to the bottom of a skateboard

4.6.2 Strap Microphone

The strap microphone contains an electret condensor microphone element housed in a soft silicone enclosure looped on to an elastic strap. It can be worn in a variety of ways on the body – around the neck, arm, or leg – and can also be mounted to various pieces of athletic equipment, such as a bicycle or racquet. It has an integrated fur windscreen, with slip-on windscreens for additional wind protection.

Figure 63 : The ProxiMic Strap Microphone, worn around the neck

4.6.3 Base Station

The Base Station contains a wireless audio receiver, micro SD card connector, headphone jack, and the required circuitry to properly store the audio signals from the microphones as WAV format files on the SD card. While the base station works in stand-alone mode, it also connects to GoPro brand cameras using the manufacturer's 30-pin rear connection port. When connected, the Base Station automatically starts and stops recording when the camera does, enabling easier sync with video and simpler file organization.

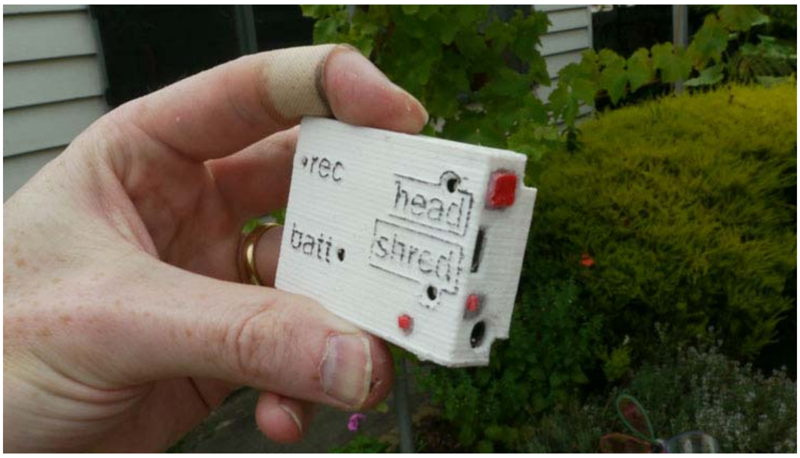


Figure 64 : The ProxiMic Base Station

4.7 User Testing (informal)

As the proximal recording system developed, I sought to test it on other athletes. Due to difficulties with the system itself and the challenges of integrating with professional athletes and filmmakers, these tests did not advance past the informal stage. As the system proved very suitable for snowboarding, there were two attempts to test with professional snowboarders. A Strap Mic, Surface Mic, and base station were sent to a leading ski and snowboard film production company in Wyoming. Despite the company's best intentions, the system proved too complicated to integrate into their production and was sent back. Additionally, a test was organized with professional ski and snowboarders in Japan. However, a flaw in circuit design that manifested at low temperatures under -10C meant that the Strap and Surface microphones only transmitted intermittent audio when on snow, leading to the cancellation of the test.

Locally, the system was tested with a Victorian Football League Australian Rules Football club. Two players were recorded during competition. Due to the terms of a verbal agreement with the club, neither the club nor the players can be identified. However, audio examples are permitted, and can be heard in Video 10. One of the requirements that the club made was that the system needed to be worn entirely under the athlete's clothes. A single strap mic and base station were placed in the players GPS holsters, a spandex undergarment with a pocket between the shoulder blades. This less-than-ideal microphone placement meant that the audio captured during the game had noise artefacts from the players' clothing. While the relationship with the club did not advance to more formal user testing, two valuable conclusions could be drawn from the test. The first is a sonic glimpse of the tremendously variable sound environment on the football field. While much time is spent running or standing still in relative quiet, when a player handles the ball the sound of teammate voices and body impacts is very loud. The sound levels distorted the Strap Mic. The second conclusion is that wearable microphones need to be extremely versatile to work in a professional context where cosmetic concerns override auditory concerns.

Video 10: Audio example, strap microphone, Australian Rules Football - https://vimeo.com/121640074

4.8 Conclusions – signal to noise

The newly-design proximal recording system proved an effective way to record my own athletic activities. It worked well as a companion to commercial Point of View cameras, and provided substantial improvements over existing technology. The development of the proximal recording system enabled the following findings:

- Recording proximal sounds can be effectively accomplished with body-worn microphones.
- Proximal sounds can also be recorded using piezoelectric “contact” microphones mounted directly on the athlete’s equipment
- Proximal recording, through isolating individual sounds, offers flexibility in mixing and post-production that allow the sound mix to align with the athlete’s perceptual reality.
- Recording an athlete’s body at the extremities is fraught with difficulties. Certain sounds, such as the athlete’s breath, can be difficult to capture during dynamic movements or high speeds.

Recording an athlete’s body at the extremities is fraught with difficulties not easily overcome by existing technology. The development of lightweight wireless microphones removed the noise and inconvenience of wired microphones, but wind noise was still a challenge. One effective way of recording an athlete’s equipment is to use piezoelectric “contact” microphones, isolating the sound made by the equipment from wind, environmental sounds, and the athlete’s own proximal sounds. This isolation allows for maximum flexibility in mixing the collection of proximal sounds in ways that are in tune with the athlete’s perceptual reality. This flexibility is not afforded by other techniques, such as binaural recording.

One interesting preliminary conclusion is that isolating individual sounds in the athlete's soundscape affords greater creative freedom when mixing. The more isolated a sound is, the more finely its level and spatial position in the mix can be adjusted to suit the notation of the activity or creative concerns. Isolation can be understood in two ways – the first as isolation from other sounds in the environment, the second as isolating from the artefacts created by the microphone itself such as wind noise. The athletic auditory experience is multi-layered – proximal recording begins to peel these layers apart. To use Bruno Latour's language, it articulates these layers of sound events.

Certain layers of the athletic auditory experience remained especially frustrating to capture and reveal, however. The breath of an athlete during dynamic movements remained especially obstinate. In addition, the wide dynamic range of some sounds, such as the voices of Australian Rules Football players, overloaded the existing design. These and other design challenges formed the criteria for designing the successor to the proximal recording system.

5 The ProxiMic

5.1 Introduction and Chapter Summary

In October 2013 I began developing the second version of the proximal recording system to address some of the design challenges revealed by version one in chapter four. On the whole, I used a similar design methodology: creating a new electronics design which became a platform for experiments in microphone enclosures and mounting systems.With this second version, the surface mic, strap mic, and base station were all condensed into a single device. This device, called the ProxiMic, features both a piezoelectric and electret condenser microphone in the same housing, recording both to internal flash memory. The development timeline for the ProxiMic can be seen in Figure 65.

To highlight important moments in this design, this chapter is structured according to four significant design revisions in the development of the ProxiMic. Versions 1 and 2 were less successful, attempting to cut wind noise through the use of multiple microphone elements. Version 3 was the first design to integrate both piezoelectric and electret microphones in the same housing. Version 4 modified this design to better capture the internal sounds of athletes when worn in direct contact with the skin.

The ProxiMic was tested with two users in a participatory design trial. The design trial involved a multi-stage process where users were interviewed, recorded during sport, and then created their own mix of these recordings. In both cases, these users favoured a mixture of proximal sounds and internal sounds. These self-mixes added additional points of articulation to the athlete's sound worlds. This design trial shows promise for a larger scale investigation.

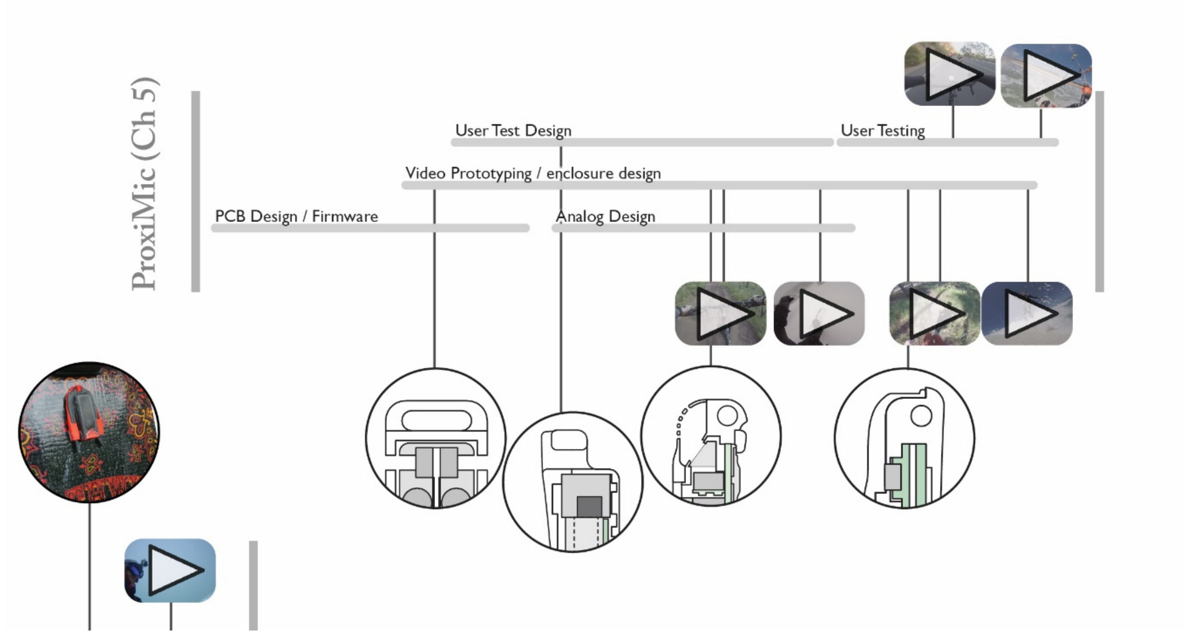


Figure 65: ProxiMic development timeline

5.2 Design Elements

5.2.1 ProxiMic Design Specification

The results from testing the surface mic, strap mic, and base station when evaluating the proximal recording system outlined several next steps. To summarize, these included:

- a more versatile system for mounting and wearing the microphone
- a more reliable sound recording technique to supplement or replace wireless audio
- increased resistance to wind
- wider dynamic ranges for piezoelectric and electret microphones
- waterproof to accommodate water sports, sweat, and other environmental extremes

To address these design issues, a new circuit architecture was engineered and fabricated. The overall circuit topology can be seen in Figure 66. Most notably, the circuit features four possible channels of audio recording and on-board flash storage, eliminating the need for wireless audio. Additionally, a USB port was included to download the recorded files and charge the battery, buttons were placed to start and stop recording, and LED lights displayed the recorded state. These features were designed on to a 6-layer PCB measuring 15mm by 41mm by 1mm, with components mounted on both sides.

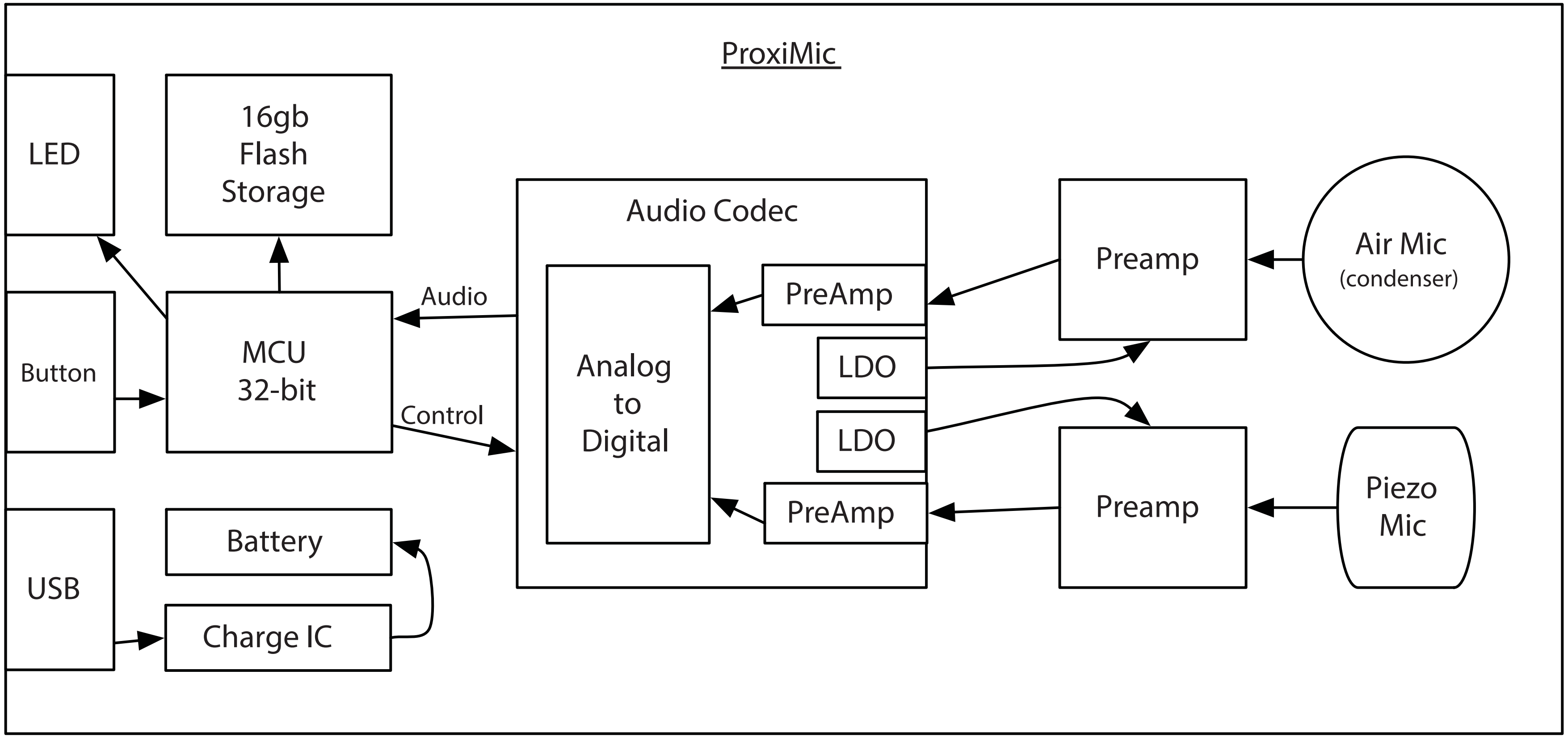


Figure 66: ProxiMic circuitry block diagram

5.2.2 ProxiMic – circuitry

While certain aspects of the design, such as the battery charging circuitry, LED display, and Buttons involved commonly practiced design techniques,[161] two main features are worth discussing in detail:

5.2.2.1 Four-Channel Modular Analog Front-End:

Using a simple wire-mount system with four connection points (see Figure 67), the main circuit board could be configured to record up to four channels of audio at a time. These were connected to an Analog Devices ADAU1772 Codec, with four channels of analog to digital conversion and two independent power channels under digital control (known as “Mic Bias” channels).[162] Connections between analog inputs, power, and ground, could be reconfigured by replacing components on the main board. As the ADAU1772 has its own internal pre-amp, with a range of -12db to +39db, the gain of each channel could be adjusted digitally in real-time.

This configuration allowed for a modular design. Up to four microphone capsules could be connected to the main board directly. Alternately, independent analog pre-amp PCBs could be designed and connected to input, power, and ground channels without having to re-design the entire main board. This modular system had a number of benefits, including the ability to experiment with a host of different microphone capsules and piezoelectric elements. Each substantial revision of the case design included a companion revision of the analog circuitry.

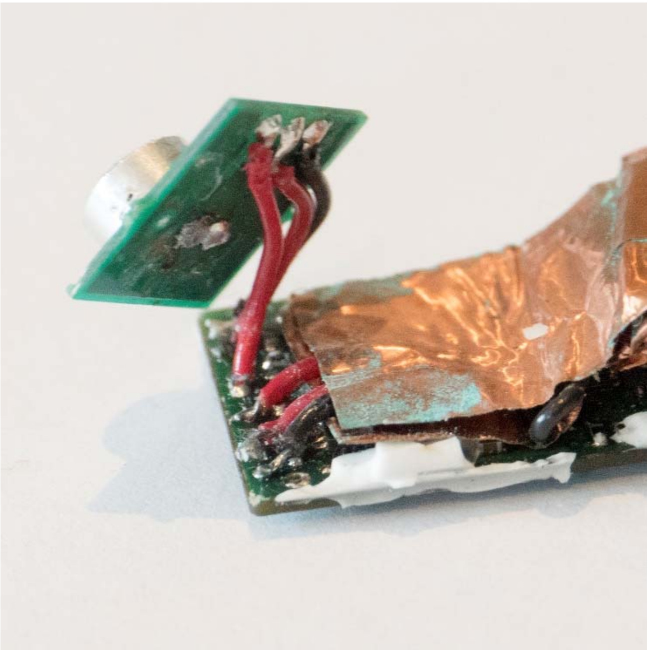


Figure 67: ProxiMic analog connectors and electret microphone preamp

[161] (Prasad, 2009), (White, 2011)
[162] (Devices)

5.2.2.2 On-Board Flash Storage and DSP:

The analog front-end and A/D converter were connected to a microcontroller with DSP capabilities, and a micro SD card that provided 16 gigabytes of internal storage. The channel format and sample rate were configurable through updating the embedded firmware of the device. When plugged in to a computer via a micro USB port, the files could be downloaded for editing and mixing. To synchronize audio across a number of ProxiMics, a highly accurate crystal oscillator was used to provide a clock for the sample rate of the audio. Several hand claps could provide a point of synchronization, as could software such as Pluraleyes by Red Giant.[163]

In ProxiMic versions four and five, the on-board DSP was used to provide real-time compression for the incoming audio signals. Compression was achieved through adjusting the gain for each channel of the ADAU1772 codec, not through applying digital signal processing to the incoming signal. Due to the tremendous variations in sound levels present in an athlete's environment, this compression helped to extend the dynamic range of the microphones during moments with especially loud sound levels.

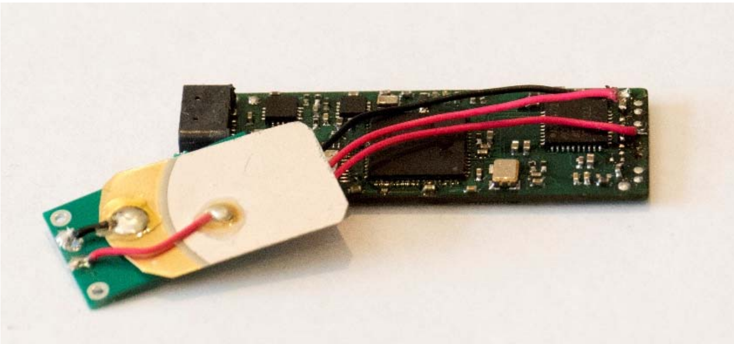


Figure 68: ProxiMic circuit, top side

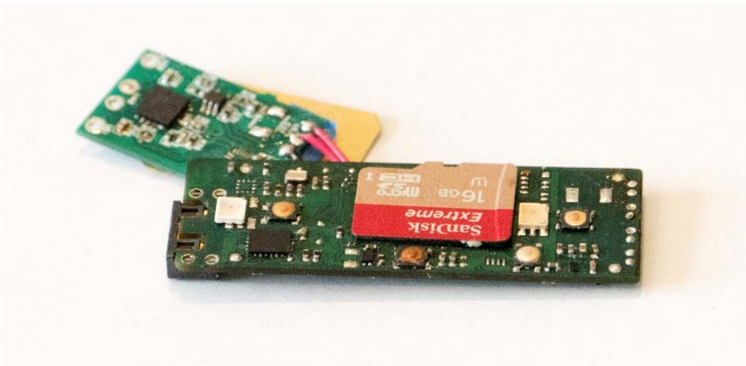


Figure 69: ProxiMic circuit, bottom side

5.2.3 ProxiMic fabrication techniques

The techniques used to fabricate the ProxiMic improved upon those used for the proximal recording system. Circuits were assembled using a custom-made pick-and-place

[163] (RedGiant, 2013)

tool with a vacuum pickup nozzle (Figure 70). This approach helped expedite the difficult task of placing over 100 components on a miniature circuit board. Enclosures were still 3D printed, although these prints were performed on a Miicraft 3D printer capable of much higher resolutions than the Rapman used previously (Figure 71). These prints were then used to create silicone moulds for polyurethane resins (Figure 72). As these resins are available in a number of different durometers, this technique allowed for an expanded range of material choices. The ability to combine hard and soft materials proved crucial in the final evolution of the design.

Figure 70: Manual pick-and-place circuit assembly machine

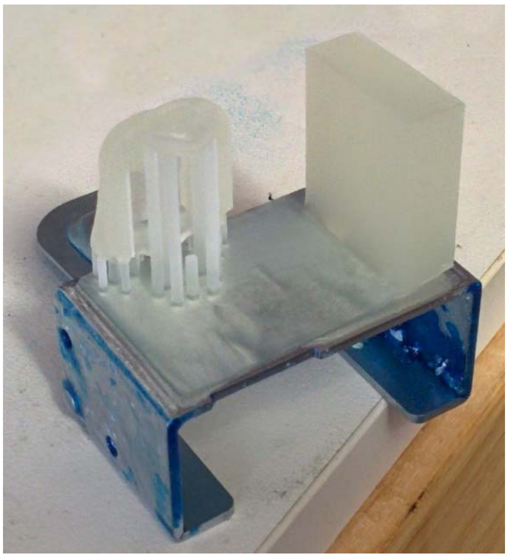


Figure 71: 3D prints from the Miicraft 3D printer

Figure 72: Silicone tooling and polyurethane resins for the ProxiMic

5.2.4 ProxiMic – mixing techniques, re-spatialization

An additional element in the suite of expanded techniques used to develop the ProxiMic involved the mixing and spatialization of the sounds recorded. As shown in Figure 73, ambisonic spatialization techniques were used. The position of each microphone could be encoded according to its elevation and azimuth from the listener. These positions could then be decoded for a variety of speaker arrangements. For some videos, the position of individual microphones was automated to move during playback. An example of this automation data for one foot during trail running is shown in Figure 74.

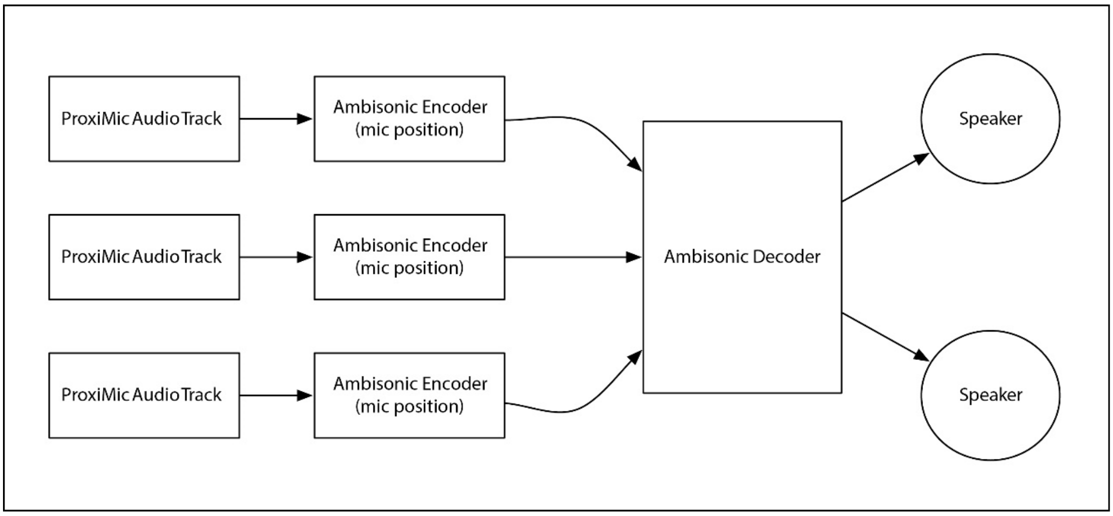


Figure 73: Spatialization block diagram

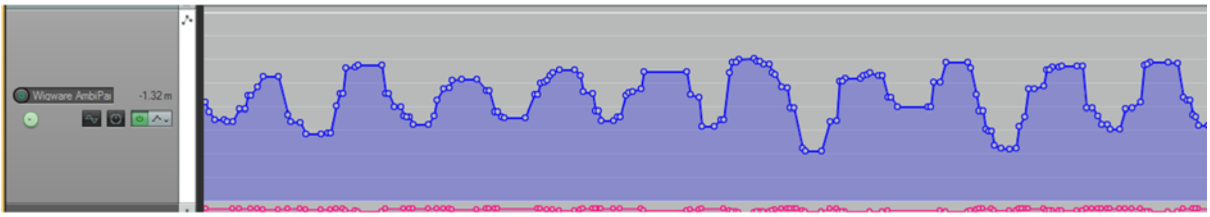


Figure 74: Ambisonics automation for running foot - azimuth

5.2.5 Video Prototyping

As described in secion 4.5.3, a “video prototyping” method was used to quickly iterate through new microphone designs. In comparison to the proximal recording system, though, the video prototypes for the ProxiMic were somewhat less structured, occurred more frequently, and included a wider range of sporting activities.

5.3 ProxiMic Iterations

5.3.1 ProxiMic v1, v2

5.3.1.1 Design Description

The first two designs of the ProxiMic used a similar outline to the strap microphone described in Chapter 4. These designs used multiple microphone elements with the intent to reduce wind noise. They also experimented with a variety of air pathways from the exterior of the case to the microphone element itself. The design of these pathways continued in later designs of the ProxiMic, using intuition rather than acoustic measurements as a guide. Versions 1 and 2 represent a transitional phase in development of the ProxiMic, and are included here for reference.

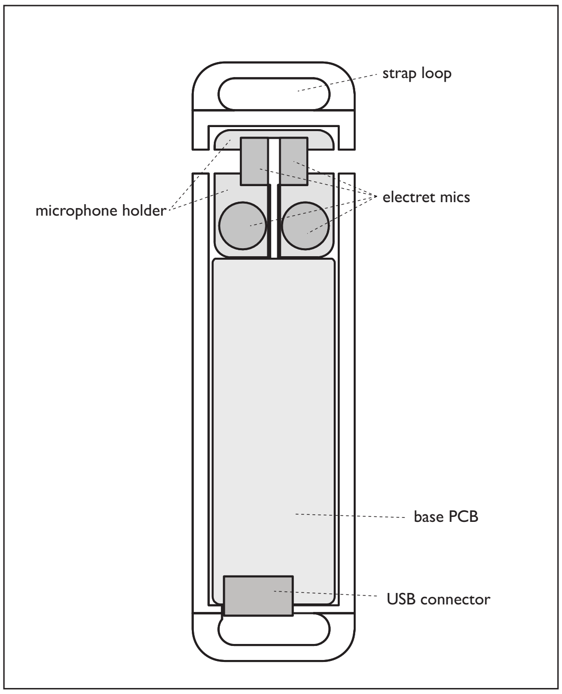


Figure 75: ProxiMic v1, cross-section, top view

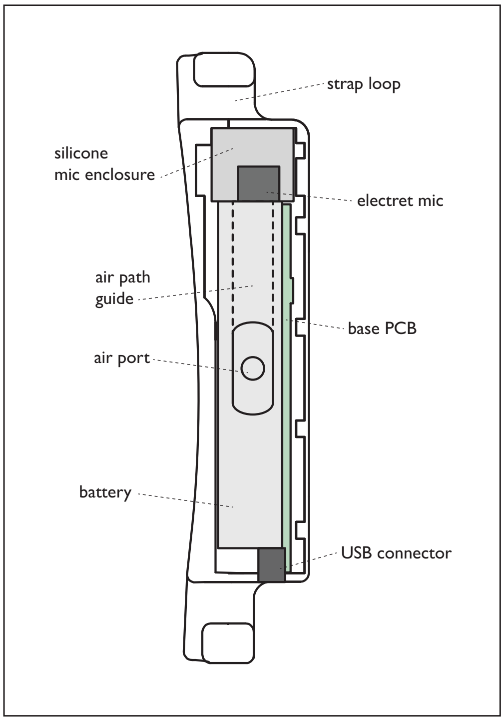


Figure 76: ProxiMic v2 cross-section, side view

Figure 77: ProxiMic v2, device view

5.3.2 ProxiMic v3

5.3.2.1 Design Description

The most significant breakthrough in the design of the ProxiMic involved two main design features. The first feature was the inclusion of both piezoelectric and electret microphones in a single housing. The second feature was the re-design of the housing to accommodate wearing the microphone with a strap or mounting the microphone to athletic equipment. The electret microphone was positioned behind several layers of acoustic baffles in an effort to reduce wind noise, and surrounded in a soft silicone “bumper” to reduce vibration noise. The piezoelectric microphone was pressed up against the edge of the case. Contact with any part of the case would be amplified by the piezoelectric mic.

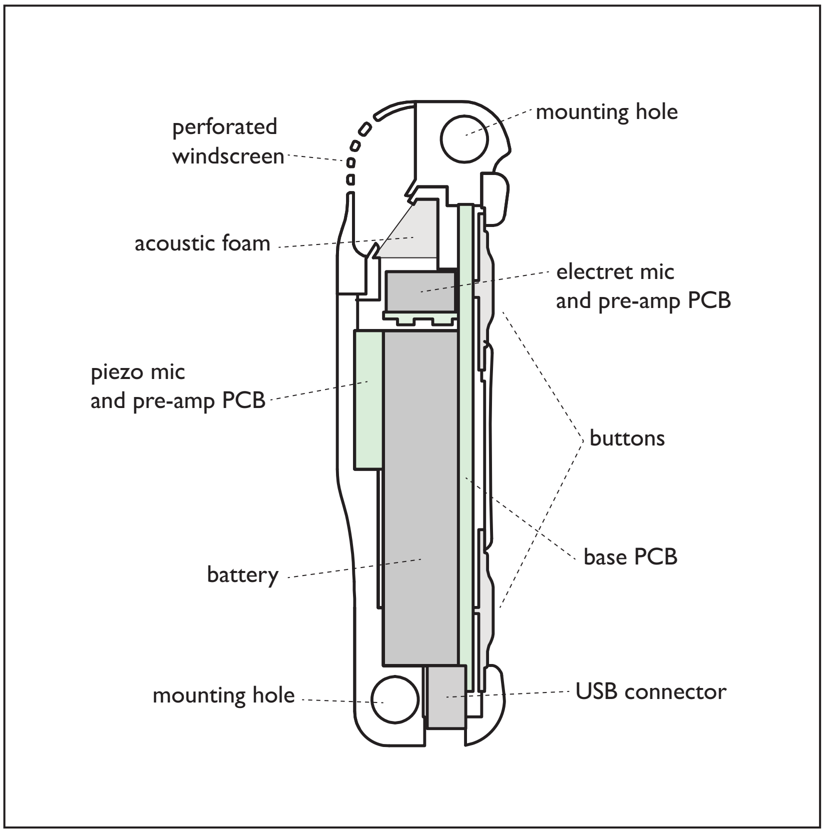


Figure 78: ProxiMic v3 cross section diagram

Figure 79: ProxiMic v3 device

The enclosure featured two pass-through holes that could be used to attach a strap or to secure the microphone to its equipment mount. The equipment mount could be adhered to flat surfaces or attached via zip ties to other pieces of equipment.

Figure 80: ProxiMic v3 equipment mount

Figure 81: ProxiMic v3 equipment mount on bike

5.3.2.2 Video Prototypes

Several video prototypes were created with the ProxiMic v3 from April to July, 2014. Video 11 shows the ProxiMic used to record mountain biking, while Video 12 features snowboarding. Both of these videos were recorded in similar ways, with one ProxiMic attached to a bike or a snowboard and one strapped around the neck. The ProxiMic functioned well enough to record in the field without major failures or other incidents. The hard plastic design was uncomfortable to wear after several hours, however.

The sonic results from the video prototypes were clear – the improvements in circuitry and case design captured richer and more vivid sounds than possible with the proximal recording system. The windscreen design was effective in reducing wind noise substantially. Internal sounds, however, remained hard to capture. As the case was made of hard plastic, moisture on the skin made it slide around with each movement of the body. The microphone amplified these small movements as scratches and slips, often overshadowing the relatively subtle internal bodily sounds of breathing and pulse. These concerns were addressed in v4.

5.3.2.2.1 Mountain Biking

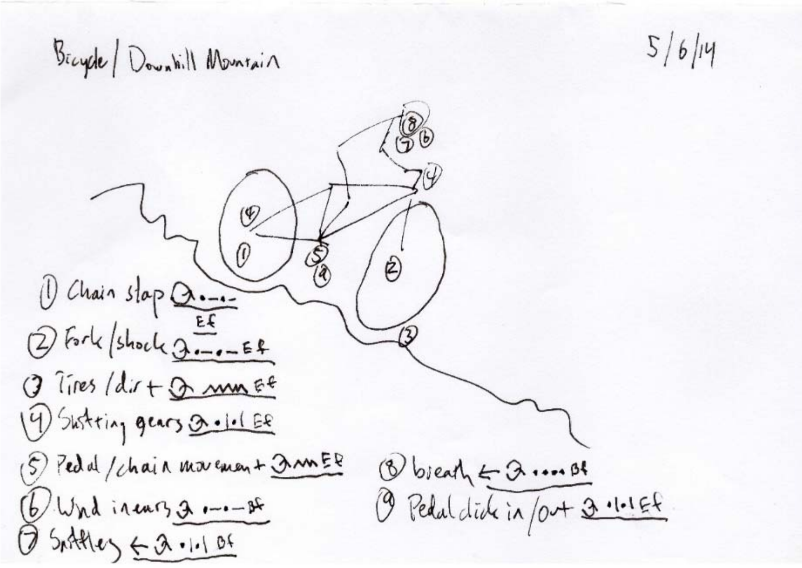


Figure 82: Notation example, downhill mountain biking

Video 11: ProxiMic recording, mountain biking - https://vimeo.com/121610004

5.3.2.2.2 Snowboarding

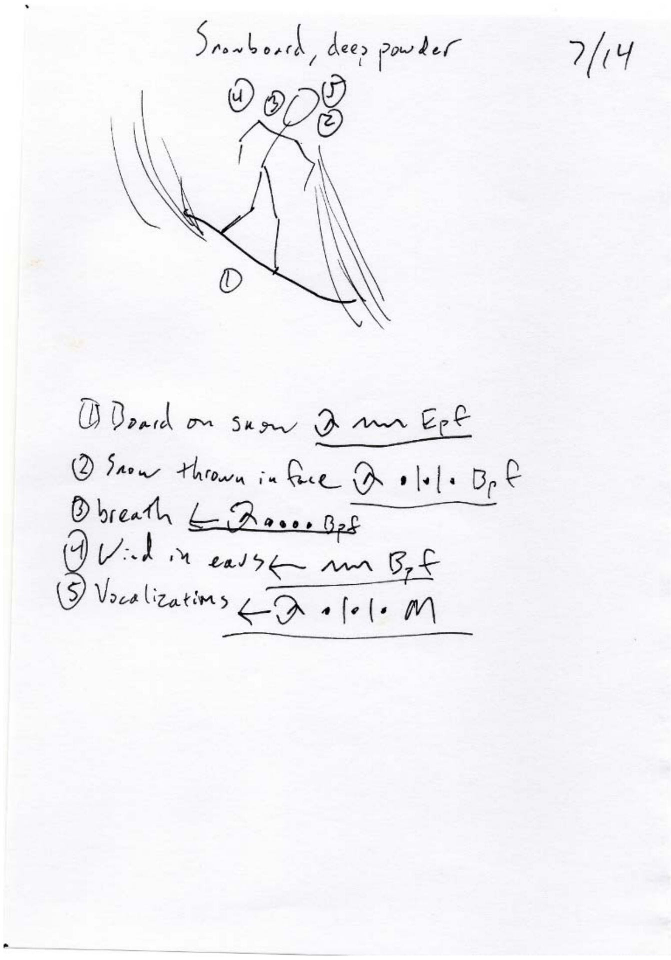


Figure 83: Notation example, snowboarding in deep powder

Video 12: ProxiMic recording, snowboarding - https://vimeo.com/121618260

5.3.3 ProxiMic v4

5.3.3.1 Design Description

The final revision of the ProxiMic used similar circuitry to v3, but had a re-designed enclosure. This enclosure tried to address the following problems with previous versions:

- Small movements of the microphone on the skin covered up internal sounds recorded by the piezoelectric microphone
- The microphone was uncomfortable to wear for long periods of time
- The mounting system still favoured flat surfaces
- The microphone was not yet fully waterproof, which ruled out water sports

To address these concerns, v4 implemented the following design changes:

- The case combined hard and soft materials for comfort, while still allowing sound to be transmitted directly to the piezo microphone. The soft materials clung to the skin, reducing the amount of audible scratches.
- A removable windscreen system enabled customization of the microphone for various situations
- With the appropriate windscreen in place, the design was made waterproof
- A new holster for the microphone was developed that enabled compatibility with commercially available camera mounts

The hard-soft over-molded case was produced with two silicone moulds per part. The hard component was produced first using polyurethane resins. This part was then placed in a second mould, where soft polyurethane was injected using a syringe. For this design, the best combination of durometers was a 70D for the hard component and 50A for the soft component.

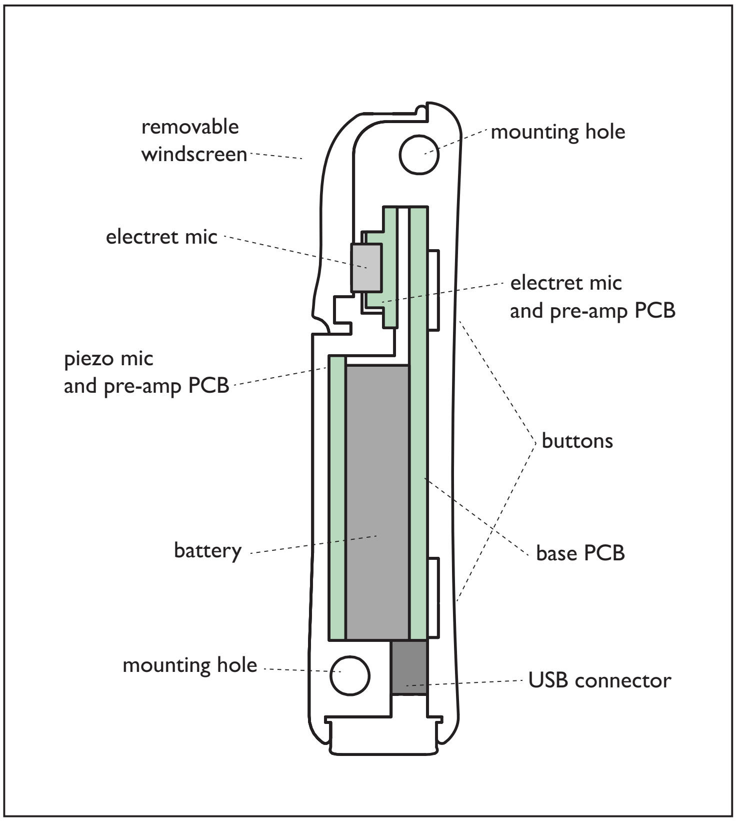


Figure 84: ProxiMic v4 cross-section, side view

Figure 85: ProxiMic v4 views

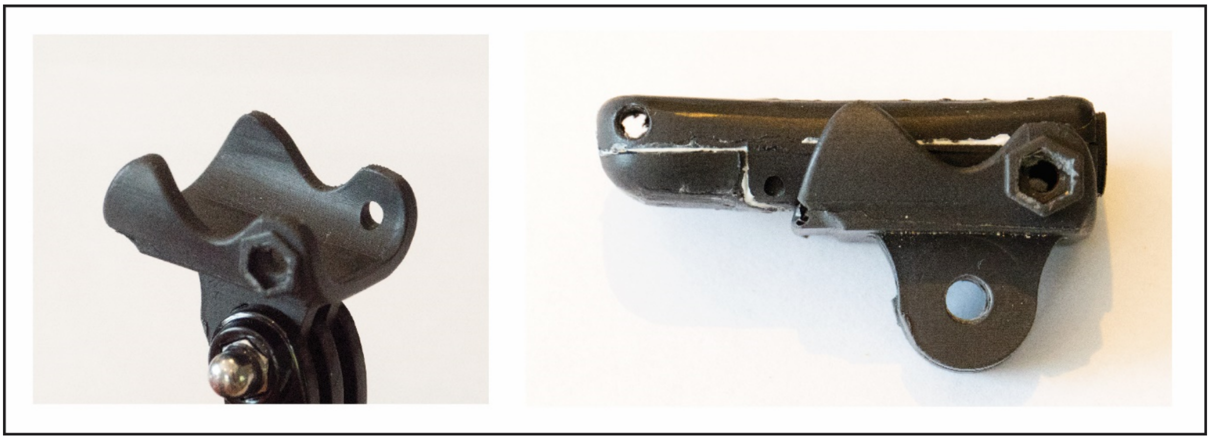


Figure 86: ProxiMic v4 camera compatible mount

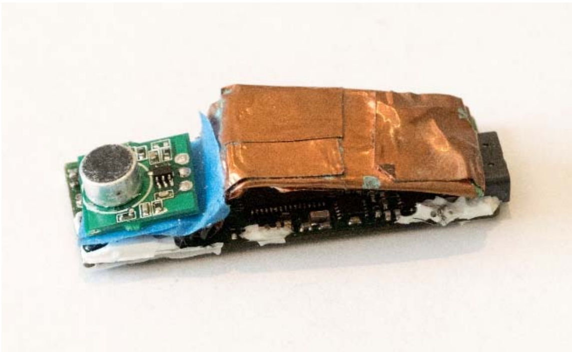


Figure 87: ProxiMic v4 circuit and case components

A new feature of the ProxiMic v4 was a system of interchangeable windscreens. While ProxiMic v3 achieved a good balance between wind reduction and microphone sensitivity, it was not waterproof. The waterproof membranes necessary for sound reduction had the unfortunate effect of reducing overall microphone sensitivity. For v4, two windscreens were designed – one "land" windscreen (Figure 88) modelled on v3, and the other "water" windscreen using a combination of designs from v1 and v2. For maximum sensitivity and minimal wind noise surpression, the microphone could be used without a windscreen.

Figure 88: ProxiMic v4 windscreens

In addition to the now-typical strap for wearing the microphone, a new "holster" was designed. This holster featured a semi-circular connector that interfaced with existing camera mounting systems made by GoPro and other manufacturers. By connecting with this system, the ProxiMic could now use a number of different equipment mounts, increasing its versatility. These mounts include bar mounts, flat surface mounts, chest mounts, and others. The flat surface mounts were used to attach the ProxiMic to a surfboard, while the bar mount enabled the microphone to easily attach to a bike frame.

5.3.3.2 Video Prototyping

Video 13 shows trail running recorded with the ProxiMic v4. To capture the feet and breath in detail, I decided to follow a microphone placement strategy similar to previous recordings of running (Section 4.5.5) using a ProxiMic strapped around my neck and two ProxiMics strapped around my ankles. All of these used the "land" windscreens. This video represents a significant turning point in the PhD. It is the first completed video prototype in which the breath and pulse of the athlete are clearly audible. Adding to this enhanced level of detail, the nuances of the interactions between the soles of my shoes and the surface textures of the trail is clearly audible. Compared to the video prototype of running in Chapter 4, the sounds captured here are much more detailed and dynamic. My own movements, in this example, are also much more vigorous, with the microphones moving at higher speed and with greater impact forces.

The spatialization technique used in this video is similar to that described in Section 5.2.4. The movement of each foot, and of my head, is spatialized individually using Ambisonics. The positioning data for each of these microphones has been entered in post production, with the right foot moving between lateral angles of 60 and 120 degrees, and the left foot between 240 and 300 degrees. The breath and throat are panned at 0 degrees. As a point of comparison, Video 14 is a binaural recording from the same route.

Video 15 shows the ProxiMic v4 in the water recording the sounds of surfing. This video is able to capture some of the sounds involved in paddling and waiting for a wave to come. However, due to author's lack of experience, not enough time was spent riding the wave to create an effective articulation of this sport.

5.3.3.2.1 Trail Running

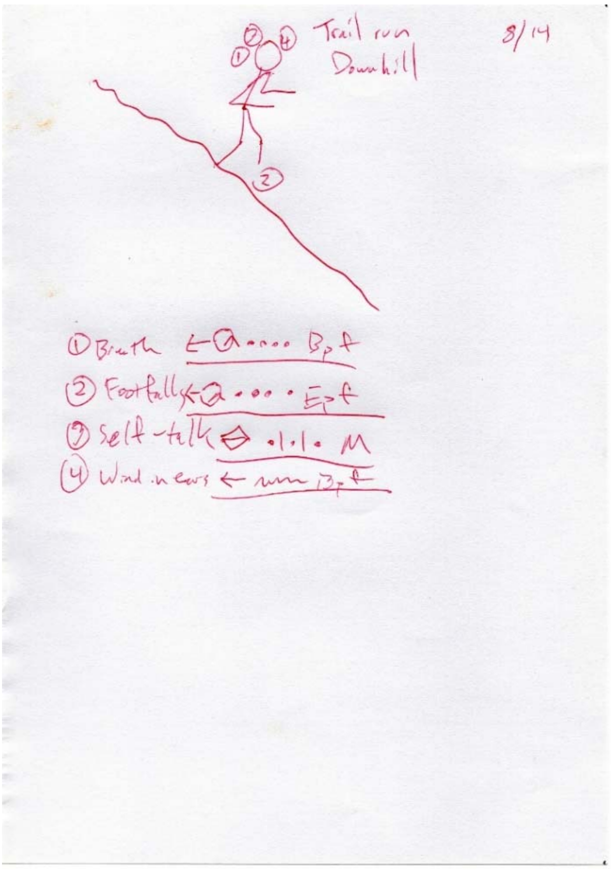
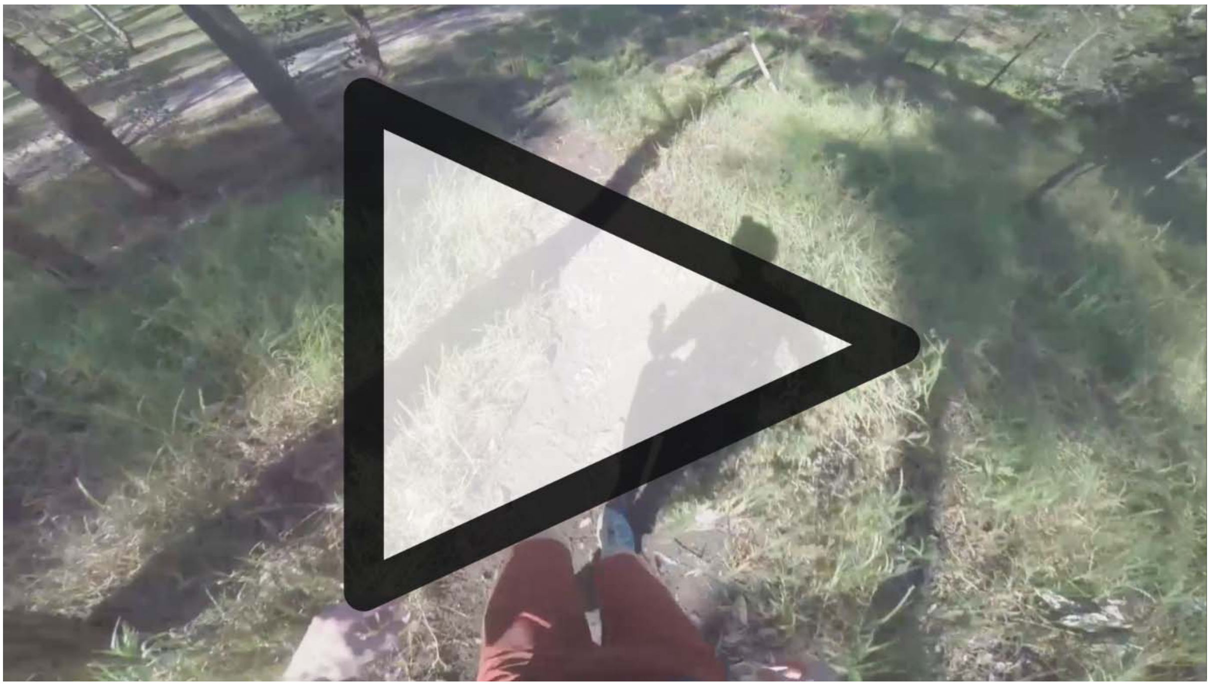


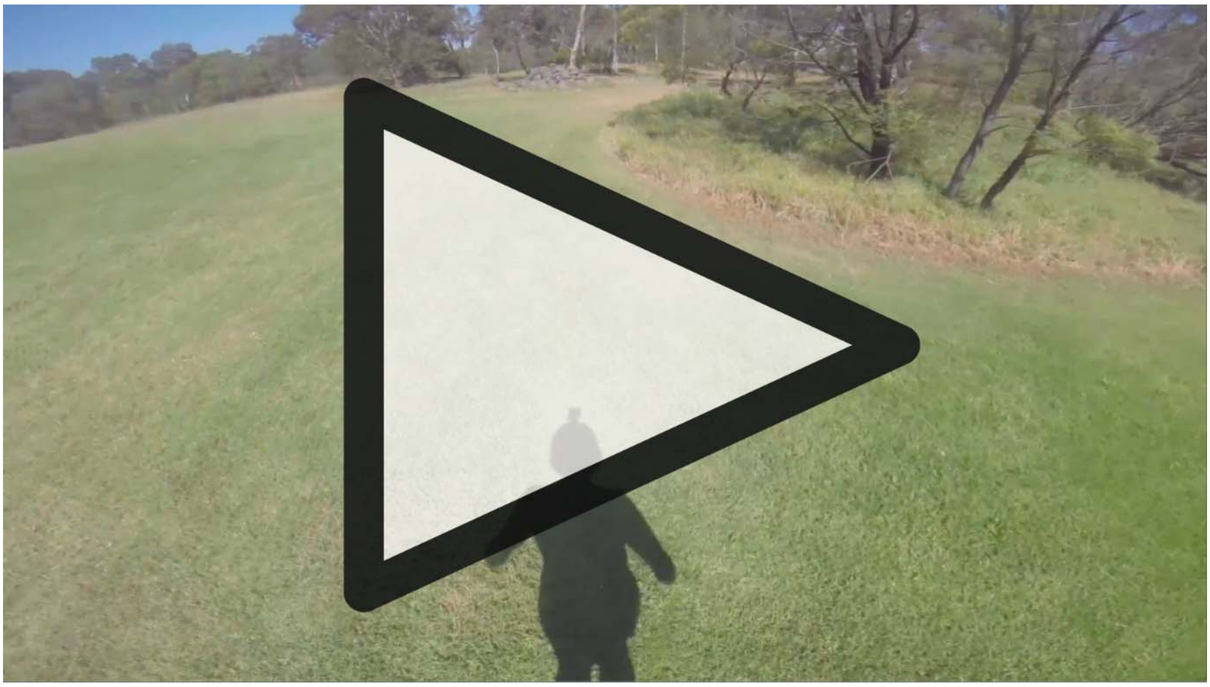
Figure 89: Notation example, trail running, downhill



Video 13: ProxiMic recording, trail running: https://vimeo.com/121435065

5.3.3.2.2 Trail running - binaural comparison

As a point of comparison to Video 13, I decided to re-visit the binaural recording techniques described in Chapter 4. During some of the runs, I wore the purpose-built binaural microphones, ear flap windscreens, and helmet. Comparing the two recording yielded similar conclusions, that binaural recordings emphasize spatial sounds more than their proximal equivalents. However, the addition of internal sounds only further highlighted the emphasis on spatial sounds in the binaural recording. The binaural recording sounded as if you were floating above the athlete – detached. The ProxiMic recordings were much more embodied, sounding like you were inside of the athlete's experience rather than outside of it.



Video 14: Binaural recording, trail running, compare to Video 13 - https://vimeo.com/121640075

5.3.3.2.3 Surfing

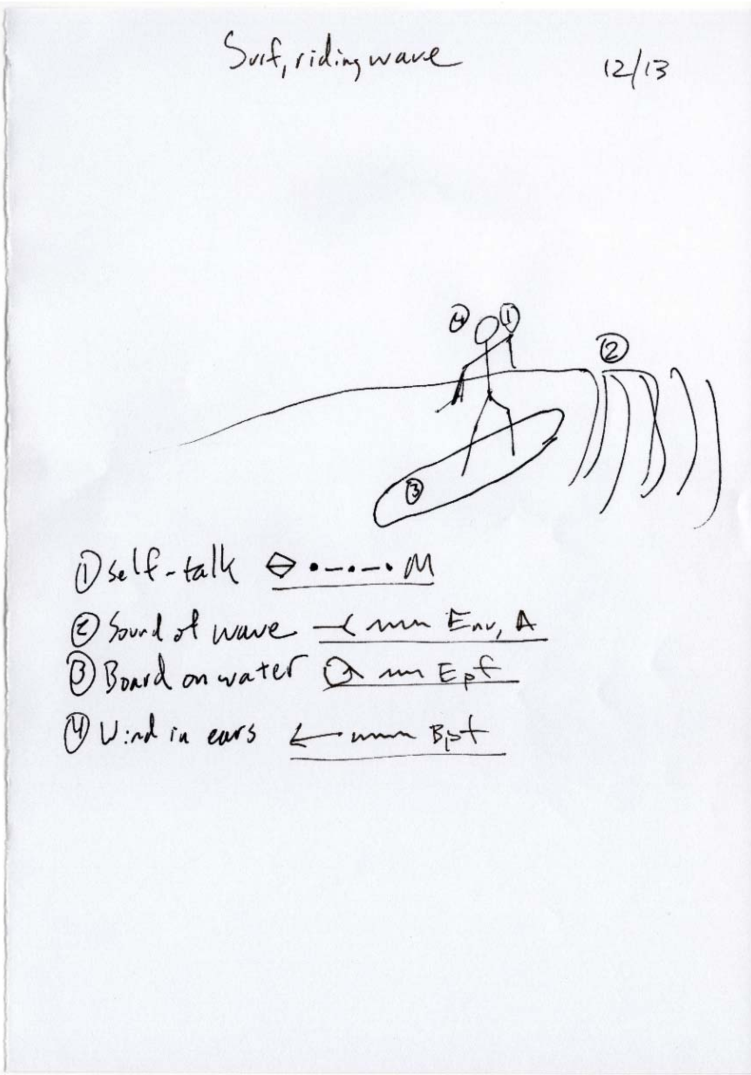


Figure 90: Notation example, surfing

Video 15: ProxiMic recording, surfing, preliminary - https://vimeo.com/121618261

5.4 Participatory Design Trials

5.4.1 Testing method and variations

The video prototyping process method used in developing the Proximal Recording system and the ProxiMic allowed for the efficient exploration of a largely unknown design terrain. While I had begun informal user testing with the Proximal Recording System in Chapter 4, user tests for the ProxiMic had a much clearer structure. The user tests, in essence, replicated the author's video prototyping process. The existing auditory experiences of the athlete, described in preliminary discussions, were notated. From that notation, microphone placements were established. Subjects wore a Point of View camera and a number of ProxiMics to record their sport, assisted by the author. Following the recording, subjects were involved in creating sound mixes to accompany the video, and provided feedback regarding how the sound correlated with or augmented their experience.

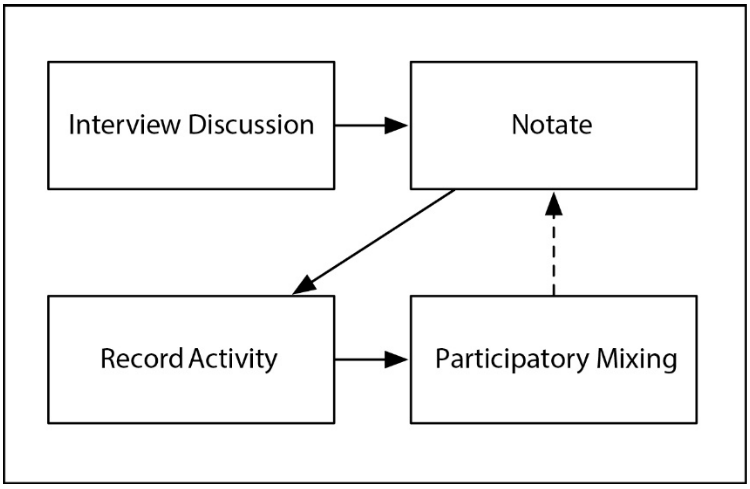


Figure 91: User testing, basic structure

The mixing of the recorded audio was perhaps the most important step in the process. As most athletes have only a passing familiarity with sound mixing software, an alternate interface was designed to allow them to easily change the levels of various microphones. This interface was designed using the program "TouchOSC," and ran on an IPad. Using a local wireless network, the PC's digital audio workstation could be selectively controlled by this interface remotely. The participants used headphones while they were mixing so that the system could be portable and consistent between tests. The mixing activity involved looping a relatively short section of video, identified by the athlete and author. The participant then brought up the level of each track independently, adjusting the mix until they were satisfied.

Figure 92: TouchOSC mixing interface

5.4.2 Road Biking

5.4.2.1 Subject Description

The first subject, Matthew, a 46 year old Melbourne resident, is an experienced road cyclist, often participating in local races with a cycling club. His training regime involves daily rides to and from work and longer training sessions on the weekend. He has maintained this routine for over 15 years. Matthew often uses a GPS device to upload his rides into Strava, an application that not only provides users with a log of their rides, but allows users to race each other on various segments of road or trail. Strava has provided Matthew with a record of his steady improvement in training over the years.

5.4.2.2 Notation

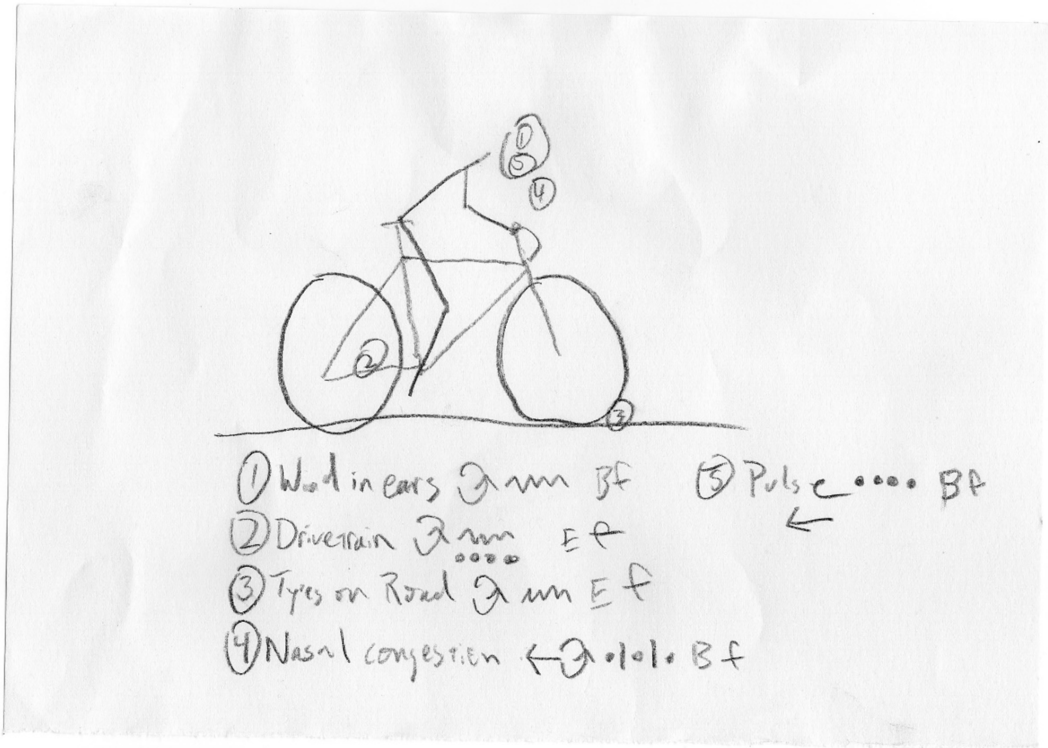


Figure 93: Notation example for user testing, cycling

Matthew reported hearing a number of sources of sound when cycling. The first was the wind in his ears, which changed qualities based on how fast he was going, whether or not he was riding in a group, and how strong a head or tailwind he was experiencing. The second came from the drivetrain of the bike, and was really a group of sounds – chain, pedals, cranks, and shifters. The third sound was his own breath, which he heard more than felt. The fourth sound was his pulse, which he heard occasionally after an especially strenuous section.

5.4.2.3 Microphone and Camera Placement, Recording

To record Matthew, two microphones were used. The first was placed around his neck, the second on his bike frame. The bike frame microphone was connected using a GoPro “handlebar” mount, and was placed on the frame at the top of the seat tube. Both microphones used the “land” windscreen. A GoPro Hero 3+ Black edition camera was worn using a GoPro chest mount, and recorded in 1080p “Superview” mode to capture the widest field of view possible. Matthew chose to record a segment of his morning commute – a popular cycling route northeast of Melbourne's CBD.

Preparing Matthew's equipment took roughly 10 minutes. One area of concern was the bicycle frame, and any scratches that the microphone might cause. This was addressed by using small pieces of electrical tape around the frame area that the handlebar mount was attached to. The GoPro mounting system provided a secure connection to the bicycle frame for the duration of the ride. After adjusting the strap length, the microphone around Matthew's neck was comfortable and did not bother him for the duration of the ride.

The microphones and camera functioned well. The audio recording was without distortion. The video camera was angled so that the road ahead was roughly centered in the shot, and Matthew's legs, arms, and handlebars were in view. Matthew's ride was somewhat typical. He rode at a comfortable pace until he was passed by a group of advanced cyclists. Exceeding his usual pace, he was able to keep up with the group for approximately five minutes until they slowly pulled away. These five minutes were the most memorable of the ride, and were chosen for later mixing.

5.4.2.4 Mixing and Evaluation

The microphones yielded four tracks – neck air, neck piezo (throat), bike air, bike piezo. These were synchronized with the video using hand claps before and after the ride. After reviewing the video with Matthew with no soundtrack, we identified a 10-minute section of riding that was particularly important to him. This included several minutes before he was overtaken by the group of passing cyclists, and his effort to stay with the group. We then looped this section while Matthew began to bring up the levels of individual tracks.

Matthew created the mix in approx. 15 minutes. For the most part, the neck air and bike air microphones contained a substantial amount of wind, leaving the piezo microphones as the primary source of "clean" audio. According to Matthew's GPS data recorded for the ride, his top speed was 55kph and his average speed was 45kph. The neck piezo microphone had little to no wind noise, and instead recorded Matthew's breath, pulse, and occasional vocalizations. The bike piezo microphone had little to no wind noise as well, and instead recorded the sounds of the tyres on the pavement, the drivetrain, and the movement of the pedals. With these four tracks, then, Matthew was able to mix between the wind-free isolated sounds of his body and bike, and the wind-filled sounds from the air microphones.

In Matthew's final mix, the sounds of the bike piezo microphone predominated, followed by the sound of his breathing and pulse, with a small amount of wind noise from the neck microphone added in. This mix did not necessarily correlate with Matthew's lived experience on the bike, where wind noise dominated. Rather, it was these sounds that he found most interesting as a listener. He expressed surprise at how "clear" the individual sounds were. While this clarity didn't necessarily exist during the ride, he found it extremely engaging when listening back. In a follow up conversation one month after testing, Matthew noted that the experience has changed his relationship to his bike. He is able to listen "into" the bike and hear sounds that before had gone unnoticed.

Video 16: ProxiMic recording, user test video, cycling - https://vimeo.com/121705315

5.4.3 Kiteboarding

5.4.3.1 Subject Description

Simon is a 33 year old Melbourne resident and avid kiteboarder. He has been kiteboarding for 5 years, and has averaged three sessions per week over the past year. While he began learning to kite in the calm waters of Port Philip Bay, for the past year he has challenged himself on the surf beaches close to Melbourne. Simon is a professional musician, and this training influences the way he hears his environment. Simon's preferred conditions for kiteboarding are winds over 20 knots from an onshore or cross-shore direction. The swell height can reach 3-5 feet, creating substantial wave faces that serve as launch ramps for jumps. Once in the air, upward pressure from the kite can hold Simon in the air for up to 5 seconds. This dynamic environment, involving many forces of nature, complex equipment, and aerial manoeuvres, creates an incredibly rich soundscape.

5.4.3.2 Notation

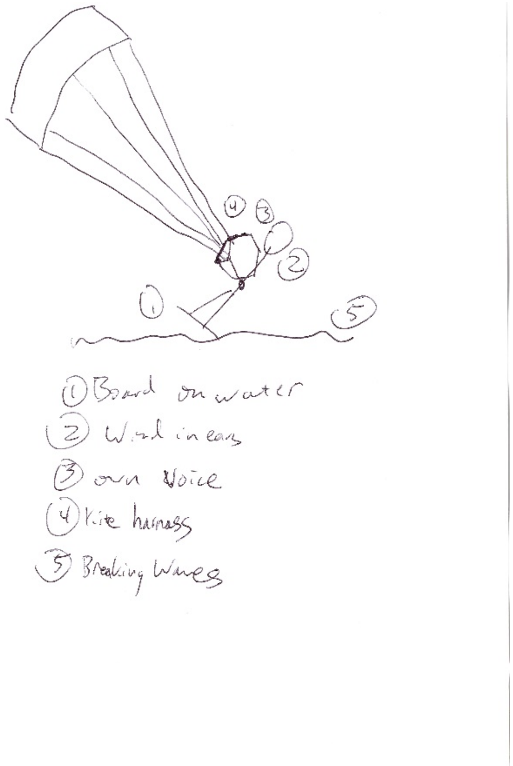


Figure 94: Notation example for user testing, kiteboarding on water

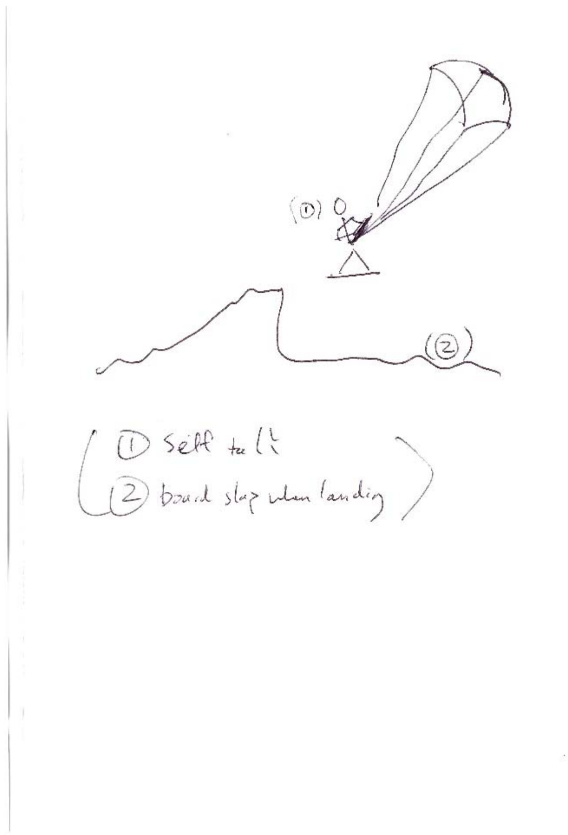


Figure 95: Notation example, kiteboarding in air

Simon remembered many sounds as part of his auditory experience – the sound of wind in his ears, waves breaking, the kite flapping in the wind, his own voice, being submerged in water after a fall, and the sound of the board planing on the water. One experience in particular stood out, though. When riding on the surface of the water, he described the experience as full of complex sound, often difficult to identify. However, when airborne, he described it as "silent." This is perhaps the clearest auditory experience that he described.

5.4.3.3 Microphone and Camera Placement, Recording

To record Simon, I placed one microphone around his neck using the strap and another to his kiteboard. The kiteboard attachment used the GoPro surf mount and a standard camera clip. Both microphones used the waterproof windscreen. The camera, a GoPro Hero 3+ Black, was worn using a standard GoPro chest mount. The filming took place at St Andrews Beach on the Mornington Peninsula in Victoria on a day of 25 knot onshore winds and 2-3 foot surf. Setting up the microphones and camera took approximately 15 minutes. We recorded 38 minutes of surfing.

There were several problems with the recording, identified when the recordings were downloaded to a PC for review. The angle of the camera, and the position on the chest, meant that the kiteboarding harness substantially obscured the shot. In terms of microphones, the neck microphone ended up slipping substantially on Simon's neck due to incorrect strap tension, resulting in scratching and rubbing noises obscuring his breathing and pulse. The air microphone on the kiteboard produced a good recording, but the analog gain of the piezo microphone was set too high, resulting in distortion even with the automatic level control engaged.

Video 17: ProxiMic recording, user test video, kiteboarding - https://vimeo.com/121631861

5.4.3.4 Mixing and Evaluation

Due to the problems listed above, the mix was somewhat compromised. Four tracks were available to Simon – neck air, neck piezo, board air, and board piezo. We identified a five-minute clip beginning 7 minutes into the filming as a particularly good stretch, including a variety of jumps and several crashes. Simon's mix emphasized the neck piezo microphone and board air microphone. A small amount of the board piezo microphone was mixed in after the board air microphone had been added. The neck air microphone was not included at all.

One of the primary effects of this mix is that it began to capture something of the "silence" of being airborne that Simon had earlier described. The level of sound coming from the board microphone is radically reduced when airborne, leaving only the internal sounds from the neck piezo microphone, and any ambient sounds captured by the board air microphone. Simon was extremely enthusiastic about this effect. Not only did it enable him to hear more specifically what was occurring during his riding, it offered the chance to communicate these sensations to his friends and family. After some reflection, though, he noted that the scratching of the microphone on his neck was less than desirable, and that the pops and clicks from the board air microphone moving in and out of the water were distracting, and reduced the effectiveness of the recording.

One clear outcome of this experience with noisy audio is that capturing the "silence" of being airborne requires very clean audio. This audio is likely to come from the piezoelectric microphones mounted on equipment and on the athlete's body, rather than air microphones. Capturing that silence also may require dynamic mixing that reduces the level of other sounds momentarily, rather than a static mix that stays constant throughout the athlete's activity.

5.4.4 Participatory Design Results

The ProxiMic system was able to record other athletes, not just the author. After the difficulties experienced during tests of the proximal recording system in Chapter 4, this in itself is a success. It was not just the fact of recording, however, but the specific ways in which the ProxiMic captured aspects of the athlete's auditory experiences that seemed to matter. The isolation of different streams of sound – breath, wind, bike, board – allowed for more flexibility in mixing and assembling these different sounds.

The mixes created by athletes do not necessarily correspond to their previous descriptions of their auditory experiences. Rather, the recording, mixing, and thinking about sound set in motion a kind of learning process. Mixing their own sounds helped the athletes hear different sonic slices of their composite experience with fresh ears. The ability to cleanly isolate these different slices through the use of piezo microphones, was especially revelatory. When performing this study in the future, repeated cycles of notation-recording-mixing could be performed to chart the evolution of an athlete's listening.

5.5 Conclusion and future directions

Over a period of 16 months, the development of the ProxiMic responded to the existing design challenges revealed in Chapter 4, opened up the recording of new sonic trajectories, and enabled successful user testing. The findings from this work are both technical and perceptual. These findings include the following:

- Combining piezoelectric and traditional electret microphones into a single enclosure that can be mounted on equipment or worn on the body provides a flexible recording system for the sounds of sport
- Internal sounds – breath, pulse, and others – often enhance representations of an athlete's auditory experience. Proper mechanical design is necessary to capture internal sounds with piezoelectric microphones.
- The process of using the ProxiMic is less a about representing an existing reality and more akin to a learning process that enables athletes to hear their sound environments in new ways.

The ProxiMic is both a product of design and a product *for* design. It has been produced through conventional design processes, such as circuit design and 3D fabrication. Its form, however, has been shaped through its ability to produce sound designs for video, captured in real-time. It enables new sound designs, new ways of recording and representing the athlete's sound environment. When athletes themselves create these sound designs, the ProxiMic becomes an instrument that allows an individual to peel back the individual layers of their sonic experience, examining each one individually and in contrast to the other. In this way, it enables athletes to learn to hear their world in new ways.

The specifics of this learning and its potential utility beyond enhancing an athlete's aesthetic awareness of sport are still unknown. The user studies shown here can be read as a prototype for a larger study involving athletes from many more disciplines. Team sports, for starters, have been almost completely ignored in my design work. Does the effectiveness of proximal recording hold up in a team environment where spatial communication between team members is vital? In addition, no women have been recorded using the system. A future study would correct these imbalances.

A future study could also challenge some of the assumptions of proximal recording itself. The ProxiMic, with its ability to record internal sounds, has already shown how important internal sounds are to athletes. There may be ways to modulate or supplement the use of the ProxiMic to capture spatial sounds and integrate them with proximal mixes, either through traditional "microphones on the outside" techniques or through new approaches. Hopefully, proximal recording can be integrated into a variety of other techniques in the future, enabling new articulations of the sound of sport for both spectators and athletes.

6 Conclusion

6.1 Contributions

The previous chapters have charted the development of a toolkit for analysing, recording, and representing the auditory experiences of athletes. This toolkit includes a notation system, new microphone designs, and mixing techniques. The development of this toolkit began with research into the history and theory of what athletes hear, incorporating findings from a variety of disciplines. The design work encompassed electronic circuit design, 3D modelling and fabrication of microphone enclosures, the creation of objects for mounting and wearing these microphones, and the exploration of studio techniques to combine the recordings of these microphones into interesting works of sound design. Taken as a whole, these new techniques for analysing, recording, and representing the auditory experiences of represent a substantial advance in the possibilities for studying the athletic soundscape and embodied sound-worlds in general.

There are three major contributions to knowledge:

- The "toolkit" for exploring the auditory perspectives of athletes, consisting of a notation system and microphone design
- An important perceptual finding regarding what athletes hear: the sound-waves that arrive at an athlete's ears do *not* necessarily constitute their auditory experiences.
- The identification of a transdisciplinary field of sports sound studies, incorporating psychoacoustics, music, audio technology, sports science, and media history.

These findings are highly interrelated. The diverse sources used for the literature review were vital in shaping many aspects of the toolkit. The toolkit, in turn, helped in the exploration of various perceptual and physical questions raised through the literature review. While each finding is significant in itself, their interconnections should also be considered.

6.1.1 The "Toolkit"

Perhaps the most substantial contribution to knowledge offered by this PhD is the "toolkit" that has been developed for exploring the auditory experiences of athletes. This toolkit includes both a notation system and a sound recording system that work together to articulate a wide spectrum of auditory experiences.

6.1.1.1 Notation System

The notation system has its basis in a literature survey of sports science and anthropology publications. This survey helped shape three sets of categories for athletic sound. Trajectory, temporality, and task relationship are the most relevant categories for describing the auditory experiences of athletes. Other categories are possible, but not as relevant. The notation system puts these categories into practice, allowing for many seemingly dissimilar athletic activities to be compared using a common language.

The notation system enabled me to catalogue my own athletic activities for more than a year. One of the results of this self-notation was that proximal sounds – those sounds created by the athlete themselves – were most numerous and likely most important. This stands in contrast to the literature survey, where proximal and spatial sounds were given roughly equal importance. For the auditory experiences of the author, pursuing solo sports, proximal sounds are the most numerous and most important.

6.1.1.2 Microphone System – the ProxiMic

Influenced by the findings of the notation, two new microphone systems were developed to capture the sounds of athletic auditory experience. Existing techniques feature microphones positioned outside of the field of play, or microphones worn by the athlete solely for the purposes of recording their voice. The new wearable microphone systems developed here were designed to capture a much broader range of sounds made by athletes. These wearable microphones can effectively capture both proximal, internal, and spatial sounds. They achieve a "focus" that can correspond to the attentional strategies of athletes by being placed close to salient sound sources. These attentional strategies can be further mimicked, interrogated, and modulated by the act of mixing these sounds back together as the soundtrack to a point-of-view video.

Placing microphones at an athlete's extremities, and on their equipment, is a complex design problem. The most effective microphone design incorporated both traditional condenser microphones and piezoelectric microphones. Piezoelectric "contact" microphones can be placed against the skin to record internal sounds, and can be mounted directly on athletic equipment to record its internal vibrations. A variety of athletic equipment can be effectively recorded this way. The most effective designs incorporated hard-soft plastic over-molding, could be worn around the neck or on other parts of the body, and had a flexible mounting system for placement on athletic equipment.

6.1.2 What athlete's (don't) hear

A further contribution to knowledge incorporates the breadth of research performed: the sound-waves that arrive at an athlete's ears do not necessarily constitute their auditory experiences. This finding is reinforced by background research, notation, and microphone development and testing. According the literature in a variety of domains, athletic attention is extremely selective and is constantly adjusted to suit the momentary demands of a particular activity. Streams of salient sounds are attended to – consciously or subconsciously – while those sounds deemed irrelevant are ignored. Other attentional strategies include blocking out sound altogether, especially in periods of high exertion.

In addition, the sound waves travelling through air that arrive at an athlete's ears only constitute two of the four trajectories of athletic sound outlined by the notation system, with internal and mental sounds excluded. Self-talk, imagined music, and sounds conducted through bone and tissue also contribute to what an athlete hears. Through the focusing capabilities of the ear, this multiplicity of sounds is once again selectively filtered. This finding was also reinforced when testing the microphone systems against binaural recordings made in the field. The preferred representations created by the ProxiMic and proximal recording system were significantly different from the simultaneous binaural recordings. In obvious ways, this finding is a fundamental fact of human hearing – we hear with our auditory cortex, not the direct vibrations from our ear drums. However, due to the dominance of "concertized," dis-embodied modes of listening that continue to influence contemporary discussions of sound, this finding deserves stating. Binaural recordings are *not* a "perfect reproduction" of auditory experience when it comes to athletes. By eliminating this elephant in the room, we can open up the field to a more vibrant spectrum of possibilities.

"What to athletes hear?" is a question that has animated my research, and yet I can now only say with some certainty what they do not hear. As to what they *do* hear, we have only propositions. These propositions, articulated by the toolkit, outline a focused, tactical soundscape with overlapping trajectories and temporalities. They allow us to predict potential patterns of hearing without denying the richness and variability of individual experience. They have also allowed me to articulate what *I* hear – the sounds of my snowboard, bike, surfboard, shoes, breathing, pulse – the sounds of cars whizzing by, waves breaking, and other voices. Using Latour's criteria for articulation, these results are positive. My world sounds radically more rich and differentiated now than it did before.

6.1.3 Sports sound studies

The literature surveyed in Chapter 2, and the approach taken in the remainder of the PhD, represent a previously unexplored transdisciplinary approach to the topic of sound and sport. My original intention with this approach was to explore the auditory experience of athletes through as many relevant frameworks as possible. Rather than simplify the question of what athletes hear, it became more complex and interconnected – a network of physical, psychological, cultural, and technological factors.

One preliminary term for this new type of inquiry is sports sound studies. This term blends the perceptual and the physical with the cultural and technological. In this way, it echoes the larger field of sound studies that has emerged in the last forty years. Sound studies originally emerged as an antidote to the narrow disciplinary approaches that had previously been applied to sound, encouraging research *across* disciplines to more fully describe and analyse the way our world sounds and how we hear it.

Sport sound studies can be tentatively positioned as a companion to the wider field of sound studies, bringing new approaches to an already rich collection of disciplines and methodologies. In their 2011 *Oxford Handbook of Sound Studies*, Karin Bijsterveld and Trevor Pinch list the variety of disciplines that intersect in sound studies proper: "acoustic ecology, sound design, urban studies, cultural geography, media and communication studies, cultural studies, the history and anthropology of the senses, the history and sociology of music, and literary studies."[164] To this list, sport sound studies adds sports science, psychology, psychoacoustics, and sport and physical culture studies.

Sound studies often suffers from the same paradigms that have rendered audio engineering immobile, considering sport from a spectator's perspective rather than as an active participant. Even as sound studies considers race, gender, sexuality, and other issues around the body, it often ignores locomotion and physical activity. Sport sound studies could provide valuable templates for interdisciplinary inquiries into the body in locomotion. In my own work, the combination of these various disciplines has been invaluable.

6.2 Future research

6.2.1 What do athletes hear, then, exactly?

There are countless opportunities for future research in the domain of sport sound studies. Perhaps the most immediate is to expand the user study initiated in Chapter 5 to include many more athletes and sporting disciplines. This study would present a very useful set of data, from interviews about athlete perceptions to notations to athlete-mixed recordings. This data would hopefully allow for a more diverse interrogation of the initial findings and contributions to knowledge outlined above. How can the toolkit developed here be applied across a wide spectrum of ages, genders, and sporting disciplines? Are there common sounds that athletes include in their mixes across this breadth of experience? How can team sports be recorded?

Another kind of study would focus on specific athletic disciplines and their unique sound-worlds. This would allow researchers to link the quality of specific sounds to performance characteristics. Throughout my candidature, this link between sound quality and performance has been suggested many times. What is the ideal sound of a footfall when sprinting on a track in a pair of racing flats? What is the ideal sound that the pole should make as the vaulter jams it into the trap? What strategies of listening can the competitive surfer use to maximize their performance on a wave? In team sports, can we perform complex micro-analyses of teammate communication that acknowledge the multi-layered soundscape of each individual athlete? While answering these individual questions was beyond the scope of this PhD, the toolkit outlined above can potentially provide the means to begin these more detailed investigations.

The results of discipline-specific studies would not only be useful to athletes, coaches, and supporting staff, they could potentially be applied to equipment design. Equipment designers and manufacturers now have the tools to create more detailed recordings as part of their design process. The shoe designer, surfboard designer, bicycle components manufacturer, and many others can now investigate their equipment from a sonic perspective. As shown in Chapter 2, sound contributes to the "feel" of equipment. These relationships

[164] (Pinch & Bijsterveld, 2012) p10

should be more comprehensively charted and explored. In this way, the toolkit for studying the sound of sport can be used to generate new sounds and new interactions.

6.2.2 Design-specific research goals

In addition to user studies, there are many areas where the ProxiMic can be further improved. One of the most pressing future design goal is to make the ProxiMic usable for the athlete themselves, without the need for researcher intervention. This likely requires new circuitry with additional connectivity options. A mobile app or other interface for monitoring and controlling multiple ProxiMics could potentially improve usability. Additional interface design with the microphone itself, including a more useful embedded display, could also be useful. The process for synchronizing and mixing audio would also need to be streamlined, potentially involving custom software. This athlete-operated microphone could in turn allow a new type of user study – athlete-guided articulations of their own sound environments.

The notation system also deserves further design exploration. Can it be used sequentially to capture complex moments, rather than its current static usage? Can it be animated to accompany moving images? In addition to these physical changes, the notation system deserves user testing in its own right. Can it be taught to coaches and athletes? Does its categorization system have relevance beyond the design goals of this PhD?

There are also additional challenges in the physical design of the ProxiMic. One of these is the challenge faced by recording competitive team sports, where microphones need to be hidden. Many of the recordings made for this PhD have involved a ProxiMic worn around the user's neck – a highly visible position. How can the ProxiMic be worn under clothes and still capture important sounds? This challenge may require new windscreen designs and new straps or other mounting techniques.

Finally, the ProxiMic and proximal recording systems both take a "microphones on the inside" approach. Because of this, they articulate certain aspects of an athlete's experience while potentially neglecting others. A further area of design would involve re-examining the "microphones on the outside" approach to find potential links between inside and outside. The result might be an expanded or alternative toolkit that could potentially lead to new connections, categories, and other propositions for a newly differentiated athletic soundscape.

6.3 Distance travelled

One way to evaluate the distance travelled in the work described here is to return to the gravel paths of Melbourne's Birdwood Avenue and the variety of morning joggers. How could we now approach the rich variety of their auditory experiences? We could begin by asking them a few pointed questions, observing their running, and notating the sounds that emerge. We could step through the various trajectories of sound – mental, internal, proximal, spatial – to uncover sounds that had become automatic and subconscious. We might assume that those concerned with their running technique would attend to the sounds of their footfalls, consciously or subconsciously, while those in the final kilometres of a limit-pushing training session might turn inwards, focusing on mental sounds.

After asking someone a few pointed questions, we could place one or more ProxiMics at various positions around their body, strap on a wearable camera, and record the sounds that we believe to be salient. Following this, we could spend the evening making a quick “mix” of the audio before repeating the process in the next morning’s run – making still further adjustments. Was the heartbeat the most important, the breath, the sound of our own footfalls, the breathing of a training partner? By slicing up the audible world and then re-assembling it, we learn something about what it is made of.

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8 Appendix

8.1 Ethics application for user study

8.1.1 Ethics Approval Letter

RMIT UNIVERSITY Design and Social Context College Human Ethics Advisory Network (CHEAN)
Sub-committee of the RMIT Human Research Ethics Committee (HREC)

Notice of Approval

Date:	21 May 2014
Project number:	CHEAN B 0000018613-04/14
Project title:	Ears in Motion
Risk classification:	Low Risk
Investigator:	A/Professor Lawrence Harvey and Daniel St Clair
Approved:	From: 21 May 2014 To: 18 July 2015

I am pleased to advise that your application has been granted ethics approval by the Design and Social Context College Human Ethics Advisory Network as a sub-committee of the RMIT Human Research Ethics Committee (HREC).

Terms of approval:

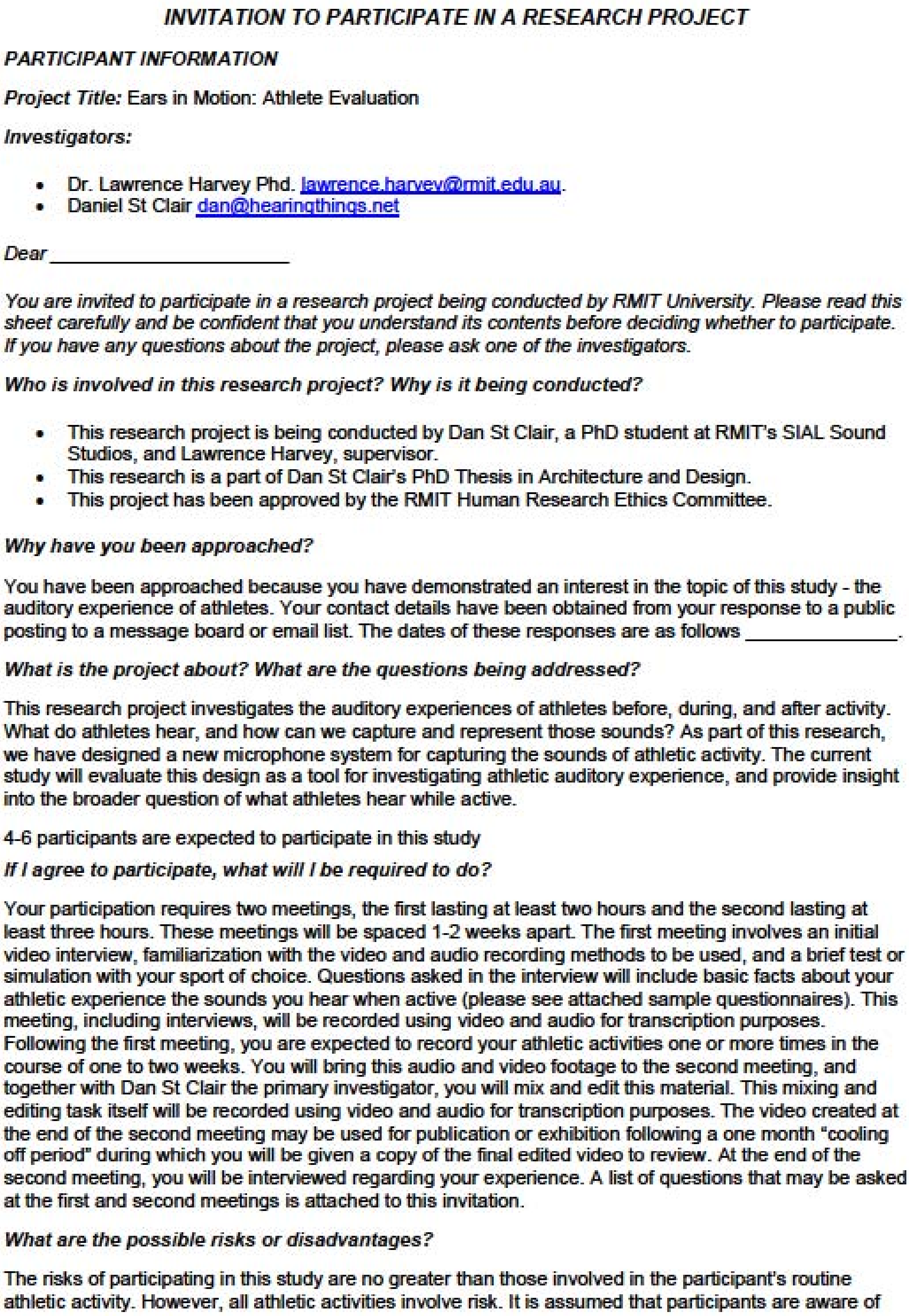
1. **Responsibilities of investigator**
   It is the responsibility of the above investigator/s to ensure that all other investigators and staff on a project are aware of the terms of approval and to ensure that the project is conducted as approved by the CHEAN. Approval is only valid whilst the investigator/s holds a position at RMIT University.
2. **Amendments**
   Approval must be sought from the CHEAN to amend any aspect of a project including approved documents. To apply for an amendment please use the 'Request for Amendment Form' that is available on the RMIT website. Amendments must not be implemented without first gaining approval from CHEAN.
3. **Adverse events**
   You should notify HREC immediately of any serious or unexpected adverse effects on participants or unforeseen events affecting the ethical acceptability of the project.
4. **Participant Information and Consent Form (PICF)**
   The PICF and any other material used to recruit and inform participants of the project must include the RMIT university logo. The PICF must contain a complaints clause including the project number.
5. **Annual reports**
   Continued approval of this project is dependent on the submission of an annual report. This form can be located online on the human research ethics web page on the RMIT website.
6. **Final report**
   A final report must be provided at the conclusion of the project. CHEAN must be notified if the project is discontinued before the expected date of completion.
7. **Monitoring**
   Projects may be subject to an audit or any other form of monitoring by HREC at any time.
8. **Retention and storage of data**
   The investigator is responsible for the storage and retention of original data pertaining to a project for a minimum period of five years.

In any future correspondence please quote the project number and project title.

On behalf of the DSC College Human Ethics Advisory Network I wish you well in your research.

Suzana Kovacevic
Research and Ethics Officer
College of Design and Social Context
RMIT University
Ph: 03 9925 2974
Email: suzana.kovacevic@rmit.edu.au
Website: www.rmit.edu.au/dsc

8.1.2 Ethics Consent Form



INVITATION TO PARTICIPATE IN A RESEARCH PROJECT

PARTICIPANT INFORMATION

Project Title: Ears in Motion: Athlete Evaluation

Investigators:

- Dr. Lawrence Harvey Phd. lawrence.harvey@rmit.edu.au.
- Daniel St Clair dan@hearingthings.net

Dear ______________________

You are invited to participate in a research project being conducted by RMIT University. Please read this sheet carefully and be confident that you understand its contents before deciding whether to participate. If you have any questions about the project, please ask one of the investigators.

Who is involved in this research project? Why is it being conducted?

- This research project is being conducted by Dan St Clair, a PhD student at RMIT's SIAL Sound Studios, and Lawrence Harvey, supervisor.
- This research is a part of Dan St Clair's PhD Thesis in Architecture and Design.
- This project has been approved by the RMIT Human Research Ethics Committee.

Why have you been approached?

You have been approached because you have demonstrated an interest in the topic of this study - the auditory experience of athletes. Your contact details have been obtained from your response to a public posting to a message board or email list. The dates of these responses are as follows ______________.

What is the project about? What are the questions being addressed?

This research project investigates the auditory experiences of athletes before, during, and after activity. What do athletes hear, and how can we capture and represent those sounds? As part of this research, we have designed a new microphone system for capturing the sounds of athletic activity. The current study will evaluate this design as a tool for investigating athletic auditory experience, and provide insight into the broader question of what athletes hear while active.

4-6 participants are expected to participate in this study

If I agree to participate, what will I be required to do?

Your participation requires two meetings, the first lasting at least two hours and the second lasting at least three hours. These meetings will be spaced 1-2 weeks apart. The first meeting involves an initial video interview, familiarization with the video and audio recording methods to be used, and a brief test or simulation with your sport of choice. Questions asked in the interview will include basic facts about your athletic experience the sounds you hear when active (please see attached sample questionnaires). This meeting, including interviews, will be recorded using video and audio for transcription purposes. Following the first meeting, you are expected to record your athletic activities one or more times in the course of one to two weeks. You will bring this audio and video footage to the second meeting, and together with Dan St Clair the primary investigator, you will mix and edit this material. This mixing and editing task itself will be recorded using video and audio for transcription purposes. The video created at the end of the second meeting may be used for publication or exhibition following a one month "cooling off period" during which you will be given a copy of the final edited video to review. At the end of the second meeting, you will be interviewed regarding your experience. A list of questions that may be asked at the first and second meetings is attached to this invitation.

What are the possible risks or disadvantages?

The risks of participating in this study are no greater than those involved in the participant's routine athletic activity. However, all athletic activities involve risk. It is assumed that participants are aware of the risks of participating in their chosen athletic activity.

If you are unduly concerned about your responses to any of the questionnaire items or if you find participation in the project distressing, you should contact Peter Burke as soon as convenient on (03) 9925 2251 or at humanethics@rmit.edu.au. Mr Burke will discuss your concerns with you confidentially and suggest appropriate follow-up, if necessary.

What are the benefits associated with participation?

The benefits of participating in this study include a greater awareness of the role of sound in the participant's own athletic practice. This information may be used to further one's skill level or otherwise enhance one's participation in their chosen activity.

What will happen to the information I provide?

- We expect results to be published in peer-reviewed journals and in the Appropriate Durable Record for Dan St Clair's PhD research, accessible to the general public in the RMIT Online Repository after publication. Video of your athletic activities, created as a part of the collaborative editing and mixing process mentioned above, may be shown to the public at an exhibition or online.
- Any information that you provide can be disclosed only if (1) it is to protect you or others from harm, (2) if specifically required or allowed by law, or (3) you provide the researchers with written permission.
- Audio, video, and transcripts from your interviews and athletic activities will be securely stored on encrypted hard drives in locked file cabinets for the duration of the study. This data will not be accessible to other participants in the study. This data will be stored for five years after the end date of the study in locked storage at RMIT University. Your name will not be published, and will be disclosed only to the investigators of this study named above. However, as video and audio of your athletic activities may be shown to the public, your identity may be discerned by people familiar with you.
- Unless directed otherwise, you may be identified by your real name in publication. At your request, a pseudonym may be used to identify you. Direct quotes from your interviews may be published.
- The research data (i.e. the raw information and/or images) will be kept securely at RMIT for 5 years after publication, before being destroyed. Whereas the final research paper will remain online.

What are my rights as a participant?

- The right to withdraw from participation at any time
- The right to request that any recording cease
- The right to have any unprocessed data withdrawn and destroyed, provided it can be reliably identified, and provided that so doing does not increase the risk for the participant.
- The right to be de-identified in any photographs intended for public publication, before the point of publication
- The right to have any questions answered at any time.

Whom should I contact if I have any questions?

- SIAL Sound Studios, Main office – 03 9925 9786

What other issues should I be aware of before deciding whether to participate?

Please be aware that you will be creating short videos of your athletic performances that will be exhibited to the public. As a participant in the creation, editing, and sound mixing of these clips you will be able to decide which segments of your performance become public and which do not.

Yours sincerely,

Lawrence Harvey, Associate Professor RMIT University

B.Mus (Canberra), M.Mus (University of Melbourne), PhD (RMIT)

Dan St Clair, PhD Research Student RMIT University

BA (Wesleyan University), MFA (School of the Art Institute of Chicago), MA (Wesleyan University)

If you have any complaints about your participation in this project please see the complaints procedure at Complaints with respect to participation in research at RMIT [ctrl + click to follow]/
http://www.rmit.edu.au/research/human-research-ethics

1. I have had the project explained to me, and I have read the information sheet
2. I agree to participate in the research project as described
3. I agree:
   The following provide some common examples, but should be modified to suit:
   to undertake the tests or procedures outlined above
   to be interviewed and/or complete a questionnaire
   that my voice will be audio recorded
   that my image will be taken (*Note: If you are using photographic images, further points need to be covered in the consent form– see under Supporting information on the Applying for human research ethics approval page)*
4. I acknowledge that:

   (a) I understand that my participation is voluntary and that I am free to withdraw from the project at any time and to withdraw any unprocessed data previously supplied (unless follow-up is needed for safety).
   (b) The project is for the purpose of research. It may not be of direct benefit to me.
   (c) The privacy of the personal information I provide will be safeguarded and only disclosed where I have consented to the disclosure or as required by law.
   (d) The security of the research data will be protected during and after completion of the study. The data collected during the study may be published, and a report of the project outcomes will be provided to RMIT University.

Participant's Consent

Participant: ____________________________ Date: ______________
(Signature)

8.2 Table of references for literature survey and notation system

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